EXHIBIT E

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE SECRETARY

DECLARATION OF JOSEPH F. TRUNGALE IN SUPPORT OF TEXANS FOR A SOUND ENERGY POLICY'S PETITION TO INTERVENE AND CONTENTIONS

I Joseph F. Trungale, declare pursuant to 28 U.S.C. § 1746, on personal knowledge and under penalty of perjury, that the following is true and correct:

This declaration is submitted in support of Texans for A Sound Energy Policy's ("TSEP") Petition to Intervene and Contentions.

1. I am a resident of Travis County, Texas. I am over 21 years of age and have never been convicted of a felony.

2. I am the principal and project manager of TRUNGALE ENGINEERING & SCIENCE. I have reviewed the portions of the Early Site Permit ("ESP") Application for the Victoria County Station Site proposed by Exelon Nuclear Texas Holdings, LLC ("Exelon").

3. Attached as Exhibit E-1 is a report I prepared entitled *Effect of Diversions from the Guadalupe River on San Antonio Bay and Estuary Health* associated with Exelon's ESP Application.

4. A copy of my resume accompanies this report as Exhibit E-2.

I, JOSEPH F. TRUNGALE, DECLARE UNDER PENALTY OF PERJURY UNDER THE LAWS OF THE UNITED STATES OF AMERICA THAT THE FOREGOING IS TRUE AND CORRECT.

Executed this 20 day of January, 2011.

Joseph F. Trungale

EXHIBIT E-1

Effect of Diversions from the Guadalupe River on San Antonio Bay and Estuary Health

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1.0 INTRODUCTION

This report presents the results of an analysis of the effects of changes to freshwater inflows to San Antonio Bay that would be expected from increased diversions from the Guadalupe River for the Exelon Nuclear Power Plant Project. Based on this analysis, I disagree with the finding presented in the Early Site Permit Application (ESPA) that suggests that this project would have no major impacts on the aquatic health of the Guadalupe Estuary and San Antonio Bay. The application fails to address water needs to protect the health of aquatic resources of San Antonio Bay. Water extractions required to meet the needs for this project would result in lowering of freshwater inflows into San Antonio Bay causing an increase in the severity, frequency and duration of "man made" drought conditions. This increase would likely lead to an alteration in the ecosystem structure by either reducing overall fisheries production or by favoring one fisheries species production at the expense of others, thereby reducing biodiversity (Pulich et al. 1996). Specifically, increased diversion would result in salinity conditions unsuitable to many estuarine species including the Blue Crab, a primary food source for the Federally Endangered Whooping Crane.

After describing the basic framework for analysis of freshwater inflows, this report describes the effect of water management on freshwater inflows into San Antonio Bay. This involves developing estimates of hydrologic time series data for natural, existing and potential or proposed future inflow conditions. This step is accomplished via the application of a Water Availability Model (WAM) developed by Texas Commission on Environmental Quality (TCEQ) and modified and employed by the South Central Texas Regional Water Planning Group (Region L).

Freshwater inflows expected under the proposed operations of the Exelon project were compared to target inflows determined by Texas Parks and Wildlife Department (TPWD). The freshwater inflow needs studies (FINS) determined that a minimum flow of approximately 1.15 million acre feet per year, with an appropriate monthly distribution, is necessary to protect the health of the San Antonio Bay ecosystem. The proposed operations of the Exelon plant, since they rely on existing unperfected water rights, would make no attempt to limit diversions subject to these freshwater inflow targets and thus these diversions would cause an increase in the amount of time in which the targets are not met. While FINS clearly states that naturally occurring periods of low flows result in events in which these target flows are not satisfied, the study explicitly warns that "an increase in the severity, frequency, or duration of drought flows will alter the ecosystem structure by either reducing overall fisheries production or by favoring one fisheries species production at the expense of others, thereby reducing biodiversity." (Pulich et al. 1996) The operations of the Exelon project will result in a significant increase in the severity, frequency and duration of these "manmade" drought conditions.

Next, a two-dimensional finite element salinity and circulation model (TxBLEND) (TWDB 1999) was used to simulate changes in salinity conditions predicted by the proposed inflows. These simulations demonstrate that operation of the Exelon project will result in a dramatic change in salinity conditions in the bay resulting in unsuitable habitat conditions for the Blue Crab (a primary food source for the Whooping Crane) and unsuitable drinking water for the Whooping Cranes in areas adjacent to its winter territories. The operations of the Exelon project therefore represent a clear threat to the long term viability of this species.

Based on this analysis it is reasonable to expect that the project will result in an increase in the severity, duration and frequency of manmade drought conditions over the long term and in unacceptably high salinity conditions during naturally low inflow periods.

1.1 Response to analysis presented in the ESPA

The ESPA includes an analysis that attempts to relate some components of the freshwater inflow regime (spring and fall freshets and summer low flows) directly to the abundance of select marine species. Unfortunately, this simplification of bay health and the factors that regulate it, produced an analysis that explains very little of the variation in species abundance. While this approach may ultimately advance understanding of the relationship between inflow and species abundance, this approach is not yet well documented in the scientific literature. More problematic than the approach, is the way in which it was employed in the report.

Having developed simple linear regressions that explain little of the overall variation, the study purports to apply these regressions to alternative inflow scenarios. The problem is that there is almost no difference between the scenarios selected in terms of total freshwater inflow. The baseline scenario selected for this study references the TCEQ WAM (HDR 1999). This version of the model includes an annual diversion for Certificate of Adjudication 18-5178 (a proxy used to represent potential water supply for the proposed Exelon project) equal to 105,081 acre feet per year out of a permitted amount of 106,000 acre feet per year. Since this model already assumes essentially the full exercise of this water right, it appears that the only change made to "Comparative Scenario One" (used to evaluate the impact of the project) was to change the monthly demand pattern while maintaining the annual diversion amount. It is no surprise that a regression, which explains little variation, applied two flow scenarios that represent the same annual diversion, would produce results that show "small" difference. This analysis is an example of burying the impacts of the project in the proposed baseline (i.e. assuming the impacts have already occurred) and does not provide the kind of analysis necessary to support decisions that will affect a resource as ecologically valuable as San Antonio Bay.

Apparently there is some controversy as to the accuracy of historical use reported with Certificate of Adjudication 18-5178. While the TCEQ continues to rely on the 105,081 (based on records obtained from the South Texas Water Master by HDR during the initial development of this model), the South Texas Regional Water Planning Group, has since adjusted this figure from 105,081 acre feet per year to 4,199 acre feet per year.

Adding to this confusion the ESPA report reported that water use under GBRA/UCC rights at the GBRA Saltwater Barrier did not exceed 51,670 acre feet per year from 2000 to 2006 a figure that is inconsistent with records obtained from the South Texas Water Master in August 2008. According to the TCEQ list of active water rights in the Guadalupe Basin, GBRA/UCC hold seven permits in the lower basin (3873 and 5173-5178) with permitted amount totaling approximately 175,500 acre feet per year. Reported diversions for Certificate of Adjudication 18-5178, one of these GBRA/UCC water rights, are provided in Table 1.

Table 1 Reported diversions for Certificate of Adjudication 18-5178

Permited	35,333	35,333	35,333	106,000
	Mun	IND	IRR	
Year	5178-400	5178-401	5178-402	Total
1992	50,336	0	0	50,336
1993	54,766	0	0	54,766
1994	62,903	7,740	34,438	105,081
1995	35,127	3,429	16,104	54,659
1996	35,230	7,128	0	42,357
1997	35,259	3,749	0	39,007
1998	43,850	13,908	0	57,758
1999	48,777	8,985	1,890	59,652
2000	35,333	11,712	0	47,046
2001	35,333	18,772	4,421	58,526
2002	31,469	19,760	0	51,229
2003	34,934	9,980	0	44,914
2004	35,159	0	0	35,159
2005	34,682	18,218	0	52,900
2006	35,333	9,560	0	44,893
2007	30,127	3,333	0	33,460
2008	18,265	0	0	18,265

In any case this "surplus" 100,000+ acre feet per year of unperfected water has been identified in a number of potential water management strategies including the Lower Guadalupe Water Supply Project (LGWSP) to meet GBRA needs as well as the Exelon Nuclear Project. (Note - while GBRA is a potential supplier of water for the Exelon project, the demands identified in the LGWSP for GBRA needs are distinct and in addition to the water needs of Exelon.)

Even assuming a useful, simple statistical approach to relate species abundance to freshwater inflows could be developed, this regression should be applied to the real differences in inflows that can be expected from the development of this project. At minimum this suggests using the Region L WAM to represent present conditions. A better approach would be to evaluate the flows that have naturally occurred. This would provide some meaningful context to understand the significant alterations to freshwater inflows that have already occurred, before moving ahead on even greater water diversions. The present report uses estimates of both natural inflows and the Regional L present conditions model runs for the long term analysis of drought severity, frequency and duration (Section 4.0). Measured inflows based on USGS gage data are the basis for the salinity - circulation modeling for the 1988-89 period (Section 5.0).

2.0 DETERMINATION OF FRESHWATER INFLOW NEEDS IN TEXAS BAYS AND ESTUARIES.

Recognizing the importance of maintaining freshwater inflows, the Texas Legislature has passed several pieces of legislation with the goal of maintaining a sound ecological environment for Texas Bays and Estuaries (Senate Bill 137 (1975), House Bill 2 (1985) and Senate Bill 683 (1987)). These early legislative initiatives evolved into an approach that is now commonly referred to as the "State Methodology". Among its most important features were the development of perhaps the most comprehensive estuarine monitoring program ever created and the development of a suite of modeling and analysis tools (TWDB 1990, TWDB 1999) to support development of freshwater inflow recommendations. An early step of this methodology is the development of statistical relationships between freshwater inflows and an index of the biological conditions, referred to in the analysis as "productivity." Salinity gradients predicted by these inflows are compared to species abundance maps to access the estuarine conditions produced by these inflow recommendations to protect bay health. While most of the literature on estuarine science continues to recognize the importance of freshwater inflow on estuarine health by creating and preserving low salinity nurseries, transporting sediments, nutrients and organic matter downstream, and affecting estuarine movements and reproductive timing (Longley 1994, Montagna et al. 2002: SAC 2004, SAC 2009), development of simple regression equations that directly relate flows to biology has proven elusive. This is perhaps not surprising given the complexity of the system, the relative paucity of the data (even in Texas where this data is more abundant than anywhere else in the world) and the simplicity of the statistical formulations that have been developed up to this time. Recent attempts to relate specific components of the inflow regime similar to the approach taken in the Exelon permit application (e.g. spring freshets and or summer low flows) hold some promise for uncovering these relationships, however these approaches have proven unsuccessful, and that failure is apparent in the analysis presented in the permit application.

Much of the recent literature on the management of flows to protect a sound environment, while recognizing the need to better explain direct causal relationships, has focused on more holistic approaches to protect ecosystems (Poff et al. 1997, Bunn and Arthington 2002). This has led to a focus on habitats, which in estuaries are significantly influenced by salinity conditions (BIO-WEST 2007). Alber (2002) presents a conceptual model for estuarine freshwater inflow management that is summarized in Figure 1.

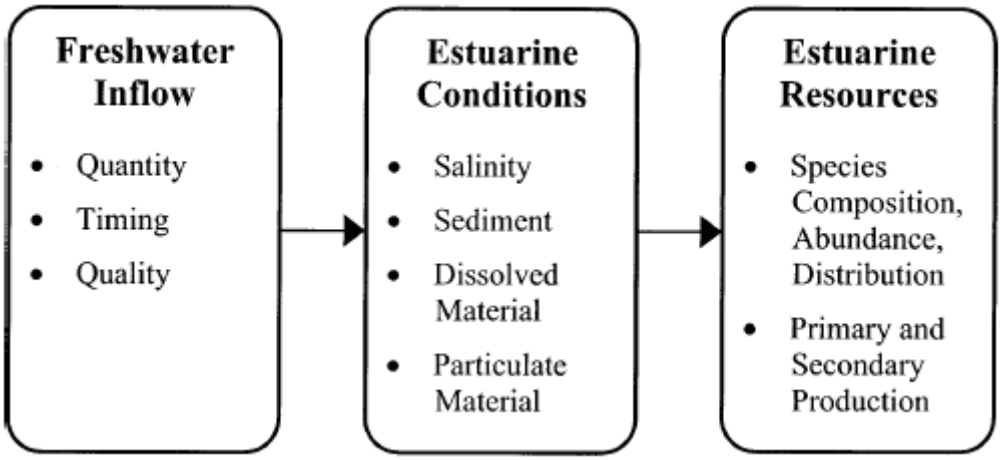

Figure 1 Schematic diagram of the effects of freshwater inflow (from Alber 2002)

The most recent legislative initiative in Texas related to freshwater inflows (Senate Bill 3, 2007) established the Texas Science Advisory Committee for Environmental Flows (SAC). The SAC produce a guidance document for the determination of freshwater inflows for Texas Bays and Estuaries. (SAC 2009) Acknowledging a range of approaches, the SAC recommended an approach between the simple flow-productivity model employed in earlier studies and the complexity of a more complete model. This inflow-salinity-biology paradigm was employed by the Senate Bill 3 Bay and Basin Science Team (BBEST) working on the Galveston Bay system (TSJ BBEST 2009) and is currently being used by the Guadalupe San Antonio BBEST to evaluate flow recommendations for San Antonio Bay. This approach is the basis of the salinity analysis performed in Section 5.0 of this report.

3.0 EFFECTS OF WATER MANAGEMENT OF FRESHWATER INFLOW INTO SAN ANTONIO BAY

Operations of the Exelon Project will result in significant decrease in freshwater inflows as compared to the natural and current conditions.

Freshwater inflow to bays and estuaries are considered "master" variables. Their primary functions are to transport sediments and nutrients necessary for the long term health of the system and to set the salinity conditions suitable for the estuary to serve its nursery function for the different plants and animals in the bay. (Longley 1994) Therefore the first step in assessing the potential impacts of a new water diversion on the ecological health of San Antonio Bay is to develop estimates of freshwater inflows. A reasonable set of inflow estimates should include natural, current and future conditions. Estimates of natural conditions serve a baseline against which to evaluate existing and proposed alterations. Natural systems have evolved in response to the magnitude, duration, frequency of inter and intra annual variations in inflow conditions. Alteration of these conditions beyond some point will likely lead to a shift in ecosystem structure. Therefore some understanding of these conditions is an important starting point in any evaluation. The current conditions should also be evaluated to understand and explain how past alterations have resulted in the state of the ecological health observed currently. Finally, responsible planning requires that some effort be made to predict the freshwater inflow conditions based on reasonable estimates of proposed future diversions.

Long term estimates of freshwater inflows assuming natural, current and future water use scenarios are determined through the application a Water Availability Model (WAM). WAMs have been developed for each of the 23 river basins in Texas at the direction of the 75th legislature. The primary purpose of these models is to apply water use scenarios to historical flow conditions to predict water availability for existing and future water rights permits. WAMs are essentially accounting models that track stream flow and diversions throughout a river basin and the resulting outflow to the estuary. The Guadalupe – San Antonio (GSA) WAM has also been modified and used for long term water planning by the Senate Bill 1 South Central Water Planning Group (Region L) and thus includes many of the proposed future water development and management plans.

The GSA WAM was used to develop estimates of natural, current and future inflows into San Antonio Bay. Naturalized inflows are flows for which the effects of human alterations have been removed. These include surface water diversions, wastewater return flows and water impounded in reservoirs and the evaporation associated with these impoundments. These flows should also account for reductions in spring flows from ground water pumping. When the GSA WAM was first developed it was believed that groundwater models for the Edwards Aquifer produced inaccurate results. The 2006 Region L water plan included an estimate of natural flows correcting for the effect of groundwater diversions. These have been used in the this report as the best estimate of natural conditions. A WAM has also been developed to simulate the effect of current conditions which includes existing water use and return flow rates. These model simulations do not reproduce historical flows rather they simulate flows that would have occurred in the past had water demands and returns been held constant through the

historical record. For example when the current conditions run simulation reports flows for 1940, these values estimate the flow that would have occurred assuming a repeat of 1940 hydrology but with present water use[1].

Proposed water management strategies including the Exelon project will result in additional reductions in freshwater inflows. While these reductions may be tempered to some extent by increased wastewater return flows (assuming more aggressive reuse projects are not developed), major expansions of existing diversions and new water rights permits are included in the South Central Texas Regional Plan. While the Exelon projects represents the largest single increase in water use, the plan also calls for increased diversions from Canyon Reservoir and full exercise of other existing water rights to meet long term growth in basin water demands. Since the proposal for the Exelon water right assumes that this water will be made available from an existing, though currently unperfected water rights, there are no special conditions that would limit diversions subject to the needs of the bay. The project has the potential to effectively dry up the river before it reaches San Antonio Bay. Commitment of water for the Exelon project has made it necessary for GBRA to seek an application for additional diversions to satisfy demands that had previously been identified as being met by the Lower Guadalupe Water Supply Project (TWDB 2006) but will be unavailable if Exelon exercises their reservation agreement with GBRA. While it is true that there are a number of other water rights that are not exercising their full permitted amount, and the cumulative impact of these smaller individual increases in diversions should not be dismissed, due to its proximity to the bay and the seniority of the permit that would likely be used to supply this water, the exercise of the this water right for Exelon would have especially detrimental effects to bay health relative to the other growing demands in the basin.

4.0 EVALUATION OF LONG TERM CHANGES IN FRESHWATER INFLOW REGIME

Decreased freshwater inflows to San Antonio Bay, to supply water for the Exelon project, would result in significant increase in the severity, frequency and duration of drought conditions.

Currently the best available science on the freshwater inflow needs for San Antonio Bay is presented in "Freshwater Inflow Recommendation for the Guadalupe Estuary" (Pulich et al. 1999). The study is commonly referred to as the Freshwater Inflow Needs Study (FINS). In this study a team of estuarine ecologists "recommends MaxH (1.15 million ac-ft) inflows as the lowest target value to fulfill the biological needs of the Guadalupe Estuary on a seasonal basis." MaxH stands for maximum harvest and is the result of an optimization program developed by the TWDB to determine the flow that produces the greatest amount of fisheries biomass subject to a number of constraints and objectives. Similarly MinQ is another output from the optimization program which meets slightly different objectives. MaxH and MinQ were among the flows considered by TPWD in developing their recommendation. The report goes on to state that

> "There have been, and will continue to occasionally be, times when nature does not provide the water to meet the recommended MinQ or MaxH inflows to San Antonio Bay. The biological effects of these reduced flows on the Guadalupe Estuary fisheries productivity and biodiversity are examined here. Maintenance of productivity of economically important and ecologically characteristic sport or commercial fish and shellfish species and the food webs that support them are goals identified in the Texas Water Code Section 11.147(a). The freshwater inflow targets presented in this document are designed to meet the requirements for beneficial

[1] Unlike the model natural and future flow scenarios, the long term time series referred to as "current conditions" in flows analysis is not the same as the flows that are used to simulate salinity for existing conditions. For the purposes of salinity simulations the present situation is estimated based on the actual flows that were measured or calculated using a rainfall runoff model for the years simulated.

inflows as described in the Texas Water Code Section 11.147(a). A major concern of the TPWD is that an increase in the severity, frequency, or duration of drought flows will alter the ecosystem structure by either reducing overall fisheries production or by favoring one fisheries species production at the expense of others, thereby reducing biodiversity."

Time series analysis of flows under natural, current and proposed conditions demonstrates marked increase in the severity, frequency and duration of drought resulting from human alterations.

Severity of drought is defined here as the shortfall or magnitude by which flows fall below the level that has been determined to be necessary to protect the sound ecological environment of the estuary. Table 2 shows the average and maximum shortfalls under the three flow scenarios. The average shortfalls under the proposed conditions are about 50% greater than natural in May to almost nine times greater than natural in April. From the last column on the left we see that the maximum shortfalls under the proposed management scenario are equal to the target flow. This means that under the proposed scenario the river would, at times, be completely dewatered. These results clearly demonstrate an increase in the severity of drought conditions beyond those that would be expected under natural conditions. Severity is important for a number of reasons. The first and most obvious being, that as flows decrease, habitat conditions in the bay become less and less suitable resulting in more negative impacts on the marine community. The second related issue is that while there may be some uncertainty with the exact values in the target inflow recommendations, as flows continue to decrease further below these targets this uncertainty decreases as well; at some point there is little question that conditions will become stressful to the marine community.

Table 2 Severity of drought conditions under natural, current and proposed flow conditions.

		Average Severity of Drought			Maximum Severity of Drought		
Month	MaxH	Natural	Current	Proposed	Natural	Current	Proposed
Jan	111,200	31,814	44,016	62,907	91,386	99,397	111,200
Feb	124,200	33,717	47,389	66,703	98,635	107,602	124,200
Mar	52,420	4,697	12,607	28,696	28,084	38,403	51,832
Apr	52,420	3,034	12,007	27,733	23,545	36,912	52,420
May	222,600	106,969	132,218	151,230	179,592	199,514	215,029
Jun	162,700	59,488	86,417	104,178	145,714	161,490	162,700
Jul	88,610	22,345	47,346	63,156	71,485	87,437	88,610
Aug	88,330	20,809	44,423	59,791	71,845	86,989	88,312
Sep	52,420	5,919	19,024	32,476	32,634	51,097	52,420
Oct	52,420	4,733	17,524	34,947	25,134	38,881	52,420
Nov	73,830	13,058	23,229	39,433	55,182	64,068	73,802
Dec	66,200	9,861	18,509	35,561	41,149	49,060	66,172
All		29,644	46,520	63,491	179,592	199,514	215,029

The duration of drought events would also be expected to substantially increase under the water management plan that includes the proposed Exelon project. A drought event is defined here as the continuous period of time during which flows remain below recommended freshwater inflow targets. Table 3 shows the duration of individual drought events under the three scenarios. The number of drought events is reasonably consistent among all three scenarios (92-99 events) however the duration of these events would be considerably longer under the proposed future condition. Under natural conditions only four drought events lasted more than 6 months and only one lasted more than a year, that maximum duration event being the 17 months representing a repeat of the historical hydrology from October 1955 to February 1957. Under the proposed plans 17 drought events would be expected to last more than 6 months and one, from November 1953 to February 1957 would result in freshwater inflows below their recommended targets for 40 continuous months. This is important because the freshwater inflow recommendations, given the time lag involved in the circulation of freshwater into the

bay, are in part predicated on antecedent conditions. Consistently failing to meet the minimums for extended periods, will require longer periods of normal inflows before conditions become suitable again.

Table 3 Duration of drought conditions under natural, current and proposed flow conditions.

Duration (months)	Natural	Current	Proposed
1	43	38	36
2	26	24	16
3	7	13	19
4	6	8	4
5	4	3	6
6	2	4	1
7			1
8		1	
9	1	2	3
10	1	2	1
11	1		1
12			1
13		1	1
14		1	1
15			
16			
17	1	1	
18			
19			
20			
21			1
22		1	
23			
24			1
25			
26			
27			
28			
29			
30			
31			
32			
33			
34			
35			
36			
37			
38			
39			
40			1
41			
Total	92	99	94

Finally, the frequency of drought conditions would be substantially increased with the implementation of the plans for the Exelon project. Frequency of drought conditions is defined here as the number of months in which the target flows are not met. These frequencies are presented in Figure 2 as the percent of months over the 56 year WAM simulation period during which the flows would be expected to be below recommended levels. Clearly, as the FINS notes, there are times when even under natural conditions the targets would not be satisfied, however the proposed project increases these

occurrences particularly in the spring and fall when failure to satisfy the flow recommendations would rise from around 10% of the time to over 30% of the time. Drought conditions would be expected three times more often under the proposed plan than would have occurred under natural conditions.

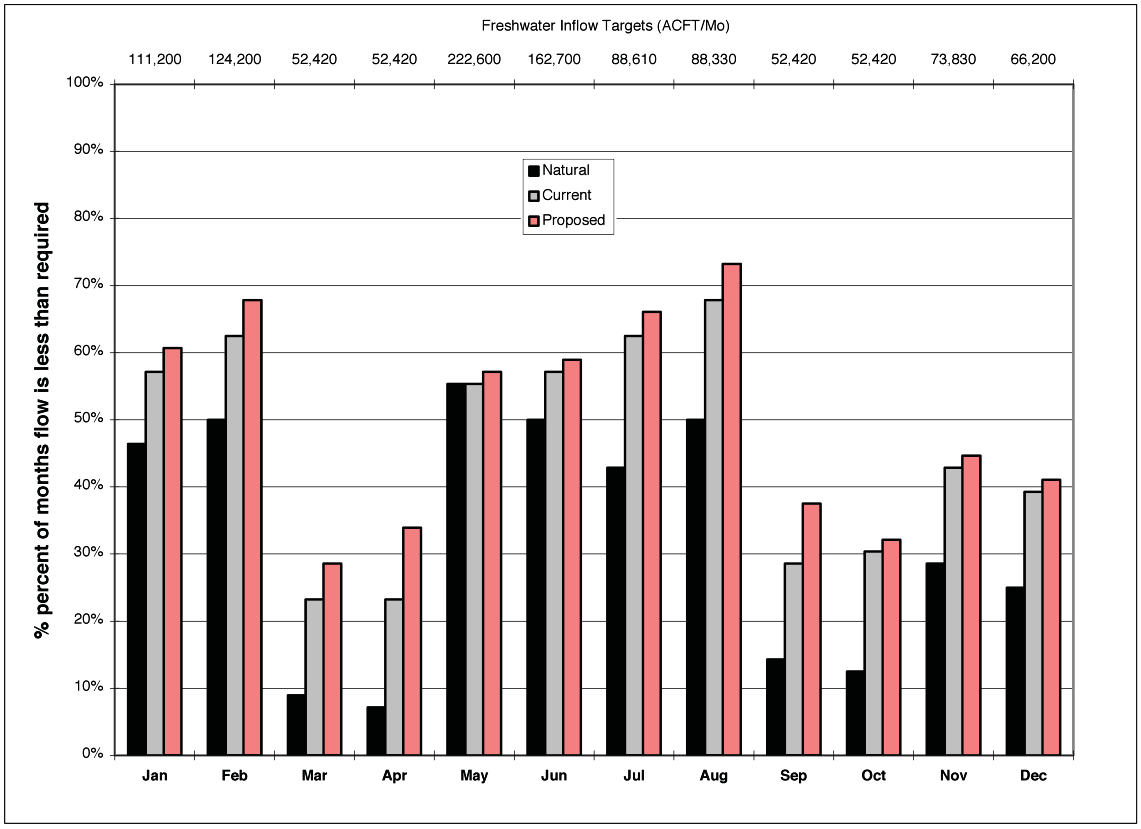

Figure 2 Frequency of drought conditions under natural, current and proposed flow conditions.

5.0 PREDICTION OF CHANGES IN BAY SALINITY RESULTING FROM INCREASED DIVERSIONS

These drought conditions will result in salinity conditions that are unsuitable for Blue Crabs (a primary food source for the Federally Endangered Whooping Crane) and unsuitable drinking water for the Cranes themselves. These impacts on their primary food and water sources pose a substantial threat to the Cranes' long term viability.

The methodology employed by TPWD to determine the freshwater inflow targets for San Antonio Bay relied in part on analysis of the results of a two-dimensional finite element model (TxBLEND) to simulate salinity conditions under alternative flow regimes. Based on analysis of long term monitoring in the bay, TPWD determined salinity preference zones and suitability of other habitat parameters for economically and environmentally important finfish and shell fish. The areas of suitable habitat (area falling within these preference zones) were calculated for several flow regimes. The report concluded that "fisheries samples vs. modeled salinity gradients clearly established that average salinity gradients correlated with peak densities of target species would be best provided by FWI regimes at least equal to the Max H case." (Pulich et al. 1999) The finding for MaxH targets was supported by time series analysis of salinity regimes and total fisheries harvest predicted by regression equations.

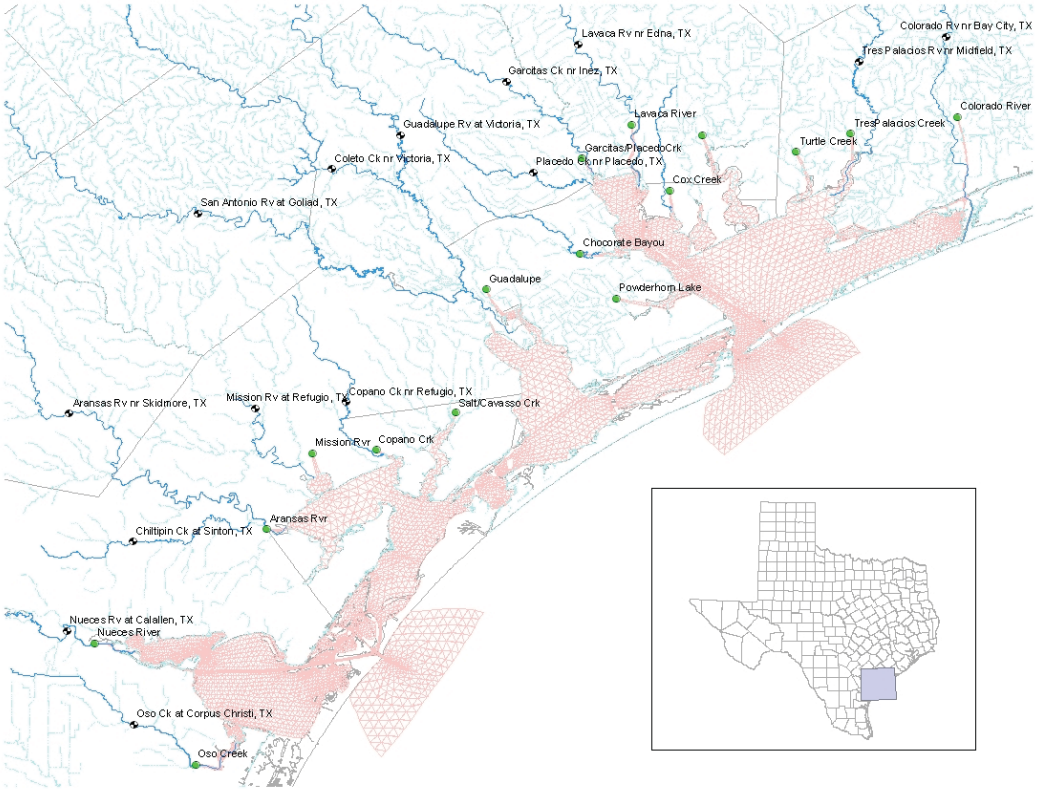

Figure 3 TxBLEND Four Bay Model Mesh

To evaluate the effect of the proposed Exelon project, salinity gradients have been predicted using the TxBLEND model with the freshwater inflow adjusted to reflect natural, current and proposed conditions. Recall that the natural and future flow scenarios are based on WAM model predictions of freshwater inflow, while the current conditions scenario represent the salinities predicted with flows that were observed and estimated from rainfall runoff calculations. The TxBLEND model was used to simulate the 2 year period from 1988-89. This period was initially selected because it represented the period of overlap between the existing WAM and TxBLEND models (Figure 4), the TxBLEND model has recently been updated to cover the period from 1987-2009. While this update provides a longer simulation of the salinity model (TxBLEND), the WAM model period of record still limits the analysis to years before 1990. As this analysis is primarily concerned with the effect of increased diversions during low flow periods, the analysis results presented below only include 1988 and 1989.

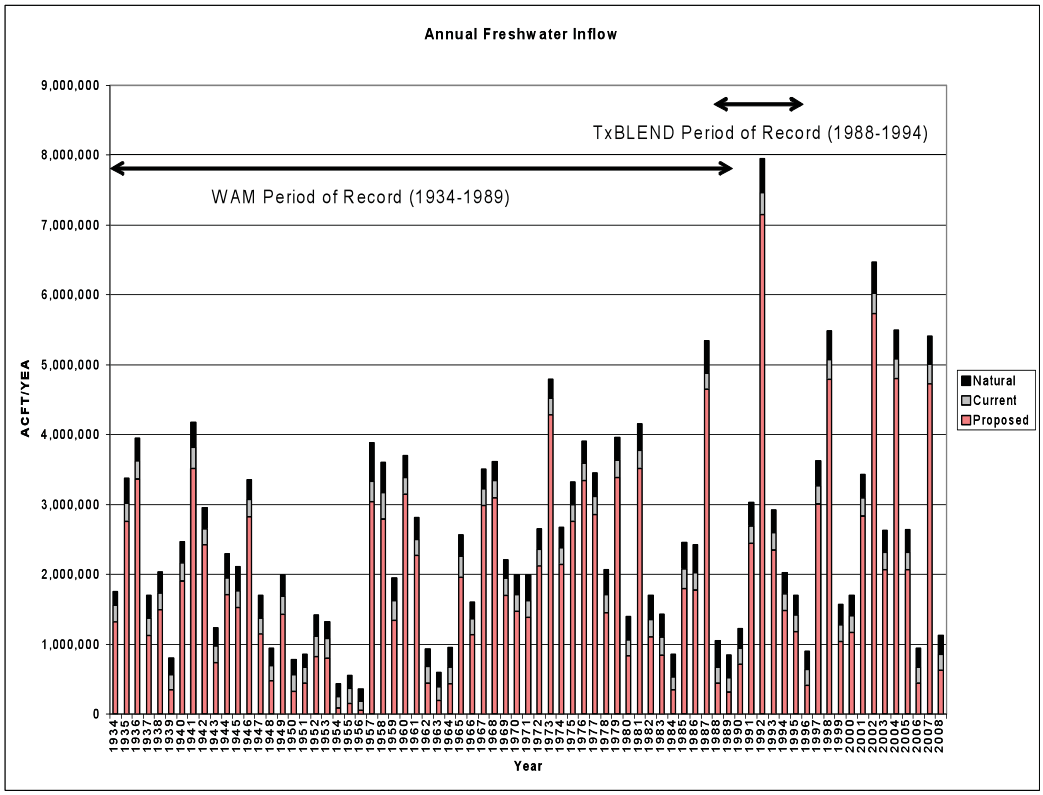

Figure 4 Annual Inflow into San Antonio Bay

Monthly maps of isohalines produced by these simulations depict a shift from a condition that under natural conditions would be viewed as a severe drought but would still provided reasonable salinity refugees (Figure 7) to a condition under proposed management that very little suitable salinity areas occur (Figure 7).

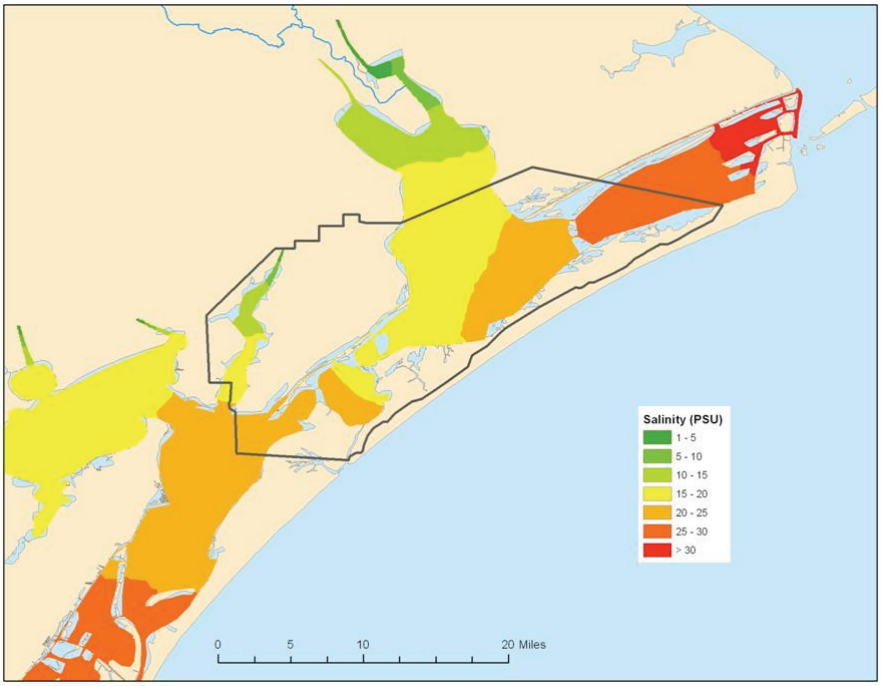

Figure 5 Natural Conditions Simulated Salinity (February 1989)

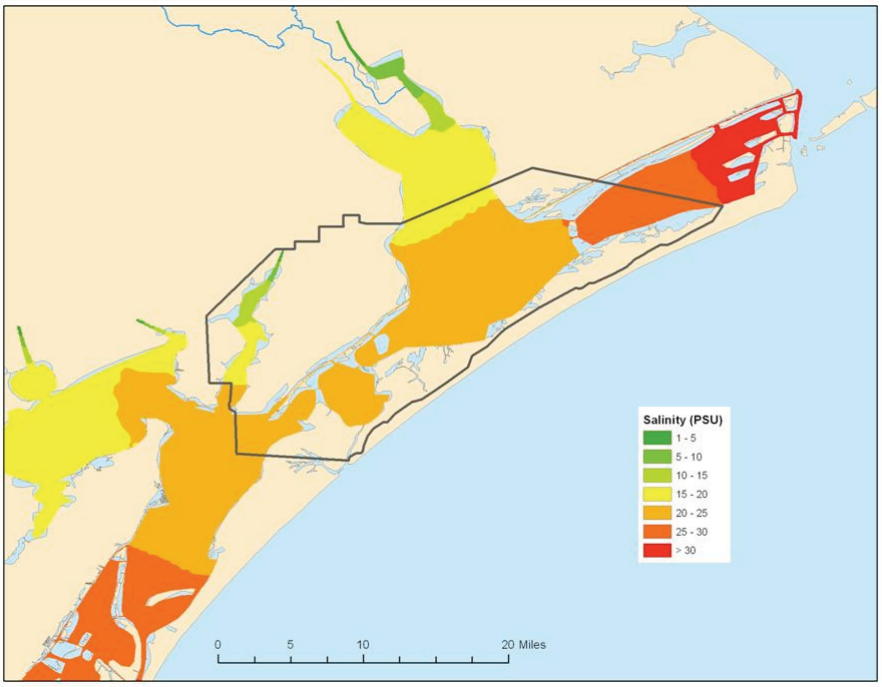

Figure 6 Current Conditions Simulated Salinity (February 1989)

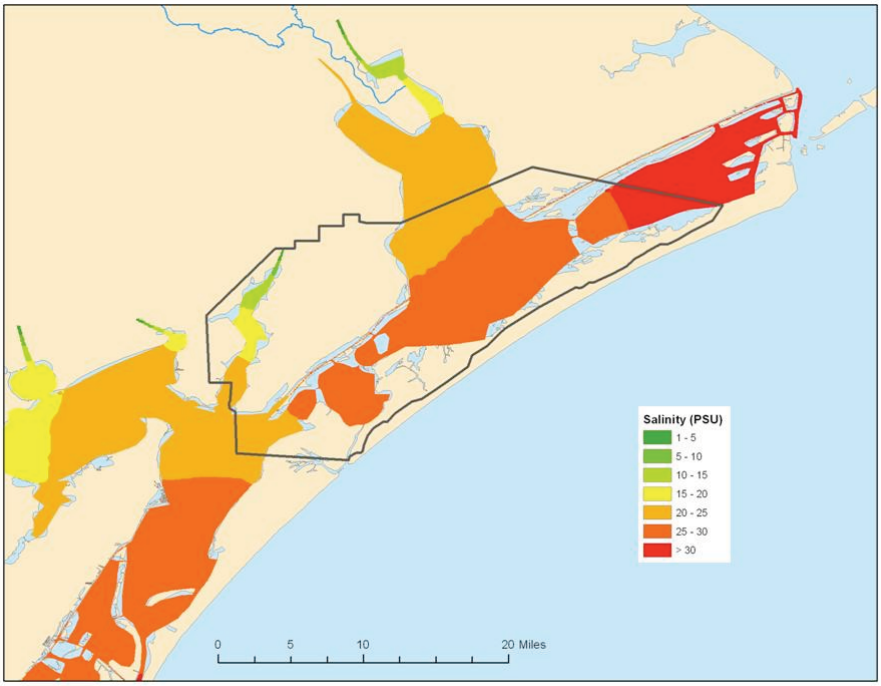

Figure 7 Proposed Simulated Salinity (February 1989)

The simulation also shows that under more natural FWI conditions, the salinity gradient in the bay even during these low flow year tend to return to a state where large areas of the preferred salinity zones exist yet under the proposed condition much of the bay remains mesohaline (20-50 PSU) even in the spring. Figure 8 - Figure 10 focuses on the parts of San Antonio and Mission Aransas Bays that are within the designated critical habitat of the federally endangered Whooping Crane. These figures show the percent of that bay area that is within the different salinity ranges for the two year simulation from 1988-1989.

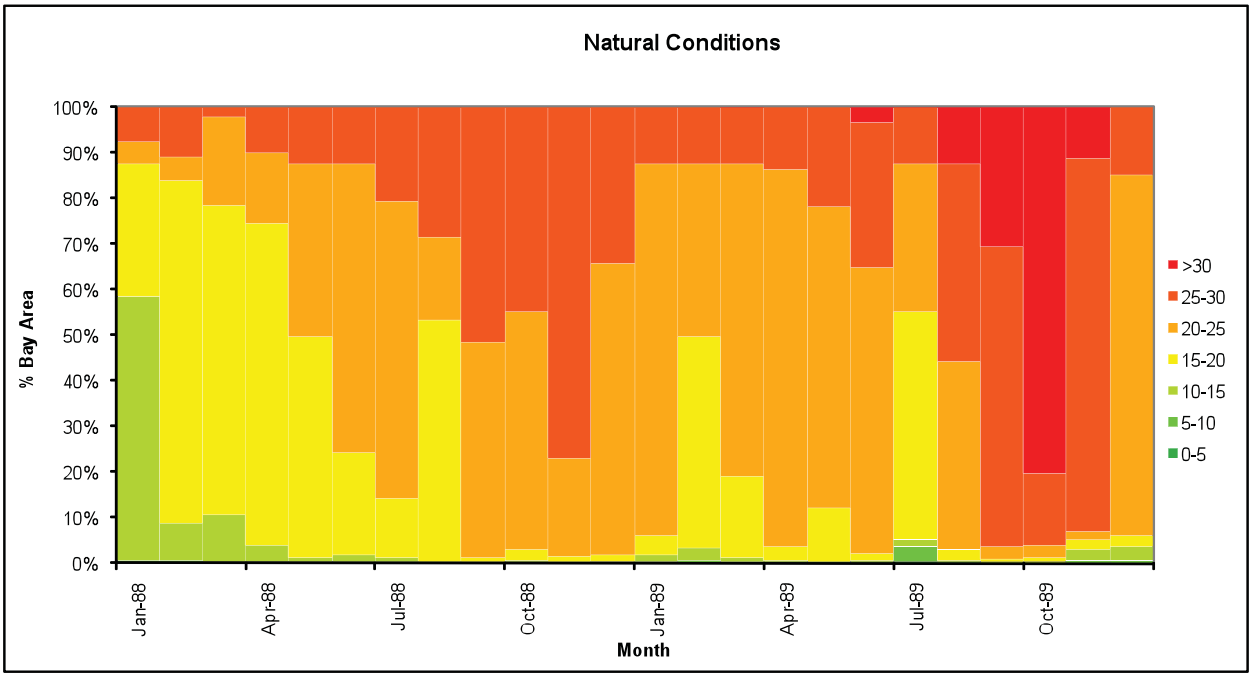

Figure 8 Natural Conditions - Percent of Bay Area within Salinity Ranges

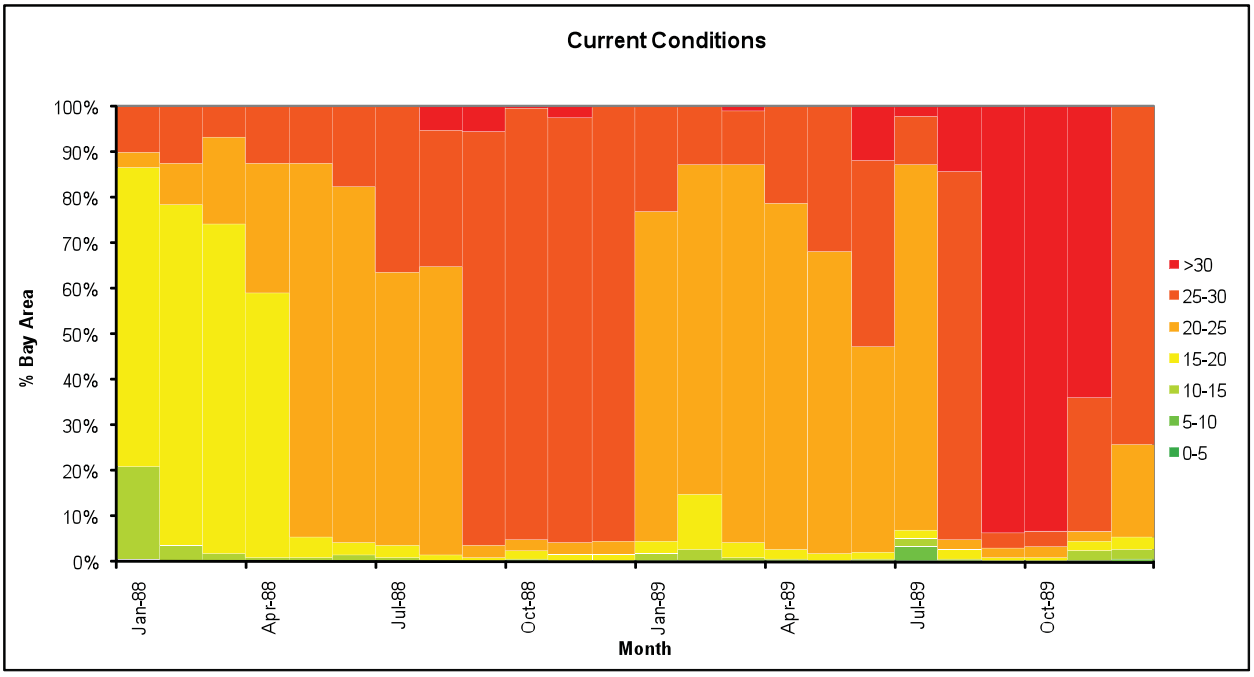

Figure 9 Current Conditions - Percent of Bay Area within Salinity Ranges

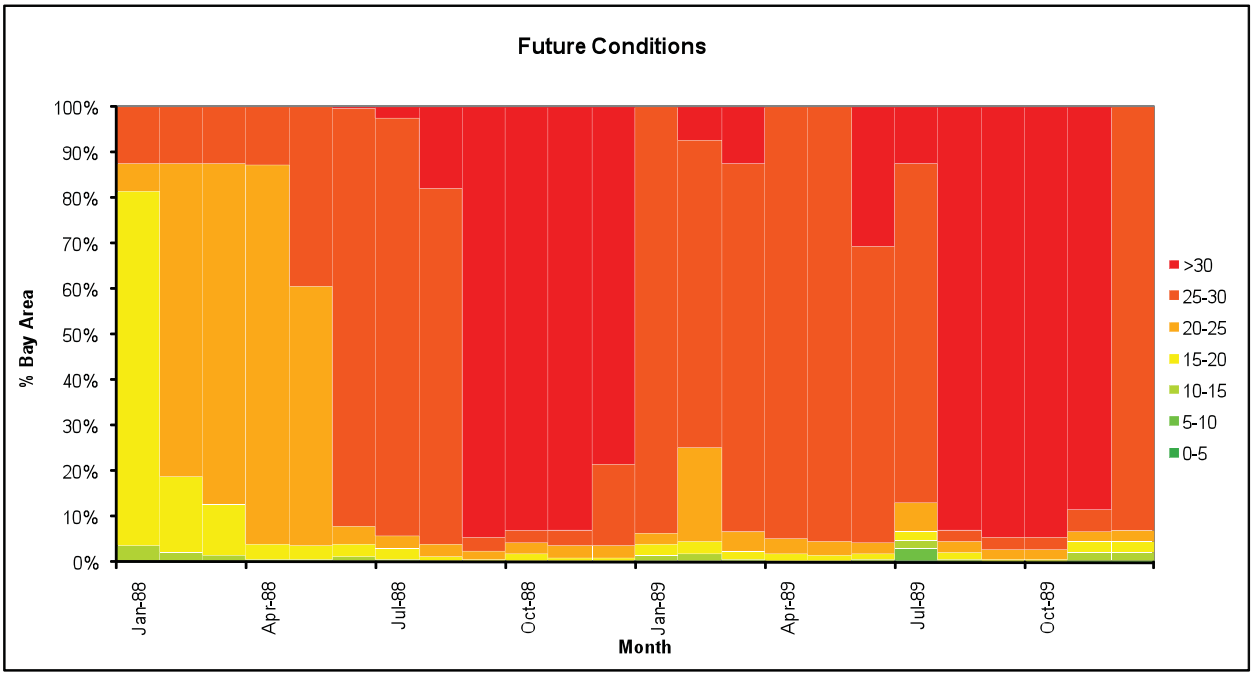

Figure 10 Proposed Conditions - Percent of Bay Area within Salinity Ranges

5.1 Model Validation

This report has focused on the period of time from 1988-1989 in order to estimate the effect of proposed development on salinity conditions during a low flow period. The TxBLEND model has recently been extended to cover the period from 1987-2009. Prior to this extension, the TWDB had calibrated the model based on the period from 1987-1997. Calibration is a process of adjusting model parameters, in this case dispersion and bottom roughness coefficients, to improve the models performance at predicting hydrodynamic and circulation estimates. The extension to 2009 has allowed the TWDB to perform a model validation. In a model validation the model is executed using an independent dataset (1998-2009), and result are compared with observed values without making any adjustments to model calibration parameters. Based on this analysis the TWDB concluded that "TxBLEND captures major salinity trends in the system reasonably, but high frequency fluctuations are more difficult to simulate. The model also performs better at mid and lower bay locations than in the upper estuary." (TWDB 2010) While these caveats might raise concerns were the model employed to track hourly or daily fluctuations near the mouth of the Guadalupe River, it supports the way the model has been used in this study, namely to track course time step (monthly) changes in salinity in the Whooping Crane Critical habitat area in the lower part of the bay.

Figure 11 shows the location of salinity monitoring stations used in the calibration and validation analysis. The green sites were active in the early period and were used in both the validation and calibration analysis, the red site labeled GBRA 1 is a relatively recent station deployed in 2004 and is used only in the validation analysis.

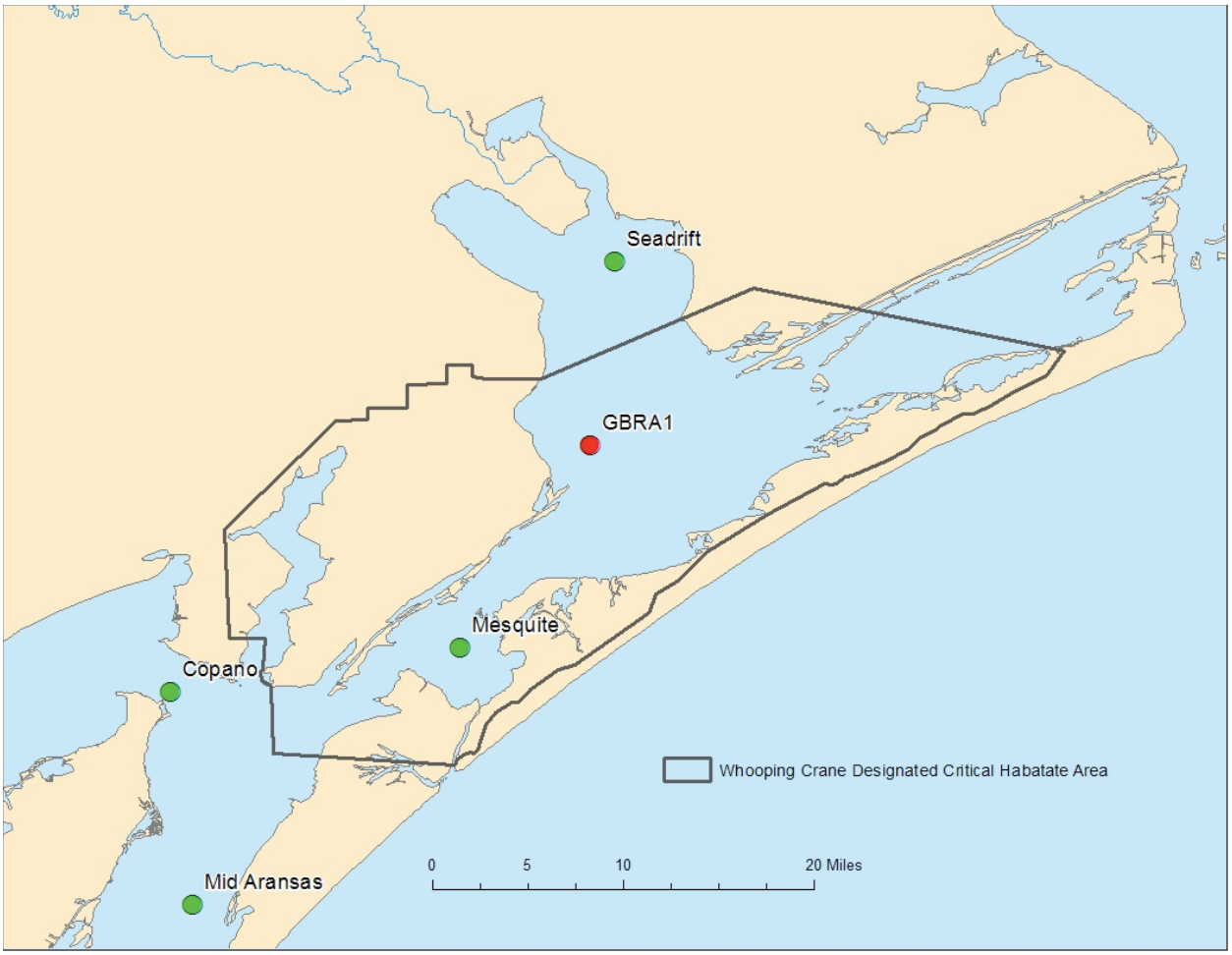

Figure 11 Location of the Salinity Monitoring Station with Whooping Crane Designated Critical Habitat Area.

For both the sites within the Whooping Crane designated critical habitat, Mesquite Bay and GBRA1, the TxBLEND model explains a high degree of the daily average salinity. TWDB reports an r^2 equal to 0.90 for Mesquite Bay for the calibration analysis and 0.86 for GBRA1 for the validation analysis. Figure 12 and Figure 13 from the calibration and validation report demonstrate how the model accurately tracks salinity at these two sites.

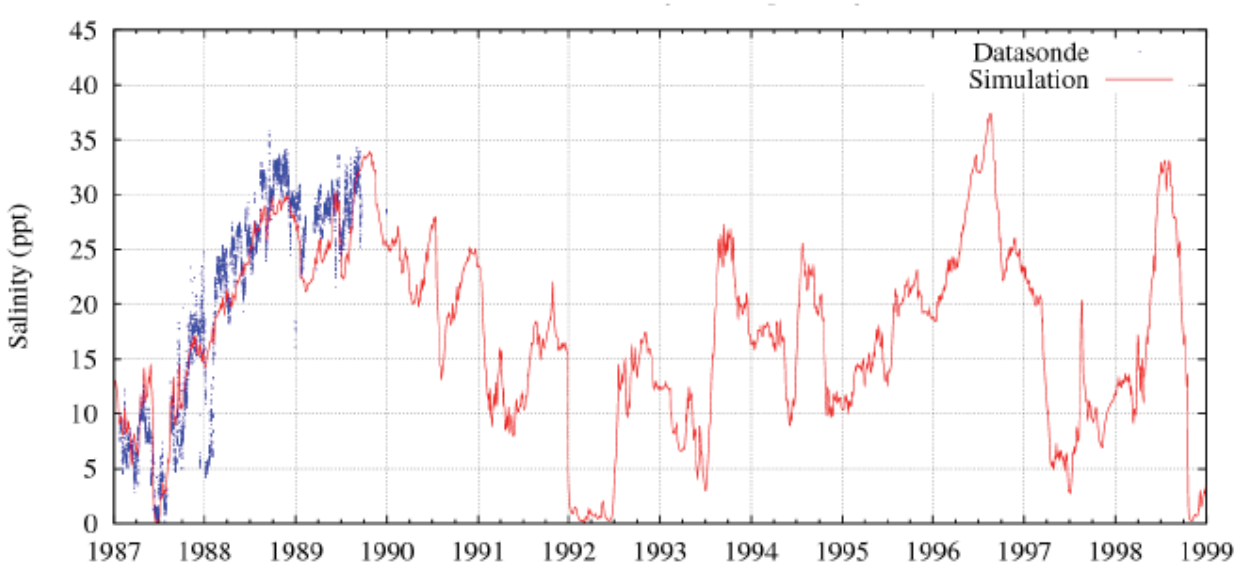

Figure 12 Observed (blue) versus simulated (red) salinities in Mesquite Bay for a period including 1987 to 1990, with additional simulated salinities up to 1999. (TWDB 2010, Figure 31.)

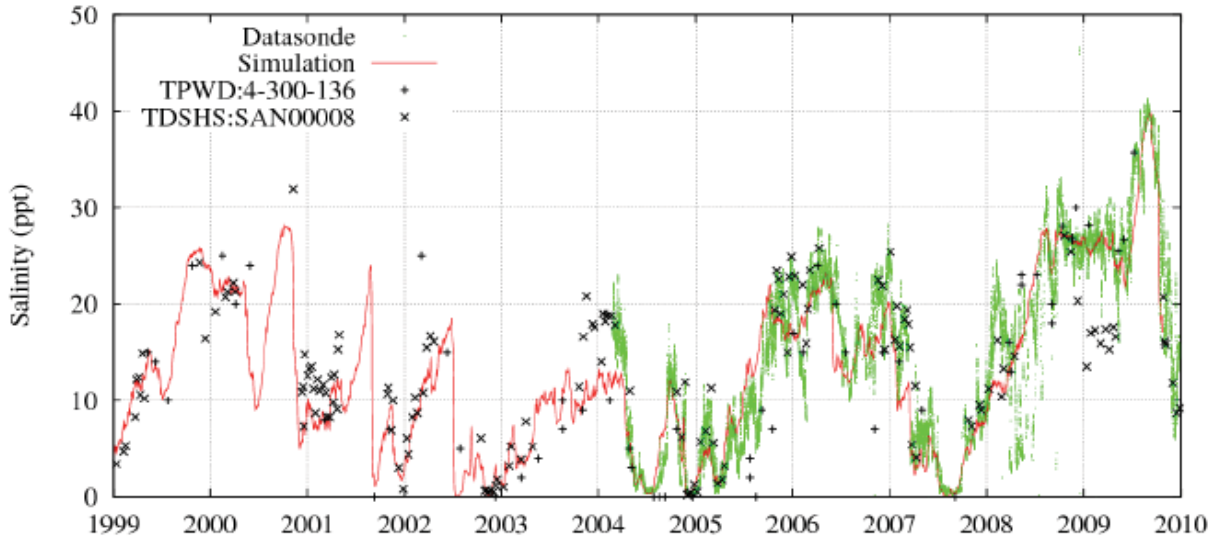

Figure 13 Simulated (red) and observed (green, + or x) salinities at the GBRA-1 site in San Antonio Bay for the period 1999-2009. The GBRA-1 station (green) is located at 28.2597 N, -96.7736 W. Data collected by TPWD (+) was from grid cell 4-300-136 located at 28.2615 N, -96.7771 W. Data collected at TDSHS (x) SAN00008 site was located at 28.2464 N, -96.7692 W (TWDB 2010 Figure 41.)

6.0 DISCUSSION

The recommendations in the FINS report were developed based on a number of analyses. One of the more important was a comparison of the percent of the bay area for which there is preferred salinity zones for the various marine species. Table 4 shows the percent of the bay area that corresponds with the peak density salinity zones, for the months that the species are most abundant. The current area for Blue Crab (2.7%) is less than half of what it would be under natural flow conditions (7.6%) and there is almost no Blue Crab preferred habitat (1.2%) assuming the Exelon operations.

Table 4 Peak Density Salinity Zone Area of Critical Habitat Area for San Antonio and Mission Aransas Bays

Target Species	Salinity (ppt)	Occurrence	Natural	Exisitng	Proposed
White Shrimp	5 - 10	Jul - Dec	0.4%	0.4%	0.4%
Blue Crab	5 - 15	Jan - Jun	7.6%	2.7%	1.2%
Brown Shrimp	10 - 20	Apr - Sep	24.1%	7.0%	2.2%
Gulf Menhaden	5 - 10, 15 - 20	Jan - Dec	22.4%	13.1%	6.4%
Atlantic Croaker	5 - 20	Feb - Jul	38.9%	20.2%	5.7%
Bay Anchovy	20 - 25	Jan - Dec	40.5%	35.8%	15.2%
Pinfish	25 - 30	Jun - Nov	40.5%	45.7%	35.2%

Because the WAM period of record ends in 1989, a prediction of salinity conditions for the 2008-09 drought assuming the Exelon project were not attempted in this report, however a comparison of the inflow regime in 1987-89 with that of 2007-09 suggests that the findings from the analysis of the early period are applicable to the later. In both three year periods, inflows were high in the first year and significantly diminished in the subsequent two years. Figure 14 and Figure 15 show the monthly average salinities at GBRA1 (observed in the later period and modeled in both periods) and the corresponding freshwater inflows.

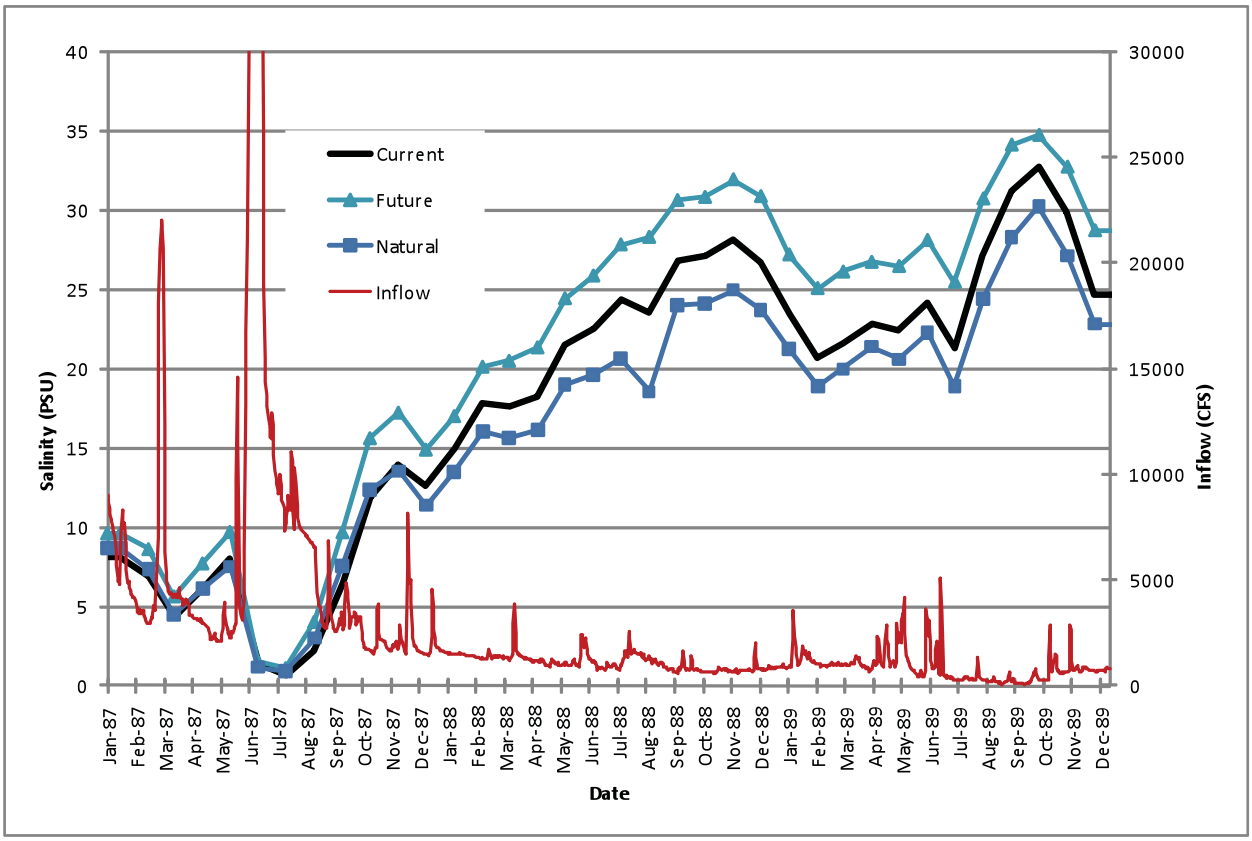

Figure 14 Simulated salinities at GBRA1 location (right y-axis) and Guadalupe Inflows (left y-axis) for a period including 1987 to 1989.

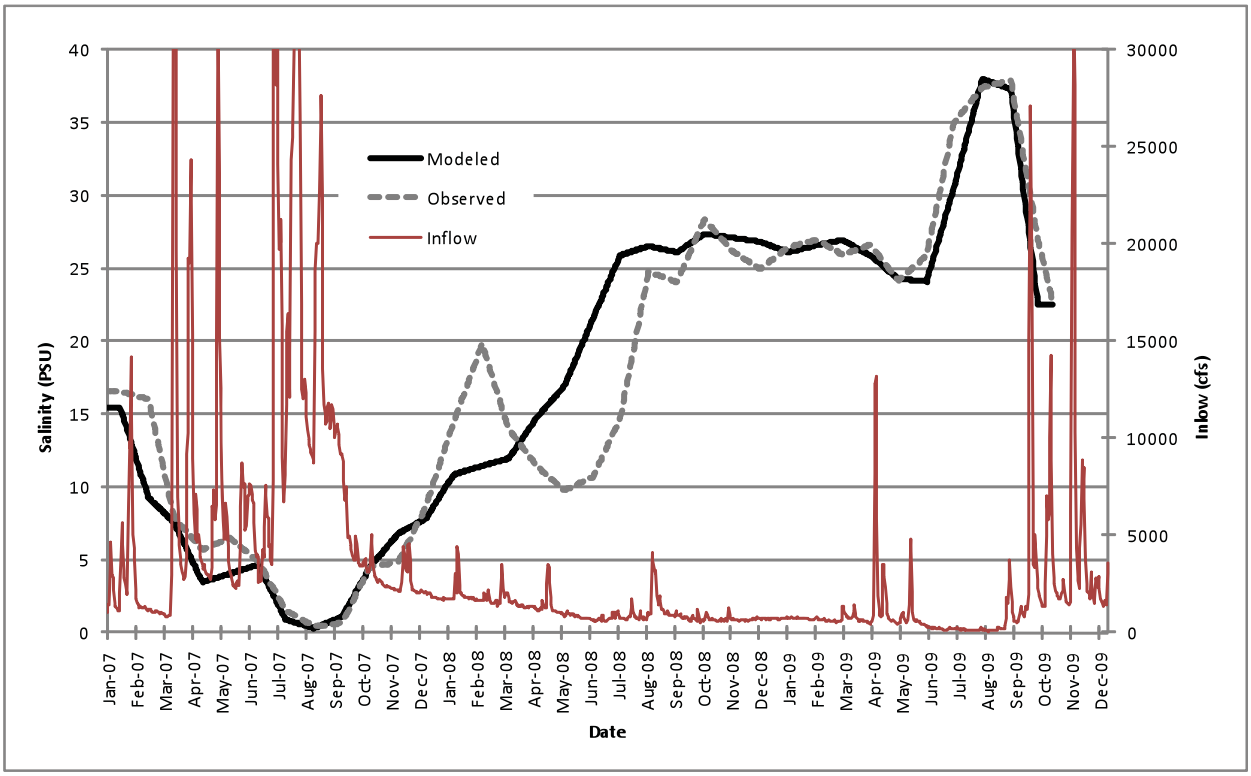

Figure 15 Observed and simulated salinities at GBRA1 location (right y-axis) and Guadalupe Inflows (left y-axis) for a period including 2007 to 2009.

Stehn reports that 1988-89 and 2008-09 among the highest levels of Whooping Crane mortality on record (pers comm.). Sass (2010) has concluded that low freshwater inflows can cause salinity in the bay to approach that of seawater about 35 PSU, a finding consistent with the above analysis, and that this can negatively effect blue crab and wolfberry abundance as well as force Whooping Cranes to seek fresher water away from the relative protection of its territory.

7.0 CONCLUSION

Ecological studies, such as the FINS develop for San Antonio Bay, are complex and carry some uncertainty. This is particularly true for estuary studies with the many complex physical, chemical and biological interactions taking place over such a wide range of spatial and temporal scales. Drawing direct relationships between quantity for freshwater inflow and the health of Whooping Cranes is therefore challenging. The analysis presented in this report clearly demonstrates that continuing down the path of greater diversions of water from the Guadalupe River as is envisioned via the development of the Exelon Nuclear project will lead to an increase in the severity, duration and frequency of manmade droughts. This analysis further indicates that these diminished inflows will lead to stressful salinity conditions in the bay for many of the marine species present including the Whooping Cranes important food source, the Blue Crab.

REFERENCES

Alber, M, 2002: A conceptual model of estuarine freshwater inflow management. Estuaries 25 (6B), pp 1246-1261.

BIO-WEST. 2007. Final Report Matagorda Bay Health Evaluation Habitat Assessment. Technical report prepared for the Lower Colorado River Authority and San Antonio Water System.

Bunn, S.E., and A.H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30: 492-507

Cadman, L. R. and M. P. Weinstein. 1988. Effects of temperature and salinity on the growth of laboratory-reared juvenile blue crabs Callinectes sapidus Rathbun. Journal of Experimental Marine Biology and Ecology 121:193-207.

GBRA (Guadalupe-Blanco River Authority), 2009. Response to TCEQ request for information regarding WRPERM 12378 Application, December 11, 2009.

Guillory, V., H. Perry, P. Steele, T. Wagner, W. Keithly, B. Pellegrin, J. Peterson, T. Floyd, B. Buckson, L. Hartman, E. Holder, and C. Moss. 2001. The blue crab fishery of the Gulf of Mexico, United States: A regional management plan. Gulf States Marine Fisheries Commission. Ocean Springs, MS.

Hamlin, L. 2005. The Abundance and Spatial Distribution of Blue Crabs (*Callinectes Sapidus*) in the Guadalupe Estuary Related to Low Freshwater Inflow Conditions. M.Sc. Thesis. Texas State University-San Marcos: USA.

HDR Engineering, Inc. 1999, Water Availability in the Guadalupe – San Antonio River Basin, Texas Natural Resource Conservation Commission, December 1999.

Longley, W.L. 1994. Freshwater inflows to Texas bays and estuaries: ecological relationships and methods for determination of needs. Texas Water Development Board and Texas Parks and Wildlife Department, Austin. 386 pp. Matsumoto, J., 1992. Users Manual for The Texas Water Development Board's Circulation and Salinity Model: TxBLEND. Texas Water Development Board.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestergaard, B. Richter, R. Sparks, and J. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. Bioscience 47: 769-784.

Pugesek, B.H., M.J. Baldwin, and T.V. Stehn. 2008. A low intensity sampling method for assessing blue crab abundance at Aransas National Wildlife Refuge and preliminary results on the relationship of blue crab abundance to whooping crane winter mortality. Proceedings of the North American Crane Workshop 10:2008:13-23.

Pulich, Jr., W., W.Y. Lee, C. Loeffler, P. Eldridge, J. Hinson, M. Minto, and D. German. 1998. Freshwater inflow recommendation for the Guadalupe Estuary of Texas. Coastal Studies Technical Report No. 98-1. Texas Parks and Wildlife, Austin, TX. 100pp.

SAC (Science Advisory Committee). 2004. Final Report, Science Advisory Committee Report on Water for Environmental Flows. Texas Senate Bill 1639, 78th Legislature. October 26, 2004. Prepared for Study Commission on Water for Environmental Flows. www.twdb.state.tx.us/EnvironmentalFlows/pdfs/SAC%20FINAL%20REPORT_102704.pdf.

SAC (Science Advisory Committee). 2009. Methodologies for Establishing a Freshwater Inflow Regime for Texas Estuaries Within the Context of the Senate Bill 3 Environmental Flows Process, Report # SAC-2009-03. Document Version Date: June 5, 2009. Austin, TX.

Sass, R. 2010. Grus Americana and a Texas River: A Case for Environmental Justice" published by the James A. Baker III Institute for Public Policy, Rice University (Nov. 9, 2010)

http://bakerinstitute.org/publications/GCC-pub-SassGrusAmericana-110910.pdfSouth Central Texas Regional Water Planning Group. 2005. Initially Prepared 2006 Regional Water Plan, Vol. II.

Texas Administrative Code online at http://info.sos.state.tx.us/pls/pub/readtac$ext.ViewTAC.

TWDB (Texas Water Development Broad), 1990. User's Manual for the Texas Water Development Board's Estuarine Mathematical Programming Model: TxEMP. Texas Water Development Board, Austin, Texas.

TWDB (Texas Water Development Broad), 1997 Water for Texas August p. 2-23 – 2-29.

TWDB (Texas Water Development Broad), 1999. User's Manual for the Texas Water Development Board's Hydrodynamic and Salinity Model: TxBLEND. Texas Water Development Board, Austin, Texas.

TWDB (Texas Water Development Broad), 2006. 2007 Texas State Water Plan. Texas Water Development Board, Austin, TX.

TWDB. 2010. TxBLEND Model Calibration and Validation for the Guadalupe and Mission-Aransas Estuaries. Texas Water Development Board, Austin, Texas. 45 pp.

TSJ BBEST (Trinity and San Jacinto and Galveston Bay Basin and Bay Expert Science Team) .2009. Environmental Flows Recommendations Report. Final Submission to the Trinity and San Jacinto Rivers and Galveston Bay Basin and Bay Area Stakeholder Committee, Environmental Flows Advisory Group, and Texas Commission on Environmental Quality. pp. 172.

EXHIBIT E-2

JOSEPH F. TRUNGALE, P.E.

Project Principal / Project Manager

EDUCATION

- PhD (Pursuing candidacy), Aquatic Resources, Texas State University (San Marcos, TX)
- M.S. Engineering, University of Washington (Seattle, WA), 1996
- B.A. English Literature, Georgetown University (Washington, DC), 1990

COMPUTER EXPERIENCE

- Surface Water Modeling (TxBLEND, WRAP, HEFR, RMA-2, River-2D, HEC-RAS)
- Statistical Software Packages (S-Plus, R, Conoco, Primer)
- Productivity (MS Excel, Word, Power Point)
- GIS (ArcView/ArcInfo, Spatial Analyst, 3D Analyst)
- Database (Access, SQL)
- HTML, FORTRAN, VB, C

PROFESSIONAL/TECHNICAL AFFILIATIONS

- Texas State Board of Professional Engineers – Professional Engineer No. 92040

TECHNICAL REPORTS, PUBLICATIONS AND CONFERENCE PRESENTATIONS

- Trungale Engineering and Science, (August, 2010) Environmental Flow Regime Analysis and Recommendations Report, Cypress Flows Project, Austin, Texas.
- Trungale Engineering and Science, (April, 2010). Flows Atlas - Senate Bill 3 (2 separate reports - Trinity-San Jacinto and Sabine-Neches), National Wildlife Federation, Austin, Texas.
- Trinity San Jacinto Basin and Bay Expert Science Team. (December, 2009), Environmental Flows Recommendations Report, Austin, Texas.
- Espey Consultants, Inc. and Trungale Engineering and Science. (August, 2009), Galveston Bay Salinity Zonation Analysis for the Trinity-San Jacinto and Galveston Bay Basin and Bay Expert Science Team, Austin, Texas
- Texas Commission on Environmental Quality. (August, 2008), Review of Desk-top Methods for Establishing Environmental Flows in Texas Rivers and Streams, Austin, Texas
- BIO-WEST, Inc. (March 2008). Lower Colorado River, Texas Instream Flow Guidelines, Colorado River Flow Relationships to Aquatic Habitat and State Threatened Species: Blue Sucker. Round Rock TX. Lower Colorado River Authority and San Antonio Water System.
- Trungale Engineering and Science, (July, 2007). Instream Flow Needs for the Brazos River near Glen Rose, Texas, Friends of the Brazos River, Austin, Texas.
- Trungale, J.F., K.B. Mayes, R.E. Moss, and L.J. Kleinsasser. (October, 2003). Using water availability models to assess alterations in instream flows. River Studies Draft Report Texas Parks and Wildlife Department, Austin, Texas.
- Kleinsasser, L.J., Jurgensen, T.A., Bowles, D.E., Boles, S., Aziz, K., Saunders, K.S., Linam, G.W., Trungale, J.F., Mayes, K.B., Rector, J., Renee Fields, J., Portis, K., Steinmetz, G., and Moss, R.E. (February, 2004). Status of Biotic Integrity, Water Quality, and Physical Habitat in 16 of 30 Wadeable East Texas Streams. River Studies Report No. 19, Texas Parks and Wildlife Department, Austin, TX.
- Saunders, K.S., K.B. Mayes, T.A. Jurgensen, J.F. Trungale, L.J. Kleinsasser, K. Aziz, J.R. Fields, and R.E. Moss. (August, 2001). An evaluation of spring flows to support the upper San Marcos River

spring ecosystem, Hays County, Texas. River Studies Report No. 16. Texas Parks and Wildlife Department, Austin, Texas.

- HDR Engineering, Inc., (January, 2001) South Central Texas Regional Water Plan, Texas Water Development Board , Austin Texas.
- HDR Engineering, Inc., (December 1999) Water Availability in the Guadalupe-San Antonio River Basin, Texas Natural Resource Conservation Commission, Austin, Texas.

FIELDS OF EXPERIENCE

Mr. Joseph F. Trungale is a professional engineer and the principal of Trungale Engineering & Science in Austin, Texas. He has 15 years of experience working in water resource planning and environmental flow studies, including work for the river basin commission responsible for raw water supply for Washington D.C., as a consultant with HDR Engineering where he worked on Texas regional planning and water availability modeling and as the surface water hydrologist for the Texas Parks and Wildlife River Studies program. Mr. Trungale is currently an independent consultant with expertise in instream flow studies to quantify the effects of changing flow regimes on aquatic habitat. His expertise extends to groundwater-springflow studies, freshwater inflows for bays and estuaries, and regional and state water planning including water availability analysis and water rights review. Mr. Trungale has a masters degree in Engineering from the University of Washington and is currently pursuing PhD candidacy at Texas State in Aquatic Resources.

Colorado and Lavaca River Basins and Matagorda Bay and Basin Expert Science Team (BBEST):

Mr. Trungale was selected to serve as a member of this Senate Bill 3 committee in February 2010, focusing upon issues related to environmental flows.

Trinity and San Jacinto River Basins and Galveston Bay and Basin Expert Science Team (BBEST):

As Texas Senate Bill 3 Expert Science Team member, Mr. Trungale developed science based flow recommendations for rivers in the Trinity and San Jacinto River Basins and freshwater inflow for Galveston Bay. This included analysis of hydrology & hydraulics, biology, water quality and geomorphology to refine/validate hydrology based instream flow recommendations. He applied a salinity zonation approach to predict ecologically relevant salinity response to changes in freshwater inflows. Co-authored "Science Based Environmental Flow Regime for the Trinity River, San Jacinto River, and Galveston Bay."

Caddo Lake/Cypress Basin Environmental Flows Study - Caddo Lake Institute

Manages scientific studies to determine ecosystem flow needs for Caddo Lake and associated wetlands. Developed recommendations for subsistence, base and high flow targets and conducted field studies to address priority research issues. Developing approaches to implement and monitor flow recommendations through an adaptive management process.

Brazos River Instream Flow Study - Texas Rivers Protection Association & Friends of the Brazos River

Mr. Trungale has analyzed Brazos River Authority systems operation permit application and evaluated effects on instream flows to support environmental and recreation flow needs. Mr. Trungale characterized flow regimes under pre-development and currently modified management scenarios using a WAM developed for the Brazos River Systems Operations Permit application which seeks to appropriate water from the Brazos River.

Lower Colorado River Instream Flow Study – Lower Colorado River Authority/San Antonio Water System

Mr. Trungale developed models to evaluate effects of flow alterations, specifically related to a proposed water development projects to provide water from the Colorado River to the City of San Antonio. He was responsible for several components including 1.) perform reconnaissance to determine study sites 2.) develop conceptual study flow charts 3.) collect physical and hydrologic data to model and characterize hydraulic habitat. 4.) analyze results, recommendation flow targets and prepare final report.

Review of Desk-top Methods for Establishing Environmental Flows in Texas Rivers and Streams – Texas Commission on Environmental Quality

Mr. Trungale provided technical support to workgroup tasked with evaluating the current default method for determining instream flow needs, primarily for the purpose of defining special conditions within water rights permits. This included making comparisons between naturalized and gauged flows and between Lyons method and values derived from Indicators of Hydrologic Alteration (IHA) software as well as comparing estimates from desktop methods and recommendations from a comprehensive site specific study.

Statistical Analysis of Galveston Bay Salinity/Inflow relationship - National Wildlife Federation

Mr. Trungale developed multivariate regression for salinity as a function of inflows and antecedent salinity in support of the development of special conditions to proposed water rights permits related to reuse.

Galveston Bay Freshwater Inflow – Galveston Bay Conservation and Preservation Association

Member of Galveston Bay Technical Advisory group to test validity of the state of Texas freshwater inflow recommendations and suggest alternative approaches.

Evaluations of Proposed Water Supply Alternatives for DFW and North Texas – Texas Committee on Natural Resources

Mr. Trungale evaluated and recommended alternative water supply options for the City of Dallas that could be used to meet future demands without building Marvin Nichols reservoir. In addition, he estimated costs associated with raw water, pipelines, and water treatment.

Kinney County Groundwater Management – Kinney Country Farmers and Ranchers Association

Mr. Trungale supported the coalition of ranchers and farmers to protect local wells and springs from excessive groundwater diversions and transfers. He evaluate previous and current studies, including Groundwater Availability Modeling (GAM) and provided support recommendations for springflow needs and approaches to meet these needs.

San Antonio Bay Freshwater Inflow Evaluations in relations to the Lower Guadalupe Water Supply Project - D.M O'Conner Ranches

Mr. Trungale evaluated state methodology to determine freshwater inflow needs including evaluation of data, development of regressions relating inflows to ecological health, optimization and circulation modeling and validation.

San Marcos River Foundation Instream Flow Permit Application – San Marcos River Foundation

Mr. Trungale provided technical guidance to the San Marcos River Foundation, a local non-profit which had applied for a permit for the protection of instream and freshwater inflows in the Guadalupe River.

He also performed Water Availability Modeling (WAM) to support permit application,evaluated completed applications, and researched TCEQ permitting policy to evaluate precedence and authority of the agency to grant such permits. Finally, Mr. Trungale evaluated state methodology to determine freshwater inflow needs for San Antonio Bay and continues to monitor activities to the Commission on Environmental Flows and their Science Advisory Committee.

Evaluation of Impacts of Exelon Nuclear Power Plant on Freshwater Inflows to San Antonio Bay

Developed inflow estimates for natural, current and future conditions using TCEQ Water Availability Models and water development projects proposed by South Central Texas Regional Water Planning Group. Evaluated the impact of changed conditions on the severity, frequency and duration of drought conditions. Simulated salinity regimes using 2-dimensional finite element circulation and transport model under alternative management scenarios to quantify changes in preferred salinity zones for economically and environmentally important finfish and shellfish.

Surface Water Hydrologist
1999 - 2004 Texas Parks and Wildlife Department San Marcos, TX

Mr. Trungale's work at TPWD encompassed a large scope of projects including, collecting and analyzing field data and developing hydraulic and habitat models to determine instream flow needs to support healthy ecosystems. In addition, he collected physical and biological data including surveying stream cross sections and benchmarks with levels, total stations and GPS, measuring discharge with flow meters, collecting bathymetry with digital transducer and echosounder connected to GPS units, characterized and mapped stream cover and substrate, collected biological data, primarily fish, using seines, boat and backpack shockers, and limited collecting of chemical data primarily using automated data loggers. He performed statistical and time series analysis on hydrologic and hydraulic data, specifically calculating watershed and stream channel and flow statistics that have biological significance, e.g. Indicator of Hydrologic Variability (IHA) (central tendency, recurrence intervals, frequency and duration) and/or that may be used to develop/refine instream flow standards and requirements. Also Dr. Trungale developed and ran 1D and 2D hydrodynamic models including PHABSIM, River2D and SMS/RMA2, water quality models (SNTEMP and BASINS). Developed spreadsheet and GIS tools to analyze outputs of habitat preference/utilization. At TPWD, Mr. Trungale served as an agency expert on issues related to surface water hydrology in statewide permitting and planning including review of major water right applications, water availability modeling, reservoir yield calculations and departmental and state water planning process.

Water availability Models to Assess Alterations to Instream Flows

Mr. Trungale used water availability models to assess alterations to instream flows under current conditions and full authorized use assumptions. He developed monthly benchmark flow values at 72 sites throughout Texas based on a percentage of daily naturalized median flow (similar to the regulatory default method) and calculated the frequency of meeting or exceeding these benchmarks under natural and modeled assumptions. Finally, Mr. Trungale characterized the level of alteration based on the difference in percent of time targets are met between natural conditions and full authorized use.

Guadalupe Instream Flow Study

Mr. Trungale was responsible for characterizing flow regime at three sites on the Guadalupe River by reviewing and comparing historical stream flow records, calculating flow statistics, and producing cumulative frequency graphs. He also collected physical and biological data at three sites on the Guadalupe River by several methods, including surveying cross section depths and water surface elevations, taking velocity measurements according USGS protocol and calculating discharge, collecting

bathymetry data using boat mounted Echosounder/GPS system, making substrate and cover calls and fish collections. Mr. Trungale developed 1D (PHABSIM) and 2D (SMS/RMA2 and River2D) hydraulic-habitat models including calculating stage-discharge relationship (rating curve), running and calibrating models and producing maps of model depths, velocities and habitat.

Canyon Permit Amendment Review

Mr. Trungale analyzed alternatives proposed by Guadalupe-Blanco River Authority to subordinate downstream hydropower rights to upstream storage for municipal supply. He then calculated flow frequency curves for each of the alternatives and a suite of parametric and non-parametric statistics called Indicators of Hydraulic Alteration (IHA) that describe the magnitude of monthly water conditions, magnitude and duration of annual extreme water conditions, timing of annual extreme water conditions, frequency and duration of high and low pulses amend rate and frequency of change in water conditions.

GIS-Database of Instream flow needs determinations

In order to better assess where instream flow needs have been determining in the State of Texas, Mr. Trungale developed a geodatabase identifying locations where instream flow determinations have been made either as result of water rights permit applications or for site-specific studies. He also extracted output from Texas Water Availability Models (WAM) to calculate flow statistics at primary control points. he then created an interactive map including water rights diversion points, locations where instream flows have been determined, streams of significant ecological significance and flow statistics at primary (gage) locations based on naturalized and currently regulated flows. .

Regional Environmental Monitoring Assessment Program (REMAP)

Mr. Trungale's involvement in REMAP included, collecting physical and biological data for small streams in East Texas including surveying cross section depths and water surface elevations, measuring velocity according USGS protocol and calculating discharge. He also made substrate and cover calls, and developed spreadsheets to calculate summary statistics for 200+ sites. The calculated statistics for each cross section included calculation of wetted width, maximum and median depth for current water surface elevations, bank full and flood prone areas. Mr. Trungale also summarized fish species collected at each site. Using GIS Software, Mr. Trungale calculated drainage areas for 200+ sites using digital elevation models and land use density for each site according to Anderson scale and land use land cover data sets. Finally, Mr. Trungale developed programs to calculate regionalized Index of Biotic Integrity (IBI) for fish and benthic macroinvertebrate metrics.

Allen's Creek Reservoir Project

During the planning and negotiations phase of this project, Mr. Trungale calculated instream flow requirements according to Lyons method (permit/regulatory method) environmental flow consensus criteria (planning method) as well as several additional criteria to 1.) limit diversions to some percentage of total flow or 2.) relax instream flow requirements during drought. In addition, he calculated reservoir yield, including iterative calculation of monthly evaporation, when meeting different instream flow requirements and bank full flow (1.5 year recurrence flow) using log-Pearson's Type III statistic. Once an agreement was made between TPWD and the applicant, he began an instream flow study on the Brazos River, which included, collecting bathymetry data using echosounder and GPS for approximately 2 mile segment downstream of Allen's Creek. Mr. Trungale corrected this data based on changes in water surface elevation over the two day data collection period, developed TIN and GRID models of the bathymetry for use in 2-D hydrodynamic model and began developing and testing 2-D hydrodynamic model.

Evaluation of Spring Flows to Support the Upper San Marcos River Spring Ecosystem, Hays County Texas

Mr. Trungle characterized flow regime by reviewing and comparing historical stream flow records, calculating flow statistics, and producing cumulative frequency graphs. He also developed 1-D hydraulic-habitat model (PHABSIM) including calculating stage-discharge relationship (rating curve), by performing log-log regression between observed stage and discharge pairs at 28 cross sections, calculating velocities at each station within each cross section at a range of discharges using Manning's equation to solve for "n" at each station (in this context "n" acts as a roughness distribution factor across the cross section), calculating weighted usable area as a function of flow for target species (in this case five native plant species) by relating habitat suitability indices to modeled depths and velocities, and performing time series analysis to calculate weighted usable area over period of record to access historical variable and duration of "good" habitat conditions. In addition, Mr. Trungle developed stream temperature model (SNTEMP) using results from hydraulic modeling and additional observed data to create inputs for stream temperature model including latitude, elevation, travel time, stream width, shading data, and historical meteorological data (used for alternative scenarios). Finally, he modeled net heat flux = Solar Radiation + atmospheric radiation + vegetative radiation + evaporation + convection + conduction + friction-water's back radiation on a monthly time step, validated results against observed water temperatures, and predicted flow rates at which temperature thresholds might be violated.

Project Engineer

1997 - 1999 HDR Engineering, Inc. Austin, TX

Developed water availability models and regional water plans. Principle programmer for state water availability models for the Guadalupe and San Antonio River Basins. Project manager for new reservoir alternatives in South Central Texas Regional Planning Study. Integrated long-range water supply plans for state sponsored regional planning studies based on demand projections, availability of new supplies, cost and environmental impacts. Modified reservoir yield simulation models for analysis and assessment of water supply alternatives on a daily time step. Models evaluated both the reliability of these alternatives to supply water as well as there impact on natural and aquatic resources downstream. Other projects included sizing and laying out potential pipeline routes and accessing costs for municipal water, sewer and drainage structures.

Guadalupe River Basin Water Availability Model

Principle modeler for the Guadalupe San Antonio Water Availability Model (GSA WAM). Built a GSA water rights dataset which included reviewing permits, assign priority dates and assigning diversion location to a geographical coordinate. Calculated monthly distribution factors, created storage -area curves, and estimate historical evaporation rates. Modified naturalized flow sets including updated spring flow sets. Made basin specific modifications to the WAM source code to calculate daily operations for Canyon Reservoir to meet FERC and hydropower daily flow requirements, included modifications to handle special permits (Braunig/Calveras/Victoria), and Medina/Diversion Lake leakage. Setup alternative scenarios looking at changing return flow assumptions, exclusion of cancelable and term permits, and accounting for reservoir sedimentation. Performed model runs to validate and present results.

South Central Texas (Region L) Water Planning

Project manager for the SB1 Region L planning study for five new reservoir alternatives in the GSA. Managed a $20,000 budget and supervised the work of other project engineers. Calculated availability

for water diversion into storage facilities with the constraints of meeting downstream senior water rights and bay and estuary flow requirements. Calculated reservoir yields subject to local evaporation and meeting a three-tiered environmental flow pass through, the impact of diversion at the site and at the mouth of the bay and the unit cost of water for the project. Summarized yield estimates, costs, implementation/feasibility issues.

Corpus Christi Water Supply Update

The City of Corpus Christi's main water supply sources include the Choke Canyon - Lake Corpus Christi reservoir system and the recently completed Mary Rhodes pipeline from Lake Texana. Updated evaporation calculations based on new estimates from the Texas Water Development Board. Also made model modifications to experiment with different source blending options and meeting the instream flow requirements of the 1995 Agreed Order.

Environmental Criteria Refinement Study

Modified Texas Water Development Board's reservoir yield model (SIMDLYYD) to accept monthly flows, pass throughs for senior downstream water rights and bay and estuary flows and daily flows from a nearby reference gage and convert the daily to monthly values. The model performs a mass balance on a proposed reservoir, passing flows to meet environmental targets based on triggers and iterating on storage to calculate evaporative losses. Calculated reservoir yield by increasing diversions until reservoir volume goes to zero. Included options for "stacking" pass throughs for instream flows on top of flows for bays and estuaries. Performed this analysis on 7 proposed reservoirs in the South Central region. At one site, Sandies Creek, made additional model runs to examine the effects of changing pipeline capacity. Compared resulting flows at the diversion site and the bay inflow with pre-project flow by calculating cumulative exceedence and monthly medians. Finally, ran fish production and salinity models to evaluate Bay and Estuary impacts.

EXHIBIT F

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE SECRETARY

DECLARATION OF RONALD L. SASS IN SUPPORT OF TEXANS FOR A SOUND ENERGY POLICY'S PETITION TO INTERVENE AND CONTENTIONS

I, Ronald L. Sass, Ph.D., declare pursuant to 28 U.S.C. § 1746, on personal knowledge and under penalty of perjury, that the following is true and correct:

1. I am a resident of the Harris County, Texas. I am over 21 years of age and have never been convicted of a felony.

2. This declaration is submitted in support of Texans for a Sound Energy Policy's ("TSEP") Petition to Intervene and Contentions. Any expressions of opinion are based on my best judgment.

3. Much of my opinion on the deleterious effect on the Aransas National Wildlife Reserve ("ANWR") whooping crane population due to a reduction in freshwater inflow to San Antonio Bay, by such possible future users as Exelon's proposed nuclear power plant, is presented in my paper "*Grus Americana and a Texas River: A Case for Environmental Justice"* published by the James A. Baker III Institute for Public Policy, Rice University. A copy of this report is attached as Exhibit F-1 to this declaration.

4. The relevant opinions I presented therein are:

    a) The well-being and viability of the Texas whooping crane population is directly related to the flow of freshwater from the combined Guadalupe and San Antonio River System into San Antonio Bay.

    b) A minimum flow of freshwater into San Antonio Bay between the months of July and October is required, below which the whooping crane will exhibit a high probability of physical stress and increased mortality during its stay at the ANWR.

    c) Although this freshwater inflow depends in part on the natural variation in the hydrological cycle over the river basins, it is significantly reduced by human usage and consumption. Consequently, the freshwater inflow may soon reach a value that is inconsistent with a viable whooping crane population, placing the flock in imminent danger.

    d) The predicted impacts from climate change and hydroclimate models for the Guadalupe River and San Antonio River basins lead me to conclude that by 2100 there will be dramatic reductions in precipitation and runoff, resulting in lower

> river flows. Also, there will be increased evaporation from San Antonio Bay, leading to increased salinities. These impacts very likely will equate to a freshwater deficit of 270,000 acft/yr or more by 2100.

5. In addition to the contents of this paper and in light of additional points recently raised by Exelon, I am providing additional opinions that support TSEP's contentions to the Exelon Early Site Permit Application.

6. In its June 24, 2010 updates to sections 2.4 and 5.11 of its Environmental Report, Exelon questions the 2008-9 mortality count (23 birds) stating, for example,

> During the 2008-2009 overwintering season at ANWR, above-normal upland and water hole use was noted, scattering the cranes over a geographical area beyond their typical territory (USFWS 2009a). As described in the January 2009 USFWS aerial census report, "This makes it very difficult to determine the identity of pairs and family groups and leads to much uncertainty during the census count" (USFWS 2009a). Limited visibility due to weather conditions and smoke from prescribed burns, as well as flight time limitations, were noted on multiple census flights, adding to the difficulty in spotting the widely dispersed cranes (USFWS 2009a). Considering these and other factors, it is possible that the extent of whooping crane mortality during the 2008-2009 overwintering period could be lower than reported.

   Exelon Letter to USNRC No. NP-10-0010, dated June 24, 2010, updated ER pages 2.4-11; 5.11-7)

7. This statement questions the validity of the method used to perform a census count of the cranes. Exelon fails to fully describe the long-established U.S. Fish & Wildlife Service census methodology. For example, the aerial census method can be relied upon because the cranes establish clearly delineated territories, which are known to the observers. The same cranes will return year after year to the same territories (a phenomenon known as territorial fidelity). The observers are familiar with each territory, and are able to track the life history of particular cranes or crane pairs, or family units (two adults plus and one or two juveniles) with considerable accuracy. Exelon also fails to consider that whooping crane pairs and family units are never widely separated. If one member of the family unit ventures to a distant site, every member of the family does likewise. In particular, juveniles never stray from their parents during their time at Aransas. Thus if one member of the family unit that was present at the start of the winter is later consistently absent from that group, it can be considered to be a mortality. Out of the 23 cranes that died during the 2008-09 winter, 16 were juvenile birds. These juveniles did not just wander off during the census. Therefore these crane behaviors and especially the tightness of the pairs and family units, makes it relatively easy to identify the absence of any individual bird. Repeated absences of known birds can only be explained by mortality.

8. In its June 24, 2010 update, Exelon states in addition,

> Furthermore, the flock departed ANWR relatively early in 2009 (USFWS 2009b). Previous research has indicated that birds will generally migrate earlier than usual when food availability allows for rapid fattening and good physical condition (Studds and Marra 2007).

Exelon Letter to USNRC No. NP-10-0010, dated June 24, 2010, updated ER pages 2.4-11; 5.11-7.

9. This argument plainly does not support a miscounted mortality rate, as it cites an irrelevant study and also relies on flawed reasoning. First, the work of Studds and Marra reports on the American Redstart, a small migratory warbler with a considerably different behavior pattern than the whooping crane. A comparison of the two species behaviors is highly questionable. Second, Exelon implies that missing birds had simply migrated early. According to the USFWS reports, the majority of the mortality had occurred between January and the March 15th 2009 census (21 birds), and this is many weeks before the earliest migration. (Tom Stehn, Report on Whooping Crane Census Flight, March 15, 2009, http://www.ccbirding.com/twc/2009/ 2009_0315.htm.) Third, the statement implies that there was a higher than usual availability of food during that period. This is flatly contradicted by the official reports of USFWS observers. According to observers, "Food resources were considered to be very poor throughout the 2008-09 winter. The fall wolfberry crop was way below average, and blue crabs were scarce from December through March." USFWS 2009b. And, "These are the worst conditions I have ever observed for the cranes at Aransas, with some birds looking thin and with disheveled plumage." Tom Stehn, Report on Whooping Crane Census Flight, March 15, 2009, http://www.ccbirding.com/twc/2009/2009_0315.htm).

10. In its June 24, 2010 update, Exelon draws attention to the fact that of the reported 23 crane deaths, "only four crane carcasses were recovered".

11. The implication is that "without a body" one cannot be sure of a death. I draw an entirely different conclusion. A death in the wild seldom results in a body being found. Many local predators such as the alligator are constantly on the lookout for dead or dying food animals. A dead carcass has a very short lifetime in the wild. Furthermore the territory of a bird is sometimes remote and inaccessible. The chance of finding a carcass, even in the absence of predators is remote. The telling fact is that four carcasses in a single year is extraordinary. I reviewed a spreadsheet from the USGS National Wildlife Health Center in Madison, Wisconsin documenting the known whooping crane carcasses and causes of death. In the nearly six decades from 1951 to 2009, only 18 carcasses have ever been found at ANWR. Four in one year is an extraordinary number and is indicative of an extraordinary number of deaths during that winter.

12. In its June 24, 2010 update, Exelon draws on a report by Slack et al. (also known as the SAGES Report) saying,

> However, as discussed previously, empirical research indicates that the crane diet is rich and varied, and even when blue crab and wolfberry numbers are low,

cranes can meet their daily energy and protein requirements by efficiently foraging on foods such as insects, snails, and razor clams (Slack et al. Aug 2009).

Exelon Letter to USNRC No. NP-10-0010, dated June 24, 2010, updated ER pages 2.4-12; 5.11-7.

13. The report by Slack et al. is a compilation report based upon a variety of studies on the whopping crane. It is primarily concerned, as stated by its title, with "Linking Freshwater Inflows and Marsh Community Dynamics in San Antonio Bay to Whooping Cranes." The work was funded by the Guadalupe-Blanco River Authority and the San Antonio River Authority and sponsored by Texas A&M University. The SAGES Report was compiled from a large number of graduate student studies undertaken between 2003 and 2007. The period of field data collection by each graduate student was as reported below for the field study portions of the work:

Spatial and temporal patterns of *Lycium carolinianum* Walt. (the Carolina Wolfberry) in the salt marshes of Aransas National Wildlife Refuge
Graduate student project: Rachel Butzler – Stephen Davis (thesis advisor); data collected during the winters of 2003-04 and 2004-05

Spatio-temporal patterns of biophysical parameters in a microtidal, bar-built, subtropical estuary of the Gulf of Mexico
Graduate student project: George Gable – Stephen Davis & Dan Roelke (thesis coadvisors); data collected during 2004 and 2005

Hydrologic connectivity across a tidal marsh-pond landscape at Aransas National Wildlife Refuge (Texas, USA)
Graduate student project: Matthew Driffill – Stephen Davis (thesis advisor), data collected during 2007

Patterns in blue crab abundance in shallow salt-marsh and bay habitats of the Texas Gulf Coast
Graduate student project: Danielle Greer – R. Douglas Slack (PhD advisor); data collected from October 2004-March 2006.

Blue crab settlement and recruitment patterns in shallow habitats of the Texas Gulf Coast
Graduate student project: Danielle Greer – R. Douglas Slack (PhD advisor); Data collected October 2003 to September 2005.

Whooping crane foraging ecology: Gains, costs, and efficiency of foraging
Graduate student project: Danielle Greer – R. Douglas Slack (PhD advisor), data collected during winters 2003-04 and 2004-5.

Spatial and temporal winter territory use and behavioral responses of whooping cranes to human activities

Graduate Student Project: Kristin E. LaFever – R. Douglas Slack (thesis advisor); data collected December 2003-April 2004 and October 2004-April 2005.

14. Although each project has different starting and stopping times, the majority of the work related to dietary needs of the whooping crane. It covered the winters 2003-04 and 2004-05. The season 2004-05 had the third highest inflow rate between July and December since 1988. The season 2003-04 had a low but not critical inflow rate during the same period. Thus the model that was developed by SAGES was based on two years of empirical data, and neither of these two years was extraordinary in terms of ecosystem stress due to low inflow, and neither had an exceptional whooping crane mortality. Finally, the SAGES model assumed an inverse relationship between salinity and wolfberries (ie, higher salinities mean fewer wolfberries), but used a positive relationship between salinities and blue crabs (ie, as salinity increases, so too does blue crab abundance). As a result, as salinity in the model was increased, wolfberry abundance declines, but was simply replaced by purported increases in blue crab abundance. This aspect of the SAGES work was universally criticized (for example, in comments from representatives of USFWS, Texas Parks & Wildlife Department, and Dr. Chavez-Ramirez to name a few), as it is the first field study to suggest a positive relationship between salinity and blue crabs, and did not appear to be well-supported by the underlying SAGES student studies.

15. In contrast, the related field work reported in the PhD thesis of Felipe Chavez-Ramirez (who also worked under the direction of Douglas Slack) was conducted during the winters of 1992-93 and 1993-94. In contrast to the SAGES work, Chavez-Ramirez worked in a year of high inflow and low whooping crane mortality (1992-93) and in a year of low inflow and high whooping crane mortality (1993-94). The first year was one of high abundance of wolfberries and blue crabs. The second year was one of food scarcity. Nevertheless, the whooping cranes did not significantly change their dietary habits, eating wolfberries and blue crabs almost exclusively during both the year of abundance and the year of scarcity. Chavez-Ramirez's comparison of the results of the two years allows him to reach a much different conclusion from that of the SAGES report, namely,

> The proportion of energetic intake contributed by different food items varied by month within and between winters. Based on energetic contribution to overall energy intake, blue crab was the most significant food item during most months of both winters. Wolfberry was the second most significant source of energy for cranes. Differential mortality between study winters and differences in reproductive success in subsequent breeding seasons suggest energy stores obtained on the wintering grounds are of great importance in determining overwinter survival and overall fitness (i.e., subsequent reproduction) of Whooping Cranes" (page iv)
>
> [and]
>
> "During the two winters of study Whooping Cranes were capable of storing large quantities of energy reserves only during the first year (1992-93) when DEI

> [Dietary Energy Intake] greatly exceeded DEE [Dietary Energy Expenditure] during all months (Table 11). Because of the differences in potential for energy storage during the two seasons, one would expect greater survival of cranes during the first winter relative to the second year. Actual Whooping Crane mortality recorded during the two years of study supports this prediction. Whooping Crane mortality was zero during the 1992-93 winter, while, seven Whooping Cranes were confirmed dead (and possibly up to 12 cranes may have died) during the winter of 1993-94." (pages 82-83)

16. The SAGES report is also in direct opposition to the work of Pugesek et al. 2008. These authors sampled blue crabs in marshes on the Aransas National Wildlife Refuge from 1997 to 2005 to determine whether whooping crane mortality was related to the availability of this food source. These authors summarized their findings as follows:

> For four years, 1997 to 2001, we sampled monthly from the fall through the spring. From these data, we developed a reduced sampling effort method that adequately characterized crab abundance and reduced the potential for disturbance to the cranes. Four additional years of data were collected with the reduced sampling effort methods. Yearly variation in crab numbers was high, ranging from a low of 0.1 crabs to a high of 3.4 crabs per 100-m transect section. Mortality among adult cranes was inversely related to crab abundance. We found no relationship between crab abundance and mortality among juvenile cranes, possibly as a result of a smaller population size of juveniles compared to adults. (Abstract, page 13)

17. The abundance of blue crabs is important to the well being of the whooping crane, but that begs the issue of the correlation of whooping crane mortality with freshwater inflow into San Antonio Bay. The year of very high mortality observed by Pugesek et al. was the year 2000-01 in which there was a low crab count and a high mortality of cranes (six dead). It was also a year of fairly low inflow. Conversely the three years of high crab count were 1998-99, 2002-03 and 2003-04; all were years of adequate to high inflow rates. Regardless of these data, the correlation between river inflow and whooping crane mortality is strong, indicating that perhaps salinity-dependent variables other than blue crab abundance are also important.

18. Following is a list of **Materials Reviewed**:

> Chavez-Ramirez, F. 1996. Food availability, foraging ecology and energetics of wintering whooping cranes in Texas coast. PhD Dissertation. TAMU, College Station, Texas. 105 pp.

> Pugesek, B.H., M.J. Baldwin, and T.V. Stehn. 2008. A low intensity sampling method for assessing blue crab abundance at Aransas National Wildlife Refuge and preliminary results on the relationship of blue crab abundance to whooping crane winter mortality. Proceedings of the North American Crane Workshop 10:2008:13-23.

Slack, R.D., W.E. Grant, S.E. Davis III, T.M. Swannack, J. Wozniak, D. Greer, and A. Snelgrove. 2009. Linking freshwater inflows and marsh community dynamics in San Antonio Bay to whooping cranes. Final Report. Texas A&M AgriLIFE. August 2009. Also known as the San Antonio-Guadalupe Estuarine System (SAGES) study.

Stehn, Tom. 2008. The relationship between inflows, blue crabs, salinities, and whooping cranes. U.S. Fish and Wildlife Service Technical Report.

19. A copy of my resume accompanies this declaration as Exhibit F-2.

I, RONALD L. SASS, DECLARE UNDER PENALTY OF PERJURY UNDER THE LAWS OF THE UNITED STATES OF AMERICA THAT THE FOREGOING IS TRUE AND CORRECT.

Executed this 21 day of January, 2011.

Ronald L. Sass

EXHIBIT F-1

James A. Baker III Institute for Public Policy
Rice University

Grus americana and a Texas River: A Case for Environmental Justice

By

Ronald Sass, Ph.D.

Fellow in Global Climate Change
James A. Baker III Institute for Public Policy
Rice University

November 9, 2010

These papers were written by a researcher (or researchers) who participated in a Baker Institute research project. Wherever feasible, these papers are reviewed by outside experts before they are released. However, the research and views expressed in these papers are those of the individual researcher(s), and do not necessarily represent the views of the James A. Baker III Institute for Public Policy.

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Introduction

Fall in Texas, especially along the Gulf Coast, is not so much heralded by crisper air or changing leaves as it is by the arrival of millions of migratory birds, most of which are only stopping over briefly on their way to even warmer climes in Mexico and beyond. The largest and most magnificent of these nomadic species does not pass through but spends the winter season, as do many human "snow birds," in their favored and unique location on the Texas coast. I am, of course, referring to the whooping crane (*Grus americana*).

The object of this paper is to discuss the role Texans must play for the survival of the whooping crane. We will focus primarily on the wild, free living, nonexperimental and growing Wood Buffalo-Aransas National Wildlife Refuge whooping crane population, and the importance of the Guadalupe-San Antonio River system to the survival of this endangered species during its stay in the wintering grounds in Texas.

Description

The adult whooping crane is an unmistakable bird. Standing approximately 5 feet high, it weighs in at between 14 and 17 pounds. A wingspan of 7 to 8 feet gives the crane plenty of lift for the long migratory flights between Canada and Texas. The body feathers are snow white except for black primary feathers at the wing tips and a black "mustache" sweeping back from its beak. Red skin and a few black thin feathers define the crown of the bird. A long yellow-green beak adapted for "spear fishing" or digging matches in color the bird's golden-yellow eyes. Exposed portions of the legs and toes are black. Juvenile whooping cranes, on the other hand, have black primary wing feathers, but their body plumage is a cinnamon-mottled white that even covers the head. As the bird matures, the cinnamon color of its mottled feathers gradually diminishes to the snowy white of the adult. Interestingly, young whooping cranes have blue eyes that later turn yellowish.

Range

The whooping crane lives exclusively in North America. It is one of only two crane species living in North America. The other is the sandhill crane, found in great numbers in and around the marsh areas of coastal Texas. Although both species occupy some of the same general territory, the sandhill crane, numbering about 650,000 birds (International Crane Foundation, 2010), has several nesting areas as well as many wintering areas across North America.

The only extant natural, self-sustaining flock of whooping cranes, numbering 247 birds in 2009 (Stehn, 2010), nests and fledges at the Wood Buffalo National Park (WBNP)—located on the border between northern Alberta, Canada, and the Northwest Territory—and winters exclusively in the Aransas National Wildlife Reserve (ANWR) in Texas. Migration between Aransas and Wood Buffalo occurs in both spring and fall.

In 1975, efforts to establish a second migratory wild flock were attempted at Gray's Lake National Wildlife Refuge in southeastern Idaho. Eggs were transferred from whooping cranes at Wood Buffalo to nests of greater sandhill cranes in Idaho. These orphaned whooping cranes, however, failed to form pair bonds with each other and suffered high mortality rates. Perhaps their foster parents were unable to teach them how to be whooping cranes. Consequently, the program was discontinued in 1989 with no surviving whooping cranes.

In the 1980s, U.S. and Canadian naturalists made other attempts to establish an experimental flock as insurance in case disaster struck the Aransas-Wood Buffalo flock. In 1993, 33 captive-reared cranes were released at the Kissimmee Prairie of central Florida to establish a nonmigratory flock. After multiple bird additions, this flock numbered 87 in 2001 but is now dwindling and was down to 29 in 2009.

In 1999, governmental, nonprofit, and private organizations united to form the Whooping Crane Eastern Partnership (WCEP) to establish a new, migratory flock of whooping cranes trained to migrate between Wisconsin and coastal Florida. Chicks were conditioned to follow an ultra-light aircraft at the Necedah National Wildlife Refuge in central Wisconsin. The aircraft guided them

on their first migration south. In the fall, the young whooping cranes and a team of pilots and biologists began the 1200-mile journey to Chassahowitzka National Wildlife Refuge in Florida. The birds now spend the winter in Florida and return unassisted to Wisconsin in the spring. In 2009, this flock numbered over 100 birds and appears to be successful.

The whooping crane population at one time covered a much larger geographic range. Fossil remains dating back several million years have been found in Pleistocene formations throughout Florida (International Crane Foundation, 2010; S. L. Olson, 1972). Pleistocene fossils or prehistoric remains are also catalogued from sites in California (Miller, 1927), North Dakota, Illinois, Idaho, Michigan, Kentucky, Virginia (Brodkorb, 1967), and Arizona (Cracraft, 1968). Miller (1928) describes the Pleistocene record rather poetically. He states:

> "Again we find the asphalt beds of McKittrick and of Rancho La Brea telling a comparable story of the freshwater migrants. Snow Geese, Gray Geese and White-fronted Geese, Sand-hill and Whooping cranes, a host of bare-footed mud-probers such as Red-backed Sandpipers, Long-billed Dowitchers, and Yellow-legs, pattered or stalked about the Pleistocene marsh or wedged across the sky in a landscape picture that is hard to dissociate from the tang in the air which often forces even the sluggish unfeathered biped to at least a local migration."

Whooping cranes, although extending from central Canada to Mexico and from California to the Atlantic coast, probably never gained major abundance. Their numbers were thought to be around 1500 in the mid-1800s. The number of birds and their species range shrank rapidly in the second half of the nineteenth century. Except for a small nonmigratory population living in southwestern Louisiana, breeding birds had disappeared from all historic U.S. breeding sites by the 1890s. By 1900, ornithologists were predicting that the whooping crane was "doomed to extinction." Habitat loss and land use change due to westward expansion of settlers, unregulated hunting for sport and food, and the popularity of egg and specimen collecting at the turn of the century were the major factors leading to the species decline (International Crane Foundation, 2010).

Governmental Protection

From 1918 to the present, the Migratory Bird Treaty Act has protected the whooping crane, along with most American migratory birds. This statute states that it is unlawful to pursue, hunt, take, capture, kill, or sell birds listed therein ("migratory birds"). The statute does not discriminate between live or dead birds and also grants full protection to any bird parts, including feathers, eggs, and nests. The Migratory Bird Treaty Act does grant the secretary of the interior the authority to establish hunting seasons for any of the migratory game bird species listed in the statute. In actuality, the U.S. Fish and Wildlife Service (USFWS) has determined that hunting is appropriate only for those species for which there is a long tradition of hunting, and for which hunting is consistent with their population status and their long-term conservation. Although the Migratory Bird Treaty Act lists some 170 species to be "game birds," less than 60 species are typically hunted each year. The whooping crane is on this list, but there has never been a designated hunting season for it. Subsequent laws now protect the whooping crane.

In spite of this act, by 1945 only a remnant of a formerly stable population survived, and this remnant leads a precarious life because of the species' conspicuousness—its large size and white plumage—and its migratory habits. For many reasons, it is a marvel that whooping cranes have held on as long as this (Stevenson and Griffith, 1946). As a case in point, the Louisiana flock, which contained 13 birds in 1938, was down to one bird in 1947 and vanished by 1950. Similarly, in 1941 the Aransas-Wood Buffalo flock contained only 16 birds and was barely holding its own (International Crane Foundation, 2010). Happily, this flock numbered 247 birds in 2009 because of the active protection provided by the governments of the United States and Canada.

Literally inspired by the plight of the whooping crane, Congress passed the Endangered Species Preservation Act in 1966. The law authorizes the secretary of the interior to make a list of endangered domestic fish and wildlife and allows the Fish and Wildlife Service to spend up to $15 million per year to buy habitat for listed species. It also directs federal land agencies to preserve endangered species habitat on their lands "insofar as is practicable and consistent with their primary purpose." The whooping crane was listed as endangered throughout its range on

March 11, 1967. With the support of the Nixon administration, Congress, by an almost unanimous vote, passed the completely rewritten Endangered Species Act of 1973. The new law distinguishes threatened from endangered species, allows listing of a species that is in danger in just part of its range, allows listing of plants and invertebrates, authorizes unlimited funds for species protection, and makes it illegal to kill, harm, or otherwise "take" a listed species. In effect, the law makes endangered species protection a very high priority of the government. The whooping crane remains an endangered species to this day. Whooping cranes currently are protected in Canada, where they are classified as endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), created in 1977 as a result of a decision made at the Conference of Federal-Provincial-Territorial Wildlife Directors held in 1976 in Fredericton, New Brunswick.

Breeding Habitats

Extending over 11 million acres, Wood Buffalo National Park is Canada's largest national park and one of the largest in the world. The park plays a key role in the preservation and protection of the whooping cranes by providing and protecting the nesting habitat of the last remaining Canadian migratory flock. The park was originally established in 1922 to protect the free-roaming bison herds of the area. The fact that the whooping crane nested in the park was not known until discovered in 1955. The nesting area for the whooping crane is located in the remote north-central corner of the park. It is a fragile complex of marshes, shallow ponds and lakes, streams, and bogs. There is no public access. Today, the park supports and protects diverse ecosystems containing several rare species besides the whooping crane (Parks Canada, 2010).

The cranes usually arrive at WBNP in late April or early May, just as the ice and snow are melting from the marshes. They need to arrive by early spring in order to begin nest building in a timely fashion. The young chicks will need to utilize the entire short summer to grow, learn to fly, and gain endurance for the migration with their parents in fall. Thus the adult pair takes only a few days to select a place to nest, showing considerable preference for the same general area where they have previously nested. Several pairs have been observed to nest in the same areas for as long as 22 years. They usually build their nests at ground level on small islands of grassy

wetland sedges where hopefully the young are relatively protected from predators. The female crane normally lays two eggs, but generally only one chick survives. If both chicks are lost, there is usually not enough time to start a second brood before it is time to leave for the journey south. Both male and female share incubating the eggs until they hatch in approximately 30 days. The young birds are not ready to fly until they are about 80 or 90 days old. The juvenile has only a short time to develop skill in flying because the family needs to be ready to depart before the first freeze, usually in early October (U.S. Fish and Wildlife, 2007).

These nesting territories, termed "composite nesting areas," vary considerably in size, ranging from about 0.8 to 29 square miles, averaging approximately 2.5 square miles or 1,600 acres. Adjoining pairs usually nest at least 0.6 miles apart; however, nests have been recorded as close as 435 yards from each other. From the initiation of egg laying until chicks are a few months of age, the activities of pairs and family groups, including foraging for food and water, are restricted to their specific breeding territory (U.S. Fish and Wildlife, 2007). The principal foods of the whooping crane in their breeding territory are mollusks and crustaceans, insects, minnows, frogs, and snakes. Thus, the nesting territory must contain a diverse ecosystem and be chosen carefully.

The Northern Boreal Plains of the Wood Buffalo Park provide such habitats. It is characterized by a poorly drained, flat topography. The uniform relief, porosity, and solubility of the bedrock have produced a drainage type that is primarily vertical and percolating rather than horizontal across the surface of the land. Water percolating through the soil and bedrock causes saturation of the plains surface. This has created karst landforms in areas of gypsum bedrock. Other phenomena include salt flats, underground streams, sinkholes, and saline streams. The boreal plains are a mosaic of muskeg, meandering streams, shallow lakes and bogs, and boreal forest, an ideal habitat for the foraging whooping crane. Wood Buffalo National Park is also a home to many species of wildlife typical of the northern boreal forest, some of which are predators of the juvenile whooping cranes. Bears, wolves, moose, lynx, marten, wolverines, foxes, beavers, and snowshoe hares are but a few of the wild mammal species found (Parks Canada, 2010).

Migration Habitats

The distance between the whooping crane breeding grounds in Canada and the wintering grounds in Aransas, Texas, is approximately 2,500 miles. Flying at about 30 mph, they cover between 200 and 400 miles per day at altitudes from 1,000 to 6,000 feet. Actual speeds, altitudes, and daily distances depend on wind and weather conditions as well as conditions on the ground between flights. The migration route is long but narrow (about 300 miles wide). The migration route is through Texas, Oklahoma, Kansas, Nebraska, South Dakota, and North Dakota in the United States, and Saskatchewan and Alberta in Canada. Cranes rest and feed in all these states. The central part of the Platte River in Nebraska has been considered "the most valuable part" of the whooping crane's entire migration route. It is composed of wet meadows, sloughs, and crop fields along the river and shallow waters in the river where the birds can roost at night. Most whooping cranes that stop on the Platte River spend only a few days before continuing their migration, but a few have tarried more than a month on the Platte. Not all whooping cranes stop on the Platte River but do use wetlands, small lakes, and ponds in other states along the migration corridor. Whooping cranes generally migrate as individuals, pairs, or family groups. At times they may form small flocks of between five and 35 birds. On occasion, one or two individual whooping cranes can be observed migrating with flocks of sandhill cranes. Whooping cranes generally migrate during daylight hours, but can originate before sunrise and/or continue after sunset, thus spending less time on the ground and covering large distances in a migration day. Fall migration tends to be longer than spring migration, probably because of the biological need to nest early in the spring (The Crane Trust, 2010). The bird's first fall stop often occurs in northeast Alberta or northwest Saskatchewan, about 310 miles southeast of their departure area in WBNP. Local weather conditions influence distance and direction of travel, but whooping cranes generally are capable of reaching the autumn staging grounds in the north-central portion of the Saskatchewan agricultural area on the second day of migration. Most of the cranes remain there for two to four weeks while they feed on waste grain in barley and wheat stubble fields and roost in the many wetlands. The remainder of the migration from Saskatchewan to the wintering grounds at ANWR is usually rapid, probably weather-induced, and may be completed in a week. Food intake during migration is not well documented but probably includes frogs, fish, plant

tubers, crayfish, insects, as well as agricultural grains. The largest amount of time on the ground is spent feeding in harvested grain fields (U.S. Fish and Wildlife, 2007).

Winter Habitat in Texas

Aransas NWR was originally established by President Franklin D. Roosevelt in 1937 as a "refuge and breeding ground for migratory birds and other wildlife … for use as an inviolate sanctuary, or for any other management purpose, for migratory birds … and to conserve (A) fish or wildlife which are listed as endangered species or threatened species … or (B) plants." The refuge complex comprises more than 115,000 acres, including the Blackjack Peninsula (Aransas proper), Matagorda Island, and other smaller units. About 22,000 acres of salt flats on ANWR and adjacent islands are used as winter territories by the whooping cranes.

Aransas NWR provides vital resting and feeding wintering grounds for the whooping crane as well as other migratory birds and native Texas wildlife. It is one of more than 545 national wildlife refuges spanning the United States and managed by the U.S. Fish and Wildlife Service. The National Wildlife Refuge System is the only national system of lands dedicated to conserving our wildlife heritage for today and generations yet to come.

Whooping cranes occupy the Aransas NWR and adjacent areas from October to April, or over half the year. Pairs and families generally occupy and defend discrete territories averaging approximately 290 acres. Sub-adults and unpaired adults congregate in small flocks outside areas of family territories (U.S. Fish and Wildlife, 2007).

A thesis by Lafever (2006) contains much of what is known about whooping crane behavior in their winter habitat. She investigated spatial and temporal winter behavior and behavioral responses of five territorial whooping crane families at Aransas National Wildlife Refuge during the winters of 2003-2004 and 2004-2005. The five whooping crane territories observed ranged from the northern end to the southern tip of Blackjack Peninsula in Aransas County. All territories studied were adjacent to the Gulf Intracoastal Waterway (GIWW) or adjacent to a bay located on the GIWW. Territories were primarily composed of salt-marsh habitat, which can be

described as a mosaic of marsh vegetation and intermittently inundated ponds. Inundation and salinity of ponds varied throughout the year, depending on tidal cycles, precipitation, and freshwater inflows from the Guadalupe and San Antonio Rivers located north of Blackjack Peninsula. Observations were conducted from December 2003 through April 2004, and October 2004 through April 2005.

As might be expected, both adult and juvenile cranes spent the majority of the day foraging (63 percent and 66 percent, respectively). Alert behavior comprised 15 percent of the cranes' time-activity budgets; preening or resting, and movement each constituted approximately 7 percent of the time-activity budget. Adults were more alert than juveniles in January-February. The proportion of time spent on other behaviors did not differ by age.

Overwinter use of territories varied spatially and temporally. Flight occurrence was highest in November-December, coinciding with establishment of territorial boundaries upon arrival at the wintering grounds. Movement velocity (meters traveled/minute) also tended to be highest in November-December, which may be due to territorial defense and foraging activities. Use of land, open water, and edge habitats (land and water interface) within territories appeared to fluctuate with primary food item availability. Disproportionate use of land habitat by several crane families coincided with peak production of wolfberry (*Lycium carolinianum*) fruit, which occurs in November-December. Edge habitat was used disproportionately to its availability throughout the winter, most likely because this habitat type provided refuge for blue crabs (*Callinectes sapidus*), an important food item for whooping cranes. Several families also used open water disproportionately to its availability.

The winter diet of whooping cranes consists predominantly of blue crabs along with various species of clams, and the plant wolfberry. The wolfberry matures at about the time the crane arrives at ANWR and is essentially gone by the end of December. After that, most food foraging occurs in the brackish bays, marshes, and salt flats on the edge of the mainland and on barrier islands. In a year of high crab abundance, whooping cranes can consume seven to eight crabs per hour (80 crabs per day), totaling 80-90 percent of their diet. In contrast, during years of low blue crab abundance, cranes consume an average of only three crabs per hour (about 35 crabs per

day). The average abundance of blue crabs in the San Antonio Bay system varies throughout the year. The crab population is relatively low during the months of November through January. It is high during the rest of the time the whooping crane is in residence.

The blue crab lives in estuarine and tidal areas and other shallow coastal waters, to a maximum depth of around 90 meters. It is found on muddy and sandy bottoms in coastal areas, but may move to greater depths in cold winters. When air temperatures drop below 50°F (10°C), adult crabs leave shallow, inshore waters and seek deeper areas where they bury themselves and remain in a state of torpor throughout the winter. In this state they are unavailable to the whooping crane.

Blue crab growth is regulated by water temperature. Growth occurs when water temperatures are above 59°F (15°C). Water temperature above 91°F (33°C) is lethal. Blue crabs are susceptible to sudden drops in temperature.

Salinity is important to the blue crab, but requirements vary by life stage. Generally optimum salinity is 3-15 parts per thousand (ppt). Maximum abundance is between 10 and 20 ppt. Below 5 ppt and above 30 ppt the blue crab is absent. Larvae are sensitive to salinities below 20 ppt, but juvenile and adult crabs can cope with everything from freshwater to highly saline marine conditions. After mating, the female will migrate to high salinity waters in lower estuaries, sounds, and near-shore spawning areas. They overwinter before spawning by burrowing in the mud. Most females spawn for the first time two to nine months after mating, usually from May through August the following season. Larvae are filter feeders, and live a planktonic existence in the high-salinity surface waters near the spawning grounds, as do the pre-juvenile megalops. The juveniles gradually migrate into shallower, less-saline waters in upper estuaries and rivers where they grow and mature. Males generally migrate farther upstream, preferring low-salinity waters, whereas females tend to stay in lower rivers and estuaries. Sexual maturity is reached after 18 to 20 post-larval molts, generally at the age of 1 to 1 1/2 years. Males continue to molt and grow after they reach sexual maturity. It is generally accepted that females cease to molt and grow (terminal molt) when they mature and mate and the cycle repeats itself.

The juvenile crabs are the preferred diet for the whooping crane and generally can be found in the marshes of their territory. Marsh, sea grass beds, and wetlands are crucial for blue crabs to flourish. Juvenile crabs avoid predation by seeking refuge in these habitats, and a symbiotic relationship develops between them and the vegetation. Crabs strip the aquatic vegetation of grazing mollusks and, in turn, are provided with extra cover and food—circumstances under which strong recruitment is almost guaranteed.

However, consider the effects of a prolonged drought without water restrictions. It starts with less flowing of freshwater into the estuary from the San Antonio and Guadalupe Rivers. This is followed by reduced primary productivity (growth of algae, sea grass, and phytoplankton). This reduction limits the food supply for organisms at the lower levels of the food chain (zooplankton, mollusks), which in turn limits the food supply of blue crabs. Such a sequence leads to fewer crabs for the whooping crane to eat, causing them to become excessively stressed or threatened (Sutton, 2005).

Occasionally, cranes fly to upland sites, requiring freshwater to drink when their territorial waters become too saline. Whooping cranes do not drink water that is more saline than 23 ppt. While upland, they may take foods such as acorns, snails, crayfish, and insects, and then return to the marshes to roost. Uplands are particularly useful when partially flooded by rainfall, burned to reduce plant cover, or when food is less available in the salt flats and marshes. Agricultural croplands adjacent to ANWR are rarely visited.

High fall tides and heavy rains sometimes flood tidal flats. In these circumstances, the birds forage almost exclusively on blue crabs and wolfberry in flooded areas. In December and January, tidal flats typically drain as a result of lower tides, and the birds move into shallow bays and channels to forage primarily on clams, although blue crabs are occasionally captured while probing the bottom. Clams are a significant dietary item when water depths are low, temperatures cold, and following drought when the blue crab population is low. Smaller blue crabs (5 cm or less in width) are preferred and are swallowed whole. Larger crabs, when eaten, are pecked into pieces before being swallowed (U.S. Fish and Wildlife, 2007).

Threats to the Whooping Crane in Texas

SEC. 4. [16 U.S.C. 1533] of the 1973 Endangered Species Act lists five categories of factors detrimental to the well-being of the whooping crane. These factors are as follows:

- The present or threatened destruction, modification, or curtailment of its habitat or range
- Overutilization for commercial, recreational, scientific, or educational purposes
- Disease or predation
- The inadequacy of existing regulatory mechanisms
- Other natural or manmade factors affecting its continued existence.

The U.S. Fish and Wildlife International Recovery Plan for the whooping crane (USFWS, 2007) details a variety of threats that address these categories. These threats are (A)-1 human habitat; (A)-2 freshwater inflow; (B)-1 shooting; (B)-2 disturbance; (C)-1 diseases and parasites; (E)-1 life history; (E)-2 food availability/sibling aggression: climate factors; (E)-3 loss of genetic diversity; (E)-4 red tide; (E)-5 chemical spills; (E)-6 collisions with power lines; (E)-7 fences and other structures; (E)-8 collisions with aircraft; and (E)-9 pesticides. Although several of these threats may appear to be solely from natural causes, all are or can be influenced through human intervention. Human habitat, shooting, chemical spills, pesticides, disturbance, and collisions with various human appliances are obviously directly associated with human intervention. Human intervention in the case of loss of genetic diversity, red tide, life history, and food availability is less direct, but can be affected by aggressive management such as that done by the U.S. Fish and Wildlife Service and the Canadian Wildlife Service. One threat that at first appears to be of natural origin but in reality is greatly influenced by human actions is the question of freshwater inflow. Maintaining an adequate supply of freshwater inflow to San Antonio Bay may very well be the single most important factor determining the future sustainability of the world's population of wild whooping cranes.

Effects of Freshwater Inflow

Freshwater is essential to crabs, and there are more crabs in the bays when freshwater is plentiful. The highest commercial blue crab catch in San Antonio Bay, according to one study, came during three years when the Guadalupe River was pouring 3 million acre-feet of water annually into the bay. How much freshwater is the right amount? The answer is hard to come by. Floods may come and wipe out the oyster reefs for a couple of years. Droughts may do the same thing. No one seems to worry about too much freshwater in the bays, but drought is a concern. The last great drought began in 1948 and ended in 1957. During its peak in 1956, the bays received 14 percent of their average freshwater inflows. San Antonio Bay received only 196,000 acre-feet of water, or 8.4 percent of its average. Up and down the coast, the oyster crop disappeared, white shrimp declined drastically, the high salinity in Upper Laguna Madre blinded black drum and scored them with lesions, and the blue crab population in the estuary dropped.

Without sufficient freshwater from the Guadalupe-San Antonio Rivers, the salinity of the estuary system can approach that of seawater at approximately 35 ppt. A salinity of that magnitude negatively affects the blue crab and the wolfberry populations, as well as those of other organisms that are all vital sources of food for the whooping crane. A higher salinity also causes the whooping crane to seek fresher water away from the relative protection of its territory.

But what is a sufficient flow of freshwater needed to sustain a healthy ecosystem in the estuary?

The drought of record is the baseline for scientific study of the freshwater inflows. Such factors as historical inflows, nutrient and sediment loads, circulation, and salinity patterns were studied and compared to a fisheries analysis to determine how much water is needed to sustain the productivity of San Antonio Bay. Similar studies have been performed for other estuaries of the Texas coast, and numbers have been produced stating the amount of water needed to keep the bays relatively productive, provided the water is distributed in a seasonal pattern (Berryhill, 2003). The value for San Antonio Bay is estimated to be 1.1 million acre-feet—about a third of what is available in a water abundant year (Texas Parks & Wildlife Department [TPWD], 2007). The modeled maximum harvest freshwater inflow (Max H) is slightly below the median flow of

1.5 million acre-feet annually. In the Guadalupe Estuary, blue crabs are most abundant in salinities that average between 10 and 25 ppt. TPWD data suggests that water inflows greater than 1.3 million acre-feet annually result in low enough salinities in the estuary to produce high numbers of blue crabs. In San Antonio Bay, the years with the highest harvests all had inflows greater than 3 million acre-feet. Therefore, according to Longley (1994), the salinity level should remain between 10 and 20 ppt for approximately 60 to 80 percent of the time for maximum production of the blue crab species as well as the white shrimp, gulf menhaden, and brown shrimp.

Whooping crane territories in the ANWR area include brackish marshland pools. With sufficient water flow and normal tides, these pools are connected to each other and with the flowing waters of the estuary system. This allows for a flow of water that keeps these pools at a salinity level at a value low enough for the whooping crane to draw its drinking water. Normally, tides in this area are highest in November-December and lowest in February-March. If the flow of freshwater into the marsh system is also low during these later months, the marsh pools may become disconnected from the bay system. Evaporation at this time, especially if the temperature is warm, will deplete these pools of water that no longer can be replaced. This condition would result in the marsh having much higher salinities than the bay itself. If fact, the salinity may become higher than 35 or 40 ppt, or much higher than the maximum salinity of 23 ppt of water that is drinkable by the whooping crane. This condition would cause the whooping crane to seek water outside its territory. It could explore territories of other whooping cranes for water that might result in aggressive behavior from the occupant crane and possible injury to the crane. It might also fly upland where the water is fresh, but where there is a higher probability of the crane being attacked or possibly killed by resident predators or by ingesting pesticides. These conditions might also lead to many whooping cranes to congregate at the same watering place, resulting in the chance for a diseased or parasite-carrying crane to infect others.

A chart of whooping crane winter mortality expressed as a percentage of the flock population and the corresponding average river flow into the Guadalupe Estuary from the combined Guadalupe and San Antonio Rivers during the six month critical period of bay productivity from July to December is shown ordered by year (1988-2009) in Figure 1a, and ordered by river flow

in Figure 1b. Flow data is obtained by combining data collected by the U.S. Geological Survey (USGS) at the Victoria, Texas, Gauge Station (USGS 08176500) in the Guadalupe River and at the Goliad, Texas, Gauge Station (USGS 08188500) in the San Antonio River. It is expressed in units of 1000 cubic feet per second. Whooping crane mortality during the winter seasons at Aransas NWR was collected by Tom Stehn of the USFWS (2009).

Figure 1a does not suggest an apparent linear or exponential correlation between mortality and river inflow. Figure 1b does show clearly that a high rate of winter mortality (>1.1 percent) always occurs during years of low water flow. In the 13 years recorded with inflows equal to or less than 2,350 cu ft/sec, the average winter mortality rate was 2.81 percent of the whooping crane population, whereas in the eight years with inflows greater than 2,300 cu ft/sec, the average winter mortality rate was 0.38 percent of the population. Using these data, we hypothesize that mortality greater than 1.1 percent is associated with total river flow during the test months of less than 2,350 cu ft/sec. The data could be organized like this in a Fisher 2x2 exact probability test:

		Flow	
Mortality (percent)	<2.35	>2.35	Total
<1.1	6	8	14
>1.1	7	0	7
Total	13	8	21
P = 0.0148			

Knowing that over a period of 21 years, 13 of these years had average July to December flow rates less than 2,350 cu ft/sec and eight had flow rates greater that 2,350 cu ft/sec and that in seven of these years the whopping crane mortality was greater than 1.1 percent, what is the probability that the years of high mortality would be so unevenly distributed between years of high and low river inflow? Invoking the null hypothesis by postulating that there is no correlation between river flow and crane mortality, and using the Fisher 2x2 exact probability test, the probability of the observed distribution of flows and mortality can be calculated exactly (one tailed test). The Fisher Exact Probability Test is an excellent nonparametric technique for analyzing discrete data (either nominal or ordinal), when the two independent samples are small

in size. It is used when the results from two independent random samples fall into one or the other of two mutually exclusive classes (NIST/SEMATECH e-Handbook, 2010).

For our particular distribution of mortality and river inflow, the probability that they are not correlated (the null hypothesis) has a P value of only 0.0147. Thus the chance that mortality and river inflow are indeed correlated as suggested is very significant. Other variables must also play an important role in whooping crane deaths. For example, Gil de Weir (2006) conducted a very thorough study of the demographics of the whooping crane wherein she considers several environmental variables such as extreme temperature, heavy precipitation, salinity, food scarcity, hurricanes, and drought that might also cause winter mortality of whooping cranes. Here we are concerned only with deaths at ANWR. There is also a high mortality rate of hatchlings and the very young juveniles at WBNP. Plus, predators are always present, not only at the breeding grounds and along the flyway, but also at ANWR.

River Inflow and Whooping Crane Mortality

The quantity and quality of freshwater that enters the Guadalupe Estuary System has a direct but complicated bearing on the well-being and, indeed, the survival of the whooping crane population that winters there. Currently low-flow years are not infrequent. Any additional loss of freshwater flowing into the bay system would significantly increase the number of low-flow years and seriously threaten the continued existence of the whooping crane.

Freshwater inflow comes primarily from the San Antonio and Guadalupe Rivers. Because Matagorda Island separates the estuary and bay system from the Gulf of Mexico, there is little direct exchange between San Antonio Bay and Gulf waters, although some exchange of salt water from the Gulf to the Bay does occur via Pass Cavallo to the north and Cedar Bayou to the south.

The Guadalupe River begins in two forks in western Kerr County, the north and south forks. These two branches converge near Hunt, Texas. From there the river continues to flow southeast for 230 miles, passing through Kerr, Kendall, Comal, Guadalupe, Gonzales, DeWitt, and

Victoria counties. It then forms the boundary between southern Victoria County and Calhoun County and between Calhoun and Refugio counties before reaching its mouth on San Antonio Bay. By the time the river reaches Victoria (USGS gauge #8176500 at Victoria), its flow rate averages about 2,005 cu ft/sec (1.453 million ac ft/yr). The minimum annual flow was 131.6 cu ft/sec (95,300 ac ft/yr) in 1956 and the maximum annual flow was 6,993 cu ft/sec (5.063 million ac ft/yr) in 1992.

The San Antonio River originates in central Texas near San Antonio and follows a roughly southeastern path through the state. The 240-mile-long river crosses five counties: Bexar, Goliad, Karnes, Refugio, and Wilson. It eventually feeds into the Guadalupe River about 10 miles from San Antonio Bay. Its average discharge (1940-2008) is 825 cu ft/sec (597,300 ac ft/year) measured at Goliad (USGS gauge #8188500). The annual freshwater contribution of the San Antonio River to the San Antonio Estuary system is about half that of the Guadalupe River, but because it passes through the San Antonio public water system, it has a much higher nutrient content.

The Guadalupe's drainage area is about 6,070 square miles while the basin area of the San Antonio River is about 3,921 square miles, or roughly two-thirds as large as the Guadalupe River basin. Together they collect runoff and spring water from an area that is nearly 10,000 square miles. Freshwater inflow to San Antonio Bay is realized primarily from these two rivers with a small additional amount from direct coastal runoff and from ungauged small creeks and streams that empty into the estuary-bay system. Legislatively mandated studies to determine freshwater inflows necessary to conserve healthy productivity of San Antonio Bay recommend 1.15 million ac ft/yr or roughly half of the average annual freshwater inflow from the Guadalupe and San Antonio Rivers. As stated previously, the Texas Parks & Wildlife Department data suggest that water inflows greater than 1.3 million acre-feet annually result in low enough salinities in the estuary to produce a healthy number of blue crabs. A level of flow this abundant produces a bay salinity of from 10 to 25 ppt. These freshwater flows are necessary to provide suitable drinking water for the whooping crane. Otherwise, they would be required to fly inland to find fresh drinking water (TPWD, 1998). Tragically, no mechanisms to guarantee critical river flows are provided by Texas water laws.

In 2000, the San Marcos River Foundation applied for a water right that would leave 1.15 million acre-feet in the river, in accordance with the flows recommended by TPWD for the Guadalupe estuary. The application was denied in 2003 but was appealed and, in February 2005, was sent back by the court to the Texas Council on Environmental Quality for a rehearing. Conservation flows were proposed in Senate Bill 3 in the Texas Legislature in 2005 and passed by the House in 2007 (International Recovery Plan, 2007). The law creates an extensive public process, soliciting input from scientists and stakeholders in each river basin to determine how much water is needed to keep the state's rivers and coastal estuaries healthy, and how to ensure that water is protected. Final flow allocations will be determined by the Texas Commission on Environmental Quality (Texas WaterMatters, 2010). The process is ongoing and subject to considerable political debate. No immediate decision is evident.

In 2002, American Rivers named the Guadalupe on their annual list of the 10 most endangered rivers in the United States because of the inflow issue. "If the state of Texas doesn't take action to ensure that water keeps flowing in the river, existing and proposed diversions could dewater the river and deprive San Antonio Bay and Aransas Bay of needed freshwater," said American Rivers President Rebecca R. Wodder (Sierra Club, 2002). Projections indicate the river will be significantly threatened during periods of low flow and could cease to flow into the bay if all currently authorized water-use permits are utilized (National Wildlife Federation [NWF], 2004).

In a report titled *Bays in Peril,* a "danger" ranking was given to San Antonio Bay because drought periods were predicted to increase by 250 percent, and years with low freshwater pulses in the spring were calculated to increase 26 percent from naturalized levels (NWF, 2004). Texas Water Development Board data indicate natural droughts already threaten the Guadalupe ecosystem. Withdrawals of surface and groundwater for municipal and industrial growth are predicted to leave insufficient inflows to sustain the ecosystem in less than 50 years. Modeling indicates that if all existing water rights were exercised during a repeat of the 1950-1956 droughts, estuary inflows would be reduced by 17 to 43 percent below current levels and by 36 to 72 percent below historic levels, depending on the year (Norman Johns, National Wildlife Federation, Austin, TX, pers. comm., in Fitzhugh and Richter, 2004). Additionally, there are

pending water right applications for much of the remaining unappropriated water in the Guadalupe (International Recovery Plan, 2007).

Water rights continue to be granted on the Guadalupe, even though some sections of the river are already over-appropriated. Greater San Antonio will continue to grow, with population expected to double by mid-century (San Antonio Water System, 2003). In stream reservoir construction, water diversions and water usage will continue to increase in the future, further reducing freshwater inflows. The Guadalupe and San Antonio rivers are a major source of water for Region L of the Texas Water Plan. Projected total water demand for south central Texas (Region L) is the sum of water demand projections for municipal, industrial, steam-electric power generation, mining, irrigation, and livestock uses. Projected changes in the total water demand by use category from 2000 to 2060 are: municipal, 187 percent; industrial, 179 percent; power generation, 362 percent; mining, 159 percent; agricultural irrigation, -21 percent; and livestock, unchanged. The total expected increase in water usage amounts to an increase in demand for river water by approximately 150 percent (SCTRWPG, 2010).

The Added Threat from Future Climate Change

Most of Texas, climatologically, has a modified marine climate. It is classified as "subtropical," with four zones:

- The eastern third of Texas has a subtropical humid climate that is most noted for warm summers.
- The central third of Texas has a subtropical subhumid climate characterized by hot summers and dry winters.
- The broad swath of Texas from the mid-Rio Grande Valley to the Pecos Valley has a subtropical semi-arid climate.
- The basin and plateau region of the Trans-Pecos features a subtropical arid climate that is marked by summertime precipitation.

The marine climate is caused by the dominant onshore flow of tropical moist air from the Gulf of Mexico. This airflow is modified by a decrease in moisture content from east to west, as well as

by intermittent seasonal intrusions of drier continental air. The four zones of subtropical-humid, subhumid, semi-arid, and arid account for the changes in moisture content of the flow of Gulf air across the state (Larkin and Bomar, 1983).

The Guadalupe River Basin falls mainly in the subtropical subhumid zone. Current annual precipitation levels in this area range from a low of 25 inches in the west to 40 inches in the east. The Intergovernmental Panel on Climate Change (IPCC) precipitation levels for the entire region are predicted to fall by 5 to 20 percent by 2100. The IPCC (2007) predicts a positive temperature change of 3.5°C (6.3°F) or more in this same area.

As the climate warms, evapotranspiration will increase with a subsequent loss of soil moisture, and the net amount of water added to the watershed (precipitation minus evaporation) will certainly decrease. Thus the consequences of climate change are predicted to result in a temperature increase of 3.5°C (6.3°F) and a net decrease in annual precipitation of 15 percent along the Guadalupe River and, subsequently, on San Antonio Bay by the year 2100.

A climate study appearing in May 2007 (Seager et al.) models the hydroclimate in the southwestern United States using the A1B climate scenario, which amounts to a very rapid economic growth with a balance of many different energy sources and a mid-century peaking of the world population. This paper presents convincing evidence that both precipitation and evaporation will decrease over the next several decades consistent with the above estimates. The authors assert, "There is a broad consensus among climate models that this region will dry in the 21st century and that the transition to a more arid climate should already be underway. If these models are correct, the levels of aridity of the recent multiyear drought or the Dust Bowl and the 1950s droughts will become the new climatology of the American Southwest within a time frame of years to decades."

In the current case of the Guadalupe River, by the time the river reaches USGS gauge #8176500 at Victoria, its flow rate averages about 2005 cu ft/sec (1.453 million ac ft/yr). The average is, however, far from normal. It is often said of the Guadalupe River that a normal flow is not normal! The years from 1951 through 1956 were severe drought years in South Texas. During

this time, the flow of the Guadalupe River stayed below 1000 cu ft/sec, averaging only 508 cu ft/sec. This is only one-eighth of the average flow and far below the water needed for a healthy San Antonio Bay, not to mention human needs along the lower river. The largest annual flow rate occurred in 1992 and was nearly 7,000 cu ft/sec, resulting in flooding conditions along the river. Flows in other years are almost randomly distributed.

River flow depends primarily on runoff from precipitation over the entire watershed and secondarily from springs in the Edwards Aquifer. The Guadalupe River watershed is 6,070 square miles in area. An average flow rate of 2005 cu ft/sec or 1.453-million ac ft/yr predicts a required runoff from 6,070 square miles of 0.37 ft (112 mm). A study (Reed, Maidment, and Patoux, 1997) using model calculations and observed data suggests a relationship between precipitation and runoff for precipitation levels above about 700 mm/year to be related in a linear fashion by the equation

$$R = 0.510P - 339.1 \qquad \text{(Equation 1)}$$

where R = runoff in millimeters (mm) and P = precipitation in mm. This equation predicts that for an expected runoff of 112 mm, the predicted precipitation for that runoff would be 884 mm or 35 in/year.

Although we do not have a complete precipitation data set for the entire river basin, a proxy value for San Antonio might serve to test the relationship between precipitation and river flow. Annual precipitation data from 1936 to 2007 for San Antonio is available from the National Weather Service Forecast Office Austin/San Antonio. A plot of the river flow at Victoria vs. precipitation at San Antonio shows the data to be somewhat scattered with a tendency for higher flow rates at higher precipitation rates. A least squares analysis of the data yields a best-fit linear relation of

$$F = 50.6 * P + 466 \qquad \text{(Equation 2)}$$

where F = Annual flow rate (cu ft/sec) from the Guadalupe Basin and P = Annual precipitation (inches) at San Antonio.

From equation 2, a postulated precipitation rate of 35 in/yr equates into a calculated flow rate of 2,237 cu ft/sec, a value quite close to the average reported observed flow rate of 2,005. It is interesting to note that for a given precipitation rate of zero, the flow rate is still 466 cu ft/sec. This figure would correspond to water input from sources other than precipitation runoff, such as from springs in the Edwards Aquifer. The two major springs contributing to the flow of the Guadalupe River are the San Marcos Springs and Comal Springs, located on the down dip of the Edwards Aquifer in the Guadalupe River Basin. The summed measured "expected" flow from these springs is given as 457 cu ft/sec (Reed, Maidment and Pateau, 1997). This value is very close to the intercept value of 466 cu ft/sec in equation 2, above.

Using the above data, the effect of climate change on the Guadalupe River can be estimated. Two aspects will be discussed: 1) the change in frequency of drought events and 2) the decrease in the general flow from the Guadalupe Basin.

Assuming that climate change will result in a decrease in precipitation of 15 percent by the year 2100, differentiation of equation 1 shows that the ratio of the change in runoff to precipitation is 0.510, or the basin runoff is reduced by approximately 50 percent of the change in precipitation, or 7.5 percent. If the probability distribution of annual flows remains the same except for a shift of -7.5 percent in the actual flow values, then the average annual flow will drop from 2005 to 1840 cu ft/sec and the number of years with annual flow of 1000 or less cu ft/sec will increase from 17 to 23. The most probable flow rate (9 years) is 401-600 cu ft/sec. The average river flow change from 2005 cu ft/sec to 1840 cu ft/sec corresponds to a decrease of 120,200 ac ft/yr in the annual flow of water from the Guadalupe River to San Antonio Bay.

The San Antonio River also supplies freshwater runoff to San Antonio Bay. On the average, this flow adds about a third of the flow from the Guadalupe River. The climate change caused reduction in the annual flow of this river will be approximately 42,000 ac ft/yr. This would bring the total reduction in the freshwater river inflow to the San Antonio Bay to essentially 162,200 ac ft/yr, a very significant loss of renewal water.

Another factor when considering the health of San Antonio Bay is the loss of freshwater through increased evaporation caused by climate change. The IPCC (2007) projected temperature change by 2100 directly along the coast of the Gulf of Mexico is approximately 3.0°C. Using data generated by Gerald North (2008), the change in open water evaporation due to a temperature increase in the Guadalupe River Basin is about 0.15-0.16 inches per month per 1°F rise in temperature. Therefore, an increase of 5.4°F (3.0°C) is 0.81 to 0.86 inches per month, or approximately 10 inches per year. San Antonio Bay is approximately 130,000 acres in size. An additional annual loss of 10 inches of water due to increased evaporation caused by climate change means that 108,300 additional ac ft of freshwater input (from Guadalupe and San Antonio Rivers) would be required in order to maintain a stable salinity.

In summary, the effects of climate change on the hydroecology of the Guadalupe River and San Antonio Bay are severe. A summary of projected climate changes and resulting effects on this system are given in Table I.

In a warming world where the Texas State Water Board projects that Texas' water demand will increase 27 percent by 2060, no gain in rainfall actually would be a loss. However, a precipitation loss of 15 percent by the end of this century will be of serious concern when attempting to satisfy this demand. Our water resources are already vulnerable and climate change predictions consistently suggest that the situation will only become worse within the next several decades.

In bays and estuaries such as San Antonio Bay, behind the barrier islands separating the Texas mainland from the Gulf of Mexico, freshwater and saltwater combine to create the environment that marine life need to live and flourish. The state's aquaculture industry is particularly sensitive to adequate amounts of freshwater and periodic increases in salinity. Because of climate change, evaporation rates in the bays will increase and replacement freshwater from river flow into lagoons and bays will decline. The effect on the bays will be much higher salt concentrations, less nutrient input, and less frequent flushing resulting in lower water quality overall. Salt tolerance of some species may be exceeded, causing changes in the food web, a reduction in marine productivity, and subsequent decline of bird species, especially the whooping crane.

Threat to Whooping Cranes by Increased Need for Electric Power Generation

The large projected increase in the population of Texas will require increased industry and business as well as more electrical power. All will require freshwater from the rivers. The number of people living currently in region L of Texas (the watersheds of San Antonio and Guadalupe Rivers) is approximately 2.5 million. This number is expected to grow to 4 million by 2050, an increase of 60 percent. The number of people in San Antonio alone is projected to increase from 1.35 million in 2010 to 2.3 million in 2050, an increase of 70 percent. The direct requirement for more municipal water to satisfy this increase in people will be high, but the projected increase in cooling water needed for the production of new electrical power for this increased population will be even more significant.

New power plants will need to come on line in order to meet an increased demand for electricity. Because of the requirement for large amounts of cooling water, these plants will of necessity be built on or near to bodies of water. Exelon Corporation is one of the nation's largest electric companies with 10 nuclear power plants throughout the United States. It has applied for an "early site permit" (ESP) with the Nuclear Regulatory Commission (NRC) for an 11,500-acre site in Victoria County to build a new nuclear power plant (NRC, 2010). If approved, the early site permit would effectively reserve the property for new nuclear construction for up to 20 years with the possibility of renewal for another 20. Unlike a combined construction and operating license, an early site permit does not authorize construction of a new plant nor does it require details on the type, number, and size of the reactors.

Although no specific plant design has been chosen for the Victoria site, Excelon Corporation presented a set of bounding plant parameters for future site development. This plan is based on the addition of power generation consisting of one or more reactors or reactor modules. These reactors or groups of modules (the number of which may vary depending on the reactor type selected) would be distinct operating units. Each unit would consist of a plant of one or more modules that would not exceed 4500 Megawatt thermal (MWth) of nuclear generating capacity (NRC, 2010).

Of the 104 nuclear power reactors currently licensed to operate in the United States, 69 are pressurized water reactors (PWR) and 34 are boiling water reactors (BWR). Both types of reactors operate on similar principles. In both systems, a closed water system flows through the reactor core and is heated by its thermal energy.

In a PWR, the water is maintained under high pressure over 2,000 psi so it does not boil even when heated to temperatures near 500°F. The heated water travels through a steam generator where it exchanges heat with a separate water system at lower pressure, turning it to steam. This steam then drives a turbine that produces electricity. The steam exits the turbine and is condensed by cooler river water. The condensed water cycles back through the steam generator where it goes through another cycle.

In a BWR, the water flowing through the reactor is directly turned to steam at or near the normal boiling point. The steam spins the turbine generating electricity. The steam then enters a condenser where it exchanges heat with isolated river water, condenses and returns to the reactor for another cycle (UCS, 2007).

The river cooling water is either passed through the system once, heated, and returned to the river (once-through cooling system) or discharged into a cooling pond where it cools to ambient temperature and recycled through the system (closed-loop cooling system). The proposed Exelon reactor will more than likely be cooled by a closed-loop system because the ESP calls for a 4,900 acre cooling pond on site. The ESP reads: "The cooling basin is one of the major features on the site. The cooling basin has a surface area of about 4900 acres. The cooling basin is part of the nonsafety-related cooling system that has the design function of dissipating the heat load in the circulating water system. The basin is formed by approximately 11 miles of perimeter embankment dams that consist of clay or clayey sand fill that are constructed above ground. Internal earth dikes inside the cooling basin will be used to guide the circulating flow from the cooling basin outfall structure to the cooling basin intake structure to optimize the effective cooling area."

Both types of reactors operate at near 33 or 34 percent efficiency. The ESP states that a total of 4500 MWth of capacity will be generated at each of the reactor modules. This would amount to about 1500 Megawatt electric (MWe) per reactor module. The company indicates in a press release that it will generate about 3,000 MW of electrical power, enough to serve 1.85 million typical Texas homes. It also indicates that Excelon is planning on two modules (Excelon, 2008). Excelon also indicates that the electricity produced will be used for a constant "base load" demand rather than responding to "peak load" changes in electrical usage demands, and therefore the reactors will operate 24 hours a day every day.

The amount of water needed for cooling the system is the amount of water necessary to exchange 4500 MW of thermal power. This amount of water is essentially independent of reactor type and method of cooling. In a closed-loop cooling system, the net amount of water removed from the river is makeup water that is supplied to the cooling basin intermittently throughout the year. This water compensates for the inventory lost due to evaporation, blowdown, and seepage. "Blowdown" is the portion of the circulating water flow that is removed in order to maintain the amount of dissolved solids and other impurities at an acceptable level. Evaporation losses result from the operation of both the circulating water system and any applicable ultimate heat sink and auxiliary cooling-system cooling towers. The cooling basin inventory also accounts for a very small drift loss from the applicable cooling towers. Other than the river, the only natural inflow into the cooling basin is direct rainfall because the cooling basin is self-contained and has no other contributing drainage area. The cooling basin receives return effluents from the various plant's facilities and systems, not including the radiation waste discharges.

The COLA that Excelon originally filed in 2008 estimated that this makeup water would not exceed an average of 75,000 acre ft/year. This represents 75,000 acre ft/year less entering San Antonio Bay, a situation that certainly will adversely affect the salinity of the system and, consequently, the health of the whooping crane.

Summary

Of all the natural winter sites historically habited by the whooping crane all over the United States, including the entire Texas Gulf Coast, only the Aransas National Wildlife Reserve remains viable. Why the whooping crane has chosen this place above all others to spend the winter is a mystery, yet it is an amazing fact. It surely must be because ANWR has the best available climate with the most favorite food, favorable water, and minimally disturbed territory, or else some other location would have won the selection by the bird. I believe that all of these contributing factors are at risk and therefore so is the whooping crane. Historically, as has been pointed out in this paper, 13 of the last 21 years had river inflow from the Guadalupe-San Antonio Rivers low enough to stress the whooping crane. In seven of those 13 years, an excessive fraction of the birds died. The future is even less bright. Human populations in the river basins are predicted to increase by 60-70 percent in the next 40 years. These new people and related industrial requirements will place heavier usage on the rivers, depleting and polluting the crane's habitat. Increased population means increased electrical power needs. Coal-fired power plants as well as nuclear reactor-powered electrical generators require large amounts of cooling water from the rivers. By 2100, climate change will decrease river inflow by 7-8 percent due to increased temperature in the basins. Inland precipitation will decrease by 15 percent and coastal temperature increases will increase evaporation from San Antonio Bay by over 108,000 ac ft/yr. Climate change alone will increase the frequency of low annual flow by 35 percent. At best, the whooping crane is currently under threat from poor freshwater inflow into the San Antonio Bay system. The future looks much more bleak and will take all of the technological goodwill and know-how that we as humans can muster in order to stabilize or perhaps, if we are really smart, increase health and well-being of our fellow Texans, the whooping cranes.

References

Berryhill, M. 2003. "The Whoopers Table." *Texas Parks and Wildlife Magazine.* July 4. http://www.tpwmagazine.com/archive/2003/jul/ed_4/ 2003

Brodkorb, P. 1967. "Catalogue of fossil birds. Part 3 (Ralliformes, Ichthyornithiformes, Charadriiformes)." *Bull. Fla. State Mus*. 11:99-220.

Cracraft, Joel. 1968. "The Whooping Crane from the Lower Pleistocene of Arizona." *The Wilson Bulletin* 80: 490. Wilson Ornithological Society.

Excelon Corp. 2008. "Exelon Generation Submits License Application For New Nuclear Energy Plant." News release. http://www.exeloncorp.com/Newsroom/pages/pr_20080903_GenerationB.aspx?k=Victoria.

FitzHugh, T.W. and B.D. Richter. 2004. "Quenching urban thirst: growing cities and their impacts on freshwater ecosystems." *Bioscience* 54 (8): 741-754.

Gil de Weir, K. 2006. "Whooping crane (*Grus americana*) demography and environmental factors in a population growth simulation model." Ph.D. dissertation. Texas A&M University, College Station, Texas.

International Crane Foundation. 2010. "The Whooping Crane." http://www.savingcranes.org/whooping-crane.html.

U.S. Fish and Wildlife Service. March 2007. *International Recovery Plan, Whooping Crane.* Third Edition.

LaFever, K. E. 2006. "Spatial and temporal winter territory use and behavioral responses of whooping cranes to human activities." Master's thesis. Texas A&M University, College Station, Texas.

Larkin, T. J. and Bomar, G. W. 1983. "The Climate of Texas." http://atmo.tamu.edu/osc/TXclimat.htm.

Longley, W.L. (ed.). 1994. "Freshwater inflows to Texas bays and estuaries: ecological relationships and methods for determination of needs." Texas Water Development Board and Texas Parks and Wildlife Department, Austin, Texas.

Miller, Loye. 1928. *The Antiquity of the Migratory Instinct in Birds: The Condor* 30, no. 1: 119-120.

National Wildlife Federation. 2004. "Bays in Peril, A Forecast for Freshwater Flows to Texas Estuaries."

NIST/SEMATECH. 2010. *e-Handbook of Statistical Methods*. http://www.itl.nist.gov/div898/handbook/.

North, Gerald. 2008. "Texas Water & Global Warming." Far West Texas Climate Change Conference. El Paso, Texas. June 17.

Nuclear Regulatory Commission. 2010. Early Site Permit Application-Victoria County Station. http://www.nrc.gov/reactors/new-reactors/esp/victoria.html.

National Wildlife Federation. 2004. "Bays in Peril: A Forecast for Freshwater Flows to Texas Estuaries."

Parks Canada. 2010. "Wood Buffalo National Park of Canada." http://www.pc.gc.ca/pn-np/nt/woodbuffalo/natcul/ natcul1.aspx.

Reed, S., Maidment. D. and Patoux, J. 1997. "Spatial Water Balance of Texas." Center for Research in Water Resources University of Texas at Austin. http://www.crwr.utexas.edu/gis/gishydro03/Library/wbtexas/wbtexas.htm.

San Antonio Water System. 2003. *Quarterly report on water resources*, *July-September, 2003*. San Antonio, Texas.

South Central Texas Regional Water Plan Group. 2010. http://www.regionltexas.org/2011_rwp2.php.

Seager, R. et al. 2007. "Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America." *Science* 316, 1181.

Sierra Club. 2002. "Texas' Guadalupe River is one of America's most endangered rivers." News release. http://texas.sierraclub.org/press/newsreleases/american_rivers.html.

Stehn, Tom. 2010. *Whooping Crane Recovery Activities*. U.S. Fish and Wildlife Service.

_____. 2009. Private communication.

Stevenson, James O. and Richard E. Griffith. 1946. *Winter Life of the Whooping Crane: The Condor* 48: 160-178. University of California Press on behalf of the Cooper Ornithological Society.

Sutton, G. 2005. *Fewer Crabs—Fewer Fish*. Texas Parks & Wildlife Department. http://www.tpwd.state.tx.us/fishboat/fish/didyouknow/bluecrabdecline.phtml?print=true.

The Crane Trust. 2010. http://www.whoopingcrane.org/Whooping_Crane.html.

Texas Parks & Wildlife Department. 2007. "Freshwater Inflow Recommendation for the Guadalupe Estuary of Texas." http://www.tpwd.state.tx.us/landwater/water/conservation/freshwater_inflow/guadalupe/index.phtml.

Texas Parks & Wildlife Department. 1998. "Freshwater Inflow Recommendation for the Guadalupe Estuary of Texas." Coastal Studies Program Resources Protection Division. Austin, Texas.

Texas WaterMatters. 2010. http://www.texaswatermatters.org/flows.htm.

Union of Concerned Scientists. 2007. *Got Water?* Issue brief.

U.S. Fish and Wildlife Department. March 2007. *International Recovery Plan Whooping Crane*. Third Edition.

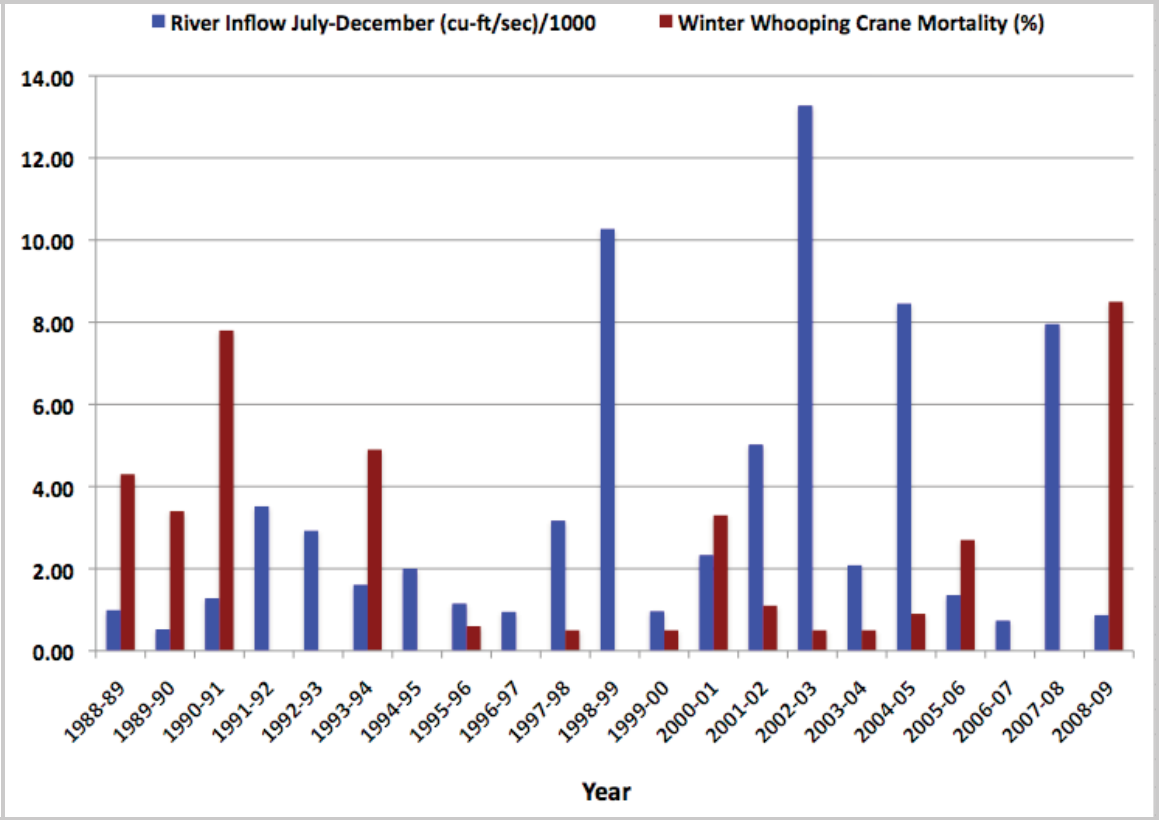

Figure 1a. A chart of whooping crane winter mortality expressed as a percentage of the flock population and the corresponding average river flow into the Guadalupe Estuary from the combined Guadalupe and San Antonio Rivers during the six month period from July to December is shown ordered by year (1988-2009).

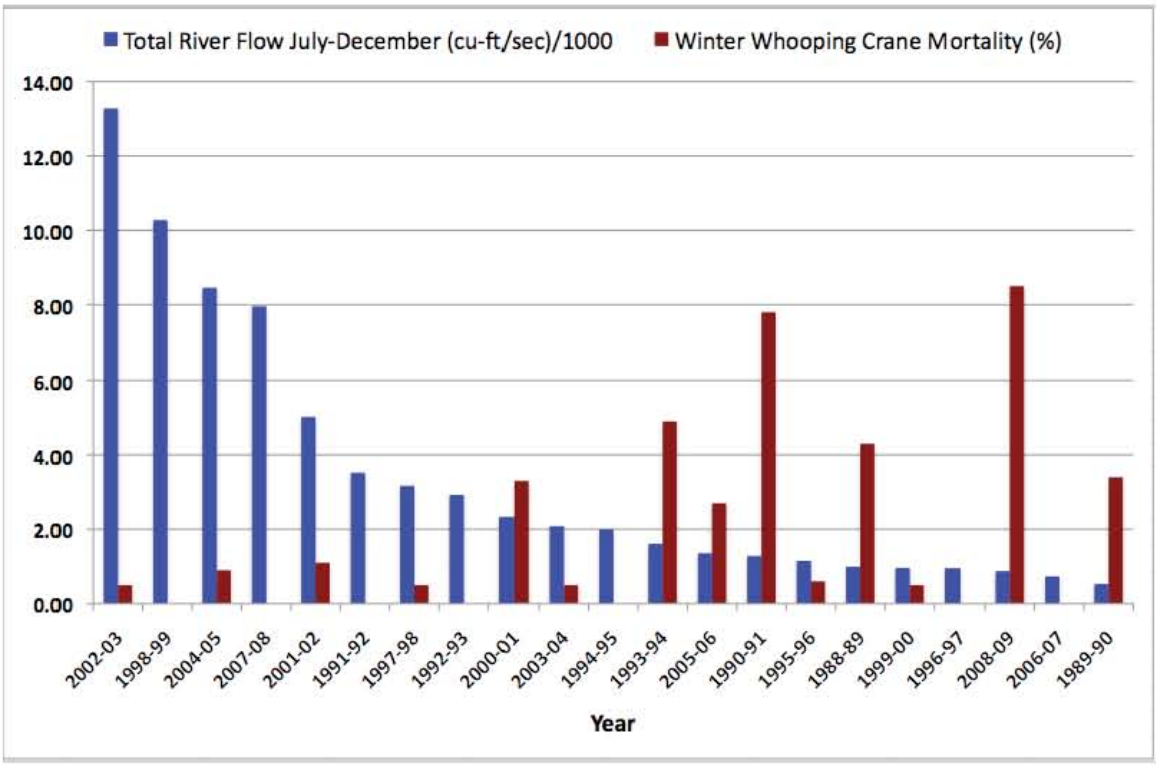

Figure 1b. Same data as in Figure 1a, except it is ordered by decreasing river flow from July to December.

Table 1. A summary of climate changes from the present to 2100 and the resultant effect on the hydrology of the Guadalupe River and San Antonio Bay.

Climate Change Cause	**River-Bay System Effect**
River basin temperature changes by >3.5°C	Annual river basin runoff decreases by 7-8 percent
Inland Precipitation decreases by 15 percent	Average river flow decreases by 120,200 ac ft/year in Guadalupe River and 42,000 ac ft/year in the San Antonio River.
	Frequency of years with annual flow less than 1,000 cu ft/sec increases by 35 percent
Coastal temperature changes by 3.0-3.5°C	Evaporation from San Antonio Bay increases by 108,000 ac ft/year, resulting in a total freshwater deficit of 270,200 ac ft/yr with respect to current climate conditions.

EXHIBIT F-2

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EDUCATION: University of Southern California, Ph.D. (Chemistry), 1957.
Augustana College, Rock Island, B.A. (Chemistry), 1954.

CURRENT POSITION Harry C and Olga K. Wiess Professor of Natural Sciences, Emeritus
Professor Emeritus of Chemistry and Ecology & Evolutionary Biology, *Rice University*

EXPERIENCE:
Chair, Ecology and Evolutionary Biology Department, *Rice University*, 1987-2005
Professor of Biology, Chemistry, and Education, *Rice University*, 1993-2005.
Scholar, James A. Baker Institute for Public Policy, 2003-present
Visiting Professor, Nanjing Agricultural University, Nanjing, China, 2000.
Adjunct Professor, *University of New Hampshire*, 1999-present
Acting Chair of the Department of Education, *Rice University*, 1995-96.
Visiting Research Scientist, *NASA*, Langley, VA 1988-1989.
Chairman of Biology Department, *Rice University*, 1981-1987.
Adjunct Professor of Medicine, *Baylor College of Medicine*, 1977-present.
Professor of Biology and Chemistry, *Rice University*, 1975-1993.
Adjunct Professor of Biophysics, *Baylor College of Medicine*, 1974-1977.
Adjunct Professor of Biochemistry, *Baylor College of Medicine*, 1969-present.
Master, Hanszen College, *Rice University*, 1964 and 1966-1968.
Professor of Chemistry, *Rice University*, 1966-1975.
Visiting Professor of Theoretical Chemistry, *Cambridge University,* England, 1965.
Associate Professor of Chemistry, *Rice University*, 1962-1966.
Assistant Professor of Chemistry, *Rice University*, 1958-1962.
Research Fellow, *Atomic Energy Commission*, *Brookhaven National Laboratory*, Long Island, New York, 1957-1958.
Predoctoral Fellow, *National Science Foundation*, University of Southern California, 1954-1957.
Chemist, *United States Army, Rock Island Arsenal*, 1951-1954.

PROFESSIONAL ACTIVITIES

RESEARCH: Work is conducted in the Wetland Center for Biogeochemical Research at Rice University. Since 1988 this group has been studying the generation of biogenic atmospheric trace gases and the biological processes in waterlogged plant-soil environments leading to their formation. These gases, principally methane and nitrous oxide are important contributors to global climate change and major components of the chemical system responsible for stratospheric ozone depletion. Our work originally focused on projects sponsored by the National Aeronautics and Space Administration in

the tundra and boreal forest wetlands of Northern Canada and Alaska. Our current interests are in process studies of methane production and possible mitigation strategies for methane gas emissions from rice paddies and natural wetlands, the source of nearly half of all methane gas emitted annually to the global atmosphere.

Under the sponsorship of the US Department of Agriculture and the Ministry of Agriculture of the People's Republic of China. I traveled extensively in China to develop a cooperative effort between our laboratory and scientists in China for the study of gas emissions from Chinese and Indian rice paddies. This work began in May 1993 and has culminated in a joint research program with the National Agricultural University at Nanjing the Chinese Academy of Science Atmospheric Sciences Laboratory and the University of New Hampshire.

Most recently I have initiated a study of science policy issues related to global, regional, and local climate change. The first project is to consider various facets of the urban heat island effect in Houston, Texas. This work is sponsored jointly in the Rice University Center for the Study of the Environment and Culture and the James Baker Institute of Public Policy.

INTERNATIONAL ACTIVITIES

Convenor, *International Global Atmospheric Chemistry Program* Committee on Trace Gas Exchange in Rice Paddies (RICE). Committee members are scientific experts on atmospheric chemistry from the United States, Germany, Australia, Philippines, China, India, Thailand, and Japan. This committee is a part of the program in International Global Atmospheric Chemistry (IGAC) of the International Geosphere Biosphere Program (IGBP). The IGBP is part of the International Committee of Scientific Unions with the United States represented by the National Academy of Science. As part of this committees activities I am an editor for a book published by the Japanese National Institute of Agro-Environmental Sciences, which is the "Proceedings of CH_4 and N_2O Workshop" held in March,1992 at Tsukuba, Japan.

Member AGU Committee on Global Environmental Change. The purpose of this committee is to foster global environmental change science, to assure a home in AGU for all involved disciplines and individuales and, to provide scientific background for policy decisions. Global environmental change is meant to include large-scale chemical, biological, geological, and physical perturbations of
the Earth's atmosphere, oceans, land surfaces, and hydrologic cycle, with special attention to time scales of decades to centuries and to human-caused perturbations.

Consultant Embrapa Meio Ambiente (Embrapa Environment). Government of Brazil. Conduct workshops, train scientists, and set up experimental system to measure tracegas emissions from Brazilian irrigated rice fields.

Consultant Advisor on Graduate Programs, The Joint Graduate School of Energy and Environment King Mongkut' s University of Technology, Bangkok, Thailand

Member, Scientific Organization Committee, Workshop on GHG Emissions from Rice Fields in Asia, Chinese Academy of Science Soil Science Institute, Nanjing, China,

Consultant *Environmental Protection Agency* on Global Climate Change Issues in Agriculture. Activities I have participated in for the EPA have included workshops on various aspects of trace gas emissions, contributions to publications on atmospheric trace gases and mitigation of these gases from agricultural sources. I also serve as part of the oversight committee to monitor the EPA's program in the Philippines on the effects of increased carbon dioxide and ultraviolet radiation on agricultural crops in Asia.

Consultant *United Nations Development Program.* As a member of the External Advisory Committee to the International Rice Research Institute, I monitor the inter-regional research program on methane emission from rice fields in China, India, Indonesia, Philippines, and Thailand.

Lead Author *Organisation for Economic Co-operation and Development*. Co-authored the IPPC Guidelines on National Greenhouse Gas Inventories: Methane Emissions from Rice Cultivation (Reference Manualand Workbook). Also represented the OECD as an expert at the Twelfth Session of the IPCC in Mexico City, 1996.

Member, *National Science Teachers Association* Facilities Task Force. This committee addresses various questions of school science laboratory design and safety. It also keeps track of various regulations relating to laboratory use by students and helps teachers to be aware of them. The committee also publishes recommended designs for laboratory renovation and construction.

EDUCATIONAL ACTIVITIES

Co-director, Rice University Center for Education, 1988-date
The Center for Education at Rice University was established in 1988 as the administrative umbrella for a number of projects in school improvement in pre-kindergarten through twelfth grade.

The mission of the Center is to improve the education of children at all grade levels by identifying, fostering, and coordinating individual

projects to improve teaching and learning in pre-college environments in ways that cut across their usual isolation from each other.

Over the past several years, the Center Directors have developed several successful and ongoing programs in science, mathematics, writing, Asian and multicultural studies, early children's literacy, and in the relationships between Latino students, their families, and schools. These programs operate primarily in Houston and in some surrounding districts.

OTHER EDUCATIONAL ACTIVITIES

Minority Honors Pre-Med Academy Co-Director, 1988-1998.
College Board, Science Advisory Committee, Member 1989-1994.
Educational Testing Service, Chemistry Achievement Test Committee, 1988-1994
Academy of Science and Technology, Conroe, TX. Member Academy Advisory Council, 1988-1992.
National Center for Atmospheric Research, Education Effort Committee, 1988-date
Baylor College of Medicine, "Minority Research Apprentice Programs", Advisor, 1985-1987
Houston High School for the Health Professions, Science Curriculum Consultant, 1985-date
Fund for Improvement of Post-secondary Education, Consultant for the Life Sciences Program , 1984,1985
National Science Foundation Program to Train Master Teachers in Secondary Science Education, Mentor, 1983-1988
Conroe Texas Independent School District, Consultant, 1984-date.
Houston Mathematics and Science Improvement Consortium, Director, 1984,1985.

HONORS:

The Texas Hall of Fame for Science, Mathematics and Technology, 2002
Meritorious Service Award, 2001, Association of Rice Alumni
Piper Professor for 1999, Piper Foundation, San Antonio, Texas
Citation for Excellence in Refereeing by the editors of the American Geophysical Union journals. 1998.
National Research Council Senior Research Fellow (NASA), 1988.
The Rice University Honor Certificate for Teaching, 1985.
The George R. Brown Prize for Superior Teaching, 1981.
The Rice University Student Association Mentor Recognition Award, 1976.
The Rice University Award of Highest Merit, 1972.
The George R. Brown Prize for Excellence in Teaching, 1967, 1969, 1970.
Salgo-Noren Distinguished Professor Award, 1966.
Guggenheim Foundation Fellowship (Cambridge University), 1965.
Senior Class Teaching Award, 1964.
Atomic Energy Commission Postdoctoral Fellowship, 1957-1958.
Sigma Xi, 1957.
Phi Lambda Upsilon, 1955.
National Science Foundation Predoctoral Fellowship, 1954-1957.
Phi Beta Kappa, 1954.

PROFESSIONAL SOCIETIES:

American Geophysical Union
National Science Teachers Association

RECENT PRESENTATIONS,WORKSHOPS AND OTHER ACTIVITIES (1993-2005):

"Process study of methane emission from rice paddies, " Jiangsu Academy of Agricultural Sciences, Nanjing, China, May 17, 1993

"A four year study of methane emission and production in Texas rice fields", Agro Environmental Protection Institute, Ministry of Agriculture, Tianjin, China, May 21, 1993.

Invited keynote address, International Symposium on Climate Change, Natural Disasters and Agricultural Strategies, Beijing Agricultural University, Beijing, China, May 26, 1993.

"Rice Cultivation and Trace Gas Exchange" (invited), Global Atmospheric Biospheric Chemistry: The first IGAC Scientific Conference, Eilat, Israel, April 18-22, 1993, with H. U. Neue.

"Options for Reducing Methane Emissions from Rice Cultivation" (invited), White House Conference on Global Climate Change, Washington D.C. June 10-11, 1993.

STELLA Model Demonstrations, Update (invited), Spring Meeting of the Cooperative University-Based Program in Earth System Science Education, Langley Research Center, Hampton, VA, June 22-23, 1993.

Methane Emission from Rice Paddy: IGAC Foci (keynote address), All Asian Workshop-Cum-Training Course on Methane Emission Studies, National Physical Laboratory, New Delhi, India, September 20-24, 1993.

"Methane Emission: Five Year Study at Rice University" (Invited), All Asian Workshop-Cum-Training Course on Methane Emission Studies, National Physical Laboratory, New Delhi, India, September 20-24, 1993.

IGAC Approach to Measurement Procedures (Invited), Federation of Asian Scientific Academies and Societies Seminar on Global Environment Chemistry, New Delhi, India, Sept. 27-Oct. 1, 1993.

"Tracegas Exchange with the Biosphere-I " (Invited), Federation of Asian Scientific Academies and Societies Seminar on Global Environment Chemistry, New Delhi, India, Sept. 27-Oct. 1, 1993.

"Methane Emission: Five Year Study at Rice University " (Invited), Regional Research Laboratory, Bhubaneswar, India, October 2, 1993.

"Methane Emission from Rice Fields in the United States" (Invited) International Symposium on Climate Change and Rie, International Rice Research Institute, Los Baños, Philippines, March 14-16, 1994.

Member, External Advisory Committee, United Nations Development Program, Interregional Research Program on Methane Emission from Rice Fields, Los Baños, Philippines, March 17-18, 1994.

Rice Cultivation and Trace Gas Exchange, CH_4 and N_2O Workshop, National Institute for Agro-Ecological Sciences, Tsukuba, Japan, March 23-25, 1994.

International Global Atmospheric Chemistry-Global Change & Terrestrial Ecosystems Task Team; Inaugural Meeting, Oxford UK, 8-9 December, 1994.

"A Multi-year Study of Methane Emissions from Texas Rice Fields, " Engineering Faculty, Tulane University, New Orleans, LA, March 10, 1995

"Methane Emission from Rice Paddies; A Process Study " (invited), International Symposium on Soil-Source and Sink of Greenhouse Gases, Institute of Soil Sciences (CAS), Nanjing, China, September 14-30, 1995.

Opportunities for Mitigation of CH4 Emissions from Agricultural Sources (invited IPCC Symposium), American Society of Agronomy Annual Meeting, St. Louis, MO, October 29-Nov 3, 1995.

Convenor, The NASA Workshop on Regional Assessment of Tracegas Emissions from Rice Fields of China, Rice University, November 7-9, 1995.

Member, External Advisory Committee, United Nations Development Program, Interregional Research Program on Methane Emission from Rice Fields, Bangkok, Thailand, November 19-25, 1995.

"The China Experience." Lecture Series, Rice University Homecoming December 1-3, 1995.

"Climate and Change." Rice University Summit of the Minds, February 3, 1996

"Global Change," Toward the 21st Century, Topics in Contemporary Science, Rice University, April 8, 1996.

"Who Will Feed Asia?" Rice University Alumni College, April 26-28, 1996.

Participant, IPCC/OECD Meeting of Experts on Emission Factors for Methane from Wetland Rice Cultivation, Bangkok, Thailand, April 30-May 2, 1996.

"Agricultural Practices and Other Factors Influencing Methane Emissions from Rice Fields" (Invited), IPCC/OECD Meeting of Experts on Emission Factors for Methane from Wetland Rice Cultivation, Bangkok, Thailand, April 30-May 2, 1996.

International Geosphere Biosphere Program Wetlands Workshop on Classification, University of California at Santa Barbara, May 16-20, 1996.

Convenor, The NASA Workshop on Regional Assessment of Tracegas Emissions from Rice Fields of China, Beijing, China, June 5-7, 1996.

Participant, Intergovernmental Panel on Climate Change Working Group I, Sixth Session, Mexico City , Mexico, September 10, 1996.

"Global Change: Are We Warming Up?", Rice University Families Weekend, October 4-5, 1996.

"Wetlands and Global Climate Change," Wetland Biogeopchemistry Institute, Louisiana State University, Baton Rouge, October 17, 1996.

"Mechanisms of Methane Emission from Flooded Agricultural Systems: A Modeling Study. Tulane University, New Orleans, April 4, 1997.

Rice Environmental Conference 1997, February 1, 1997 Panel Participant: The Scope of Technology in Environmental Protection

IGAC Science Advisory Council Meeting, Toronto, Ont., Canada, May 16-19, 1997.

IPCC Scientific Steering Committee, Expert Group on Methods for the Assessment of Country Greenhouse Gas Inventory Quality, National Institute of Public Health and the Environment, Bilthoven, Netherlands, November 5-7, 1997.

"Mechanisms of Methane Emission from Flooded Rice Fields: A Modelling Study. " Max-Planck-Institut für Terrestrische Mikrobiologie, Marburg, Germany, November 10, 1997

"Mechanisms of Methane Emission from Flooded Rice Fields: A Modelling Study. " UFZ-Centre for Environmental Research, Department of Soil Sciences, Bad Lauchstaedt, Germany, November 13, 1997.

TRAGNET Working Group to Synthesize Trace Gas Research in Managed and Natural Ecosystems. National Center for Ecological Analysis and Synthesis, Santa Barbara, California, December 2-6, 1997.

"A semi-empirical model of methane emission from irrigated rice fields." (Invited) Workshop of the Interregional Research Program on Methane Emission from Rice Fields in Beijing China, August 10-15, 1998 sponsored by the United Nations Development Programme Global Environmental Facility and the International Rice Research Institute.

"Exchange of methane and other trace gases from rice fields: a model system for wetland emission modeling." (Invited) The Ninth Symposium of the IAMAS Commission on Atmospheric Chemistry & Global Pollution (CACGP) and Fifth Scientific Conference on the International Global Atmospheric Chemistry Project (IGAC), Seattle, Washington, 19-25 August 1998.

"A semi-empirical model of methane emission from irrigated rice fields." The Ninth Symposium of the IAMAS Commission on Atmospheric Chemistry & Global Pollution (CACGP) and Fifth Scientific Conference on the International Global Atmospheric Chemistry Project (IGAC), Seattle, Washington, 19-25 August 1998.

"Methane emissions from rice fields: Effect of rice cultivars and plant height." The Ninth Symposium of the IAMAS Commission on Atmospheric Chemistry & Global Pollution (CACGP) and Fifth Scientific Conference on the International Global Atmospheric Chemistry Project (IGAC), Seattle, Washington, 19-25 August 1998.

"Global Warming and Climate Change." The Association of Rice Alumni, Alumni College, November 7, 1998. Washington, D.C.

"Agricultural Sources of Methane and Nitrous Oxide: Methane from Rice Agriculture" Invited background paper. IPCC/OECD workshop, "Good Practice in Inventory Preparation: Agricultural Sources of Methane and Nitrous Oxide." Wageningen Agricultural University (The Netherlands). February 24-26, 1999.

"Modeling Methane Emissions from Chinese Rice Paddies." Agro-Meteorological Research Center of Chinese Academy of Meteorological Sciences, Beijing, China. May 24, 1999.

"Regional and Country Level Assessment of Methane from Rice Paddies." Institute of Remote Sensing, Chinese Academy of Sciences, Beijing China, May 25, 1999.

"Factors Affecting Methane Emissions from Rice Paddies: Modeling and Remote Sensing." Institute of Natural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing, China, May 26, 1999.

"A GIS Based System for Estimating Methane Emissions from Rice Paddies." Chinese Ecological Research Network, Chinese Academy of Sciences, Beijing, China, May 27, 1999.

"Modeling Methane Emissions from Chinese Rice Paddies." Nanjing Agricultural University, Nanjing, China, May 31, 1999.

"A GIS Based System for Estimating Methane Emissions from Rice Paddies." Chinese Ecological Research Network, Institute of Agricultural Modernization and Remote Sensing, Changsha, China, June 7, 1999.

"Modeling Methane Emissions from Chinese Rice Paddies." Guangxi Academy of Agricultural Science, Nanning, China, June 9, 1999.

"A GIS Based System for Estimating Methane Emissions from Rice Paddies." Chinese Ecological Research Network Tropical Forest Station at Xi-shuang-ban-na, China, June 14, 1999.

"Monitoramento e mitigação da emissão de metano pela cultura do arroz." Invited talk to the First Brazilian Irrigated Rice Congress and the XXIII Irrigated Rice Cultivation Meeting, Pelotas, RS, Brazil, August 4, 1999.

"Modeling and Remote Sensing of Methane Emissions from Rice Paddies". Nanjing Meteorological Institute, Nanjing, China, March 25, 2000

"Global Ecosystem Dynamics", A short course, Nanjing Agricultural University, Nanjing, China, March 19-24, 2000

Session convenor: Biogeochemistry of C and N in Soils I. American Geophysical Union Spring Meeting, May 30-June 3, 2000, Washington, D. C., with S. Frolking

Session convenor: Biogeochemistry of C and N in Soils II Posters, American Geophysical Union Spring Meeting, May 30-June 3, 2000, Washington, D. C., with S. Frolking

"A Process Model of Methane Production, Oxidation and Transport in Paddy Rice Ecosystems" Invited talk, American Geophysical Union Spring Meeting, May 30-June 3, 2000, Washington, D. C., with Li, C. Zhang, Y. , Huang, Y., and Butterbach-Bahl, K

"Spatial Variability in Methane Emissions from Rice Fields", Department of Earth, Oceans, and Space, University of New Hampshire, August 16, 2000

"Spatial Variability in Methane Emissions from Rice Fields", Departments of Ecology & Evolutionary Biology and Earth Systems, University of California at Irvine, Nov. 3, 2000

"Seasonal and Spatial Variability of Methyl Halide Emissions from Rice Paddies near Houston, Texas" Fall Meeting of American Geophysical Union, December 15-19, 2000, San Francisco, California. With Redeker, K. , Andrews, J., Fisher F. and. Cicerone, R. J.

"Spatial and temporal variability in methane emissions from rice paddies: Implications for assessing regional methane budgets", Workshop on GHG Emissions from Rice Fields in Asia, Chinese Academy of Science Soil Science Laboratory, Nanjing, China, Feb. 26, 2001.

"Spatial Variability in Methane Emissions from Rice Fields", Nanjing Agricultural University, Nanjing, China, March 1, 2001.

"Spatial Variability in Methane Emissions from Rice Fields", Chinese Academy of Science, Atmospheric Science Laboratory, Beijing, China, March 8, 2001.

"Spatial Variability in Methane Emissions from Rice Fields", The Joint Graduate School of Energy and Environment King Mongkut' s University of Technology, Bangkok, Thailand, September 26, 2001.

"Remote Sensing of Methane Emissions from Rice Fields", The Thailand Research Fund, Program on Greenhouse Gas Emissions Assessment. Bangkok, Thailand, September 28, 2001

"Five lectures on Ecology and Global Change" Presented during an ecotourism trip on the Peruvian Amazon River. Sponsored by the Rice Alumni Association, October 20-28, 2001

"Can you see China from Texas", Rice's Best: Winners of Rice University's Teaching Awards 1999-2000, Rice School of Continuing Studies, November 19, 2001

"Global Measurement Standardization of Methane Emissions from Irrigated Rice Cultivation", Embrapa Meio Ambiente (Embrapa Environment), Jaguaruna, SP, Brazil, January 29, 2002.

"An Extensive Survey of Gaseous Emissions from Rice Paddy Agriculture", with Redeker, K R, Meinardi, S, :Blake, D, and Cicerone, R. American Geophysical Union, Spring meeting, Washington, DC., May 28-31, 2002

NACP Methane Workshop, Breakout session on process studies in atmospheric methane emissions, University of New Hampshire, September 10-12, 2002.

"Mitigation of Methane Emissions from Rice Fields", Non-CO2 Network Project on Agricultural Greenhouse Gas Mitigation, Environmental Protection Agency, Washington, DC, December 2-3, 2002.

"How difficult is it to believe in global warming?" Scientia Lecture, Rice University, April 13, 2004

"Climate Change: Magnitude of the Problem & Potential Solutions," Panelist, September 14, 2004, Rice University

"How difficult is it to believe in global warming?" Society of Rice University Women, January 31, 2005

Shell Conference on Climate Change and Coastal Cities, Workshop leader, Febuary 9-10, 2005

"How difficult is it to believe in global warming?" Rice University Alumni College, Feb 26, 2005

"Climate Change and Texas", TexPIRG Annual Meeting, University of Houston, Houston,Texas, March 5, 2005

"Urban Heating and Global Climate Change", Brays Bayou Association meeting, April 18, 2005,

"Climate Change and Houston", Houston City Breakfast Club, Houston City Club, April 20, 2005

"Climate Change: Magnitude of the Problem & Potential Solutions', Emerson Unitarian Church, May 1, 2005

"Climate Change and You", Houston Women's Club, Post Oak Grill, May 2, 2005

"How difficult is it to believe in global warming?" Houston Rotary Club. Braeburn Country Club, May 19, 2005

"How difficult is it to believe in global warming?" Texas Regional Consorium 11th Annual Meeting, Austin, Texas, July 13-15, 2005.

PUBLICATIONS:

Books:

CH_4 and N_2O Global Emissions and Controls from Rice Fields and Other Agricultural and Industrial Sources, NIAES Japan, 1994, Editors K. Minami, A. Mosier and R. L. Sass.

Journal Articles and Book Chapters:

1. Sass, R.L. and Donohue, J. (1957) The Unit Cell and Space Group of HCN Tetramer. **Acta Cryst**., 10:375.

2. Sass, R.L., Vidale, R. and Donohue, J. (1957) Interatomic Distances and Thermal Anisotropy in Sodium Nitrate and Calcite. **Acta Cryst**., 10:567-570.

3. Sass, R.L. and Donohue, J. (1958) The Crystal Structure of $S_4N_4H_4$. **Acta Cryst**., 11:497-504.

4. Sass, R.L. (1960) A Neutron Diffraction Study on the Crystal Structure of Sulfamic Acid. **Acta Cryst**., 13:320-324.

5. Hastings, J., Corliss, L., Elliott, N. and Sass, R.L. (1961) Magnetic Structure of Chromium Selenide. **Phy. Rev**., 122:1402-1406.

6. Church, J.F. and Sass, R.L. (1962) A Study of the Crystal Structure of Trimethyl cis-Cyclopropane-1,2,3-tricarboxylate. **Chem. Ind**. 1574.

7. Sass, R.L. and Scheuerman, R.F. (1962) The Crystal Structure of Sodium Bicarbonate. **Acta Cryst**., 15:77-81.

8. Strieter, F.J., Templeton, D.H., Scheuerman, R.F. and Sass, R.L. (1962) The Crystal Structure of Propionic Acid. **Acta Cryst**., 15:1233-1239.

9. Scheuerman, R. F. and Sass, R.L. (1962) The Structure of Valeric Acid. **Acta Cryst.**, 15:1244--1247.

10. Sass, R.L. and Ratner, L. (1963) Crystal Symmetry of the Dimer of Cyclobutene-1,2-dicarboxylic Acid Dimethyl Ester. **Acta Cryst**., 16:433.

11. Higgs, M.A. and Sass, R.L. (1963) The Crystal Structure of Acrylic Acid. **Acta Cryst.**, 16:657-661.

12. Brackett, E.B., Brackett, T.E. and Sass, R.L. (1963) The Crystal Structure of Barium Chloride, Barium Bromide and Barium Iodide. **J Phys. Chem**., 67:2132-2135.

13. Sass, R.L., Brackett, T.E. and Brackett, E.B. (1963) The Crystal Structure of Strontium Bromide. **J. Phys. Chem**., 67:2862-2863.

14. Sass, R.L., Brackett, E.B. and Brackett, T.E. (1963) The Crystal Structure of Lead Chloride. **J. Phys. Chem**., 67:2863.

15. Brackett, E.B., Brackett, T.E. and Sass, R.L. (1963) The Crystal Structure of Calcium Bromide. **J. Nucl. and Inorg. Chem**., 25:1295-1296.

16. Bugg, C.E., Lawson, J.B. and Sass, R.L. (1964) The Crystal Symmetry of Several Diazonium Salts. **Acta Cryst**.,17:767-768.

17. Dyke, M. and Sass, R.L. (1964) The Crystal Structure of Strontium Bromide Monohydrate. **J. Phys. Chem**., 68:3259-3262.

18. Bugg, C.E., Desiderato, R. and Sass, R.L. (1964) An X-Ray Diffraction Study of Nonplanar Carbanion Structures. **J. Am Chem. Soc**., 86:3157-3158.

19. Roth, W.R., Bang, W.B., Geobel, P., Sass, R.L., Turner, R.B. and Yu, A.P. (1964) On the Question of Homoconjugation of cis,cis,cis-1,4,7- Cyclononatriene. **J. Am. Chem. Soc**., 86:3178-3179.

20. Desiderato, R. and Sass, R.L. (1965) The Crystal Structure of Ammionium Tricyanomethide, $NH_4C(CN)_3$. **Acta Cryst**., 18:1-4.

21. Bugg, C.E. and Sass, R.L. (1965) The Crystal Structure of Pyridinium Dicyanomethylide, $C_8H_5N_3$. **Acta Cryst**., 18:591-594.

22. Kilpatrick, J.E. and Sass, R.L. (1965) Structure of the X^P Matrices in the Simple Harmoniuc Oscillator Representation. **J. Chem. Phys**., 42:2581-2586.

23. Sass, R.L. and Bugg, C.E. (1967) The Crystal Structre of Potassium p-Nitrophenyldicyanomethide. **Acta Cryst**., 23:282-288.

24. Desiderato, R. and Sass, R.L. (1967) The Crystal Structure of cis-2- Butene Episulfone. **Acta Cryst.**, 23:430-433.

25. Dyke, M. and Sass, R.L. (1968) The Crystal Structure of Dipotassium Tetranitroethide. **J. Chem. Phys**., 72:266-268.

26. Kronfeld, L.R. and Sass, R.L. (1968) The Crystal Structure of Dibenzothiophene Sulfone. **Acta Cryst.**, B24:981-982.

27. Herdklotz, J.K. and Sass, R.L. (1969) The Crystal Structure of 4-Methyl- thiomorpholine-1,1-dioxide. **Acta Cryst**., B25:1614-1620.

28. Edmonds, J., Herdklotz, J.K. and Sass, R.L. (1970) The Crystal Structure of Ammonium 1,1,2,6,7,7-Hexacyanoheptatrienide. **Acta Cryst**., B26:1355-1362.

29. Sass, R.L. and Lawson, J. (1970) The Crystal Structure of p-Sulfobenzene- diazonium Inner Salt. **Acta Cryst**., B26:1187-1189.

30. Presley, C.T. and Sass, R.L. (1970) The Crystal Structure of 2.6-Dichloro-4- Diazo- 2,5-cyclohexadien-1-one. **Acta Cryst**., B26:1195-1198.

31. Beall, R., Herdklotz, J. and Sass, R.L. (1970) Molecular Properties of Local Anesthetics: The Crystal Structure of Procaine Hydrochloride. **Biochem. Biophys. Res. Commun**., 39:329-334.

32. Beall, R., Herdklotz, J. and Sass, R.L. (1970) A Refinement of the Crystal Structure of ß-Isoprene Sulfone. **Acta Cryst**., B26:1633-1635.

33. Herdklotz, J. and Sass, R.L. (1970) The Crystal Structure of Acetylcholine Chloride: A New Confirmation for Acetylcholine. **Biochem. Biophys. Res. Commun.**, 40:583-588.

34. Sass, R.L. (1970) Molecular Properties of Local Anesthetics: The Crystal Structure of 2-Diethylaminoethyl p-Methoxybenzoate Hydrochloride. **Biochem. Biophys. Res. Commun**. 40:833-838.

35. Sass, R.L. (1970) Exploring the Nerve Cell. **The Rice Review**, Vol. 5, No. 1.pp. 16-21.

36. Sass, R.L. (1971) Profile of the Rice Experience. **The Rice Review**, Vol. 6, No.1.

37. Gansow, O.A., Beckenbaugh, W.M. and Sass, R.L. (1972) Carbon-13 Nuclear Magnetic Resonance of Pharmaceutical Agents: Benzocaine Hydrochloride Anesthetics. **Tetrahedron**, 28:2691-2696.

38. Kahler, G.A., Fisher, F.M. and Sass, R.L. (1972) The Structure of the Hinge Ligament of Spisula Solidissima. **Tex. Soc. Elect. Micro**., 4:4-8.

39. Herdklotz, J., Werness, P. and Sass, R.L. (1973) The Crystal Structure of 2 Diethylaminoethyl p-Nitrobenzoate Hydrochloride. **J. Cryst. Mol. Struct**., 3:271-275.

40. Billups, W. E., Chow, W. Y., Leavell, K. H., Lewis, E.S., Margrave, J. L., Sass, R. L., Shieh, J. J., Werness, P. G., Wood, J. L. (1973) Structure and Thermochemistry of Benzocyclopropenes. The Question of Bond Fixation and Strain Energy. **J. Am Chem. Soc.**, 95:7878-7880.

41. Sass, R.L. and Werness, P. G.(1973) Acetylcarnitine: on the Relationship Between Structure and Function. **Biochem. Biophys. Res. Commun**., 55:736-742.

42. Mahajan, V. and Sass, R.L. (1974) The Crystal Structure of Acetylcholine Perchlorate. **J. Cryst. Mol. Struct**., 4:15-21.

43. Sass, R.L. and Nichols, T.D. (1974) Crystal Structure of Tetramethylammonium 1,1,2,4,5,5-hexacyanopentadienide. **Zeit. Cristall**., 140:1-9.

44. Goldstein, M.A., Schroeter, J.P. and Sass, R.L. (1974) Optical Diffraction Analysis of the Cardiac Z Band. **Fed. Proc**., 33:1333.

45. Goldstein, M.A., Schroeter, J.P. and Sass, R.L. (1974) Unit Cell Z Lattice in Cardiac and Skeletal Muscle. **J. Cell Biol.**, 63:114a.

46. Goldstein, M.A., Schroeter, J.P. and Sass, R.L. (1975) Z Lattice in Mammalian Skeletal Muscle Having Different Z Band Widths at Rest Length. **J. Cell Biol.**, 67:137a.

47. Shieh, J.J. and Sass, R.L. (1975) The Molecular Structure of Palmitylcarnitine Chloride. **Biochem. Biophys. Res. Commun**., 64:304-310.

48. Phillips, G.N., Quiocho, F. Sass, R.L., Werness, P, Emery, H. Knapp, F. and Schroepfer, G. J. Jr. (1976) Sterol Biosynthesis: Establishment of the Structure of 3-Bromobenzoylyoxy-5-Cholest-8-en-15-ol. **Bioorganic Chem**., 5:1-9.

49. Marsh, M.E., Hopkins, G., Fisher, F.M. and Sass, R.L. (1976) Structure of the Molluscan Bivalve Hinge Ligament, A Unique Calcified Tissue. **J. Ultrastruct. Res**., 54:445-450.

50. Kahler, G.A., Sass, R.L. and Fisher, F.M. (1976) The Fine Structure and Crystallography of the Hinge Ligament of Spisula Solidissima. **J. Com. Physiol.**, 109:209-220.

51. Kahler, G.A., Fisher, F.M. and Sss, R.L. (1976) The Chemical Composition and Mechanical Properties of the Hinge Ligament in Bivalve Molluscs. **Bio. Bull.**, 151:161-181.

52. Goldstein, M.A., Schroeter, J.P. and Sass, R.L. (1977) Optical Diffraction of the Z Lattice in Canine Cardiac Muscle. **J. Cell Biol.**, 75:818-836.

53. Marsh, M., Hamilton, G. and Sass, R.L. (1978) The Crystal Sheaths from Bivalve Hinge Ligaments. **Calc. Tiss. Res.**, 26:45-51.

54. Goldstein, M.A., Schroeter, J.P. and Sass, R.L. (1979) The Z Lattice in Canine Cardiac Muscle. **J. Cell Biol.**, 83:187-204.

55. Marsh, M.E. and Sass, R.L. (1980) The Molluscan Bivalve Hinge Ligament: A Review. **Tex. Soc. E.M. Journal**, 11:9-14.

56. Marsh, M.E. and Sass, R.L. (1980) Aragonite Twinning in the Molluscan Bivalve Hinge Ligament. **Science**, 208:1262-1263.

57. Goldsteinm, M.A., Stromer, M.H., Schroeter, J.P. and Sass, R.L. (1980) Optical Reconstruction of Nemaline Rods. **Experimental Neurology**, 70:83-97.

58. Goldstein, M.A., Stromer, M.H., Schroeter, J.P. and Sass, R.L. (1980) Optical Diffraction and Reconstruction of Z Bands in Skeletal Muscle. **J. Cell Biol.**, 87:261a.

59. Goldstein, M.A., Schroeter, J.P. and Sass, R.L. (1981) The Z band lattice in a slow skeletal muscle. **Tex. Soc. E.M. Journal**, 12:19.

60. Marsh, M.E., Summerall, R.D. and Sass, R.L. (1981) Lysosomes and the Modulation of Cell Morphology in the Isthmas Region of the Outer Mantle Epithelium of the Extuarine Clam, Rangia cuneata. **J. Ulstruct. Res.**, 77:146-159.

61. Marsh, M.E. and Sass, R.L. (1981) Matrix Mineral Relationships in the Scallop Hinge Ligament. **J. Ulstruct. Res.**, 76:57-70.

62. Goldstein, M.A., Schroeter, J.P. and Sass, R.L. (1982) The Z Band Lattice in a Slow Skeletal Muscle. **J. Muscle Res. and Cell Motility**, 3:333-348.

63. Marsh, M.E. and Sass, R.L. (1982) Phosphoproteins in the extrapallial fluid and shell of clams. **J. Cell Biol.**, 95:125a.

64. Goldstein, M.A., Schroeter, J.P., and Sass, R.L. (1983) Widened Z bands in cardiac hypertrophy. **J. Mol. Cell. Cardiol. Suppl**. (Symposium at Jouy-en Josas, France).

65. Zimmer, D.B., Goldstein, M.A., Schroeter, J.P., and Sass, R.L. (1983) Additional evidence for a simple multi-subunit Z band in striated muscle from localization of alpha-actinin. **J. Cell Biol.**, 97:51a.

66. Goldstein, M.A., Zimmer, D.B., Schroeter, J.P. and Sass, R.L. (1983) Additional evidence for a Z band model derived from cardiac muscle. **J. Mol. Cell Cardiol**. Vol. 15 Supplement.

67. Marsh, M.E. and Sass, R.L. (1983) Calcium-binding phosphoprotein particles in the extrapallial fluid and innermost shell lamella of clams. **J. Exp. Zool**., 226:193-203.

68. Marsh, M.E. and Sass, R.L. (1983) Distinct calcium pools within a calcium- binding phosphoprotein. **Fed. Proc**., 42:1924.

69. Sass, R.L. and Marsh, M.E. (1983) A calcium binding phosphoprotein with modified histidine residues. **Fed. Proc**., 42:2000.

70. Schroeter, J.P., Goldstein, M.A. and Sass, R.L. (1983) Modeling filamentous structures of the Z band using DRAW3D. **Proc. of the Prophet Users Meeting** Bolt, Beranek and Newman, Airlie, Virginia.

71. Goldstein, M.A., Zimmer, D.B., Schroeter, J.P. and Sass, R.L. (1983) Alpha actinin in filaments of the Z band lattice. **Proc. of the International Symposium on the Contractile Proteins.** Institute of Histology, University of Sassari, Italy.

72. Sass, R.L. and Marsh, M.E. (1983) $N^{\dagger}$- and N^{π}-histidinoalanine: naturally occurring cross-linking amino acids in calcium binding phosphoprotein. **Biochem. Biophys. Res. Commun.**, 114:304-309.

73. Marsh, M.E. and Sass, R.L. (1984) Phosphoprotein particles: calcium and inorganic phosphate binding structures. **Biochemistry** 23:1448-1456.

74. Goldstein, M.A., Schroeter, J.P. and Sass, R.L. (1984) The Z Band Lattice in Mammalian Muscle. **Proc. International Congress for Cell Biology**, Tokyo Japan.

75. Goldstein, M.A., Michael, L.H., Schroeter, J.P. and Sass, R.L. (1984) The Z Band Lattice Before, During and After Tetanic Contraction in Skeletal Muscle. **J. Cell. Biol**., 99:434a.

76. Sass, R.L. and Marsh, M.E. (1984) Histidinoalanine: a naturally occuring cross-linking amino acid. **Methods in Enzymology.** 106:351-355.

77. Marsh, M.E. and Sass, R.L. (1985) Distribution and Characterization of Mineral Binding Phosphoprotein Particles in Bivalvia. **J. Exp. Zool**. 234:237-242.

78. Goldstein, M.A., Michael, L.H., Schroeter, J.P. and Sass, R.L. (1986) The Z Band Lattice in Skeletal Muscle Before, During and After Tetany. **J. Musc. Res. and Cell Motility**, 7:527-536.

79. Goldstein, M.A., Michael, L.H., Schroeter, J.P., and Sass, R.L. (1987) Z Band Dynamics as a Function of Sarcomere Length and the Contractile State of Muscle. **FESAB J.,** 1:133-144.

80. Goldstein, M.A., Michael, L.H., Schroeter, J.P., and Sass, R. L. (1988) Structural states in the Z band of skeletal muscle correlate with states of active and passive tension. **J Gen. Physiol.**, 92, 113-119.

81. Goldstein, M.A., Michael, L.H., Schroeter, J.P., and Sass, R.L. (1989) Two Structural States of Z bands in Cardiac Muscle, **Am J. Physiol**. 256 (Heart Circ. Physiol. 25), H552-H559.

82. Wilson, J.O., Crill, P.M., Bartlett, K.B., Sebacher, D.I., Harriss, R.C. and Sass, R.L. (1989) Seasonal Variation of Methane Emissions from a Temperate Swamp, **Biogeochemistry,** 8, 55-71.

83. Edwards, R.J., Goldstein, M.A., Schroeter, J.P., and Sass, R.L. (1990) The Z-Band Lattice in Skeletal Muscle in Rigor, **J. Ulstruct. and Molec. Struct. Res**., 102, 59-65.

84. Austin, J.D., R.E. Converse, R.L. Sass and R. Tomlins (1990) Coordinating Secondary School Science and Mathematics, **School Science and Mathematics**, 92, 64-68.

85. Goldstein, M.A., J.P. Schroeter, and R.L. Sass (1990) Two Structural States of the Vertebrate Z Band, **Electron Microscopy Reviews**, 3, 227-248.

86. Sass, R.L., F.M. Fisher, P.A. Harcombe, and F.T. Turner (1990) Methane Production and Emission in a Texas Agricultural Wetland, **Global Biogeochem. Cycles,** 4, 47-68.

87. Fisher, F.M., R.L. Sass, P.A. Harcombe and F.T. Turner (1990) Methane Production and Emission in Texas Coastal Rice Fields, **Internat. Rice Res. Newsletter**, 15, 31-32.

88. Bartlett, K.B., P.M. Crill, R.L. Sass, R.C. Harriss, and N.B. Dise. (1992) Methane Emissions from Tundra Environments in the Yukon-Kuskokwim Delta, Alaska, **J. Geophys. Res.** 97, 16,645-16,660.

89. Sass, R.L., K.B.Bartlett, P.M. Crill, N. Dise, and R.C. Harriss (1992) Methane Production and Distribution in an Alaskan Tundra Lake, **J. Geophys. Res.** (to appear in a issue dedicated to the ABLE-3A mission to Alaska).

90. Sass, R.L., F.M. Fisher, F.T. Turner and P.A. Harcombe, (1991) Mitigation of Methane Emissions from Rice Fields: Effects of Incorporated Rice Straw, **Global Biogeochem. Cycles** 5, 275-287.

91. Camacho, Z., W. A. Thomson, R. L. Sass, L. P. Driskill and J. P. Denk (1991) The Honors Premedical Academy: Increasing Access to Medical Careers, **The Advisor**, 12, 20-23.

92. Sass, R.L., F.M. Fisher, F.T. Turner and M.F. Jund, (1991) Methane Emission from Fice Fields as Influenced by Solar Radiation, Temperature and Straw Incorporation, **Global Biogeochem. Cycles,** 5, 335-350.

93. Sass, R. L., F. M. Fisher, Y.B. Wang, F. T. Turner, and M. F. Jund, (1992) Methane Emission from Rice Fields: The Effect of Flood Water Management, **Global Biogeochemical Cycles**, 6, 249-262.

94. Turner, F. T. , M. F. Jund, R. L. Sass, and F. M. Fisher, (1992) Relationships among methane emission from flooded ricefields, solar radiation, straw incorporation, and yield, **Internat. Rice Res. Newsletter**, 17, 34-35.

95. Sass, R. L., O. T. Denmead, R. Conrad, J. Freney, M. Klug, K. Minami, A. Mosier, H. U. Neue, H. Rennenberg, W. H. Su, M.-X. Wang, (1992) Exchange of methane and other trace gases in rice cultivation, **Ecological Bulletins**, 42, 199-206.

96. Sass, R. L. and F. M. Fisher, (1992) CH_4 emission from paddy fields in the United States, **Proceedings of CH_4 and N_2O Workshop**, pp 46-56, March 25-26, National Institute of Agro-Environmental Sciences, Tsukuba, Japan.

97. Sass, R. L., F. M. Fisher, S. T. Lewis, M. F. Jund, and F. T. Turner. (1994) Methane Emissions from Rice Fields: Effect of Soil Properties, **Global Biogeochemical Cycles**, 8, 135-140.

98. Sass, R. L. and F. M. Fisher (1994) Methane Emissions from Texas Rice Fields, A Five Year Study, with F. M. Fisher, Monograph for **International Symposium on Climate Change and Rice**, International Rice Research Institute, Los Baños, Philippines.

99. Neue, H. U. and R. L. Sass (1994) Rice Cultivation and Trace Gas Exchange, In R. G. Prinn, ed. **Global Atmospheric-Biospheric Chemistry**, Plenum Press, New York.

100. Sass, R. L. and F. M Fisher (1994) CH_4 Emission from Paddy Fields in the United States Gulf Coast Area, pp. 65-77. In K. Minami, A. Mosier and R. L. Sass eds. **CH_4 and N_2O Global Emissions and Controls from Rice Fields and Other Agricultural and Industrial Sources**, National Institute of Agro-Envorinmental Sciences, Yokendo, Tokyo, Japan.

101. Sass, R. L. (1994) Summary Chapter for Methane, pp 1-7. In K. Minami, A. Mosier and R. L. Sass eds. **CH_4 and N_2O Global Emissions and Controls from Rice Fields and Other Agricultural and Industrial Sources**, National Institute of Agro-Envorinmental Sciences, Yokendo, Tokyo, Japan.

102. Sass, R. L. and F. M. Fisher (1996) Methane Emission: Five Year Study at Rice University with F. M. Fisher, In: **All Asian Workshop-Cum-Training Course on Methane Emission Studies**, National Physical Laboratory, New Delhi, India, September 20-24.

103. Sass, R. L. and F. M. Fisher (1996) Tracegas Exchange with the Biosphere, In: **Federation of Asian Scientific Academies and Societies Seminar on Global Environment Chemistry**, New Delhi, India, Sept. 27-Oct. 1.

104. Sass, R. L. and F. M. Fisher (1995) Methane Emissions from Texas Rice Fields, A Five Year Study. In: S. Peng, K. T. Ingram, H. U. Neue, and L. H. Ziska (eds.) **Climate Change and Rice**, Springer, Berlin, pp 46-59.

105. Sass, R. L. (1995) Mitigation of Methane Emissions from Irrigated Rice Agriculture. **IGAC Newsletter**, 1, 2-4 .

106. Sass, R. L. (1995) Mitigation of Methane Emissions from Irrigated Rice Agriculture. I**GBP Global Change Newsletter**. 22, 4-5 (1995).

107. Sass, R. L. (1995) Mitigation of Methane Emissions from Irrigated Rice Agriculture. **The Earth Observer**. 7, 64-65 (1995).

108. Sass, R. L. (1995) CH4 Flux Measurement Standardization Experiment. **IGBP Global Change Newsletter**. 22, 6 (1995).

109. Schroeter, J. P., J-P Bretaudiere, R. L. Sass and M. A. Goldstein (1996) Three-dimensional structure of the Z band in a normal mammalian skeletal muscle . **Journal of Cell Biology** 133, 571.

110. Sass, R. L. and F. M Fisher (1996) Methane from Irrigated Rice Cultivation. **Current Topics in Wetland Biogeochemistry**, Vol. 2. Wetland Biogeochemistry Institute, LSU, Louisiana. pp. 24-39.

111. Sass R. L. and F. M. Fisher (1997) Methane Emissions from Rice Paddies; A Process Study, **Nutrient Cycling in Agroecosystems**,49, 119-127.

112. Yao Huang, R. L.Sass and F. M. Fisher (1997) Methane Emissions from Texas rice paddy soils: 1. Quantitative multi-year dependence of CH_4 emission on soil, cultivar and grain yield, **Global Change Biology**, 3, 479-489.

113. Sigren, L. K., G. T. Byrd, F. M Fisher and R. L. Sass (1997) Comparison of soil acetate concentrations and methane production, transport, and emission in two rice cultuvars, **Global Biogeochemical Cycles**, 11, 1-14, 1997.

114. Sigren, L. K., S. T. Lewis, F. M Fisher and R. L. Sass (1997) The effects of drainage on soil parameters related to methane production and emission from rice paddies, **Global Biogeochemical Cycles**, 11, 151-162.

115. Huang, Y., R. L.Sass and F. M. Fisher (1997) Methane emission from Texas rice paddy soils. 2. Seasonal contribution of rice biomass production to CH_4 emission, **Global Change Biology**,3, 491-500.

116. Tyler, S. C., R. S. Bilek, R. L. Sass, and F. M. Fisher (1997) Methane Oxidation and Pathways of Production in a Texas Paddy Field Deduced from Measurements of Flux, $\partial^{13}C$, and ∂D of CH_4, **Global Biogeochemical Cycles**, 11, 323-348

117. Huang, Y.,, R. L. Sass, and F. M. Fisher, Jr. (1998). A Semi-Empirical Model of Methane Emission from Flooded Rice Paddy Soils, **Global Change Biology**, , 4, 247-268.

118. Huang, Y., R. L. Sass, and F. M. Fisher, Jr. (1998). Model Estimates of Methane Emission from Irrigated Rice Cultivation of China, , **Global Change Biology**, 4, 809-822.

119. Sass, R. L. and F. M. Fisher, Jr. (1998) Methane from Irrigated Rice Cultivation. In: D. C. Parashar (ed) **Global Environment Chemistry**, Narosa Publisning House, New Delhi, India. pp 77-94.

120. Neue, H-U. and R. L. Sass (1998) The Budget of Methane from Rice Fields. **IGACtivities NewsLetter**, 12, 3-11.

121. Huang, Y.., R.L. Sass, and F. M. Fisher, Jr. (1999) Modeling Methane Emission from Rice Paddy Soils: I. Model Development. **Pedosphere**, 9(1), 1-10.

122. Huang, Y.., R.L. Sass, and F. M. Fisher, Jr. (1999) Modeling Methane Emission from Rice Paddy Soils: II. Model Validation and Application. **Pedosphere**, 9(1), 11-24.

123. Ding, A., C. R. Willis, R. L. Sass and F. M. Fisher. (1999) Methane emissions from rice fields: the effect of plant height among different cultivars. **Global Biogeochemical Cycles**, 13, 1045-1052.

124. Bilek, R. S., S. C. Tyler, R. L. Sass and F. M. Fisher (1999) Differences in CH_4 Oxidation and Pathways of Production between Rice Cultivars Deduced from Measurements of CH_4 Flux, and $\partial^{13}C$ of CH_4 and CO_2, **Global Biogeochemical Cycles**, 13, 1029-1044.

125. Sass, R. L., F. M. Fisher, A. Ding and Y Huang (1999) Exchange of methane from rice fields: National regional and global budgets, **Journal of Geophysical Research Atmospheres**, 104, 26,943-26952

126 Sass, R. L. (1999) Methane from Rice Agriculture. Expert group Meeting on Good Practice in Inventory Preparation, IPCC/OECD/IEA Program on National Greenhouse Gas Inventories, Wageningen, Netherlands, Feb. 24-26, 1999. Invited background paper.

127 Huang, Y.., R.L. Sass, and F. M. Fisher, Jr. (1999). Contribution of Rice Biomass Production in CH4 Emission from Irrigated Paddy Soils (In Chinese). **Agro-environmental Protection** 18(4), 150-154 .

128 Sass, R. L., F. M. Fisher and Y. Huang (2000). A process-based model for methane emissions from irrigated rice fields: experimental basis and assumptions. **Nutrient Cycling in Agroecosystems**, 58, 249-258.

129 Reicosky, D. C., J. L. Hatfield and R. L. Sass (2000) Agricultural contribution to global climate change. In: (L. R. Reddy and H. F. Hodges, eds.) **Climate Change and Global Crop Productivity**. CAB International, Wallingford, UK., pages 37-54.

130 Bogner, J., R. Sass and B. P. Walter (2000) Model comparisons of methane oxidation across a management gradient: Wetlands, rice production systems, and landfill. **Global Biogeochem. Cycles**14 , 1021-1030.

131 Byrd, G., F. M. Fisher, Jr., and R. Sass (2000). Relationships between methane production and emission to lacunal methane concentrations in rice. **Global Biogeochemical Cycles**, 14, 73-83.

132 Y. Huang , J. Jiang, L. Zong, R. L. Sass and F. M. Fisher. (2001) Comparison of field measurements of CH4 emission from rice cultivation in Nanjing, China and in Texas, USA, **Advances in Atmospheric Sciences**, 18(6):1121-1130

133 Y. Huang , J. Jiang, L. Zong, Q. Zhou, R. L. Sass and F. M. Fisher. (2001) Influence of planting density and precipitation on N2O emission from a winter wheat field, **Environmental Science**, 22(6):20-23 (in Chinese with English abstract)

134 Sass, R. L. (2002) Methane in Flooded Rice. In: **Encyclopedia of Soil Sciences**, R. Lal, Ed. Marcel Dekker, New York, NY. pp. 822-825.

135 Sass, R. L. (2002) Factors Affecting Methane Emissions from Rice Paddies. In: **Encyclopedia of Soil Sciences**, R. Lal, Ed. Marcel Dekker, New York, NY. pp. 819-821

136 Sass, R. L., Fisher, F. M., Jr. and J. A. Andrews, J. A. (2002) Spatial Variability in Methane Emissions from A Texas Rice Field with Some General Implications, **Global Biogeochem. Cycles** 16, 1015.

137 Sass, R. L. & R. J. Cicerone (2002) Photosynthate allocations in rice plants: food production or atmospheric methane, invited commentary **Proc. Natl. Acad. Sci**. 99, 11993-11995.

138 Sass' R.L., A. Mosier and X.H. Zheng (2002) Introduction and Summary: International Workshop on Greenhouse Gas Emissions from Rice Fields in Asia. , **Nutrient Cycling in Agroecosystems**, 64:ix-xv.

139 R. L. Sass, Andrews, J. A. Ding, A. and Fisher, F. M. Jr. (2002) Spatial and temporal variability in methane emissions from rice paddies: Implications for assessing regional methane budgets, **Nutrient Cycling in Agroecosystems,** 64:3-7..

140 Huang, Y., Jiao, Y., Zong, L. G., Wang, Y. S. and Sass, R. L. (2002). Nitrous oxide emissions from the wheat-growing season in eighteen Chinese paddy soils: an outdoor pot experiment, **Biology and Fertility of Soils**, 36:411-417

141 HuangYao , Jiao Yan, Zong Lianggang, Zhou Quansu, Zheng Xunhua, Ronald L. Sass (2002) N_2O emission from wheat cultivated soils as influenced by soil physico-chemical properties**, Acta Scientiae Circumstantiae**, 22(5):598-602 (in Chinese with English abstract)

142 JIAO Yan, HUANG Yao, ZONG Lianggang, ZHOU Quansu, Ronald L. Sass, Frank M. Fisher (2002) Methane emission from rice paddy soils as influenced by soil physico-chemical properties, **Environmental Science**, 23(5):1-7 (in Chinese with English abstract)

143 Huang Y, Jiao Y, Zong LG, Zheng XH, Sass RL and Fisher FM, 2002. Quantitative dependence of methane emission on soil properties, **Nutrient Cycling in Agroecosystems**, 64: 157-167

144 Li, C. Qiu, J.J., Frolking, S, Xiao, X. M., Salas, W, Moore, B, Boles, S, Yao,H.,[3], and Sass, R. (2002) Changing Water Management in China's Rice Paddies and the Decline in the Growth Rate of Atmospheric Methane 1980-2000, **Geophysical Research Letters**, 29(20), doi:10.1029/2002GL015370, 2002.

145 Sass, R. L., (2003) CH4 Emissions from Rice Agriculture, In Background Papers, IPCC Expert Meetings on Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, IPCC Institute for Global environmental Strategies, Hayama, Kanagawa Japan, pp. 399-417 (http://www.ipcc-nggip.iges.or.jp).

146 Redeker, K. R., J. Andrews, F. Fisher, R. Sass and R. J. Cicerone. (2003) Inter-and Intra-Field Variability of Methyl Halide Emissions from Rice Paddies. **Global Biogeochemical Cycles,** 16(4) (DOI 10.1029/2002GBOO1874)

147 Redeker, K. R., Meinardi, S., Blake, D. Sass, R., amd Cicerone, R. J. (2003) Gaseous emissions from flooded rice paddy agriculture. **Journal of geophysical research.** 108(13) (DOI 10.1029/2002GBOO1874)

148 Jianwen Zou, 1 Yao Huang,2 and Jingyan Jiang, Xunhua Zheng Ronald L. Sass (2005) A 3-year field measurement of methane and nitrous. **Global Biogeochemical Cycles**, 19 (DOI 10.1029/2004GB002401)

EXHIBIT G

Comments on SAGES Final Report

From: Mr. Tom Stehn, of U.S. Fish and Wildlife Service

June 5, 2009

Dr. Doug Slack
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College Station, Texas 77843-2258

Dr. Slack,

I am writing to provide comments on the draft SAGES report presented in Seguin, Texas on April 29, 2009. Your study has provided valuable new information on some topics including wolfberry production and blue crab recruitment. However, I disagree with your conclusions about the relationship of inflows, blue crabs and whooping cranes. I find the SAGES study very misleading mainly because it contains false assumptions and does not properly account for existing knowledge in the scientific literature.

My comments are presented numerically, with supporting material in 4 appendices.

1. **The SAGES study results are contrary to what I have observed during 28 years at Aransas monitoring the whooping crane population.**

Data collected at Aransas National Wildlife refuge indicates a relationship between marsh salinities, blue crab populations, and whooping crane survival. In general, when inflows are high and bay and marsh salinities are low, blue crab populations do well, and whooping crane mortality is low. With reduced inflows and high marsh and bay salinities, crabs do poorly and whooping crane mortality rises dramatically. This higher mortality makes sense since blue crabs make up 80-90% of the whooping crane diet when crabs are available (Chavez-Ramirez 1996) and are the predominate food of whooping cranes (Stevenson and Griffiths 1946, Allen 1952, Blankinship 1976, Hunt and Slack 1987, Nelson 1995, Chavez-Ramirez 1996).

Observations from weekly aerial survey whooping crane distribution data, monthly surveys initiated in the 1990s of blue crab, wolfberries and salinities in the bays and marshes, as well as observations of experienced personnel, were compiled to characterize what habitats the cranes were using throughout the winter which relates to general patterns of food consumption. Variables monitored were characterized in comparison with other winters as high, medium or low for either the entire winter or portions of the winter. Whooping crane mortality was detected on weekly aerial census flights (Stehn and Taylor 2008).

Data for the past 21 winters separated into winters of high (> 1.5%) whooping crane flock mortality (Table 1), and low (<1.5%) whooping crane flock mortality is shown below (Table 2). Annual flock mortality is provided in Appendix 1.

In the last 21 winters, whooping crane mortality was high (> 1.5%) in 7 of those winters. For the 7 winters with the highest whooping crane mortality; all but one (winter of 1993) had high salinities for much of the winter. For the winters with crab populations monitored, all (n=5) had low blue crab populations. Five of 6 had notably high levels of upland use. Wolfberry production ranged from abundant to low, and the amount of clamming and acorn levels differed depending on the winter. When in a winter of high salinities and low blue crab populations, this long-term data anticipates that whooping crane mortality will be high. In the winter of 2008 with high salinities, blue crabs and wolfberries, the two major foods of whooping cranes, were both extremely low and 23 whooping cranes died (8.5% of the flock), the highest winter mortality recorded in the past 21 years.

Table 1. Habitat conditions associated with high mortality winters (>1.5%) for whooping cranes at Aransas, 1988-2008.

Winter	% Mortality	Salinities	Crane Use of Freshwater	Blue Crab	Wolf-Berry	Use of Clams	Acorns	Upland Use
1988	4.3%	High	High	-[1]	-	-	High	High
1989	3.4%	High	High	Scarce	-	-	High	High
1990	7.8%	High thru Jan. Lower Feb-Apr.	High thru Jan. Lower Feb-Apr.	-	-	-	High	High
1993	4.9%	High, 14-26 ppt[2], though usually<23ppt in connected ponds	Only seen in December	Low, small crabs re-populated marsh starting in late Feb.	Abundant	Little observed	low	Low, but moderate use following burns
2000	3.3%	High thru Dec. Low Jan.-April.	High thru Dec. Low after Dec.	Scarce, especially in mid-winter	Moderate, but still notable part of diet	Use noted	scarce	High
2005	2.7%	High	Use occurred, especially 2nd half of winter	Low	High	High	scarce	Some use on burns
2008	8.5%	High	High	Low	Low	High	scarce	High, especially on M.I.

1. Blue crabs were not monitored until 1992 when Chavez-Ramirez started his study. Refuge personnel continued monitoring blue crabs after his study was completed in 1993.
2. Parts per thousand (ppt)

A typical pattern of habitat conditions present during all 7 high mortality winters was apparent as follows;

- Blue crabs were in short supply.
- Salinities were high forcing the cranes to seek out fresh water to drink except in 1993 when salinities were high but generally stayed below the threshold that forces cranes to seek out fresh water to drink.
- Considerable crane use foraging on clams and invertebrates in open bay habitat was documented, with some exceptions.
- Considerable foraging occurred on uplands.

In an average winter, blue crabs and wolfberries are readily available when the cranes return to Aransas in the fall. High tides in late September/early October have inundated the marshes and allowed crabs to disperse into connected and unconnected ponds. Starting in October, wolfberries are flowering and fruiting into December. Usually sometime in December, the cranes have consumed many of the blue crabs in the marshes, and the wolfberry crop is well past its peak and over by the end of the year. Starting in late-November, low pressure systems that reach the coast lower temperatures and bring north winds that blow the bay waters out into the Gulf. Tides are lowered dramatically. Blues crabs tend to move from the marshes into the open bays as marsh water levels and temperatures drop. Many crabs seek out deeper water which tends to be warmer than the shallow marsh waters. Whooping crane food habits shift dramatically to foraging in open bay habitat for clams and invertebrates in the substrate. During this mid-winter period, much crane upland use may occur, especially immediately after prescribed burns that provide animal matter killed in the fire (snakes and insects) or makes acorns on the mainland readily available when the mast crop is sufficient. Upland use also occurs on barrier islands following prescribed burns, as well as on disturbed soils mostly rooted up by feral hogs with the cranes foraging on tubers including nutsedges and ground cherries. In late winter, as temperatures and tide levels increase, blue crabs start moving back into the marshes, and whooping cranes go back to feeding on crabs. Fiddler crabs may become a larger part of the diet as spring days become warmer and the fiddler crabs are higher in their burrows due to the higher marsh water levels.

A correlation has been noted between the winters of high whooping crane mortality (1988, 1989, 1990, 1993, 2001, 2005, 2008) and low river flows on the Guadalupe below the level of 1.3 million acre-feet recommended by TPWD required for a health bay/estuary system (R. Sass, Professor of Natural Sciences, Emeritus, Rice University, unpublished data). Dr. Sass came to the following conclusions:

"*1. A high (whooping crane) mortality rate is always accompanied by a low river flow and the resulting high salinity.*

2. A whooping crane response to low river flow (high salinity) is one of excess stress. This condition does not necessarily lead to death but may be manifested as lack of sufficient bodily fat and protein that will be exhibited during the spring migration and subsequent poor reproductive behavior...

3. Complete and accurate data on environmental stress that is manifested by poor migratory and reproductive behavior is hard to generate but may well be a major part of the story on salinity-diet relationships…"

For the 14 winters with low whooping crane mortality < 1.5%, all had high blue crab populations except during mid-winter periods. Blue crab populations always decline in late fall and into the winter due to consumption by whooping cranes, the draining of the marshes from low pressure systems that bring northerly winds that lower marsh water levels dramatically as bay waters are blown out into the Gulf, and crabs moving to deeper water to find warmer and deeper water. Thus, blue crab levels are always lower during mid-winter. SAGES should have focused on crab movements in and out of the marshes since without regular replenishment of blue crabs in the marsh from crab movements, the cranes will consume most of their available food supply.

Table 2. Habitat conditions associated with low mortality winters (<1.5%) for whooping cranes at Aransas, 1988-2008.

Winter	% Mortality	Salinities	Crane Use of Freshwater	Blue Crab[1]	Wolf-Berry	Use of Clams	Acorns	Upland Use
1991	0.8%	Low	Low	-	very high	Low	High	high
1992	0.0%	Moderate (10-20 ppt[2])	Low	High	High	Low	High	high
1994	0.0%	High thru mid-Dec., then lower	Medium	High into Jan., then low	High	Medium	Low	Low
1995	0.6%	high	High	High in fall, low in Jan-Feb, medium in spring	Abundant	Moderate	Moderate	high
1996	0.0%	High until mid-March rains	High thru mid-Jan., then moderate	High in fall, moderate mid-winter	High	Low	High	Moderate
Winter	% Mortality	Salinities	Use of freshwater	Blue crab	Wolfberry	Use of clams	Acorns	Uplands use
1997	0.5%	Low	None	High in fall, then moderate	High	Moderate use mid-Dec to mid-Feb.	High	Some use on burns and hog rootings
1998	0.0%	Low	Very low	High except in mid-winter	Moderate+	Low	moderate	Moderate
1999	0.5%	High	High	High in fall, but then scarce	Moderate to high	High	High	High
2001	1.1%	Moderate	Low	High in fall, then medium	High	High	moderate	Moderate
2002	0.5%	Moderate	None	High	High	Low *	High	Low
2003	0.5%	Moderate	Moderate	High in fall, low Jan-Feb. high mid-March	High	Low	High	Low, moderate on burns

2004	0.9%	Low	Low	High in fall and spring, low mid-winter	High	Low to moderate	Low	Low except moderate on burns
2006	0.0%	High first half of winter, then dropping below 23 ppt	High through Dec., low after mid-Feb.	High in fall, then moderate	High	moderate	High	Moderate
2007	0.0%	Low first half of winter, increase to 20 ppt by spring	Moderate	High except mid-winter	High	Moderate in mid-winter but very high on March 5 census	-	Moderate on burns, high on M.I. uplands/burns

[1] Blue crabs were not monitored until 1992 when Chavez-Ramirez started his study. Refuge personnel continued monitoring blue crabs after his study was completed in 1993.

[2] Parts per thousand (ppt)

The correlation between increased whooping crane mortality occurring when blue crab populations in the marshes are low invalidates the SAGES conclusion "that food is not an issue for whooping cranes except in the most extreme conditions." Without blue crabs and wolfberries available, cranes are forced to eat other foods. These other foods are not as good at meeting the energy and nutritional needs of wintering whooping cranes (Nelson 1995). If other foods such as clams, insects, tubers and snails provided everything the whooping cranes needed, then high levels of mortality would occur in both high and low blue crab winters. My observations support the observations of other researchers that the key to whooping crane well-being during winter are adequate blue crab population.

SAGES should look at flock dynamics and habitat conditions at Aransas over more than 2 decades and compare them with inflow data including possible time lag affects.

2. **The SAGES study results fail to account for the conditions observed during the 2008 winter at Aransas.**

The conclusions of the SAGES study fails to account for the record level of whooping crane mortality during the 2008 winter (8.5%). Neither of the crane winters in which the SAGES project collected blue crab data were anything near as bad for the cranes compared with 2008.

CHARACTERIZATION OF THE 2008 WINTER AT ARANSAS

The fall of 2008 had the worst crop of wolfberries I had ever observed at Aransas in the past 28 years. Data from a transect walked on November 10th, 2008 found only 12 wolfberry fruits and no wolfberry flowers on one transect about 150 meters long that we have been monitoring for years. The previous November, on the same transect, we had counted 416 flowers and 60 fruits. The SAGES study concludes that wolfberry production is negatively affected by high summer salinities, which fits in this case since the area experienced an

extreme drought and salinities were high. The cranes did not get much benefit from the wolfberry crop in the fall of 2008. Moderate numbers of blue crabs were available when the cranes first arrived, but numbers quickly tapered after the cranes started feeding on the crabs. Commercial whooping crane boat captain Tommy Moore emailed me on November 11th:

> "There are no wolfberries. It is like that all over the marsh. I have been watching the cranes' feeding habits and only every once in a while do I see one pluck a wolfberry from the vegetation. They are mostly digging for fiddler crabs is my guess. I have not seen a blue crab consumed this year (on 4 trips). We did see a snake eaten on Ayres Island. Looks like a tough year."

A food survey done by refuge personnel on December 1, 2008 found only one blue crab and 2 wolfberries. Salinities were measured at 30 parts per thousand (ppt) at the refuge boat ramp and 43 in unconnected ponds at the refuge boat ramp marsh. The same day, an emaciated subadult crane unable to stand was picked up near the refuge boat ramp. The next blue crab survey on December 30th found zero blue crabs, and that finding was replicated on monthly surveys the remainder of the winter.

On January 7, 2009, I spoke with Karen Meador of Texas Parks and Wildlife Department (TPWD), Rockport. She stated that ongoing bay sampling was finding low numbers of blue crabs, but not at alarmingly low levels. However, commercial blue crab harvest was very low and crabbing pressure was down. Salinities were very high, measured at 30 ppt in Copano Bay.

From my aerial census flight report on January 8, 2009 I wrote …"Although the Tour Boat Captains occasionally see cranes catching a crab, many of the birds have switched to eating razor clams in open bay habitat. The increased amount of crane use in open bay habitat on the flight (n=79 out of 228) is indicative of the food stress the population is facing."

Monthly crab surveys done the rest of the winter and spring also failed to find any blue crabs. Although the whooping crane tour boat captains would occasionally find a whooping crane eating a large blue crab, the overall consumption of blue crabs was way below the norm and extreme low. The very low availability of blue crabs and wolfberries during the 2008 winter for the cranes was correlated with record high mortality. Seventeen juveniles and 6 white-plumaged birds died, a record total of 23 cranes (8.5% of the flock).

Information on specific causes of mortality was obtained on the two intact carcasses recovered. The first bird captured live died as it was being transported to medical help. A necropsy done by the National Wildlife Health Lab in Madison, Wisconsin showed the bird was extremely emaciated and only found an injured knee that could have contributed to the bird's death. A white-plumaged bird had been seen limping with restricted foraging ability in Saskatchewan in the 2008 fall migration. It is possible that was the same bird as the one picked up live at Aransas and had been unable to get enough food over an extended period of time. The low levels of food availability at Aransas were presumably too much for the bird and it continued to weaken until it could no longer stand.

The second whooping crane carcass recovered was a juvenile that was observed being aggressively picked on by a territorial male on January 13, 2009. Since the juvenile's parents flew off during the territorial encounter, I postulate that the juvenile was too weak to fly off. It was predated with 48 hours of its encounter with the territorial male. A strain of infectious bursal disease (IBD) was isolated from the carcass, the first time IBD has ever been isolated from a crane. Very little work has been done on IBD in cranes, so the disease presumably

may have been epizootically affecting whooping cranes at Aransas over a long period of time. IBD has been documented in whooping cranes and other birds including wild turkeys in Florida (Candelora et al. 2008), and may be present at captive whooping crane breeding facilities. One of the symptoms of IBD is emaciation, even when the bird is receiving adequate food supplies. However, the particular strain of IBD isolated from the Aransas whooping crane is different from other known strains, so how it affected the crane is speculative.

IBD mainly affects juvenile cranes since the virus grows in the bursa, an out pocket of the cloaca that is not present in white-plumaged cranes. Thus, the 7 mortalities of white-plumaged cranes at Aransas in the 2008 winter probably hadhad anything to do with IBD. The loss of even 7 whooping cranes ranks 2008 as a high mortality winter.

Field observations in the 2008 winter showed a correlation between low blue crab populations and high whooping crane mortality. Food supply can often be a limiting factor for wildlife populations. It makes sense that whooping cranes are going to do better when food supplies are adequate versus when food supplies are limited. SAGES seems to be denying this by suggesting food supplies are more than sufficient in crane territories. The fact that whooping crane territories appear to be approaching minimum sizes (Stehn and Prieto, In Review) suggests that territorial whooping cranes must defend a large enough area to maintain an adequate food supply for the territorial pair and their young of the year. With territories reaching minimum sizes and not observed to be getting smaller suggests that food is becoming limiting. If the wintering grounds were chock full of food for the cranes annually and that food was not a limiting factor in all but the most extreme winters, as stated by the SAGES report, I would expect to be seeing whooping crane territories continuing to get smaller and smaller until food becomes a limiting resource. Since territories are at or close to minimum sizes already, this provides evidence that food may be limiting. This is a far different conclusion than that described in the SAGES report. The inverse relationship between blue crab population size and whooping crane mortality shown by Pugesek et al. (2008) also provides evidence that food is a limiting factor (see below). I therefore do not see the relevance of the analysis done on p. 55 that hypothetically "shrinks" the size of whooping crane territories since there is evidence that this is not happening at Aransas as the cranes continue to slowly expand their range rather than increase the density of wintering cranes.

3. **SAGES study results are contrary to the conclusions of Pugesek et al. (2008). The SAGES report should attempt to explain this difference.**

For an eight-year period starting in 1993, intensive surveys were done by Pugesek et al. (2008) to estimate the number of blue crabs available to whooping cranes. The winters of 1993 and 2000 were poor crab years; the remaining six winters all had adequate numbers of blue crabs present. During the two winters with poor crab numbers, seven and six whooping cranes died respectively. In all six other winters, either zero or one whooping crane died. This showed a statistically significant inverse correlation between blue crab abundance and adult whooping crane mortality (Pugesek et al. 2008).

The SAGES report needs to explain why findings from the SAGES study which collected blue crab data only in 2 winters differs from the findings of the 8-year data set of Pugesek et al. (2008). It is a critical oversight not to have even mentioned the Pugesek et al. (2008) manuscript anywhere in the SAGES report even though I had emailed the manuscript to SAGES team members. This oversight seems to be characteristic of the SAGES study in failing to thoroughly review existing literature on many topics of the study including the relationship between inflows and blue crabs.

4. **Study results from SAGES about whooping crane foods seem in direct conflict with previous crane research. The discussion section found in scientific manuscripts that should attempt to relate current findings with previous research is missing in the SAGES report. Please discuss what field data you collected to come to different conclusions from previous studies.**

Numerous studies have found blue crabs to be an important food resource for wintering whooping cranes (Allen 1952, Stevenson and Griffiths 1946, Blankinship 1976, Hunt and Slack 1987, Nelson (1995), Chavez-Ramirez 1996). When blue crabs are scarce, the whooping crane population is under stress and does poorly (Nelson 1995, Chavez-Ramirez 1996, Pugesek et al. 2008). Allen (1952) found the diet in fecal samples to be 85% blue crab. Chavez-Ramirez (1996) found that when available, blue crabs can make up 80-90% of the diet of whooping cranes. An individual crane can consume up to 80 crabs per day. Blue crabs appear to be the most important source of energy for wintering whooping cranes contributing between 62% and 97% of overall energetic intake during different months (Chavez-Ramirez 1996). He did note that blue crabs may become a limited resource in some years. In October through December 1993, the second winter of his study, a lack of blue crabs which was only partially offset with an increase in wolfberry consumption, affected the potential for energy storage throughout the wintering period resulting in negative energy balances through the first half of the 1993-94 winter (Chavez-Ramirez 1996). Studies by Nelson (1995) of whooping crane food items (crabs, clams, wolfberry, acorns) showed that blue crabs were the highest in protein and nutrition for the whooping cranes. When crabs are not available, whooping cranes will switch to other foods, but because of the poor nutritive value of these alternate foods, whooping cranes may actually burn up fat reserves and have a net loss of energy for periods of the winter (Chavez-Ramirez 1996). Nelson (1996) noted an apparent instance of food shortage contributing to higher whooping crane mortality from late fall of 1993 to fall of 1994. This negative energy balance may also have manifested itself in greater than normal over-winter mortality and reduced nesting effort in the subsequent nesting season where 37% of the adult pairs failed to nest (B. Johns, Canadian Wildlife Service, unpublished data). This was unusual since normally just about all pairs attempt to nest annually. In addition, production was reduced from the pairs that did nest (B. Johns, Canadian Wildlife Service, personal communication). This was believed to have resulted from their reduced fat reserves that had not built up sufficiently during the previous winter.

A statistically significant inverse correlation between blue crab numbers and increased adult whooping crane mortality has been documented (Pugesek et al., 2008). It is well known that whooping cranes will eat other food items when blue crabs are not available, but energy content studies done by Nelson (1996) showed that blue crabs were higher in protein and lipids than other foods sampled. During most mid-winter periods when cranes switch their diet to eat clams, Nelson (1996) found that *Rangia cuneata* was a suboptimal energy and nutrient resource since it was low in gross energy and protein compared with the other crane foods studied.

From observations made over many winters, I can estimate food availability throughout the winter based on distribution of the cranes observed on aerial census flights as described by Chavez-Ramirez (1996). For example, severe food shortages in the 2008 winter changed crane distribution dramatically with greatly increased amounts of upland use observed, cranes utilizing game feeders, and increased clamming in open bays. These levels of use are not observed when blue crabs and/or wolfberry are available to the cranes, an indication that these other foods are suboptimal foods.

The first winter (2004) of the Sages study that did intensive blue crab sampling was a low whooping crane mortality winter (0.9% of the flock). The second and final winter (2005) of the SAGES study that did intensive blue crab sampling was a high mortality winter with 6 whooping cranes dying out of a flock of 220 (2.7%). There were noticeably more crabs present in 2004 compared to 2005. Walking surveys (n=6) found an average

of 48 crabs/hour in 2004 and 38 crabs/hour in 2005 (T. Stehn, USFWS, unpublished data). Crab surveys done on 3 consecutive days in March following the methodology of Pugesek et al. (2008) who found that the March surveys were the best reflection of overall winter crab levels, recorded 3.22 crabs/100 meters in 2004 and 1.43 crabs/100 meters in 2005. Crabs were notably scarce in the second half of the 2005 winter and the crane population was under stress, a notable difference from the second half of the 2004 winter. The SAGES report fails to account for this difference and SAGES researches did not detect the way the whooping cranes were impacted differently in these two winters. Instead, the SAGES report on page *vi* states "None of the study results indicated that habitat conditions at Blackjack Peninsula are marginal for crane survival and well-being".

5. The SAGES study fails to analyze existing data sets.

The SAGES study collected two years of field data on crane foods. Existing multi-year data sets should be analyzed as follows:

a) Analyze inflow data and bay salinities in relation to whooping crane mortality.
b) Analyze inflow data in comparison with TPWD fisheries blue crab sampling data from Aransas and San Antonio bays.
c) Analyze inflow data in comparison with commercial crab harvest data.

6. The SAGES study model assumes that blue crab numbers are directly correlated with rising salinities up to 30 ppt. This assumption is based on laboratory studies and is false!

With the blue crab well documented as the primary food of whooping cranes, one of the most crucial objectives of the SAGES study was to determine how blue crab numbers in the crane marshes were related to salinities. Page 42 of the SAGES report states; "*In the model we selected, crab density was positively correlated with salinity, which agrees with Cadman and Weinstein 1988*". On p. *vi*, the SAGES report states; "Consistent with prior studies, blue crab abundance tends to increase with bay salinity." Instead of objectively leaving the relationship between blue crabs and salinities as an unknown and collecting all possible sources of data to shed light on this relationship, the SAGES study **assumed** that more crabs were present when salinities were higher. This assumption was based on laboratory studies (Cadman and Weinstein 1988) and does not fit field conditions observed in the winter range of the whooping crane nor data collected by Texas Parks and Wildlife Department (Longley 1994, M. Fisher, TPWD, personal communication). **This assumption made by SAGES is false and pervades and invalidates the entire SAGES model and study.** Neither Longley (1994) or Mark Fisher (unpublished data) found that blue crabs were more abundant in higher salinities as assumed by the SAGES study. Texas Water Development Board (TWDB)/TPWD model results for the Guadalupe Estuary predicted a harvest of 255,500 pounds under MinQ and 379,900 pounds under the higher inflows and lower salinities of MaxH (Longley et al. 1994). The SAGES assumption did not hold true for all the drought winters I have observed when blue crabs were scarce. Field sampling shows that blue crab populations usually crash in periods of drought. Examples of this were the winters of 1989, 1993, 2000, 2005 and 2008. The assumption needs to be changed in the SAGES model. I expect this would drastically change the conclusions of the SAGES study.

On October 28, 2004 I talked with Dennis Pridgen, TPWD fisheries biologist in Rockport, Texas. He noted how zoeal and megalopal stages of blue crabs need high salinities (> 25 ppt) for high recruitment with much of the spawning occurring in the Gulf of Mexico. After successful development of megalopae, survival of early crab stages is complicated, based on synergistic effects of salinity, temperature, pollutants, predation, disease,

habitat and food availability. The first blue crab stage (2 ½ mm) and subsequent stages show the best abundance and growth when salinities are intermediate (10-20 ppt) (D. Pridgen, TPWD, personal communication). He also stated that "*Inflows between April and July will influence crab survival positively. If inflows are high during this period, the blue crab population will do well. Thus, April to July inflows are very important to the whooping crane food base.*" Notes I took from the conversation with Mr. Pridgen that were proof-read and edited by him for accuracy are provided as Appendix 3. Tom Wagner (TPWD Fisheries biologist, Rockport) in an email written to me January 5, 2005 noted "increased spring salinities will reduce juvenile blue crab growth, thus reducing energy available to cranes".

Scientific research in other estuarine systems in general demonstrates a positive relationship between inflows and blue crab populations. The SAGES study needs to exhaustively research the literature on this relationship, account for this knowledge in their report, and relate it to their field data collected on blue crabs in 2005 and 2006. Guillory et al. (2000) stated that "juvenile blue crabs are most abundant in low to intermediate salinities characteristic of middle and upper estuarine waters". Rounsefell (1964) found "low salinity marsh is an important nursery habitat for juvenile blue crabs and increased salinities may adversely impact the species" (as cited in Guillory et al. 2000). Guillory et al. (2000) found "*a blue crab recruitment index as correlated with lagged summer/early fall Mississippi River discharge (positively) and salinity (negatively), whereas commercial harvests were significantly correlated with unlagged Mississippi River discharge (positively) and salinity (negatively). They also state that the effects of discharge and salinity on blue crab recruitment and abundance were probably manifested indirectly through biotic mechanisms such as predation"*.

Longley (1994) analyzing a long-term data set reported an inverse relationship between salinities and blue crab numbers. This totally disagrees with the SAGES assumption in the model that blue crabs prefer higher salinities, an assumption that is not based on field data collected by SAGES. TPWD data shows that more blue crabs are generally found not in the highest salinity areas in the estuary but in more moderate salinity areas of 5-15 ppt (Longley 1994).

Others have written about the implications of a causal relationship between inflows and high blue crab numbers. (Kretzschamer 1990) calculated that by the year 2040, due to anticipated diversions, a predicted decrease of 555,000 acre-feet of gauged inflows in an average year into the crane's winter range was projected to cause an 8% decline in blue crab populations (Texas Department of Water Resources 1980), but could have a much larger impact in drought years (N. Johns 1994).

Texas Water Development Board data indicate natural droughts already threaten the Guadalupe ecosystem. Without sufficient inflows, wildlife resources, including fish, crabs, and shrimp, all decline. The 1.15 million acre-feet figure derived by TPWD is often quoted as an amount needed to maximize harvest of 9 marine species of commercial interest in the bays and estuaries. In the case of blue crabs, more than 1.15 million acre-feet is needed to produce high blue crab populations. TPWD data clearly show that increased water inflows result in higher blue crab numbers (Mendoza 2001). Crab survival of all life stages increases when salinities are generally below 20 ppt. Blue crabs were found to be more abundant in the Guadalupe Estuary in salinities averaging between 10-25 ppt. A simple inverse relationship exists between blue crab catch rates and mean salinity within an estuary (Longley 1994). Peak crab counts in the bays occur following periods of flooding. In San Antonio Bay, the 3 highest blue crab harvest years were all having inflows greater than 3 million acre-feet annually. Thus, to maximize blue crabs for whooping cranes to eat, managers should maximize freshwater inflows on the Guadalupe River. Providing for guaranteed minimum inflows to the bay is essential.

7. The SAGES study needs to comment on how marsh salinity levels could impact growth of sea grasses and algae in marsh ponds.

Blue crab survival in the marshes is dependent on habitat in which they can hide from predators. Vegetated habitats are favored by blue crab over un-vegetated habitats (Rozas and Minello 1998). Many of the ponds at Aransas seem to have little aquatic vegetation growing in them except for algae. I have observed increased growth of seagrasses and algae during low salinity years in the ponds. Thus, reduced inflows could increase marsh salinities, reduce growth of seagrasses, and thus limit blue crab populations.

8. The SAGES study needs to relate reduced inflows with the increased time periods that salinities in unconnected marsh ponds in the crane winter range would exceed 30 ppt.

Long-term crab sampling data compiled in May, 2009 shows blue crab bag seine catch per unit effort in San Antonio and Aransas bays per salinity zone showed no differences for salinities below 30 ppt, but showed declining blue crab populations in salinities greater than 30 ppt (Mark Fisher, Texas Parks and Wildlife Department, unpublished data). If one assumes this to also hold true in the salt marshes, I have observed multiple drought years at Aransas when marsh salinities in unconnected ponds greatly exceed 30 ppt. Crabs presumably are avoiding these hypersaline ponds, thus greatly lowering the carrying capacity of the salt marshes to sustain blue crab populations. I recommend that the SAGES study look at how often reduced inflows would increase marsh salinities in unconnected ponds above 30 ppt and how that would lower the blue crab carrying capacity of the marsh.

9. The SAGES study misuses data on the smallest age classes of blue crabs.

Whooping cranes generally do not eat the smallest size classes of blue crabs (<30 mm). This needs to be factored in to the energetic model. Whooping cranes do not eat blue crabs 11 mm or smaller. I would also estimate that blue crabs 20 mm or smaller probably don't make up a significant part of the whooping crane diet either. Whooping cranes are normally seen eating crabs something at least as large as a fiddler crab, or blue crabs 30 mm in size or greater. Crab densities used in the SAGES model (crabs per square meter) should exclude all blue crabs <30 mm since they are basically not used by whooping cranes. Although the smallest sized blue crabs may presumably be a good indication of subsequent recruitment into the larger size classes, many other bird species prey on very small crabs, and many of these small blue crabs will die at Aransas during summer when much of the marsh at Aransas dries up.

With blue crabs > 30 mm the main food of the whooping crane, it is essential that the SAGES model be able to successfully reflect many aspects of blue crab biology. Especially important would be how blue crab availability for whooping cranes changes during the course of the winter due to many factors including consumption of crabs by whooping cranes and other wildlife species, movements of blue crabs in and out of the marshes, and differential availability of blue crabs during periods of colder temperatures as noted by Chavez (1996). Yet on p. 108, the Sages report states: “Model selection procedures used to explore the density of blue crabs > 30 mm in size often resulted in non-convergence or excessively large dispersion estimates”.

Danielle Greer also failed to sample crabs in some key “bayou” habitat at Aransas. These bayous consist of very narrow channels that interconnect marsh ponds. On one blue crab survey in particular, I remember walking the marsh for over an hour and the only place I finally found crabs was in a bayou too narrow to be sampled using Danielle’s methods.

10. The important role of sediments, nutrients and organic matter brought by inflows to the Guadalupe Estuary is not accounted for in the SAGES study that seems focused on a salinity-based model only.

Blue crabs and bay and marsh productivity are impacted by sediments, nutrients, and organic matter that are brought to the estuary by inflows (Longley 1994). For SAGES to be making public statements that inflows can be reduced 90% without hurting the food base of the whooping crane based on their salinity-based model that does not properly account for the importance of sediments, nutrients, and organic matter in maintenance of bay productivity is very misleading.

11. The SAGES study fails to show the temporal aspects of whooping crane food availability.

Page 70 of the SAGES report states:

> "*The food supply for cranes appears to be more than adequate to meet their energy needs during the time period simulated. None of the study results indicated that habitat conditions at Blackjack Peninsula are marginal for crane survival and well-being. Simulation results for the 11-year period of 1997-2007 found that the metabolic energy present in wolfberry fruit and blue crabs together and in blue crabs alone, always exceeded the estimated daily energy requirements of four whooping cranes in each of the three crane territories, except under extreme marsh environment circumstances.*"

The SAGES study does not account for seasonal periods of stress for the whooping crane that occur nearly every winter. Chavez-Ramirez (1996) found major stretches of the 1993 winter when cranes used up existing energy reserves due to inadequate availability of quality foods. With blue crabs and wolfberries well documented as the preferred foods of the species, both of these items are normally in short supply in January and February. The cranes switch to foraging on clams and other benthic invertebrates. Clams and invertebrates had been present earlier in the winter but were not selected by the cranes. Therefore, one assumes that they do not "prefer" those foods. Nelson (1995) found these foods to be lower in caloric value and protein compared to blue crabs. Thus, the SAGES calculations measuring total crane food supply are meaningless when key foods are not available to the cranes for significant stretches of most winters.

On p. 147-148, the author Danielle Greer noted the change in food habits from wolfberry fruits and blue crabs to razor clams in mid-winter "*when overall food abundance was presumably low*". She noted during the second half of her final field season that cranes were not able to find blue crabs and switched their food habits to clams and insects. However, she failed to recognize how atypical this was compared to winters when whooping crane foods are sufficient and failed to correlate the stressful conditions with the death of 6 whooping cranes during her second season of field sampling.

12. The SAGES study concludes erroneously that a reduction in wolfberry production will not harm whooping cranes, with SAGES reasoning that cranes will opportunistically forage on other foods of sufficient nutrition that are present in adequate numbers in all but the most extreme winters.

The SAGES study correlates increased summer salinities in the marsh with reduced levels of wolfberry production in the fall. Wolfberries are fed on heavily by whooping cranes because of their high caloric value and because they are easily obtained. A reduction in the wolfberry crop due to decreased inflows and higher marsh salinities could negatively impact significantly the food base available for whooping cranes since wolfberries are a key component of the whooping crane diet in the fall. In 2008 with the lowest wolfberry crop I have observed in the past 21 years, the cranes had only limited numbers of wolfberries to consume. The

cranes initially fed on blue crabs in the fall. As more and more crabs were consumed and crab numbers declined, the species was in trouble. Continued food stress from the extreme low levels of wolfberry and blue crab were correlated with the highest flock mortality (8.5%) documented in the last 21 years.

The SAGES model when looking at the density of wolfberry fruits needs to estimate and take into account other wildlife species including sandhill cranes and raccoons that eat large quantities of wolfberries. In fact, the only time sandhill cranes forage extensively in salt marsh is when wolfberries are available. Thus, other wildlife species may significantly lower the quantity of wolfberries available to the whooping cranes.

13. The SAGES study fails to analyze the energetic costs of cranes being forced to leave the salt marsh to drink.

Cranes are observed leaving the marsh to seek out freshwater to drink when salinities approach or exceed 20 ppt. When marsh and bay salinities exceed 23 parts per thousand (ppt), whooping cranes are forced to make daily flights to freshwater to drink (Allen 1952, Hunt 1987). Flights are presumably made several times a day, although the number of times a whooping crane must drink fresh water daily has not been quantified. I have observed cranes on San Jose Island flying 3 miles to find the nearest fresh water. These flights use up energy, reduce time available for foraging or resting, and could make the cranes more vulnerable to predation on the uplands (Tom Stehn, USFWS, Austwell, Texas, personal communication). Thus, inflows are crucial in keeping salinity levels below the threshold of 23 ppt in coastal marshes used by whooping cranes.

Inflows which mix with Gulf waters help keep salinity levels moderate. The SAGES study should assess how reduced inflows would increase the energy demands for cranes forced to seek out freshwater sources. There could presumably also be detrimental physiological aspects for whooping cranes spending the winter in highly saline environments.

14. SAGES should analyze the spike found in blue crab recruitment in relation to inflow data.

A potentially very significant spike was found by SAGES in blue crab recruitment. Blue crab larval movements into the marshes were low except during the spikes. The study should comment on what factors may have caused this spike to occur.

15. Peer review of the SAGES study was inadequate.

The technical advisory committee convened by SAGES in 2003 and 2004 was never consulted again after those early stages of the study. Thus, the SAGES study received no technical guidance during much of the study's duration and especially during the wrap-up. Not knowing who peer-reviewed the draft report, I doubt if anyone knowledgeable about whooping cranes such as a member of the Whooping Crane Recovery Team was asked to review the final report before it was released in April, 2009.

16. The report contains errors and inconsistencies, some of which are noted below.

p. 26 - Figures 2.1 and 3.1 are very different even though the text states they are identical. Figure 3.1 which is wrong shows no link between inflows and whooping crane foods.

p. 43 – Sages assumed that "wind speed was a proxy for water turbidity". In the multiple surveys done by Mike Baldwin for the Pugesek et al. (2008) study, and the multiple walking surveys I have conducted, turbidity in the

narrow bayous seemed mostly related to schools of fish that would stir up the bottom sediments and cloud the water.

p. 44 – I do not understand why "the sample grid for Boat ramp did not include the large lake within that territory." The territorial Boat ramp cranes spend extensive periods every winter foraging in that large lake known as Redfish Slough.

p. 54 – The date selected by SAGES for whooping crane arrival (October 16) is actually the average date for the first whooping crane of the fall to arrive (T. Stehn, USFWS, unpublished data). The date of April 7 assumed by SAGES to be the average departure date is actually about when 50% of the flock has started the migration. Thus, there is inconsistency in what the two dates selected represent. If SAGES wants to choose a date when 50% of the cranes have arrived in the fall, I would choose approximately November 4th.

p. 108 – "*Model selection procedures used to explore the density of blue crabs > 30 mm in size often resulted in non-convergence or excessively large dispersion estimates*". With blue crabs > 30 mm the main food of the whooping crane, it is essential that the SAGES model be able to successfully reflect many aspects of blue crab biology. Especially important would be how blue crab availability for whooping cranes changes during the course of the winter due to many factors including consumption of crabs by whooping cranes and other wildlife species, movements of blue crabs in and out of the marshes, and differential availability of blue crabs during periods of colder temperatures as noted by Chavez (1996).

Literature Cited

Allen, R. P. 1952. The Whooping Crane – Research Reprot # 3 of the National Audubon Society. New York, N.Y. 246 pp.

Blankinship, D. R. 1976. Studies of whooping cranes on the wintering grounds. Pages 197-206 in J. C. Lewis, ed. Proc. International Crane Workshop, Oklahoma State Univ. Press, Stillwater.

Cadman, L. R. and M. P. Weinstein. 1988. Effects of temperature and salinity on the growth of laboratory-reared juvenile blue crabs. Journal of Experimental Marine Biology and Ecology 121:193-207.

Candelora, K. L., M. Spalding, S. Nesbitt, H. Sellers, J. Olson, L. Perrin, and J. Parker. 2008. Infectious bursal disease in wild populations of turkeys and sandhill cranes: preliminary findings. Abstract in Folk, M. J. and S. A. Nesbitt, editors. 2008. Proceedings of the tenth North American crane workshop. North American Crane Working Group, Gambier, Ohio, USA.

Chavez-Ramirez, F. 1996. Food availability, foraging ecology, and energetics of whooping cranes wintering in Texas. Ph.D. dissertation, Texas A & M Univ. 103 pp.

Chavez-Ramirez, F., J. T. Nelson, and R. D. Slack. 1997. Food and energy intake rates of wintering whooping cranes foraging on two selected food items. Proc. N. Am. Crane Workshop 7:259.

Guillory, V., H. Perry, P. Steel, T. Wagner, W. Keithly, B. Pellegrin, J. Petterson, T. Floyd, B. Buckson, L. Hartman, E. Holder, and C. Moss. (2000). The blue crab fishery of the Gulf of Mexico, United States: a regional management plan. Gulf States Marine Fisheries Council. Ocean Springs, Mississippi, USA.

Hammerschmidt, P. C. 1982. Population trends and commercial harvest of the blue crab (Callinectes sapidus) RATHBUN, in Texas bays, September 1978-August 1979. Management Data Series No. 38. Texas Parks and Wildlife Department, Coastal Fisheries Branch.

Hunt, H. 1987. The effects of burning and grazing on habitat use by whooping cranes and sandhill cranes on the Aransas National Wildlife Refuge, Texas. PhD thesis. Texas A & M University. 173 pp.

Hunt, H. E. and R. Slack. 1987. Winter foods of the whooping crane based on stomach content analyses. Pages 217-218, in J. C. Lewis, editor. Proceedings of the 1985 crane workshop. Platte River Whooping Crane Habitat Maintenance Trust, Grand Island, Nebraska, USA.

Johns, N. 2004. Bays in peril: a forecast for freshwater flows to Texas estuaries. National Wildlife Federation. Austin, Texas, USA.

Kretzschmar, G. E. 1990. Executive Administrator of Texas Water Development Board. Letter to USFWS, Dec. 5, 1990.

Longley, W. L., ed. 1994. Freshwater inflows to Texas bays and estuaries: ecological relationships and methods for determination of needs. Texas Water Development Board and Texas Parks and Wildl. Dept., Austin, Texas. 386 pp.

Mendoza, C. 2001. Letter in August, 2001 supporting San Marcos River Foundation. USFWS files, Aransas NWR, Austwell, Texas.

Nelson, J. T. 1995. Nutritional quality and digestibility of foods eaten by whooping cranes on their Texas wintering ground. MS Thesis, Texas A and M Univ. 95pp.

Pugesek, B. H., M. J. Baldwin, and T. V. Stehn 2008. A low intensity sampling method for assessing blue crab abundance at Aransas National Wildlife Refuge and preliminary results on the relationship of blue crab abundance to whooping crane winter mortality. In Folk, M. J. and S. A. Nesbitt, editors. 2008. Proceedings of the tenth North American crane workshop. North American Crane Working Group, Gambier, Ohio, USA.

Rounsefell, G. A. 1964. Preconstruction study of the fisheries of the estuarine area traversed by the Mississippi River-Gulf outlet project. Fishery Bulletin 63(2):373-393.

Rozas, L. and T. Minello. 1998. Nekton use of salt marsh, seagrass, and nonvegetated habitats in a south Texas (USA) estuary. Bulletin of Marine Science 63(3):481-501.

Sansom, A. 2000. Letter to TWDB. USFWS files, Aransas NWR, Austwell, Texas.

Stehn, T. 1998. Memo to Allen White, USFWS-Ecological Services. USFWS files, Aransas National Wildlife Refuge, Austwell, Texas, USA.

Stehn, T. V. 1991. Whooping cranes during the 1990-91 winter. Unpublished file report, USFWS, Austwell, Texas, USA.

Stehn, T. V. and F. Prieto. 2010. Proceedings of the eleventh North American crane workshop. North American Crane Working Group. In review.

Stehn, T. V. and T. E. Taylor. Aerial census techniques for whooping cranes on the Texas coast. In Folk, M. J. and S. A. Nesbitt, editors. 2008. Proceedings of the tenth North American crane workshop 10:146-151. North American Crane Working Group, Gambier, Ohio, USA.

Stevenson, J. 0. and R. E. Griffith. 1946. Winter life of the whooping crane. Condor 48:160-178.

Texas Department of Water Resources. 1980. Guadalupe Estuary: a Study of the Influence of Freshwater Inflows. LP-107. Austin, TX. 321 pp.

Texas Parks and Wildlife 1998. Freshwater Inflow Recommendation for the Guadalupe Estuary of Texas. Coastal Studies Technical Report No. 98-1, written by Pulich et. al. 61 pp.

Appendix 1. Mortality in the Aransas-Wood Buffalo whooping crane population 1989-2008.
High crane mortality winters at Aransas are designated by red text.

Year	Flock Size In April	Apr-Nov Mortality	Apr-Nov % Loss	Winter	Winter Mortality	Peak Winter Flock Size	% Winter Mortality	12-Month Mortality	12-Month Mortality (%)
2008	266	34[A]	12.8[A]	2008-09	23	270	8.5%[A]	57	21.4%[A]
2007	236	9	3.8	2007-08	0	266	0%	9	3.8%
2006	214	22	10.3	2006-07	0	237	0%	22	10.3%
2005	215	25	11.6	2005-06	6	220	2.7%	31	14.4%
2004	192	10	5.2	2004-05	2	217	0.9%	12	6.3%
2003	184	15	8.2	2003-04	1	193	0.5%	16	8.7%
2002	174	5	2.9	2002-03	1	185	0.5%	6	3.4%
2001	174	13	7.5	2001-02	2	176	1.1%	15	8.6%
2000	187	16	8.6	2000-01	6	180	3.3%	22	11.8%
1999	183	11	6.0	1999-00	1	188	0.5%	12	6.6%
1998	181	16	8.8	1998-99	0	183	0%	16	8.8%
1997	160	8	5.0	1997-98	1	182	0.5%	9	5.6%
1996	157	13	8.3	1996-97	0	160	0%	13	8.3%
1995	133	3	2.3	1995-96	1	158	0.6%	4	3.0%
1994	136	11	8.1	1994-95	0	133	0%	11	8.1%
1993	136	9	6.6	1993-94	7	143	4.9%	16	11.8%
1992	131	10	7.6	1992-93	0	136	0%	10	7.6%
1991	135	11	8.1	1991-92	1	132	0.8%	12	8.9%
1990	141	9	6.4	1990-91	11	146	7.5%	20	14.2%
1989	132	7	5.3	1989-90	5	146	3.4%	12	9.1%
20-Year Average		**12.8**	**7.2 %**		**3.4 (1.3%)**	**182.6**	**1.8%**	**16.3**	**9.0%**

[A] worst loss in past 20 years.

Appendix 2. Winter notes on habitat conditions during high whooping crane flock mortality taken from unpublished file reports written annually by T. Stehn.

1962-63 winter - 4 birds lost, highest as of that date.

1988-89 winter – 6 losses out of 138 (4.3%), the highest ever recorded as of that date.

The winter was notable for the amount of crane use in upland areas and freshwater ponds. Freshwater sources, mostly dugouts, provided sufficient drinking water for the cranes. Salinities in the salt marsh exceeded 23 ppt for much of the winter. An abundant acorn crop attracted numerous cranes to feed on the uplands. On the refuge, upland use totaled 17.2% of all aerial locations. In November, interior marsh pond salinities ranged between 40 and 52 ppt. Readings in the marshes on Matagorda Island were as high as 70 ppt. Salinity measurements in early December found readings in the GIWW and adjacent bays between 32-35 ppt. These bay levels were extraordinarily high, a result of the continued drought in South Texas and the resultant lack of freshwater inflows from river systems. San Antonio Bay at the refuge picnic area was 26 ppt, the lowest level documented. After heavy rains in January, marsh salinities averaged 19 ppt and the GIWW 23 ppt. The whoopers were observed no longer making flights to fresh water to drink. The lack of rain in February and March raised salinities, measured March 28 at 25 ppt in the GIWW and bays and an average of 33 ppt in the marshes. Cranes at freshwater were first observed on March 18. Such visits continued into April.

Some upland use was documented on 12 out of 22 aerial census flights conducted during the winter. Upland use was observed on all flights between Nov. 21 and March 8. On the refuge, 17.2% of all aerial locations were on uplands. With an excellent acorn crop, the cranes found an abundant food source. The census flight on March 8 noted the lowest tides of the winter. Fifty-six of the 124 cranes were located in the bays, presumably eating clams.

1989-90 winter 5 lost out of 146 (3.4%), second highest losses to date.

The winter was notable for the amount of crane use in upland areas for foraging and freshwater ponds for drinking. Marsh salinities were recorded as high as 46 ppt. An abundant acorn crop attracted numerous cranes to feed on the uplands. Blue crabs were scarce. A news article in mid-September indicated that the 1989 commercial harvest of blue crabs was down 80% compared with the previous year. Wolfberry plants on the refuge appeared stressed in summer, 1989, many without leaves. Cranes were seen at freshwater sources throughout the winter.

There was evidence of avian tuberculosis in subadult captured in 1989 winter, and similar disease in chick that died at Aransas in 1982 winter. Increased levels of oversummering whooping cranes occurred (1 in 1988, same bird again in 1989, 1 in 1991with bird dying during the summer) that could indicate disease issues. Analysis of winter mortality between 1980 and 1990 indicated higher mortality when the marshes are salty and when the cranes utilize uplands more to feed on acorns.

1990-91 winter 11 lost out of 141 (7.8%).

In August,1990 a red tide outbreak occurred in the bay but there was no evidence of a connection with subsequent winter mortality of whooping cranes. Losses were estimated at 3 adults, 3 subadults and 5 juveniles. Most losses (8 out of 11) occurred during a bad weather stretch in late December through early January along an 8-mile stretch of the refuge. Three of the losses involved chicks that had at Aransas separated from their parents. One carcass was found, but the cause of death was not determined.

Lots of upland use and use of freshwater ponds was observed. However, little upland use occurred on Matagorda Island. Lots of acorns were present on refuge uplands. Much upland use occurred through December, but cranes also were observed catching crabs. No crab counts were done. High marsh salinities < 37 ppt were recorded. Marsh salinities were lower during Feb-April with cranes drinking directly from marsh.

1993-94 7 lost out of 143 (4.9%).

Five juveniles and 2 white-plumaged birds were lost. One juvenile had separated from its parents and showed abnormal behavior prior to predation by a bobcat.

Blue crab numbers were down notably compared with the previous winter, but small blue crabs re-populated the marsh starting in late February that the cranes quickly took advantage of. Small crabs through March provided limited food for the cranes. Commercial size blue crabs were so scarce in the spring that crab fishermen removed their traps from Sundown and Dunham bays. Acorn use was low and little clamming was documented. Marsh salinities were somewhat elevated. Wolfberry crop was abundant. Winter weather was generally mild.

This was the second winter of field work by Chavez-Ramirez and crabs were at very low levels and the cranes overall lost energy reserves during much of the winter. Food resources were considered marginal. 37% of the adult pairs failed to nest in the summer of 1994.

Salinities were higher than the previous winter and were measured between 14 and 26 ppt. Summer drought raised salinities measured in the marsh at 23-26 ppt in early October, but bays were around 15 ppt. High October tides flooded the marshes and lowered marsh salinities. Marsh salinities dropped below 19 ppt by early November and stayed below the threshold of 23 ppt throughout the winter when cranes are forced to seek out fresh water to drink. Only occasional use of cranes drinking freshwater at dugouts was documented in December. Salinities that averaged 19-21 ppt in mid-January and 18-19 ppt in February dropped to 14 ppt in March. The winter report written by T. Stehn indicated the lack of blue crabs seemed to be the most significant factor related to crane winter mortality.

2000-01 6 lost out of 180 (3.3%).

Four adults and 2 juveniles died during the winter. Also possibly one subadult died. Only 1 old carcass was found.

Red tide was documented close to crane areas at the end of October.

Food sources were considered poor during the winter. It was a bad blue crab winter for the whooping cranes. Drought the previous spring and summer with lowered inflows had perhaps lowered blue crab production. Blue crabs were never abundant and were believed to make up only a small part of the whooping crane diet. Mike Baldwin walking 3 transects each 1000 meters long found a maximum of 23 crabs over a 3-day period until mid-April when he counted between 30 and 40 crabs per day. Blue crab numbers recorded by Baldwin were the worst since 1997-98, measured at only 0.24 crabs per 100 meters. They were at low levels all winter, but really scarce in mid-winter. Almost no crabs were available in December and January, resulting in more cranes foraging on upland areas. Crabs showed a slight increase in numbers at the end of February and March as tides rose slightly, but crab counts at the end of March indicated only low numbers present. The cranes spent considerable time off of their traditional territories and moved extensively in search of food, foraging in uplands or open bays. The amount of upland use was notable. Cranes were observed in unusual locations including uplands and game feeders, including a San Jose family that came over to Lamar, presumably influenced by feeders. These alternate foods were not as nutritious as blue crab (Nelson 1995).

A most unusual occurrence of 18 whoopers spent considerable time at Willow Creek and an adjacent game feeder. This unusual location was considered related to the lack of blue crab food resources. Wolfberries were available in November and December. Although not quantified, wolfberries were less abundant than in some winters, but still made up a notable part of the whooping crane diet. Use of open bays was observed January through March. Few acorns were available due to a poor mast crop. Refuge burns received heavy use initially, but use tapered off.

For the first half of the winter, salinities were high so that crane use of fresh water sources occurred on a daily basis. March salinities in October were measured at 30-35 ppt. Refuge rainfall totals in November, January and February equaled 12.29 inches and lowered marsh salinities enough so that few cranes were observed at freshwater sources Jan-April, 2001. March salinities during mid-February crab counts averaged 22.6 ppt but ranged between 15 and 46 ppt.

Data shows that when blue crab populations are low, the cranes do not do well. Blue crabs are believed to be the key whooping crane food as shown by Chavez-Ramirez (1996). The highest mortality has occurred in the two winters when the least number of crabs were present (7 died in 1993-94 and 6 in 2000-01).In all other winters 1992-93 to 2000-01, with more blue crabs available, whooping crane mortality was either zero or one. There is a correlation between low blue crab numbers and high whooping crane mortality. This makes sense since blue crabs can make up 90% of the crane diet when available (Chavez-Ramirez 1996).

2005-06 6 lost out of 220 (2.7%).

One adult and 5 juveniles were lost, but no carcasses were recovered. Mortality was higher than average and was correlated with the shortfall of blue crabs.

Wolfberries were available in November and December with a crop rated as excellent. Quality food resources were considered good throughout the fall, but declined into winter and were scarce Jan.-April, 2006. Overall, the winter was rated as fairly poor for blue crab abundance. No spring influx of blue crabs occurred. Drought started in December, 2005 and continued into spring, 2006. Use of clams and invertebrates such as mud shrimp or blood worms in open bay habitat was observed frequently as tides remained low for extended portions of the winter. Some upland use was made of prescribed burns, but acorns were scarce.

Salinities started the winter at 16 ppt as measured on Oct. 20th. That was the lowest reading of the winter. Bay salinities in November and for the rest of the winter were above 20 ppt. Bay and marsh salinities the latter half of the winter remained above 23 ppt forcing the cranes to seek out fresh water.

2008-09 23 lost out of 270 (8.5%).

63 juveniles and 7 adults/subadults died. Three carcasses found; bad knee on an emaciated subadult found still alive at the Boat Ramp; Infectious Bursal Disease isolated from an emaciated juvenile (thought to have been flightless due to its weakened condition) predated by Dunham Bay; scatted piles of white-plumaged feathers found at Upper Pump Canal.

The wolfberry crop was very limited. Blue crabs were present initially, but soon became scarce. The cranes occasionally found blue crabs all winter, but at greatly increased search effort. Low tides drained marshes for part of winter. Considerable open bay use was observed. There was remarkably high use of game feeders, including 21 whoopers on Lamar using feeders and 2 adjacent to Highway 35 north of Holiday Beach. Salinities were high throughout the winter with the cranes making daily use of fresh water to drink.

Appendix 3. Tom Stehn's notes from talk 10-28-04 with Dennis Pridgen, TPWD fisheries biologist, Rockport.

Subject: Timing of inflows to help blue crabs.

Blue crabs show a lot of variability and adapt to a wide range of conditions. Blue crabs eggs hatch, go rapidly through 7 zoeal stages and enter megalopal stages. These early stages are all carried by currents. The megalopae then change into what are commonly known as blue crab stages. The following are general rules for blue crab life cycles.

1. After the eggs hatch, zoeae and megalopal stages of blue crabs need high salinities above 21 ppt for high recruitment. Optimal salinities for egg hatching is 23-30 ppt; optimal salinity for zoeal matemorphisis is 21-28. Survival will be lower if salinities drop below optimal, say less than 15 ppt. Thus, most female crabs move into the Gulf of Mexico to spawn where salinities are conducive to survival and growth of early life stages of crabs. In drought years, spawning could occur in highly saline marshes or bays, with conditions okay for survival of early life stages, but growth of the first blue crab life stage would be low due to the high salinities.

2. After successful development of megalopae, survival of early crab stages is complicated, based on synergistic effects of salinity, temperature, pollutants, predation, disease, habitat and food availability. The first blue crab (2 ½ mm) stage and subsequent stages shows the best abundance and growth when salinities are intermediate (10-20 ppt).

3. During warm temperatures, it takes about 4 months for crabs to grow to reach 5 cm size, an approx. minimum size that cranes can easily consume. Growth rates of blue crabs are greatly reduced during periods of colder temperatures during winter. Crab eggs that hatch during August – October will not have time to allow for enough development and growth to be available for cranes until the following spring (Feb. – April) before the cranes leave for Canada by mid-April.

4. Blue crabs available for whooping cranes in the fall are ones that were generally hatched between April and July, plus older crabs surviving from the previous year. Total crab numbers with individuals ranging in size from the first crab stage (2 1/2 mm) to large adults (7 inches) are generally highest in the fall. The crabs present in the fall provide the food base for the whooping cranes during their entire winter stay, (mid-October through mid-April), although crabs that hatch in late summer would be available in the spring. Crab numbers in the salt marsh vary throughout the winter, depending on tide levels, temperatures, and predation by whooping cranes and other critters. Crabs generally move out into the bays seeking deeper water during the colder temperature and low tide periods from December into February. They will then re-populate the marshes, starting in February or March as tides rise and temperatures increase. The crabs eaten by whooping cranes in March and April generally are survivors from the spawn during the previous April-July period when survival was high due to moderate salinities and high inflows. Note that some of the crabs growing up to breeding size during the summer were carryovers from spawning the previous fall.

5. Inflows between April to July will influence crab survival positively. If inflows are high during this period, the blue crab population will do well. Thus, April to July inflows are very important to the whooping crane food base.

6. Fall rains, including tropical systems in August through October, will generally not add to the whooping crane food supply in the coming winter. However, such fall inflows are important because they lower salinities and

create an intermediate salinity regime in the fall and the following spring, which greatly helps survival of early crab stages (as in # 2 above). If spring salinities are too high, than growth of the first blue crab stages would be low, thus reducing energy available to the cranes.

7. Crabs breed between 6-8 months of the year, with spawning determined by water temperature. In Texas there may be a peak in March and April. As crabs grow larger and reach breeding size, some crabs will be spawning all the way from spring to fall. Females that breed in the fall (late October) can hold their eggs until the next spring. Increased spawning activity is not connected with inflow pulses. A peak of spawning occurs as temperatures warm up in the spring. The length of the spawning season is determined by water temperatures remaining being warm enough, with limited spawning occurring in winter in mild winters.

8. Other bay species such as white shrimp have different life cycles. Thus, this discussion about inflows and crab populations, although in general holds true for other species, varies somewhat depending on the species. For example, August rains would tend to still help white shrimp.

Appendix 4. The relationship between inflows, crabs, salinities, and whooping cranes.

by: Tom Stehn, Whooping Crane Coordinator, U. S. Fish and Wildlife Service, March, 2008

The productivity and quality of coastal waters in winter whooping crane critical habitat at Aransas is directly dependent on freshwater inflows that start hundreds of kilometers inland from the San Antonio / Guadalupe River and flow into coastal waters (TPWD 1998). Flows from springs coming from the Edwards Aquifer are also crucial, especially in times of drought when they can make up 70% of Guadalupe River water. Thus, the ongoing reduction of freshwater inflows due to human population growth is a huge threat to the whooping crane that could lead to its extinction. The survival of one endangered species, the whooping crane, and one candidate species, the Cagle's map turtle, are directly tied to maintenance of sufficient inflows (Mendoza, 2001a).

Whooping Crane Food Needs

Sufficient inflows are required to produce the necessary food for whooping cranes to survive. Inflows that carry nutrients and sediments and maintain proper salinity gradients in the estuary are needed to produce blue crabs that are the primary food for whooping cranes. Chavez-Ramirez (1996) found that when available, blue crabs can make up 80-90% of the diet of whooping cranes. An individual crane can consume up to 80 crabs per day. Studies by Nelson (1995) of whooping crane food items (crabs, clams, wolfberry, acorns) showed that blue crabs were the highest in protein and nutrition for the whoopers. When crabs are not available, whooping cranes will switch to other foods, but because of the poor nutritive value of these alternate foods, the whoopers may actually burn up fat reserves and have a net loss of energy for periods of the winter (Chavez-Ramirez 1996).

Data collected at Aransas National Wildlife refuge indicates a relationship between freshwater inflows on the Guadalupe River, blue crab populations, and whooping crane survival. When inflows are high, blue crab populations increase due to enhanced reproduction and survival, and whooping crane mortality is low. With reduced inflows, crabs do poorly and

whooping crane mortality rises dramatically. This makes sense since blue crabs make up 80-90% of the whooping crane diet. For an eight-year period starting in 1993, intensive surveys were done to roughly estimate the number of blue crabs available to whooping cranes. The winters of 1993-94 and 2000-01 were poor crab years; the remaining six winters all had adequate numbers of blue crabs present. During the two winters with poor crab numbers, seven and six whooping cranes died respectively. In all six other winters, either zero or one whooper died. There is a strong inverse correlation between blue crab abundance and adult whooping crane mortality (Pugesek et al. 2008). In addition, following the poor blue crab winter of 1993-94, 37% of the known adult pairs (17 out of 46) failed to nest following their return to Canada. This was unusual since normally just about all pairs attempt to nest annually. In addition, production was reduced from the pairs that did nest (B. Johns, CWS, personal communication). This was all believed to have resulted from their reduced fat reserves that had not built up sufficiently during the previous winter. Therefore, the very survival of the species is dependent on water management strategies that provide sufficient inflows for the bays to remain productive (Mendoza 2001b).

Whooping Crane Needs for Fresh Water

Inflows which mix with Gulf waters help keep salinity levels moderate. When marsh and bay salinities exceed 23 parts per thousand (ppt), whooping cranes are forced to make daily flights to freshwater to drink (Allen 1952, Hunt 1987). These flights use up energy, reduce time available for foraging or resting, and could make the cranes more vulnerable to predation on the uplands (Tom Stehn, USFWS, Austwell, Texas, pers. comm.). Thus, inflows are crucial in keeping salinity levels below the threshold of 23 ppt in coastal marshes used by whooping cranes.

Status of Guadalupe River flows:

Human consumption of river water in Texas is a growing resource issue as the State's population continues to expand. This is a very worrisome trend since Texas water law reserves water for people but has fewer provisions for wildlife. Leaving sufficient water in the rivers to provide bay inflows is not explicitly designated as a beneficial use of water in Texas water law. National media attention was received in spring 2001 when the Rio Grande River dried up and flows no longer reached the Gulf. This is not the only river in Texas in trouble. So many people are using water from the aquifer and the rivers in central Texas, that the downstream folks and creatures are already seeing what most Texans do not want to acknowledge; that the rivers are already over-appropriated, and absolutely no one is minding the store, when it comes to making sure any fresh water ever makes it to the bays and estuaries (Diane Wassenich, San Marcos River Authority, San Marcos, Texas, pers. comm.).

Inflows on the Guadalupe River are already insufficient and reduced over historic levels leading to increases in mean salinity and decreases in blue crabs. As water development pressures mount, freshwater inflows to the Texas bay systems are being reduced, and blue crab populations are being adversely affected. This could have an alarming impact on whooping cranes. The death of 6 whooping cranes during the 2000-01 winter emphasizes how serious an issue this is.

The Texas Water Development Board (TWDB) data indicate natural droughts already threaten the ecosystem of the Guadalupe Estuary and predict that in less than 50 years withdrawals of surface and ground waters for municipal and industrial growth will leave insufficient inflows to sustain the ecosystem (CWS AND USFWS 2007). Long before ecosystem collapse due to lack of inflows, significant adverse impacts to blue crab populations would occur (Kretzschmar 1990). By 2040, due to anticipated diversions, a predicted decrease of 555,000 acre-feet of gaged inflows (Kretzschamer 1990) in an average year into the crane's winter range is projected to cause an 8% decline in blue crab

populations (Texas Department of Water Resources 1980), but could have a much larger impact in drought years (Norman Johns, National Wildlife Federation, Austin, Texas, pers. comm.). Modeling indicates that if all existing water rights were exercised during a repeat of the 1950-1956 drought, estuary inflows would be reduced by 17% to 43% below current levels and by 36% to 72% below historic levels, depending on the year (Norman Johns, National Wildlife Federation, Austin, TX, pers. comm., in Fitzhugh and Richter, 2004). Additionally, there are pending water right applications for much of the remaining unappropriated water in the Guadalupe.

Upstream reservoir construction and water diversions for agriculture and human use reduce freshwater inflows. Many existing water rights are currently only partially utilized, but greater utilization is expected over time. Water rights continue to be granted on the Guadalupe, and some sections of the river are already over-appropriated. Withdrawals of surface and groundwater for municipal and industrial growth are predicted to leave insufficient inflows to sustain the ecosystem in less than 50 years. Projections indicate the river will be significantly threatened during periods of low flow and could cease to flow into the bay if all currently authorized water-use permits are utilized (National Wildlife Federation 2004).

The San Antonio and Guadalupe Rivers that empty into whooping crane critical habitat are calculated to need 1.24 million acre-feet per year to maintain ecosystem subsistence (TPWD 1998). Yet between 1941-1976, inflows were less than that amount in 14 out of 36 years, making its status already precarious (TDWR1980). In 2002, American Rivers named the Guadalupe on their annual list of the 10 most endangered rivers in the U.S. because of the inflow issue. In a report entitled *Bays in Peril,* a "Danger" ranking was given to San Antonio Bay because drought periods were predicted to increase by 250%, and years with low freshwater pulses in the spring were calculated to increase 26% from naturalized levels (National Wildlife Federation 2004).

Texas Water Development Board data indicate natural droughts already threaten the Guadalupe ecosystem. Without sufficient inflows, wildlife resources, including fish, crabs, and shrimp, all decline. The 1.15 million acre-feet figure is often quoted as an amount needed to maximize harvest of 9 marine species of commercial interest in the bays and estuaries. In the case of blue crabs, more than 1.15 million acre-feet is needed to produce high blue crab populations. TPWD data clearly show that increased water inflows result in higher blue crab numbers (Mendoza 2001b). Crab survival of all life stages increases when salinities are generally below 20 ppt, and the very young stages in the blue crab life cycle show much better survival when salinities are moderate. Blue crabs were found to be more abundant in the Guadalupe Estuary in salinities averaging between 10-25 ppt. A simple inverse relationship exists between blue crabs catch rates and mean salinity within an estuary (Longely 1994). Peak crab counts in the bays occur following periods of flooding. In San Antonio Bay, the 3 highest blue crab harvest years were all having inflows greater than 3 million acre-feet annually. Thus, to maximize blue crabs for whooping cranes to eat, managers should maximize freshwater inflows on the Guadalupe River. Providing for guaranteed minimum inflows to the bay is essential.

Management Actions and Needs:

The San Marcos River Foundation (SMRF) in 2000 applied for a 1.15 million acre-feet water right that would remain in the rivers to provide inflows to the bay. The application was denied in 2003 but an appeal was granted, sending the application back to the Texas Council on Environmental Quality for a re-hearing. This matter remains involved in litigation with the outcome pending. The 1.15 million acre-feet is the recommended target inflow level needed to maintain the unique biological communities of the Guadalupe Estuary (TPWD 1998) and keep the bays productive (TPWD 1998, Mendoza 2001b). Unfortunately, mechanisms to guarantee these flows are not provided by Texas water law, and critics have challenged the size of the target inflows. Water developers are saying that human needs for water

are too great, that there isn't enough water available to provide the water identified by the Texas Parks and Wildlife Department study needed to sustain the bays and estuaries, and this amount of water is higher than that actually needed to keep the bays productive. This issue has received much attention, and support is needed if conservation flows are ever going to be granted. The U.S. Fish and Wildlife Service (USFWS) wrote a letter of support for the San Marcos River Foundation's application for 1.15 million acre-feet of water that would remain in the river for wildlife. USFWS believes that providing a water right to the bays, as proposed by the San Marcos River Foundation, would be a crucial first step in guaranteeing that the bays would continue to function ecologically for all users to enjoy (Mendoza 2001b). It would be precedent setting in Texas for a water right to be designated as an inflow.

With the population of Texas predicted to double in the next 50 years, the Texas legislature has initiated a state-wide water planning effort. However, there is no direct mechanism in Texas water law to secure freshwater inflows to the bays and estuaries. Basically, the bays get whatever is left over, and portions of Texas rivers, including the Guadalupe, are already over-appropriated. In May 2007, the Texas Legislature adopted a sweeping plan intended to help ensure the state's future water supply. The legislation would require basins to develop recommendations to meet instream needs for specified bays and estuaries. The Texas Commission on Environmental Quality (TCEQ) will be required to adopt these recommendations as environmental flow standards and give consideration to water permit applicants based on conservation considerations like water levels, the environment and public need. The measure would establish the Environmental Flows Advisory Group, made up of appointed members, to oversee the process. This action was hailed by some Texas environmental groups. However, the amount of needed freshwater inflows will be determined through a stakeholder process and there is no guarantee how this will all turn out, or how identified instream needs will be met.

USFWS is very concerned about the impacts that planned diversions from the Guadalupe River would have on environmental water needs for adequate inflow to San Antonio Bay. A proposal included in the state water plan proposes a diversion at the mouth of the Guadalupe River, pumping at least 94,500 acre-feet annually back to San Antonio for municipal use. Additionally, as the San Antonio region grows, with population expected to double in the next 50 years (SAWS 2003), pumping from the Edwards Aquifer in times of drought threatens spring flows. To prevent impacts and avoid take of the whooping crane under the Endangered Species Act (ESA), USFWS has urged planners to quantify the freshwater inflow needs to maintain bay productivity and the critical habitat of the whooping crane and to account for those needs in future versions of the State Water Plan (Mendoza 2001a). Formal consultations on flow reductions must ensure that downstream water needs are met (Stehn 1998). The USFWS must take a strong stand on the inflow / whooping crane issue. On the Platte River in Nebraska, a section of designated critical habitat used by whooping cranes in migration, USFWS has determined that any new water withdrawals greater than 25 acre-feet constitutes a jeopardy call to the species under the ESA. Thus, a precedent has been set for USFWS action. All conservation groups need to do all in their power to ensure that adequate inflows from the Guadalupe River reach the bays.

Inflow level targets have not been identified to adequately support whooping cranes. Any withdrawal of water from the San Antonio / Gaudalupe River system is harmful to whooping cranes (T. Stehn, USFWS, Austwell, Texas, pers. comm.) except perhaps in times of flood. Inflow modeling is needed specifically for impacts to blue crab populations. Until this is done, water planners cannot judge how much harm river withdrawals will do to blue crabs and thus whooping cranes.

Measures to protect instream flow, fish and wildlife habitat, and freshwater inflows to bays and estuaries should be part of each regional water management plan (Sansom 2000). It is essential that the Region L water plan provide a mechanism for providing adequate inflows to San Antonio bay for the health and survival of the whooping crane population.

Any environmental analysis for groundwater use should include a detailed assessment of potential impacts to fish and wildlife found in springs, streams, rivers, and even inflows to bays and estuaries. An example of an area of concern is the Edwards Aquifer and the impacts reduced flows would have on the whooping crane found in the San Antonio and Aransas bays (Mendoza 2001a). Especially in times of drought, groundwater-fed springs can provide 70% of the inflow from the Guadalupe River. Comal and San Marcos Springs combined can make up over 30% of the base flow of the Guadalupe River and nearly 70% during periods of drought (Sansom 2000).

Management actions needed are to

a) model inflows and blue crab populations for the Guadalupe Estuary and relate to ecological needs of whooping cranes.
b) devise strategies to conserve blue crabs populations by maintaining required inflows.
c) maintain inflows to keep marsh salinities below 23 ppt. (Stehn pers. comm.)

Literature Cited

Allen, R. P. 1952. The Whooping Crane – Research Reprot # 3 of the National Audubon Society. New York, N.Y. 246 pp.

Blankinship, D. R. 1976. Studies of whooping cranes on the wintering grounds. Pages 197-206 in J. C. Lewis, ed. Proc. International Crane Workshop, Oklahoma State Univ. Press, Stillwater.

Canadian Wildlife Service and U.S. Fish and Wildlife Service. 2007. International recovery plan for the whooping crane. Ottawa: Recovery of Nationally Endangered Wildlife (RENEW), and U.S. Fish and Wildlife Service, Albuquerque, New Mexico. 162 pp.

Chavez-Ramirez 1996. Food availability, Foraging Ecology, and Energetics of Whooping Cranes Wintering in Texas. M.S. thesis. TAMU-College Station.

Hunt, H. 1987. The effects of burning and grazing on habitat use by whooping cranes and sandhill cranes on the Aransas National Wildlife Refuge, Texas. PhD thesis. Texas A & M University. 173 pp.

Hunt, H. E. and R. Slack. 1987. Winter foods of the whooping crane based on stomach content analyses. Pages 217-218, in J. C. Lewis and J. W. Ziewitz, eds. Proc. 1985 Crane Workshop. Platte River Whooping Crane Habitat Maintenance Trust and USFWS, Grand Island, Nebraska.

Kretzschmar, G. E. 1990. Exec. Administrator of TWDB, letter to USFWS, Dec. 5, 1990.

Longley, W. L., ed. 1994. Freshwater inflows to Texas bays and estuaries: ecological relationships and methods for determination of needs. Texas Water Development Board and Texas Parks and Wildl. Dept., Austin, Texas. 386 pp.

Mendoza, C. 2001a. Letter commenting on state water plan. USFWS files, Aransas NWR, Austwell, Texas.

Mendoza, C. 2001b. Letter in August, 2001 supporting SMRF. USFWS files, Aransas NWR, Austwell, Texas.

Pugesek, B. H., M. J. Baldwin, and T. V. Stehn 2008. A low intensity sampling method for assessing blue crab abundance at Aransas National Wildlife Refuge and preliminary results on the relationship of blue crab abundance to whooping crane winter mortality. In Folk, M. J. and S. A. Nesbitt, editors. 2008. Proceedings of the tenth North American crane workshop. North American Crane Working Group, Gambier, Ohio, USA.

Sansom, A. 2000. Letter to TWDB. USFWS files, Aransas NWR, Austwell, Texas.

Sass, R. 2009. The river and the whooping crane: two endangered species. Unpublished report. Natural Sciences Department. Rice University, Houston, Texas, USA.

Stehn, T. 1998. Memo to Allen White, USFWS-Ecological Services. USFWS files, Aransas NWR, Austwell, Texas.

Stevenson, J. 0. and R. E. Griffith. 1946. Winter life of the whooping crane. Condor 48:160-178.

Texas Department of Water Resources (1980) Guadalupe Estuary: a Study of the Influence of Freshwater Inflows. LP-107. Austin, TX. 321 pp.

Texas Parks and Wildlife 1998. Freshwater Inflow Recommendation for the Guadalupe Estuary of Texas. Coastal Studies Technical Report No. 98-1, written by Pulich et. al. 61 pp.

SAGES
San Antonio Guadalupe Estuarine System

Comments on SAGES Final Report

From: Blackburn Carter, P.C.

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June 8, 2009

Via E-Mail: sraabe@sara-tx.org
Steven J. Raabe, P.E.
Administrative Agent for Region L
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Re: Draft SAGES Report San Antonio Guadalupe Estuarine System Linking Freshwater Inflows and Marsh Community Dynamics in San Antonio Bay to Whooping Cranes

Dear Mr. Raabe:

In the following paragraphs, we have presented our comments on the Draft SAGES Whooping Crane Study. As will be noted, we have serious concerns with the method and conclusion of the SAGES Study. We have also included as Attachment 1 some comments and concerns regarding the SAGES report prepared by Dr. Ronald Sass, Harry C. and Olga Keith Wiess, Professor of Natural Sciences, Emeritus, Rice University.

In our opinion, the major problem with the SAGES study is the statistical relationships between salinity and blue crab abundance. The conclusion reached in the SAGES study is contradicted by most of the literature on Blue Crabs and by an analysis of long term data collected in San Antonio Bay. The faulty conclusions likely arise from an inadequate understanding of life history requirements of the crabs and poor study design. The direct result of these flawed relationships is that the greater the freshwater inflow, the worse off the Blue Crabs and thus the less food for Whooping Cranes and the opposite that increased freshwater inflow is detrimental to Whooping Cranes. This finding is strongly contradicted by a review of recent and longer term responses of the Whooping Crane population to low flows.

Longley (1994) cites over a dozen studies (p. 187-188) and concluded that higher catch rates are observed from lower salinity areas. (p. 137) Specifically for San Antonio Bay he found that "juvenile blue crabs are generally most abundant in vegetated habitats in the lower and middle bay where salinities range from 6 to 25 ppt" Trawl samples show significantly higher catches both in areas with mean salinities of less than 20 ppt and in areas influenced by the Guadalupe River flow." (p. 151 -152) While the Longley report recognized that Blue Crabs utilize different salinity zones throughout their different life stages (an issue for which the SAGES study is silent) they also found that "adult males are found in low salinity waters, where

salinities are less than 10 ppt, while females move to these lower salinity areas to mate and return to higher salinity areas afterward." (p 174)

The most recent freshwater inflow study conducted in San Antonio Bay (Pulich et al 1998) analyzed TPWD fisheries independent monitoring data and found the preferred salinity zone for Blue Crab to be between 5-20 ppt. This range is consistent with the more recent Matagorda Bay Health Evaluation (BioWest 2008) which reported similar ranges as optimal for Blue Crab. This finding is further supported in the Gulf State Regional Management Plan for the Blue Crab Fishery (Guillory et al 2003) which reported summaries for other studies that report similar preferences for lower and mid range salinities (p. 3-5)

The SAGES study cites a single laboratory study evaluating the effect of salinity on juvenile blue crab growth (Cadmen and Weinstein 1988). According to the authors of the SAGES report, one of the findings in Cadmen and Weinstein is that for "salinities below 27 ppt, blue crabs incur increasing high metabolic demands and osmoregulatory stress with decreasing salinity." Notably the abstract for that paper states that optimal growth occurs at 23 ppt though this finding is not presented in the SAGES report. This study also finds that crabs do most poorly at low salinity and high temperature though the authors of SAGES do not cite any other quantitative findings from Cadmen and Weinstein to specify at what low salinity levels these deleterious effects are manifested nor whether similar harmful effects occur at higher salinities.. While most studies on Blue Crabs and salinity acknowledge that very low salinities (< 1.0PPT in Holland et al 1971 cited in Longley, 1994) are detrimental to Blue Crab none that we've reviewed suggest that Blue Crabs only benefit from saltier conditions as is presented in the SAGES report.

So where did the SAGES report go wrong? It would be difficult to say without carefully reviewing their data, however here are a few ideas. First they do not acknowledge and therefore do not refute the long list of studies which result in relationships that contradict the one present in the SAGES report. While they include Guillory 2003 in their references, they don't mention any of the studies that he cites that suggest lower optimal salinity ranges. This leads us to suggest that they did not do a very thorough review of the literature. To completely ignore such an obviously controversial issue is perplexing.

It appears to us that life stage is an important factor in understanding the effect of salinity. One theme that seems common is the younger and smaller crabs may have a greater affinity to higher salinities. This is obviously true of the larval stages since they spawn off shore as high salinities are required for early life stages. The SAGES report acknowledges that the samples used to develop the regressions were smaller sub-adults as opposed to the sizes that Whooping Cranes eat, but they suggest that these sub-adults provide a good estimate of recruitment into the size classes consumed by cranes. An alternative hypothesis might be that these higher salinities might lead to lower recruitment into the larger class than would be achieved by salinities reflective of more accepted description of adult blue crab salinity preferences.

The main problem with this study has to do with design. Although samples were taken monthly, only about two and one half years worth of data where collected. In the second year, inflows were very low and salinities much higher than normal. The highest densities were observed in the fall of 2006 during the period of highest salinities, which leads to the conclusion that higher salinities lead to more blue crabs. This two years worth of data really represents only two data points corresponding to two seasons during which crabs migrated into the bay. This is insufficient to develop the regressions presented in this study and overturn without even acknowledging the overwhelming contradictory finding of most other studiues. Data for the periods when most crabs are off shore spawning and drifting in as juveniles are not particularly relevant to this analysis.

Other issues

The inflow salinity regressions would probably be improved by the inclusion of an antecedent flow term. After conducting the first inflow study on San Antonio Bay (Pulich 1998) the state agencies recognized this and included a term to account for inflows in the days 30-60 prior to the current day for the inflow studies on all of the other major bays in Texas. An antecedent salinity term would be even better. The "noise" about the regression equation covers about 10 ppt and thus simulated salinities do not do as good a job of predicting salinity as they could. Use of the existing salinity model for San Antonio Bay perhaps recalibrated and validated using some of the data collected in the present study would be even better.

The salinity regressions fall apart at flows less than about 600 cfs. At low flows they predict salinities that were deemed by the project team as unreasonably high and thus salinities are always cut off at 30 ppt if they predict higher than that. Sustained flows less than 600 cfs are rare in San Antonio Bay however the regressions are not useful predictors for droughts or potential future low flow scenarios predicted to result from increased diversions.

The study acknowledges that they were unable to develop a complete understanding or connectivity between the bay and the marsh and instead simply note that there is a correlation between salinities in the two areas. This is unfortunate and it would seem that a more carefully designed study could have made more progress on this critical issue.

It is unclear why the analysis focused on smaller sub-adult crabs in the marsh. It is possible that the larger adults had selected more desirable (lower) salinity conditions for mating especially in 2006 and thus insufficient numbers were collected to develop relationships for this age class.

Although not a prominent discussion in the written report, much was made of the ability of Whooping Cranes to switch from Blue Crabs to Clams or other sources when crabs are scarce. While this may happen it is not clear that these alternatives will provide satisfactory nutrition.

As a final note we mention that we have not had time to give the energy budget analysis the attention it needs but at the very least it is woefully simplistic and begs for a careful evaluation.

Thank you for the opportunity to present these comments on this very important issue.

Sincerely,

BLACKBURN CARTER, P.C.

by_____
James B. Blackburn, Jr.

Attachment

REFERENCES

BIO-WEST. 2007. Final Report Matagorda Bay Health Evaluation Habitat Assessment. Technical report prepared for the Lower Colorado River Authority and San Antonio Water System.

Cadman, L. R. and M. P. Weinstein. 1988. Effects of temperature and salinity on the growth of laboratory-reared juvenile blue crabs Callinectes sapidus Rathbun. Journal of Experimental Marine Biology and Ecology 121:193-207.

Guillory, V., H. Perry, P. Steele, T. Wagner, W. Keithly, B. Pellegrin, J. Peterson, T. Floyd, B. Buckson, L. Hartman, E. Holder, and C. Moss. 2001. The blue crab fishery of the Gulf of Mexico, United States: A regional management plan. Gulf States Marine Fisheries Commission. Ocean Springs, MS.

Longley, W.L. 1994. Freshwater inflows to Texas bays and estuaries: ecological relationships and methods for determination of needs. Texas Water Development Board and Texas Parks and Wildlife Department, Austin. 386 pp. Matsumoto, J., 1992. Users Manual for The Texas Water Development Board's Circulation and Salinity Model: TxBLEND. Texas Water Development Board.

Pulich, Jr., W., W.Y. Lee, C. Loeffler, P. Eldridge, J. Hinson, M. Minto, and D. German. 1998. Freshwater inflow recommendation for the Guadalupe Estuary of Texas. Coastal Studies Technical Report No. 98-1. Texas Parks and Wildlife, Austin, Tx. 100pp.

To: Whom it may concern

From: Ronald Sass, Harry C. and Olga Keith Wiess Professor of Natural Sciences, Emeritus, Rice University

Date: 7 June 2009.

Re: Some comments and concerns regarding the SAGES Final Report "Linking Freshwater Inflows and Marsh Community Dynamics on San Antonio Bay to Whooping Cranes"

The SAGES or San Antonio Guadalupe Estuarine System project was conducted from 2002 to 2009, although actual field data did not begin for most studies until 2004 and was ended in 2006. The studies thus spanned two winters of whooping crane residence.

The study was composed of 12 core studies, 2 complementary SAGES studies and 3 non-SAGES studies. Both empirical field studies and model calculations were performed.

Some results from the empirical studies:

1. A clear effect of river inflows on the greater bay ecosystem. Freshwater inflows to the bay tended to flow in a southwest direction along Blackjack Peninsula and along the estuarine marshes at ANWR.
2. Freshwater inflow was inversely correlated with bay salinity.
3. Patterns of salinity in San Antonio Bay strongly correlated with salinities in the tidal creeks of Blackjack Peninsula and therefore bay salinity can be used as an indicator of marsh salinity.
4. Salinity leading up to the late summer leafing period was inversely correlated with peak wolfberry abundance.
5. At the ecosystem level, blue crab abundance was significantly correlated with bay water level, wind speed as measured in the bay, and bay salinity.
6. In addition to blue crabs and wolfberries, the whooping crane diet including snails, insects, snakes, fish and clams.

7. The whooping cranes spend approximately 65% of daylight hours foraging.

Conclusions derived from model considerations predicted:

1. The available food supply appears to be more than adequate to meet the energy needs of the whooping crane. None of the results of the study show that conditions at Blackjack Peninsula are marginal for whooping crane well-being.
2. Bay salinity is higher when freshwater inflows are low.
3. Wolfberry abundance is lower when bay salinity is high.
4. Consistent with prior studies, blue crab abundance increases with bay salinity.

Comments:

Many of the report's empirical findings and model predictions are consistent with results reported in extant journal papers and organizational documents as well as with prevailing opinion. Others are in serious disagreement with well-established previous findings. Rather than review all of the SAGES report, I will concentrate on what I consider to be the most important in terms of whooping crane survival and well-being.

The relationship between river inflow and bay salinity is of key importance in defining the link between freshwater inflows and the well being of the whooping crane. Therefore it should be very carefully measured and modeled. The experimental relationship between salinity at GBRA 1 and the 28-day cumulative discharge (m^3/day) is shown in Figure 3.4. Although the authors indicate that salinity at this site is influenced by other variables such as wind, tide, direct precipitation, local runoff, etc., the model relationship used depended only on an empirical model based on the data in Figure 3.4. One striking feature of this figure is the observed widely varying salinity for the lowest measured discharges. The very lowest flow values show a measured salinity of 10 – 18 ppt. This range of salinities is not optimal (3 – 15 ppt) for the juvenile or adult blue crab, but is not particularly harmful to either blue crab or whooping crane and may be

referred to as being in the moderate range. Documented events when the measured salinity in the marshes and bay are much higher (Tom Stehn, 2009) have resulted in high mortality within the whooping crane population.

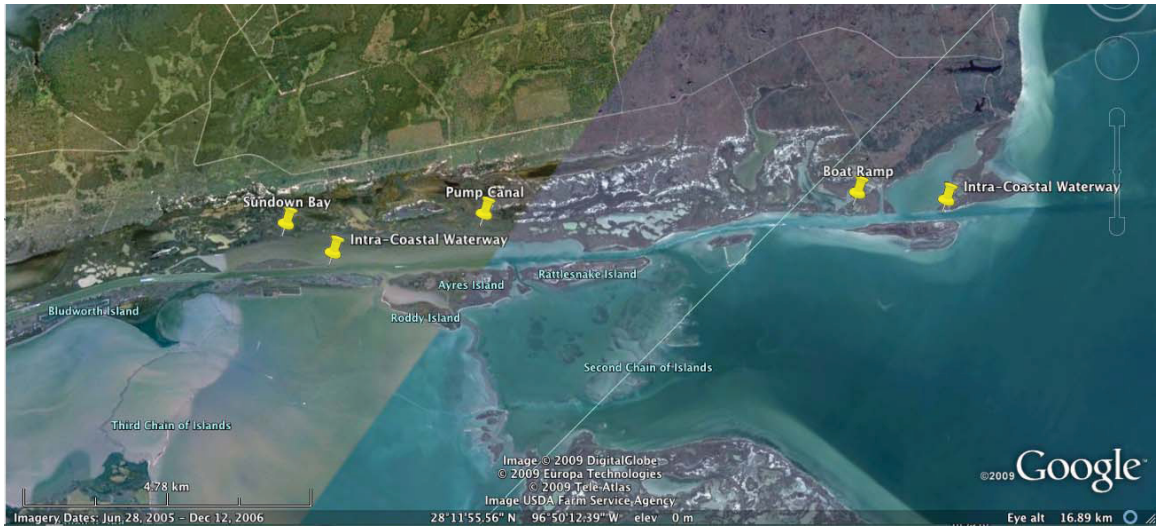
The outer tale of the data (> 10^9) is due primarily to heavy rains in late November 2004 and in July and August of 2007. These periods of high inflow are periods of high flushing of the bay system and should result in salinities near zero as shown. However, this fact truncates the majority of the data to the first third of the graph where the distribution of measured salinities is very broad for a particular inflow value, resulting in an uncertainty in salinity of at least ± 5 ppt. It is obvious from the data that there is either a low dispersion of the river water at low flow or there is a large effect of wind, tides, precipitation, etc. on the measured salinity. Thus, the use of GBRA 1 as a measure of the overall bay system salinity at any particular time is highly suspect. In my opinion, this condition invalidates a major equation in the model as well as any experimental observations relying on these data as a source of salinity values. Thus, equation 1 of the model is overly simplistic and does not take into consideration all of the important variables (*e.g.*, wind velocity and direction, tides) in calculating salinity. The authors recognize this problem by reporting a very large calculated individual prediction interval (dotted red line on Figure 3.4).

Figures 3.5 and 3.6 show the relationship between salinities at GBRA 1 and the tidal creeks associated with the three major experimental whooping crane territory sites. Figure 3.5 is based on data collected during the period from 24 Feb 2004 to Feb 25 2005. The monthly average freshwater inflow during this period ranged from 2,192 cu ft/sec (March 2004) to a high of 23,414 cu ft/sec during November 2004. All salinities shown in both figures fall below 25 ppt with a prediction interval of ±7 ppt.

A more revealing correlation between the three experimental sites and GBRA 1 is shown in figure 3.6. The correlation is qualitatively reasonable but differs in many important aspects of timing. In May 2004 the GBRA 1 salinity drops from ~15 ppt to ~5 - 10 ppt a good month before the salinity in each of the three sites drops from ~15 ppt to

a lower value approaching 0 ppt salinity. Several other time lags are obvious indicating that there is a time lag as well as a current difference between GBRA 1 and the experimental sites. .

Figure 3.6 shows a great deal of similarity in the magnitude and time change of salinity among the three experimental sites. This is probably to be expected because of the positions of the sites (Figure 1, this report). All three sites are along the intra coastal water way and are protected from the main body of water in the bay by a narrow island chain. This would suggest that changes in the water (salinity, turbidity, flow) might be slower than in the main flow stream moving from the freshwater input down the bay to the gulf.



At no time did the salinity rise above 25 ppt and was below 5ppt approximately half of the time. River inflow value did not fall below 1.58-million ac ft/yr during this measurement period. Legislative mandated studies to determine freshwater inflows necessary to conserve healthy productivity of San Antonio Bay recommends 1.15 million ac ft/yr or roughly half of the average annual freshwater inflow from the Guadalupe and San Antonio Rivers. Texas Parks and Wildlife Department data suggests that a water inflow greater than 1.3 million acre-feet annually results in low enough salinities in the estuary to produce a healthy number of blue crabs. A level of flow this abundant produces a bay salinity of from 10 to 25 ppt.

Quoting from SAGES: "*3.3.1.2 Evaluation of equations predicting peak wolfberry density and blue crab density*

We first evaluated our [ ] daily blue crab density (Eq. 3) equations by assessing the reasonableness of predictions of these equations calculated from time-series data on freshwater inflow to San Antonio Bay from the Guadalupe and the San Antonio Rivers (used to predict salinities via Eq. 1) and water level and wind…"

Equation 3 is

$$BCi,j,t = e\ (0.3751 + b1i + b2j + 1.844(wlt) + 0.1010(Salt) - 0.2597(wst))$$

where b is a habitat and site parameter, wlt is water level, salt is salinity and wst is wind speed. The report does not evaluate the relative sensitivity of the crab density with respect to the several variables used. The model is evaluated by comparison of the observed blue crab density with that calculated. The crab density calculated is for juveniles of carapace size 11 to 30 mm. This size choice is a bit troubling because the preferred dietary size for the whooping crane is that of larger crabs. Be that as it may, the study by Danielle Greer on "Patterns in blue crab abundance in shallow salt-marsh and bay habitats of the Texas Gulf Coast is concerned not so much on salinity, but rather habitat type.

Her main objectives were as follows:

1. Document spatio-temporal patterns in blue crab abundance and size-class structure within and adjacent to salt marsh at both fine and large spatial scales.

2. Investigate the effects of environmental (e.g., freshwater discharge, water temperature, vegetative cover) and random effects on blue crab abundance and size-class structure.

Her data show clear differences in the crab density that is habitat dependent and it seem evident that the work is well done and valid. Her density results by the month are interesting in that they cover the period from October 2004 to March 2006, all

months for which the freshwater inflow was higher than recommended by Texas Parks and Wildlife as stated above. Thus, it may be postulated that salinity is not a major factor in the data but rather habitat type is the dominant variable. Whether this statement is true or false was not shown by any part of the SAGES report and needs to be clarified before any statement can be made about the effects of salinity on either blue crab density or whooping crane dietary viability. What the data do show is a peak crab density in all habitats in September and October of 2005 or immediately prior to the arrival of the whooping crane followed by a steady decline until February and March 2006 (the last data points) before the spring migration of the whooping crane. In other words much of the detail may be due to the whooping crane, a variable that is not included in the model!

Summary:

As in the case of all semi-empirical model, relationships are forced by the data even though the full impact of the underlying parameters is not completely understood. Preconceptions of which parameters are the most important and which may be ignored have lead to some erroneous conclusions. The most serious of these is the dependence of the vitality of the whooping crane on river inflow caused changes in salinity. Several studies have, in the past, strongly supported the negative dependence of blue crab population density with salinity. In addition, it is strongly suggested by other data that the years of high winter mortality are all years of low river flow during July to October before the arrival of the whooping crane. This would indicate that low river flow is affecting the growth of the necessary dietary components of the crane. Spanning the observational period of the SAGES study, river inflow was high during the critical time of 2004-05 while winter mortality of the whooping crane was low (0.9%) but during the same time period in 2005-06 river inflow was low but the whooping crane mortality was high (2.7%). This same pattern has been noted between the years 1988 to 2009 resulting in the following conclusions:

1. A high mortality rate is always accompanied by a low river flow and the resulting high salinity.

2. A whooping crane response to low river flow (high salinity) is one of excess stress. This condition does not necessarily lead to death but may be manifested as lack of sufficient bodily fat and protein that will be exhibited during the spring migration and subsequent poor reproductive behavior. For example, following the poor blue crab winter of 1993-94, 37% of the known adult pairs (17 out of 46) failed to nest following their return to Canada. This was unusual since normally just about all pairs attempt to nest annually.

3. Complete and accurate data on environmental stress that is manifested by poor migratory and reproductive behavior is hard to generate but may well be a major part of the story on salinity-diet relationships. Such behavior could include the need for frequent stops along the way for "refueling" and rest, inability to gain optimal flying altitude or flying speed, susceptibility to parasites and disease, high predatory mortality during migration and poor reproductive results after migration.

Conclusions:

The SAGES report has many good qualities such as those studies relating the habitat dependence of blue crab density and the density of wolfberries on environmental parameters. I believe on the other hand, there are sufficient inconsistencies between the proposed model and the details of the various experimental observations, as pointed out above, to put the model into serious doubt. There are better models relating freshwater inflow to bay salinity. These may be adapted to give a greater degree of confidence to salinity predictions throughout the bay system and more meaningful correlations among the various data sets collected. In addition, although the work done at the three or four experimental sites are correctly done, it would be more useful in the overall picture of the bay system to expand to sites that are basically different from one another. We have no guarantee that the whole bay system responds to environmental forces in the same manner as

does those areas adjacent to the intra coastal water way and sheltered by the chain of adjacent islands.

Comments on SAGES Final Report

From: Platte River Whooping Crane Trust

Platte River Whooping Crane
MAINTENANCE TRUST, INC.

5 June 2009

To: Whom it May Concern:

From: Felipe Chavez-Ramirez and Platte River Whooping Crane Maintenance Staff

Following are some comments and concerns regarding the Sages Final Report "Linking Freshwater Inflows and Marsh Community Dynamics in San Antonio Bay to Whooping Cranes" The comments are only based on the material that begins on page 1. The specific projects in the appendix were considered in relation to the report but will not be commented on here individually as most of them have been synthesized so much it is difficult to evaluate all the details of most of those studies.

P. 9-10
The model does not include any factors that could also affect the abundance and availability of food resources, such as competitors. The salt marshes in Aransas support many wading birds and other animals that eat crabs, for example. The second model does not include demographic aspects although there was a project designed to look at this aspect and incorporated into the overall model. Energetic budgets, had they been developed, could have been related to survival and potential reproduction of the species.
The conceptual model is not 100% consistent with mathematical models presented later on.

P. 11
Considering the title and objectives outlined in this report, it seems that Table 2.2 that present summaries of empirical studies, should have a column similar to "Findings in a nutshell" perhaps named "links or relevance to whooping cranes". Some of the findings in a nutshell (water quality, hydrological connectivity, nutrient levels etc), are never incorporated into the model or considered in any way in this report.

Regarding the summary table of projects it is not clear why complementary projects were included or what the importance of them is. Some do not appear to be related to the overall model or specific objectives of the report.

P. 22.
Stated Objectives of the report are:

1. Quantify patterns of habitat use by whooping cranes in relation to changes in human-induced disturbances at ANWR,
2. Evaluate relationships among water temperature, water salinity, water depth, other physical factors, and blue crab abundance in salt-marsh habitats of ANWR,
3. Determine changes in whooping crane foraging behavior and capture rates in

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relation to abundance of blue crab and wolfberry fruit,
4. Quantify macrophytic responses in saltwater marshes to intra- and inter-annual variability in freshwater inflows, salinity, and inundation,
5. Develop a simulation model relating freshwater inflows feeding San Antonio Bay to wolfberry fruit abundance and the availability of blue crabs to whooping cranes in saltwater marshes of ANWR.

Objective 1. There is no presentation of habitat use patterns anywhere in the report. While it may have been done as part of one of the studies it does not seem to be treated anywhere in the document. The information presented in regards to habitat use deals more with behavior changes than changes in habitat use patterns.

Objective 2 appears to be missing wolfberries in addition to crabs, as an item of study.

Objective 3 is not actually accomplished as written. Whooping crane foraging is not explicitly related to abundance of blue crabs or wolf berry per se in this report. It appears that differences in crab abundances between years, is what is considered to fulfill this objective.

It is not clear how objective 4 is included in the simulation model.

Objective 5 would be more accurate if it said "abundance" rather than "availability" of blue crabs. Availability was never actually measured or presented anywhere in this report.

P. 26.
Figure 3.1 is not identical to figure 2.1 as stated in the legend of figure 3.1.

P. 28.
From report: "Based on ecologically-interpretable empirical relationships among the regional environmental factors and the salt marsh components, we parameterized a simulation model that predicts whooping crane energy balance as a function of the interaction of freshwater inflows, bay water level and wind (Figure 3.3)."

Comment:
The model as presented does not really estimate energy balance, as energy expenditure versus input is not considered explicitly, rather an estimate of the abundance and energy content of food resource items in the theoretical territories is what is really estimated by the model presented.

P. 29
Figure 3.3 suggests that wind influences wolfberry, but wind is not considered in the model for wolfberries, only the one for blue crabs.

P. 30 and 31
Despite discussions regarding factors that influence salinities, the equation presented only includes freshwater inflows. On the marsh itself, some factors that may be very important for affecting salinity

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levels at that scale are not considered at all, such as precipitation and evaporation. These factors, it is likely, would have less influence on salinity levels at the bay wide scale which is where the salinity values used in the model are obtained from. It is not clear why bay salinity is the variable used in this model instead of salinities within the actual whooping crane territories? We know through empirical observations that salinities can be very different in crane marshes versus those in bays during the same time period.

P. 33
In Equation 3a for blue crabs, temperature is ignored. Apparently this is because temperature data could not be fitted to the large crabs (according to appendix data). In addition these equations are based on small crabs which are reported elsewhere (in appendix) as not being whooping crane food items. The best model on page 117 includes water temperature.
If small crabs are going to be the basis of the model on the assumption that they will grow to a size suitable for cranes at a rate of 14 mm per month, then this variable should be included in the equation to account for growth. It is not, however, even though that is the assumption explained in the text. It would be more realistic to include estimates of crab abundance and availability based on size actually taken by whooping cranes.
The equations also do not appear to account for monthly differences in density or energy of crabs even though the empirical data presented elsewhere in the report shows that it fluctuates up and down over the winter period. Perhaps it was considered, but the report does not represent any of this in an explicit way.

P. 37
The wolfberry equation does not include factors (e.g., precipitation, temperature, wind, inundation regime, soil porewater salinity), that later on are mentioned as important variables for wolfberry. For example, on p. 38, a series of factors are considered to affect wolfberry however, none of these variables are included in the equation regarding wolfberry production.

P. 40
The legend of Figure 3.7 explains that increases in wolfberry densities were due to increases in number of wolfberry plants present (not sure where this data is as the empirical study in appendix does not report density of plants). If this is true, then there must be an upper limit of how many wolfberries you can have per meter square which should be based on the number of plants present in that meter square. It is not clear that plant density was considered in the model as only berries per meter square are presented. It is also not clear whether berries per meter square is all berries or only red ripe berries. Whooping cranes do not regularly consume the green berries.

The above information, in addition to that information on pages 48 onward, shows that in two of the territories wolfberry is not really abundant. Table 3.3A shows that in some years the peak wolfberry abundance is 0.87 berries/m square. I cannot imagine how a crane can get enough to eat in a territory that has 0.87 berries per meter square if they are consuming 100% wolfberries during those peaks as suggested by one of the empirical studies. Some of the material in the appendices reports that whooping crane feed almost exclusively on wolfberries 100% of one month of one year (after peak). If we use the approx 5 berries captured per minute reported in the appendix, and 65% of time spent foraging (39 minutes/hr), as reported in another section of the report, that comes to 195 berries per hour. The crane will need to forage 9.2 hours to fulfill its 465 kcal (which is based on 5 kg captive bird and should actually be more like 7 kg

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based on wild bird weights) required by the model. However, if the peak density is 0.87 berries per meter square there is no more than one wolfberry every 10 m (0.87 berries/m square). Which means the cranes will have to travel at least 1,950 meters every hour for the 9 hours which totals 17,550 mts. It is unreasonable to assume that a crane travels 17,550 m in a day. This is not what has been observed in the field. So with minimum peak densities ranging from 0.01-0.87 (Tables 3.5A and B) it is inconceivable and unrealistic that the crane can act in a way the model expects it to do so to acquire enough energy in those years when peak wolfberry densities are so low. There are even lower values for wolfberry density (0.01, 0.06, 0.23, etc.) presented in tables. Obviously, regardless of potential disagreements as to how much a crane can move in one day while foraging, the only way to know if a real whooping crane is spending 100% of its foraging time on wolfberries during a day is to use the habitat use patterns data which is one of the stated objectives of this project. However, there is no habitat use pattern information presented anywhere despite being and objective of this study. Field observations that were conducted could also provide information on how much distance is covered by a real whooping crane in the field which would help check how realistic or unrealistic the model assumptions are.

Considering that salinities were not allowed to go above 30ppt and the model still estimated very low wolfberry densities at some points, it is possible there would be even less wolfberries if the salinities were allowed to have been estimated above 30ppt in marsh territories.

P. 39

I am not sure how the salinity levels at GBRA1 can be considered as similar or reflective of crane marsh areas (territories). It is a good measure of what is happening in the bay itself but we do not remember ever having seen salinities higher than 35ppt in the bays relative to the marsh where salinities can exceed 35ppt on a regular basis. In addition, salinities vary in different ponds in the marsh, so it's unreasonable to assume that salinity in the bay is equal and homogeneous in the marsh itself.

P.42.

section 3.2.3

From report: "We selected a model (Eq. 3) that predicted crab density relatively well at the ecosystem level (Pearson product-moment correlation factor, rave, = 0.792) for small crabs (11 to30mm carapace width). Although this size class is slightly smaller than what whooping cranes eat, given the rapid growth of crabs (14 mm/month [Adkins, 1972]), we assumed that it provided a good estimate of recruitment into the size classes consumed by cranes."

Comments

The above statement makes some significant and unrealistic assumptions and ignores some important points:

- Abundance (or density) of prey is not equal to availability for most species in complex environments. Abundance is what is present, while availability is what the animal has access to which is rarely 100%.
- A large proportion of small blue crabs can be removed before they grow by many other species (wading birds, fish, raccoons, hogs, etc.) present in the salt marsh, so it is unrealistic to assume that all small crabs become crabs of the size cranes would eat.

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- Blue crabs could be buried due to low temperatures, maki ng them less available which is ignored in the model equation.
- There is no measure of variability in the information presented, abundance is reported per year versus by day, week, or month, (although some tables refer to days of energy deficit)
- Crabs less than 30mm were not observed to be eaten by whooping cranes in the empirical studies presented in this report (and many other observations), yet that size class is the basis to assume cranes have more than enough to eat. If recruitment was as high as assumed in the statement above, then all the crabs that were trapped would not be less than 30 mm in size all winter long.
-
- The equation does not include temperature even though it is widely recognized that temperature is highly influential on crab growth. If the assumption is that the small crabs will grow to the size eaten by cranes, then temperature effects on growth should be considered rather than assuming equal growth all winter regardless of temperature. You would also have to consider what proportion of the estimated crabs that are 11-30 mm reach the size classes suitable for cranes.

From the report: "Crabs may be influenced by water level for several reasons, which led us to assume that more crabs would usually be found in deep water rather than in shallow water. Crabs may select deeper water to avoid predation from foraging wading birds or other terrestrial or aerial predators…"

Comment
It is not clear what "deep water rather than shallow water" means here. The statement is likely to be true for crab abundance. However, beyond a certain depth blue crabs will no longer be available because cranes can either not see them or reach them. So even if we assume that deeper water has more crabs it does not mean they are available for cranes. Cranes may avoid depths greater than 80 cm to 1 m. While it is recognized that higher water level may limit predation by birds and other non-aquatic organisms, the issue that is ignored is that higher water levels may increase predation by aquatic organisms (fish, larger crabs, etc.). There is also a discussion regarding the effects of higher water buffering the effects of high or low temperatures, despite the fact that temperature is not even a variable in the equation. If the statements in the report are true, then what is the actual effect on temperature of higher water levels, what are those temperature differences, and what is the effect of temperature on variables estimated or assumed here such as crab density, crab growth and crane foraging activity.

P. 43.
From the report: "We assumed that wind speed was a proxy for water turbidity. Our original assumption was that increasing mechanisms for turbulence (e.g., wind) would increase water turbidity and subsequently increase concealment (or survival) of blue crabs in the water column (see Minello et al. 1987). In Eq. 3, crab density decreased with increasing turbidity. This indicates that crabs may be more dependent on other variables regulating

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concealment or predation risk. For instance, they may be more tied to pond edges, soft bottom substrate, high structural complexity in the water column, and/or shallow water depths than we originally assumed."

Comment

Concealment of blue crabs because of turbidity may change visual detection by cranes or other birds, as noted, and therefore availability. Water turbidity alone should not change actual crab density (which is what is reported in model results). However, it could change availability, but availability is not a factor actually estimated in this model despite references to potential crab concealment under variable conditions of wind, etc. The assumption, that crab density changes with turbidity is unrealistic, rather what changes with decreased visibility is the possibility of being eaten by a visual predator such as the whooping crane. However, changes in availability or predation risk are not included in the model.

P. 45.

From the report "We calculated an index of whooping crane energy balance within each territory (i) at time t (EBi,t) based on our estimates of numbers of wolfberries and blue crabs (TWBi,t and TBCi,t). We calculated the metabolizable energy (kcal) contained in TWBi,t (METWBi,t) and TBCi,t (METBCi,t) as: METWBi,t = TWBi,t * wtWB * GEWB * MECWB (4) METBCi,t = TBCi,t * wtBC * GEBC * MECBC (5) where wtWB and wtBC represent the weight of wolfberries (0.44 g each, Chavez-Ramirez 1996) and blue crabs (between 11 and 30 mm carapace width, 0.939 g each, Greer, in progress), and GEWB and GEBC represent the gross energy content of wolfberries (1.214 kcal / g) and blue crabs (0.785 kcal / g), and MECWB and MECBC represent the metabolizable energy coefficient of wolfberries (0.438) and blue crabs (0.355), all as reported by Nelson et al. (1996). We then calculated EBi,t as: EBi,t = (METWBi,t + METBCi,t) / (DER * NCi,t) (6) where DER represents the daily energy requirement of a free-living 5 kg whooping crane (465 kcal, Nelson et al., 1996) and NCi, t represents the number of cranes occupying territory i at time t. Thus, EBi, t > 1.0 indicates a positive energy balance and EBi, t < 1.0 a negative energy balance for the cranes in territory i at time t."

Comment

There are several flawed assumptions in the above statement as described below.

This energetic model is based on daily energy requirement of cranes, it is not considering actual energy intake. Therefore, what is estimated in this model cannot be called energy balance. This model assumes that cranes automatically consume all they need every day. Assuming equal energy requirements everyday is a flawed assumption. Also basing the static daily energy requirements is likely underestimated as it is based on the weight of birds in captivity and wild birds have been recorded up to 2 kg heavier than the 5 kg used for the estimates here.

As mentioned above, food abundance is not equal to availability, therefore it should not be assumed that all cranes get their fill every day automatically just because it was estimated that there was enough food in the environment. Food consumption was estimated in a part of this project but that information is not used to determine actual food intake rates. It would have been much more realistic to have used actual food intake and energy intake rather than just assume that energy requirements are met 100% of the time if the abundance is present somewhere in the territory. When you consider that cranes in general do not visit every square meter of their territory every single day it is illogical to assume that because there is enough energy in the territory for a crane to fulfill its daily needs it actually does. Most cranes only use a portion

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of their territory during any particular day. Since some of the empirical studies were supposed to have looked at movements throughout their territories, why was this data not used to look at the proportion of territory used by the cranes per day? The food in the portion of territory used during a day would then be the potential energy available to the crane not the food in the entire territory as the model assumes. It appears that no crane activity patterns were considered despite having observed cranes. Determining how much a crane moved in one day (the distance travelled in different habitats would dictate how much area of marsh and open water it was exposed to) would give us a better idea of how much actual food they could potentially access in their foraging activities during a day. It is unrealistic to assume that 100% of food in a territory is available to the cranes every single day, especially when there appears to be no depletion rates considered at any point in time in the model.

The weight of whooping cranes used here of 5kg is based on the one used by Nelson which is for captive whooping cranes. The weight for wild birds is known to be better represented at 7kg. Wild adult whooping cranes (unknown sex) have been weighed at 7.14 – 7.85 kg during the fall in Minnesota (Roberts 1932). Estimates of energy requirements would be greater using a bird that was 2 kg heavier than that used in the model here.

P. 45
From the report: "Our primary concern was that we neither overestimate abundance of crane food resources (specifically, wolfberries and blue crabs) nor underestimate crane energy requirements at the territory level."

Comment
It is very likely, based on the different comments in this write-up, that food was overestimated and energy requirements of cranes underestimated.
Based on the use of small crabs size classes, and not having included variations by month, there is very likely a considerable overestimation of abundance for blue crabs. But even considering that estimates are realistic for the territory it does not mean that the crane has access to every single resource in its territory every day, as discussed above.

P. 46.
From the report "Salinities predicted at high and moderate inflow rates were similar to salinities observed at the GBRA1 gauge (Figure 3.9), but salinities predicted at low inflow rates (28-day cumulative discharges < 2* 107m3 /day), were unrealistically high (>40 ppt). Thus, we put an upper bound on the predictions of Eq. 1 such that predicted salinities did not exceed 30 ppt, which is 1 ppt higher than the maximum salinity observed at GBRA1 from 2003 to 2007."

Comment
Salinities on the Aransas marshes can at many times exceed 30 ppt. This is not rare, so it is not clear why salinities in the model were truncated at 30 ppt, especially when the effects of salinities are supposed to influence crab and wolfberry factors in the marsh. By limiting the model to 30 ppt some potential negative impacts of high salinities are therefore not included in the model. For example, high salinities were shown by one of the studies in this report (appendix) to affect wolfberry growth (p.37-38 and 98-99 of report). During winter of 2008-2009, many wolfberry plants were observed dead in some areas which was likely due to the fact that they were inundated for extended periods of time with high salinities. In addition, high

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salinities have other energetically demanding actions on whooping cranes. At salinities above 23 parts per thousand, the cranes must leave the marsh to drink freshwater at upland water sources. This means cranes must fly there, which is an energetically expensive activity. Since the model is assuming the same energy needs every day and limits the higher end of salinities, it ignores energy demands at higher salinity levels present in the marsh. A crane that needs to fly everyday to drink freshwater will have greater energy expenditure than one that does not fly at all during a day.

P. 49
It is not clear what peak number of berries/meter square per year is. By peak, one would assume number of berries in October, however, the legend of Figure 3.10 says peak number of berries/meter square per year and there is a single bar for each year. Does this mean that during the time cranes are there, there will be X number of wolfberries every day, or is it during the peak date in October and therefore less wolfberries before and after that peak, or is it total wolfberries regardless of phenology during the fruiting season. It is difficult to understand how the phenology of wolfberries would graph over the time period the whooping cranes are present based on a single peak value.

P. 50
It is not clear what time steps are here, as in wolfberry above. For example, predicted and observed crab densities are compared in a graph, however, the observed data as reported in the appendix is based on monthly sampling and the model, it appears, deals with daily variations ("days of energy shortage"). Figure 3.11 says crab abundance as total number of crabs/year. This does not make sense as the cranes are only there during the winter. Are the months when the cranes were not present also part of the total number of crabs/year? It is not clear by reading just the legend, and it is not graphed or presented in any other format than crabs/year. As it is presented, it is not clear how this relates to crab abundance over a daily (model expectations) or monthly (as empirical data is presented) time steps during the winter period.

P.68
Many of the relationships and connections described in this section (Conclusions of study), which I assume are based on the empirical studies, are not included in the model itself. For example, it says "The second major area of study was on the behavioral ecology of cranes. The main objectives here were to document food habits and time-activity budgets of cranes, while investigating the effects of environmental conditions, food abundance, and human disturbance on the crane's energy balance." Many of the results regarding this information, some of which is presented in the Appendix, are not incorporated in the model. For example, time activity budget information, food habits, and foraging information, do not appear anywhere in the model. Some of this information could help to better inform and define some of the assumptions currently in the model that do not appear to relate to reality very well.

I am not sure what responses they are talking about as no behavior data is presented.

Conclusions regarding efficiency are misleading as empirical data show food items were included that were not included in the model. So while the conclusion may be referring to empirical studies, up to this point in the report the empirical studies do not show up. They are presented as appendices.

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Summary of inconsistencies and unreasonable assumptions made in the model that make the overall results of the model unrealistic:

- Salinities measured in the bay are assumed to be equal to those in the crane territories.
- Salinity levels measured in the bay are assumed and used in the model to influence crab abundances in crane territories.
- Salinity levels measured in the bay are assumed and used in the model to influence wolfberry abundance in crane territories.
- Salinity levels are truncated at 30 ppt. Empirical data shows salinity levels in the marsh exceed 30 ppt regularly. Higher salinities also have implications for whooping crane energetics and wolfberry production.
-
- Crab equations use small crab size class (11-30mm) in the model despite data presented in the appendix that mentions that the likelihood of cranes eating that size class of crabs is near zero.
- Growth of small crabs is assumed and therefore is the reason for using the small size class, yet there is no variable in any equation to account for crab growth.
- While growth of crabs is assumed, equation for crab abundance ignores temperature as a variable despite the well known fact that temperature, in combination with salinity, are import factors influencing crab growth.
-
- Biomass and energy estimated in a whooping crane territory in a particular day is assumed to be 100% available to cranes instantaneously.
- There is no consideration of actual whooping crane energy expenditure, rather energy requirement is assumed to be equal every day.
- Not clear what time steps are. For example predicted and observed crab densities are compared in a graph, however the observed data is based on monthly sampling and the model is supposed to deal with daily variations ("days of energy shortage"). The figures say crab abundance as total crabs/year. This does not make sense as the cranes are only there during the winter. Are the months when the cranes where not present also part of the total number of crabs/year? It is not clear.

Considering the large number of potentially flawed assumptions, and inconsistencies of the model assumptions to reality, it would be unwise to assume that the results and conclusions presented in this report represent reality in the field with any degree of certainty. Models of this nature should be used to explore relationships among variables, not present the results of the simulations as if they indeed represent reality at any point in time. This is particularly true of this model when so many issues regarding whooping foraging, energy expenditure, and habitat use patterns are ignored in the model. For example,

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modeling the density of blue crabs and getting similar results to empirical data is one thing, but even that information has to be qualified. The model may simulate or estimate small blue crab density very well, however, if we know and the report acknowledges this, whooping cranes do not eat this size class the conclusions that there is enough food in the territories is suspect. How food abundance is extrapolated and then assumed that whooping cranes somehow magically absorbed the energy in the environment without habitat use and foraging activity patterns being considered is quite a different story. Using similar logic we could estimate fish biomass in whooping crane territories and conclude that whooping cranes have more than enough energy in their territory to fulfill their needs. However whooping cranes eat fish only rarely (just as small crabs), so my conclusions would have to be suspect and extremely unrealistic.

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Comments on SAGES Final Report

From: Texas Parks and Wildlife Department

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Carter P. Smith
Executive Director

June 8, 2009

Dr. Todd Votteler, Executive Manager of Intergovernmental Relations and Policy
Guadalupe-Blanco River Authority
922 East Court Street
Seguin, Texas 78155

Dear Dr. ~~Votteler:~~ Todd

Staff of the Texas Parks and Wildlife Department (TPWD) have reviewed the San Antonio Guadalupe Estuarine System (SAGES) Final Report: Linking Freshwater Inflows and Marsh Community Dynamics in San Antonio Bay to Whooping Cranes. TPWD staff agrees with the report's conclusion that the relationships between inflows, blue crabs, and whooping crane energetics are complex and not well understood and request the authors of the SAGES study better identify the limitations and inconsistencies in its findings in the final report.

The initial interpretations and publicity regarding the SAGES study have surprised, and perhaps even alarmed, many in the scientific, regulatory, and conservation communities. Specifically, statements such as "In summarizing the study, researchers commented that in nearly all conditions simulated, the food supply for whooping cranes appears to be more than adequate to meet their energy needs. (GBRA press release, 04-29-09)" seem inconsistent with earlier studies regarding whooping cranes, their food, and their habitats and imply that reductions in freshwater inflows will not affect the health of whooping cranes on the Texas coast. TPWD urges the project sponsors to carefully address these concerns, especially in light of contrary findings from previous studies.

In summary, the SAGES report clearly expresses the limitations associated with any model, including the SAGES model, and acknowledges that "the relationship between salinity and crane energetics is still uncertain"; however, the way in which the findings of this study have been presented have unfortunately led to implications that changes in freshwater inflows are unlikely to affect whooping crane food availability (and, by extension, their survival). TPWD strongly encourages the authors to qualify statements regarding predictions of food availability under the model with caveats regarding the limitations of the model. TPWD staff have highlighted some of more significant limitations in the attached document.

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Please see attached specific comments. Do not hesitate to contact me at 512/389-8715 or cindy.loeffler@tpwd.state.tx.us if you have further questions or concerns.

Sincerely,

Cindy Loeffler

Cindy Loeffler, Chief
Water Resources Branch

Attachment

Cc: Tom Stehn, U.S. Fish and Wildlife Service
Joe Trungale, Trungale and Associates
Ruben Solis, Texas Water Development Board

TPWD Comments: San Antonio Guadalupe Estuarine System (SAGES) Final Report: Linking Freshwater Inflows and Marsh Community Dynamics in San Antonio Bay to Whooping Cranes

Blue crab abundance as a function of bay salinity - Despite the wealth of research and literature regarding the relationship of blue crabs and salinity, the authors only listed a single reference (Cadman and Weinstein 1988) in their discussion of this source of variation (pp. 104-105). This reference focuses on a lab study which concluded that growth was generally higher at higher salinities. This is counter to previous work on blue crabs, which suggests that salinities in the range of 5-15 ppt are optimal (In fact, the online project description by the SAGES authors states, "Although blue crabs occur over a broad range of salinities in Gulf of Mexico estuarine waters, they are most abundant in low to intermediate salinities (Guillory et al. 2001)."). Although some studies do corroborate the negative effect of low salinity on blue crab growth, many others show that abundance is often higher at low to moderate salinities. Numerous studies of blue crab growth/abundance vs. salinity should have been included for comparison, not the least of which is Longley (ed.) 1994 "Freshwater Inflow to Texas Bays and Estuaries: Ecological Relationships and Methods for Determination of Needs". A list of other pertinent references is included in the attachment. Also, TPWD Coastal Fisheries monitoring data (unpublished but available to the authors) indicate higher catch rates at salinities less than what Cadman and Weinstein reported as optimum for growth. It is not unusual for different environmental factors to act synergistically and result in animals residing in conditions where no specific parameter is at the optimum level. Without establishing a relationship between larger crab density and salinity it is not possible to predict densities under different conditions. In addition, the authors were unable to develop an adequate model for predicting density of blue crabs over 30 mm. This is important because study number 9 in the appendix (*Whooping crane foraging ecology: Gains, costs and efficiency of foraging during winter*) indicated that the cranes consume crabs >30 mm; the authors did not show empirically that the small crabs would reach the larger size during the winter months on the Aransas National Wildlife Refuge. Cadman and Weinstein concluded that crab growth rates were lowest at low salinities and low temperatures. Without being able to model the density of crabs less than 30 mm is it not possible to accurately forecast the availability of this food item to the cranes under changing inflow conditions.

Furthermore, the model is built on two offsetting premises—that higher salinities increase blue crabs as a food source and that lower salinities increase wolfberries as a food source. The equations in the model regarding these relationships appear to be linear, with a suggestion that 30 ppt is the optimal salinity for blue crab abundance. This decision was critical in the performance of the model in predicting food abundance. If the model assumptions are wrong and blue crab abundance peaks at salinities lower than 30 ppt, then it would be highly unlikely that reductions in inflows of 90% would produce adequate food resources. Even a slight modification of this assumption might not allow the SAGES team to conclude that a 100,000 acre-feet/year reduction had no noticeable effect on food abundance ("no days in which net energy balance of cranes was negative") (Final report, page 59). Statements such as this are likely to be widely-referenced as decisions are made regarding water use and allocation in the future.

Marsh salinity as a function of bay salinity - Statements are made that "more crabs were found in bay than any other habitat (p. 107)" and "density was positively related to salinity (p. 108), yet nowhere in the chapter are there any data correlating density or abundance with salinity. This is a glaring omission considering that one of the four major relationships and a primary objective of the entire study concerns salinity. The authors seem to imply that bay habitat has higher salinity (and thus greater crab density) than the other four habitats (Figure A8, p. 114); if so this should be stated and supported with tables or figures. The chapter's Conclusions section consists of three paragraphs relating crab abundance vs. habitat, yet nothing about salinity. If the crab

abundance/salinity relationship is important enough to merit one of four bullets in Executive Summary, there should be some accompanying text and literature references in the Conclusions section as well. The applicability of the model for predicting food availability for whooping cranes in their marsh territories is uncertain, as it acknowledges that "the team does not know the extent to which marsh salinity is dependent on bay salinity" (Final report, page vi). Since the model's predictions are based on measures of bay salinity, this shortcoming is significant. It is regrettable that the model did not better quantify the relationships between bay salinity and marsh salinity. This is a significant data gap as the relationship of marsh salinity to freshwater inflows is the fundamental building block for the overall model. Without an accurate marsh salinity to inflow relationship it will not be possible to accurately predict the responses of wolfberries or crabs to changing inflow conditions. In addition, an upper bound of 30 ppt was set on model predictions to constrain model results from producing "unrealistically high (>40 ppt)" marsh salinity values. The TPWD Coastal Fisheries monitoring database contains numerous instances of salinities between 30 ppt and 40 ppt in this estuary. Limiting the model to 30ppt is not realistic for this estuary, especially given the extreme low inflows at which the model is being tested.

Overall, the inability to successfully develop models linking freshwater inflows to marsh salinity, or to predict the density of crabs >30 mm would seem to render the modeling efforts unsuccessful.

Alternate Food Sources - The report suggests that alternate food sources are mathematically equivalent in their exchange in the diet of whooping cranes and even suggests that blue crab are energetically expensive for whooping cranes to consume; however, previous research has shown that whooping cranes apparently select for blue crabs when blue crabs are present (Hunt and Slack 1989; Chavez-Ramirez 1996). The SAGES authors also note in their online project description that "Chavez-Ramirez (1996) has reported that breeding success of Whooping Cranes at Wood Buffalo National Park is closely tied to the availability of their primary food (blue crabs) while they are on coastal wetlands during the winter." Much previous research has shown that whooping cranes take a variety of food items (although press releases associated with the SAGES study imply that this study is unique in documenting such findings); however, alternative food sources may not be nutritionally equivalent to blue crabs. Data collected by Greer as part of the SAGES study illustrate this, showing that in the winter of 2004-05, when blue crabs were a significant component of whooping crane diet in November and December, energy intake, protein intake, and lipid intake were much higher than in 2005-06 when blue crabs were not a significant component of the diet. Field data collected by Tom Stehn of the U.S. Fish and Wildlife Service in those same years showed that in 2005-06 blue crabs were rare in transects conducted in whooping crane territories and that whooping cranes suffered above-average winter mortalities. Finally, research by Pugesek et al. (2008) conducted from 1997 through 2005 showed that mortality of adult whooping cranes in the wintering grounds was inversely correlated with blue crab abundance as measured by transects conducted in whooping crane habitat. The SAGES authors should address the inconsistency of their findings in relationship to existing research.

Energetics as a function of salinity - The SAGES model does not consider ancillary energetic costs of high salinities. When marsh salinities are high whooping cranes are forced to fly to inland sources of fresh water, which uses energy and exposes them to additional predation risks. In their project description online, the SAGES authors note that "movements of cranes from salt marsh territories to adjacent uplands and wetlands (which may increase predation risks) increase during periods of crab shortages in the marsh (Chavez-Ramirez and Slack 1999)." Although the SAGES authors acknowledge that their model is not comprehensive, secondary effects of freshwater inflow on whooping crane fitness and survival should be acknowledged.

Competition for food resources - The SAGES model does not consider inter-specific competition for food resources. The model substitutes an increase in whooping crane group size (four birds in the territory instead of the usual 2-3); however, it is unknown whether this is an adequate representation of competition for food resources, especially in stress years, such as drought. The limitations of the model should be acknowledged when statements regarding adequacy of food resources are made.

Limited study period - The SAGES empirical study (Feb. 2003 – Dec. 2007) period did not include a year of extreme drought and low inflows, such as 1990 or 2008, and it included only one of the winters in which the U.S. Fish and Wildlife Service has documented significantly above-average mortalities (2.7% in 2005-06). Winter mortality for whooping cranes is usually less than 1%; however, in seven years since 1988 Aransas National Wildlife Refuge staff has documented significantly higher mortality (2.7% - 8.5%) which has been either anecdotally or empirically associated with high salinities and low blue crab numbers. Similarly, the simulated SAGES model runs (1997-2007) only included two years in which higher mortalities on the wintering grounds were noted, and these were two of the less severe mortality winters (2005-06 with 2.7% and 2000-01 with 3.3%). The study results also showed that diet varied greatly from winter 1 to winter 2. Although the study duration did not practically allow for wider sampling across a broader range of years, it should be noted that the study may not have sampled during environmental extremes which may occur in the whooping crane habitat.

Whooping crane foraging ecology: gains, costs, and efficiency of foraging during winter – SAGES Study Results showed that whooping crane diet varied greatly between winter 1 (2004-2005) and winter 2 (2005-2006):

> "Percent of the diet containing blue crab (all sizes combined) declined by over 80% from winter 1 to winter 2"
> "Dry mass intake of blue crabs (all sizes combined) declined 70% from winter 1 to winter 2"
> "Intake of wolfberry fruit increased 3.7-fold from winter 1 to winter 2"
> "Foraging gains were over twice as much in winter 2 as winter 1"
> "Whooping cranes foraged 3-7 times more efficiently during winter 2 than winter 1".

The authors did not explain why cranes seemingly abandoned blue crabs in winter 2 when crab density was highest during September-October of this time period in several habitat types. This would seem important if the cranes actually preferred crabs over other food items. Figure A20 should be repeated for each crab size-class. If the cranes prefer larger crabs then that size should be broken out into a separate figure. TPWD staff recommends that the relationship between food items consumed and what was actually available should be examined as well as composition of the cranes diets each winter compared to the corresponding freshwater inflow. The declining amount of inflow and thus water level from winter of 2004-05 to 2005-06 would explain the decreased availability of crabs to the cranes during winter 2. The Executive Summary (Whooping Crane Behavior, p. v) does state "Whooping cranes foraged most efficiently during the winter of 2005-2006 when water levels were lowest". Relationships such as this would be useful in each of the chapters, comparing the data collected to the amount of inflow during the respective study period.

Other information - The SAGES team did not take advantage of several existing sources of information regarding whooping crane mortality to expand their analyses. Long-term data on whooping crane winter mortality is available. It is rare that one has the luxury of such close monitoring of the entire population of a species. TPWD recommends the SAGES team correlate

the long-term mortality data with other existing historical environmental parameters, such as median inflow during different seasons, peak salinities, and blue crab abundance.

Whooping crane territories - A map depicting all known whooping crane territories on the ANWR should be included and the 4 crab/crane territories sampled noted. If the results from the 4 sampled sites are to be extrapolated to all crane territories the reader needs to be able to visualize all territories. The various crane territories are widely scattered with some adjacent to the ICWW and some on the island shoreline. These two areas are very different and are differentially affected by freshwater inflows, wind, and local runoff.

Attachment - Literature Citations

Blue crab/salinity relationships

Longley, W.L., ed. 1994. Freshwater inflows to Texas bays and estuaries: ecological relationships and methods for determination of needs. Texas Water Development Board and Texas Parks and Wildlife Department, Austin, TX. 386 pp.

This report presents in detail the relationship between blue crab abundance and salinity, and specifically models freshwater inflow and salinity effects on San Antonio Bay and its fishery resources.

Guillory, V., H. Perry, and S. VanderKooy, eds. 2001. The blue crab fishery of the Gulf of Mexico, United States: a regional fishery management plan. Gulf States Marine Fisheries Commission, Ocean Springs, Mississippi.

Chapter 3 of this plan devotes 8 pages (3-11 to 3-18) to factors affecting distribution, abundance, and survival of the different life stages of blue crab (zoeae, megalopae, juveniles and adults). Table 3.1 (p. 3-15) compares blue crab distribution by salinity from four different studies; these studies are listed below. It also contains three pages on megalopal settlement and recruitment, none of which was cited in Chapter 8 of the SAGES report.

Christmas, J.Y., Jr. and W. Langley. 1973. Estuarine invertebrate, Mississippi. Pages 255-317 *In* J.Y. Christmas, Jr. (ed.), Gulf of Mexico Estuarine Inventory and Study, Mississippi. Gulf Coast Research Laboratory.

Details 818 samples from Mississippi where blue crabs are most abundant at salinities of 10-24.9 ppt, and decline at salinities from 0-9.9 ppt and >25 ppt.

Perret, W.S., W.R. Latapie, J.F. Pollard, W.R. Mock, G.B. Adkins, W.J. Gaidry, and J.C. white. 1971. Fishes and invertebrates collected in trawl and seine samples in Louisiana estuaries. Section I. Pages 39-105 *In* Cooperative Gulf of Mexico Estuarine Inventory and Study. Phase IV. Biology. Louisiana Wildlife and Fisheries Commission.

Details 1,179 samples from Louisiana where blue crabs are most abundant at salinities of <4.9 ppt, and are nearly equally abundant at salinities from 5->30 ppt.

Perry, H.M. and K.C. Stuck. 1982. The life history of the blue crab in Mississippi with notes on larval distribution. Pages 17-22 *In* H.M. Perry and W.A. VanEngel (eds.), Proceedings of the Blue Crab Colloquium. Gulf States Marine Fisheries Commission Publication 7.

Details 3,249 samples from Mississippi where blue crabs are most abundant at salinities of 0-19.9 ppt, and decline at salinities from >25 ppt.

Swingle, H.A. 1971. Biology of Alabama estuarine areas – cooperative Gulf of Mexico estuarine inventory. Alabama Marine Research Bulletin 5:1-123.

Details 179 samples from Alabama where blue crabs are most abundant at salinities of <9.9 ppt, and less abundant at salinities from 10-29.9 ppt.

Hammerschmidt, P.C. 1982. Population trends and commercial harvest of the blue crab *Callinectes sapidus* Rathbun, in Texas bays September 1978-August 1979. Texas Parks and Wildlife, Coastal Fisheries Branch, Management Data Series 38, 69 pp.

Based on one year of bag seine data in Texas, there was no direct relationship found between catches of juvenile crabs and salinity.

Ogburn, M.B., J.L. Jackson, and R.B. Forward, Jr. 2007. Comparison of low salinity tolerance in *Callinectes sapidus* Rathbun and *Callinectes similis* Williams postlarvae upon entry into an estuary. Journal of Experimental Marine Biology and Ecology 352 (2):343-350.

Blue crab megalopae from an estuarine site were more likely to survive exposure to low salinities than those from a higher salinity coastal site. Megalopae from the coastal site exhibited increased survival after acclimation to salinities of 27 and 23 ppt for 12 hours.

Texas Department of Water Resources. 1980. Guadalupe Estuary: A study of the influence of freshwater inflows. Texas Department of Water Resources Report LP-107.

Blue crab commercial fisheries harvest showed no significant relationship to salinity, but life history and migration information indicate that adequate freshwater inflow during the summer through fall is important to good growth and survival of the stocks.

Negative Effect on blue crab growth at lower salinities:

King, E.N. 1965. The oxygen consumption of intact crabs and excised gills as a function of decreased salinity. Comparative Biochemistry and Physiology 15:93-102.

Findley, A.M., B.W. Belisle, and W.B. Stickle. 1978. Effects of salinity fluctuations on the respiration rate of the southern oyster drill *Thais haemostoma* and the blue crab *Callinectes sapidus*. Marine Biology 49:59-67.

These two studies show that consumption of oxygen increased markedly at salinities below 15-20 ppt.

Tagatz, M.E. 1968. Growth of juvenile blue crabs, Rathbun, in the St. Johns's River, Florida. Fishery Bulletin 67:281-288.

This study, with a sample size of >2,000 observations and experimental design controlled for temperature and animal size, found a small yet significant decrease in molt increment in crabs held in freshwater (<1 ppt) compared to those held at higher salinities. There was no effect on intermolt period.

Rome, M.S., A.C. young-Williams, G.R. Davis, and A.H. Hines. 2005. Linking temperature and salinity tolerance to winter mortality of Chesapeake Bay blue crabs (*Callinectes sapidus*). Journal of Experimental Marine Biology and Ecology 319 (1):129-145.

In Chesapeake Bay laboratory studies, mortality was highest in the lowest temperature (1 ^{o}C) and salinity (8 ppt) treatments.

Blue crab settlement and recruitment:

Perry, H.M., D. Johnson, C. Trigg, C. Eleuterius, and J. Warren. 1998. Application of remote sensing to settlement of *Callinectes sapidus* megalopae in the Mississippi Bight. J. Shellfish Res. 17(5):1439-1442.

Johnson, D.R. and H.M. Perry. 1999. Blue crab larval dispersion and retention in the Mississippi Bight. Bull. Mar. Sci. 65(1):129-149.

Perry, H.M., D.R. Johnson, K. M. Larsen, C.B. Trigg, and F. Vukovich. 2003. Blue crab larval dispersion and retention in the Mississippi Bight: testing the hypothesis. Bull. Mar. Sci. 72(2):331-346.

Rakocinski, C.F., H.M. Perry, M.A. Abney, and K.M. Larsen. 2003. Soft-sediment recruitment dynamics of early blue crab stages in Mississippi Sound. Bull. Mar. Sci. 72(2):393-408.

Comments on SAGES Final Report

From: Dr. P. Montagna, Texas A&M Corpus Christi

Dear Mr. Votteler,

I have had an opportunity to read the final report of the SAGES study that was posted on line and have the following comments.

1) The report only provides an abstract of each individual study in Appendix A, and one would have to download and read the complete studies individually. I just don't have time to read all the supporting documents, which I feel is necessary before I could make any comments of a substantial nature regarding the science supporting the conclusions.

I must admit to surprise at some of the findings regarding blue crab (Callinectes sapidus) biology and have some general comments about that.

2) The focus of the experimental design is to look at ponds and connectedness of ponds. I am was not aware that blue crab spawn in these ponds as suggested by the study. My understanding is that blue crab is an estuarine dependent species, which means that it spawns offshore, larvae go through several planktonic stages in the water column before settling to the bottom as juveniles. This means that the crab actually use a range of habitats at different points in its life cycle. The conventional understanding is that the salinity gradient is very important for the planktonic stages to find nursery habitat. Thus, the complete range of habitats from the inlet to the Gulf of Mexico to the mouth of the river is the entire habitat range. It appears only a small part of that range was studied.

3) There are two species of blue crab in Texas. The second one is C. similis, yet there is little mention of this in the report. In my own sampling, I have found similis to be much more abundant that sapidus. There are also at least 50 other species of crabs in Texas bays, many of which do not have an estuarine dependent life cycles. It is not clear how the study of crab larvae identified the organisms captured in the samples as sapidus.

4) Blue crab abundances have been declining along the entire Texas coast since about 2000. In general, this indicates some large scale, coast-wide phenomenon is occurring. Also, similar declines started in the early 1990's along the east coast of the US. The best guess right now is climate change, in particular the effects of temperature and dissolved oxygen are key drivers. There is not much mention of the larger scale population issues, which is critical for an estuarine dependent species.

5) The main body of the report is about the whooping crane metabolic model (Chapter 3). In general, the conceptual model on how inflow affects salinity, and how salinity affects biology is correct. However, the model depends on linking several empirical relationships. For example, there is a great deal of variability between empirical relationships between flow and salinity (Fig. 3.4), which is found everywhere. The same is true for wolfberry-salinity relationship (Fig. 3.7). A problem arises when these noisy relationships are multiplied by one another because the errors are magnified. It would have been nice is some statistics of model fit to data were calculated or if the model was validated with independent data.

6) In the model section, the empirical formula given is that blue crab increase exponentially with salinity (and some other variables). This is not likely realistic, and it would have been nice to see this plotted to determine how the multiple variables are interacting with one another. What really happens is that estuarine dependent organisms have a preferred salinity range for each part of their life cycle, and it never increases without limit. I know from TPWD reports that there is more shellfish in northeastern Texas bays, and the number drop off as you move to saltier bays to the southwest, which make me wonder if the trend within a bay system with regards to salinity is ever significant.

Hope these comments prove useful to the authors of the study.

Paul Montagna

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Comments on SAGES Final Report

From: Texas Water Development Board

Texas Water Development Board

Memorandum

June 18, 2009

From: Carla G. Guthrie, Ph.D., Natural Resource Specialist, Surface Water Resources Division
Ruben S. Solis, Ph.D., P.E., Team Lead for Bays and Estuaries

To: Matt Nelson, Team Lead, Regional Water Planning
Barney Austin, Ph.D., P.E., Director, Surface Water Resources Division

Re: Comments on Final Draft Report of the San Antonio Guadalupe Estuarine System Study, *Linking Freshwater Inflows and Marsh Community Dynamics in San Antonio Bay to Whopping Cranes*, TWDB contract no. 0704830697.

Contracted Work

The goal of the San Antonio Guadalupe Estuarine System (SAGES) Study was to evaluate the relationship between freshwater inflows and Whooping Crane (*Grus americana*) population dynamics. Specifically, TWDB (contract no. 0704830697) funded the development of an ecological model to predict marsh ecosystem responses to variation in freshwater inflows. The project scope of work identified *one deliverable*, an ecological simulation model driven by six submodels: (1) water, (2) salt, (3) macrophytes, (4) blue crab, (5) crane abundance, and (6) crane weight. While the final draft report includes description of and results from an ecological model predicting changes in Whooping Crane food supply as a result of changes in freshwater inflows, the final simulation model differs from the one outlined in the scope of work. The original model was to have related freshwater inflows to *several aspects* of marsh ecosystem dynamics. The end result, however, still achieves the overall intent of the modeling effort by relating important variables (freshwater inflow, salinity, etc.) to Whooping Crane biology. A comparison of the proposed versus final ecological model is describe in the table below.

Overall Application of Model and Study Conclusions

While the individual submodels developed in this study for salinity, wolfberry, and blue crab appear reasonable, the range of conditions over which they were applied in the report (Section 3.4) likely far exceeds the range to which they can be applied with confidence given the limited range of data available for developing the models. Model predictions are presented for scenarios in which inflows are reduced by up to 90%. At such an extreme level of inflow reduction, particularly if prolonged over time, many other significant factors such as the shifting of salinity zones, changes in bay and wetland habitat type and location, changes in nutrient loads, effects on predator/prey species, and many other effects might overwhelm and indeed

invalidate the model results as presented in this report. *A more reasonable approach might be to present results for a much narrower range of conditions to avoid this issue or to more adequately qualify the conclusions given the large uncertainties in ecosystem response to the extreme inflow conditions considered.*

Proposed Model	Finalized Model
Water submodel - includes overland sheet flow, ebb/flow of water into marsh, evaporation and temperature represented, possibly the intent was to use a hydrodynamic model	Inundation model was developed, but was ultimately not used in development of the ecological model.
Salt submodel – similar to water submodel, based on a hydrodynamic and salinity transport model to represent salinity in marsh and bay	*Salinity as a function of freshwater inflow* – based on a regression analysis
Macrophytes submodel – represents net primary production and decomposition of (all) rooted plants	*Peak Wolfberry density equation* – based on regression analysis to mean summer salinity
Blue Crab submodel – represents recruitment as a function of day of year and adult female abundance; Mortality as a function of macrophyte biomass, crane abundance and other predator abundances; and, Movement among marshes and bay as a function of temperature, salinity, and day of year.	*Blue Crab density equations* – developed for 11-30mm size class using a regression analysis to habitat type, salinity, water level, and wind velocity. The model does not represent recruitment into or out of this size class nor does it represent mortality. Although the study assumes that the 11-30mm size class serves as a good proxy for the size class consumed by cranes, the size class modeled is *smaller* than those eaten by cranes. The study provides no indication as to what percent of the 11-30mm size class recruits into a size eaten by cranes
Crane abundance submodel – represents reproduction and mortality of cranes on northern breeding grounds; migration to marsh; movements within marsh; natality as a function of body weight index and day of year; mortality as a function of body weight	Not included. Companion studies may have addressed this, but crane abundance is not explicitly in the ecosystem model. Rather, an energetics model was applied (see next comment)
Crane weight index submodel – represent changes in body weight index as a function of availability of blue crabs and other food and energy expenditures	*Whooping Crane energy balance equations* – energy balance equations were developed for wolfberries, blue crabs of the small size class (11-30mm), and for each territory. While the nutritional equivalents between wolfberries and blue crabs were determined, the study does not seem to account for potential changes in territory sizes or foraging efforts.

Specific comments:

Authors need to review and correct mis-numbered tables, figures, and or studies. Several items referenced in the tables and text do not match each other.

Supporting statements, arising from the empirical work, frequently are given, but not backed-up with either direct reference to the companion study or by statistical significance. Additionally, some of the supporting statements based on observations or literature citations are not reflected in model decisions or conclusions. For example, the report states that blue crabs will be more abundant in deeper water (p. 42), but the scenario developed to push crabs towards minimum abundance (p. 58) increased water levels 50%.

P.42: The report cites studies that demonstrate a positive response of blue crabs to increasing salinity. It is not clear whether this applies to both sexes and all size classes. If the response is not universal, discussion of the implications of this on the conclusions would be helpful.

P.46: Although the salinity model is cut off at 30 ppt, observed bay salinities on occasion exceed 30ppt. This is shown in TWDB Datasonde data for San Antonio Bay and Mesquite Bay, particularly during periods of low freshwater inflow. Salinities of this level may be rare, but would be reflective of bay conditions during low flow periods. It may be important to recognize the limited scope of the analysis when drawing conclusions about the effect of low flow conditions.

P.46: Precipitous drops in salinity as recorded at GBRA1 may be explained by shifts in freshwater a plume moving through the bay. Freshwater currents will hug the western edge of San Antonio Bay; if these currents shift towards the bay center, then they would influence sonde readings. The precipitous drops in salinity are very possibly measurements of a real phenomenon that the model isn't capturing.

Comments on SAGES Final Report

From: Mr. Kirkwood, concerned citizen

Comments on the SAGES Conclusions

I have been an interested and frequent observer of whooping crane activities at Aransas National Wildlife Refuge (ANWR) since 2001. For most of that period (2002 through 2008), I have led tours 6 days per week from November through March to the refuge on board the tour boat Wharf Cat to observe the birds. The winter of 2009, I led tours 3 days per week. During this entire period I have closely observed activities of the birds, conducted extensive readings of the available literature, and had personal exchanges with such crane experts as Tom Stehn, USFW Whooping Crane Coordinator and George Archibald, PHD, co-founder of the International Crane Foundation and known globally as the world's leading scientific authority on cranes.

I find that the conclusions of the SAGES report are inconsistent with the body of knowledge existing about the whooping cranes and inconsistent with my own personal observations.

During the period of the SAGES study, historical drought extremes did not occur. During this last winter (2008-2009), there was little or no rainfall on either ANWR or in the watershed of the Guadelupe/San Antonio River complex. This lack of fresh water resulted in much higher salinities than were considered in the report. As a result, almost no Carolina wolfberries were available to the cranes upon their arrival. This lack of wolfberry fruit correlates with the wolfberry model of the study. What the study did not do is extend the impact of a wolfberry crop failure to the survivability of the whooping crane. The wolfberry is extremely important in order to replace the fat loss whooping cranes experience on their 2500-mile migration from Canada to the Gulf of Mexico. If that boost in nourishment is not available to them, then the impact of any subsequent reduction in food availability is magnified.

The study conclusion that blue crab availability should increase with higher level salinities is also inconsistent with the literature and my observations. The <30mm crab sizes that were the focus of the study are much smaller than those I observe the whooping cranes eating. I estimate that the crabs I see the cranes eating are 60mm or larger. It is this size crab that the cranes depend on to build up their energy reserves for the journey back to Canada and for the summer nesting season. During the winter of 2008-2009, crabs of this size were almost nonexistent. I seldom saw cranes finding and eating crabs of this size all winter long. My observations are consistent with the observation of others who have witnessed the cranes foraging through this and previous drought years.

Furthermore, the SAGES study did not account for the additional energy the cranes require to forage during seasons of low blue crab availability. If the crabs are not available in the shallow water ponds of the marshes, then they are not available to the cranes even if they are abundant in the deeper water. Whooping cranes are bottom foragers. When they are in the deeper waters of the bay, they are not searching for crabs, which are not on the bottom in that habitat, but for clams and other bottom dwellers. These resources may supply biomass, but they do not supply much energy to the cranes. Consequently, the cranes resort to foraging the uplands for reptiles, small mammals, nuts, acorns, and other vegetative matter. The travel to the uplands from the wetland territories and back uses energy that is barely replenished by the forage provided by the upland terrain.

As important, the SAGES study did not address the cranes requirement for drinking water. The cranes can drink water with salinities usually present in their home territories. They cannot drink water at the much higher salinities seen this last winter. This last winter, the cranes had to travel to fresh water ponds and tanks inland for water. This additional travel not only used energy they

could ill afford, but it also exposed them to predation by the larger predators that live on ANWR around the fresh water ponds.

The winter of 2008-2009 was the worst winter for the whooping cranes since records have been kept. I observed many cranes visibly emaciated and lethargic. Some were crippled or sick. Twenty-three died. This is the largest number and the highest percentage of the flock to die since USFW has been keeping records.

In conclusion, the SAGES study is seriously flawed because it does not consider abnormal climate conditions, focuses on the wrong segment of the crab population, does not consider the importance of the wolfberry crop to the cranes on their arrival at ANWR, does not account for the additional energy required by the cranes to find and consume alternative forage, and disregards the impact of the availability of drinkable water on the cranes. The conclusions drawn by the study are neither consistent with prior studies nor with observations made by competent observers in the field.

EXHIBIT H

Appendix D
Summary of Water Management Strategies

Appendix D, Table 1
2011 South Central Texas Regional Water Plan
Water Management Strategies

	Section	Description	Short-term Unit Cost* ($/acft/yr)	Long-term Unit Cost* ($/acft/yr)	Quantity of Water (acft/yr)	First Decade Needed	Notes
Recommended Water Management Strategies	4C.1	Municipal Water Conservation	$ 648	-	72,570	2010	Unit Cost and Quantity at 2060.
	4C.3	Edwards Transfers	$ 454	-	51,875	2010	
	4C.22	Local Groundwater Supplies (Carrizo)	$ 687	$ 258	33,874	2010	Quantity is cumulative of all Recommended WMS. Unit cost is average unit cost.
	4C.36	TWA Regional Carrizo	$ 1,523	$ 512	27,000	2010	
	4C.5	Recycled Water Programs	Varies	Varies	26,756	2010	
	4C.34	Lavaca River Off-Channel Reservoir	$ 701	$ 100	26,242	2010	LNRA WMS
	4C.1	Irrigation Water Conservation	$ 143	-	20,709	2010	Maximum potential for Atascosa, Medina, & Zavala Counties.
	4C.2	Drought Management	Varies	Varies	41,240	2010	
	4C.27	CRWA Wells Ranch Project	$ 725	$ 672	11,000	2010	
	4C.30	Medina Lake Firm-Up (ASR)	$ 1,696	$ 450	9,933	2010	15 Wells size
	4C.22	Local Groundwater Supplies (Trinity)	$ 710	$ 116	4,436	2010	Quantity is cumulative of all Recommended WMS. Unit cost is average unit cost.
	4C.8	Wimberley and Woodcreek Water Supply Project	$ 2,429	$ 1,772	4,480	2010	
	4C.9	Storage Above Canyon Reservoir (ASR)	$ 1,772	$ 587	3,140	2010	Meets needs Kendall County Rural
	4C.1	Mining Water Conservation	Varies	Varies	2,492	2010	
	4C.6	Facilities Expansions	-	-	-	2010	
	4C.32	Surface Water Rights	-	-	-	2010	Acquisition of existing rights only. As new supplies and associated costs have not been quantified, this strategy is more explicitly identified as an activity consistent with the 2011 Regional Water Plan.
	4C.21	GBRA Simsboro Project	$ 982	$ 386	49,777	2020	
	4C.10	GBRA-Exelon Project	$ 641	$ 224	49,126	2020	River Diversion
	4C.20	Hays/Caldwell PUA Project	$ 1,245	$ 439	35,000	2020	CRWA, San Marcos, Kyle, & Buda
	4C.23	Brackish Wilcox Groundwater for SAWS	$ 1,245	$ 465	26,400	2020	
	4C.15	GBRA Mid-Basin (Surface Water)	$ 2,204	$ 405	25,000	2020	
	4C.4	Edwards Aquifer Recharge – Type 2 Projects	$ 2,005	$ 340	21,577	2020	Includes full spectrum of potential projects.
	4C.24	Brackish Wilcox Groundwater for Regional Water Alliance	$ 1,293	$ 536	14,700	2020	13.1 MGD Capacity
	4C.18	Regional Carrizo for SAWS	$ 1,343	$ 324	11,687	2020	
	4C.19	Regional Carrizo for SSLGC Project Expansion	$ 608	$ 293	10,364	2020	
	4C.29	LCRA-SAWS Water Project	$ 2,394	$ 555	90,000	2030	
	4C.13	GBRA Lower Basin Storage (100 acre site)	$ 104	$ 15	28,369	2030	
	4C.14	GBRA New Appropriation (Lower Basin)	$ 1,953	$ 239	11,300	2030	100,000 acft Off-Channel Storage Size
	4C.28	CRWA Siesta Project	$ 1,421	$ 497	5,042	2030	
	4C.25	Brackish Wilcox Groundwater for SSWSC	$ 1,883	$ 766	1,120	2040	
	4C.22	Local Groundwater Supplies (Gulf Coast)	$ 1,823	$ 637	161	2040	City of Kenedy
	4C.31	Seawater Desalination	$ 2,284	$ 941	84,012	2060	San Antonio Bay source.
		Purchase from WWP (GBRA)	Varies	Varies	*	2010	* Quantity already accounted for in other WMSs
		Purchase from WWP (CRWA)	Varies	Varies	*	2010	* Quantity already accounted for in other WMSs
		Purchase from WWP (BMWD)	Varies	Varies	*	2010	* Quantity already accounted for in other WMSs
		Purchase from WWP (SAWS)	Varies	Varies	*	2010	* Quantity already accounted for in other WMSs
		Purchase from WWP (SHWSC)	Varies	Varies	*	2010	* Quantity already accounted for in other WMSs
		Purchase from WWP (TWA)	Varies	Varies	*	2010	* Quantity already accounted for in other WMSs
		Purchase from WWP (LNRA)	Varies	Varies	*	2010	* Quantity already accounted for in other WMSs
		Purchase from WWP (SSLGC)	Varies	Varies	*	2010	* Quantity already accounted for in other WMSs
Alternative Water Management Strategies	4C.12	LGWSP for Upstream GBRA Needs	$ 1,506	$ 536	60,000		
	4C.13	GBRA Lower Basin Storage (500 acre site)	$ 109	$ 14	59,569		
	4C.11	LGWSP for Upstream GBRA Needs at Reduced Capacity	$ 2,565	$ 726	35,000		
	4C.16	GBRA Mid-Basin Project (Conjunctive Use)	$ 1,779	$ 425	25,000		
	4C.17	Regional Carrizo for Guadalupe Basin (GBRA)	$ 1,280	$ 454	25,000		
	4C.30	Medina Lake Firm-Up (OCR)	$ 1,197	$ 199	9,078		Site 3
	4C.22	Local Groundwater Supplies (Barton Springs Edwards)	$ 203	$ 47	1,358		Goforth WSC
	4C.26	Calhoun County Brackish Groundwater Project	$ 2,679	$ 1,064	1,344		
	4C.22	Local Groundwater Supplies (Carrizo) (Yancy WSC)	$ 517	$ 99	1,210		Yancy WSC
		Purchase from WWP (GBRA)	Varies	Varies			
		Purchase from WWP (CRWA)	Varies	Varies			
		Purchase from WWP (SAWS)	Varies	Varies			
Water Management Strategies Requiring Further Study & Funding	4C.33	Balancing Storage (ASR and/or Surface)					
	4C.7	Brush Management (Above Canyon Reservoir)	$ 897	$ 244	5,500		25% Participation
	4C.9	Storage Above Canyon Reservoir (Off-Channel)					
	4C.35	Palmetto Bend - Stage II	$ 887	$ 84	22,964		LNRA WMS
		CRWA Dunlap Project					
		Edwards Recharge and Recirculation Systems					
		Mesa Water Supply Project (SAWS)					
		Rainwater Harvesting					
		Regional Carrizo for BMWD					
		Regional Carrizo for SSLGC Project Expansion - Wilson County Option					
		SAWS Other Water Supplies (Planned RFP)					
		Seawater Desalination for Guadalupe River Basin					
		Weather Modification					

*Cost in September 2008 dollars

Recommended Water Management Strategy Total for Municipal, Industrial, Steam-Electric, and Mining Uses Only = ~737,000 acft/yr

Appendix D, Table 2
2011 South Central Texas Regional Water Plan
Recommended Water Management Strategies

Region	Section	Description	Total Capital Costs	First Decade Estimated Annual Average Unit Cost ($/acft/yr)	Water Supply Volume (acre-feet per year)						Year 2060 Estimated Annual Average Unit Cost ($/acft/yr)
					2010	2020	2030	2040	2050	2060	
L	4C.1	Municipal Water Conservation	-	$ 648	13,231	22,742	31,616	40,528	53,925	72,570	-
L	4C.1	Irrigation Water Conservation	$1,035,034	$ 143	20,087	17,561	14,429	11,421	8,543	7,238	-
L	4C.1	Mining Water Conservation	-	Varies	521	726	1,771	1,991	2,292	2,492	Varies
L	4C.2	Drought Management	-	Varies	41,240	0	0	0	0	0	Varies
L	4C.3	Edwards Transfers	$23,551,250	$ 454	45,896	47,479	48,931	49,870	50,855	51,875	-
L	4C.4	Edwards Aquifer Recharge – Type 2 Projects	$527,643,000	$ 2,005	0	13,451	13,451	13,451	13,451	21,577	$ 340
L	4C.5	Recycled Water Programs	$465,339,000	Varies	21,666	26,046	30,151	34,178	37,706	41,737	Varies
L	4C.6	Facilities Expansions	$144,560,579	-	0	0	0	0	0	0	-
L	4C.8	Wimberley and Woodcreek Water Supply Project	$33,771,000	$ 2,429	1,120	4,480	4,480	4,480	4,480	4,480	$ 1,772
L	4C.9	Storage Above Canyon Reservoir (ASR)	$37,326,000	$ 1,772	0	3,140	3,140	3,140	3,140	3,140	$ 587
L	4C.10	GBRA-Exelon Project	$280,598,000	$ 646	0	49,126	49,126	49,126	49,126	49,126	$ 224
L	4C.13	GBRA Lower Basin Storage (100 acre site)	$33,800,000	$ 104	0	0	28,369	28,369	28,369	28,369	$ 60
L	4C.14	GBRA New Appropriation (Lower Basin)	$246,849,000	$ 1,910	0	0	11,300	11,300	11,300	11,300	$ 223
L	4C.15	GBRA Mid-Basin (Surface Water)	$546,941,000	$ 1,879	0	25,000	25,000	25,000	25,000	25,000	$ 370
L	4C.18	Regional Carrizo for SAWS	$136,550,000	$ 1,343	0	11,687	11,687	11,687	11,687	11,687	$ 324
L	4C.19	Regional Carrizo for SSLGC Project Expansion	$28,189,000	$ 568	0	10,364	10,364	10,364	10,364	10,364	$ 331
L	4C.20	Hays/Caldwell PUA Project	$323,296,000	$ 1,245	0	12,000	12,000	35,000	35,000	35,000	$ 439
L	4C.21	GBRA Simsboro Project	$330,782,000	$ 982	0	30,000	30,000	30,000	49,777	49,777	$ 386
L	4C.22	Local Groundwater Supplies (Carrizo)	$166,718,000	$ 687	6,773	11,610	15,440	17,255	23,947	33,874	$ 258
L	4C.22	Local Groundwater Supplies (Gulf Coast)	$2,194,000	$ 1,823	0	0	0	161	161	161	$ 637
L	4C.22	Local Groundwater Supplies (Trinity)	$30,224,000	$ 710	2,016	3,146	3,468	3,630	3,952	4,436	$ 116
L	4C.23	Brackish Wilcox Groundwater for SAWS	$236,220,000	$ 1,245	0	12,000	21,000	26,400	26,400	26,400	$ 465
L	4C.24	Brackish Wilcox Groundwater for RWA	$127,753,000	$ 1,293	0	0	7,600	7,600	13,200	14,700	$ 536
L	4C.25	Brackish Wilcox Groundwater for SSWSC	$14,357,000	$ 1,883	0	0	0	1,120	1,120	1,120	$ 766
L	4C.27	CRWA Wells Ranch Project	$34,910,000	$ 725	11,000	11,000	11,000	11,000	11,000	11,000	$ 672
L	4C.28	CRWA Siesta Project	$53,481,000	$ 1,421	0	0	1,000	5,042	5,042	5,042	$ 497
L	4C.29	LCRA-SAWS Water Project	$1,986,684,000	$ 2,394	0	0	90,000	90,000	90,000	90,000	$ 829
L	4C.30	Medina Lake Firm-Up (ASR)	$146,237,000	$ 1,696	9,933	9,933	9,933	9,933	9,933	9,933	$ 450
L	4C.31	Seawater Desalination	$1,293,827,000	$ 2,284	0	0	0	0	0	84,012	$ 941
L	4C.34	Lavaca River Off-Channel Reservoir	$224,183,000	$ 701	26,242	26,242	26,242	26,242	26,242	26,242	$ 100
L	4C.36	TWA Regional Carrizo	$313,060,000	$ 1,523	0	27,000	27,000	27,000	27,000	27,000	$ 512

Appendix D, Table 3.
Regional Water Supply Plan Summary

County/Water User Group	Demand 2010 (acft)	Demand 2060 (acft)	Need (Shortage) 2010 (acft)	Need (Shortage) 2060 (acft)	Recommended Management Strategies to Meet Needs (Shortages)	Amount from WMS 2010 (acft)	Amount from WMS 2060 (acft)
Atascosa County		**Table 2-12**		**Table 4A-1**	**Section 4B.2.1**		
Benton City WSC	1,189	2,569	0	885	Municipal Water Conservation		153
					Local Carrizo Aquifer		1,613
					Purchase from WWP (BMWD)		
Charlotte	296	350	0	0	Municipal Water Conservation	20	43
					Drought Management	15	
					Purchase from WWP (BMWD)		
					Local Carrizo Aquifer		
					Facilities Expansions		
Jourdanton	801	1,026	112	338	Municipal Water Conservation	60	222
					Drought Management	40	
					Local Carrizo Aquifer	403	403
Lytle	479	526	141	188	Municipal Water Conservation	38	108
					Edwards Transfers	141	188
					Drought Management	24	
McCoy WSC	1,106	2,328	0	812	Municipal Water Conservation		129
					Local Carrizo Aquifer		1,613
Pleasanton	1,906	2,151	0	0	Municipal Water Conservation	156	615
					Local Carrizo Aquifer		
					Facilities Expansions		
Poteet	735	752	0	0	Municipal Water Conservation	60	213
Rural	449	97	0	0	Municipal Water Conservation	11	
					Drought Management[1]		
					Purchase from WWP (BMWD)		
					Edwards Transfers		
					Facilities Expansions		
Industrial	6	6	0	0			
Steam-Electric	7,000	7,672	263	942	Local Carrizo Aquifer	807	1613
Mining	1,298	1,509	0	0			
Irrigation	40,885	34,502	6,095	291	Irrigation Water Conservation	5369	291
Livestock	1,745	1,745	0	0			
Bexar County				**Table 4A-1**	**Section 4B.2.2**		
Alamo Heights	2,071	2,170	592	691	Municipal Water Conservation	175	865
					Edwards Transfers	592	691
					Drought Management	104	
Atascosa Rural WSC	941	1,613	546	1,218	Municipal Water Conservation		22
					Edwards Transfers	546	1,218
					Drought Management	47	
					Purchase from WWP (BMWD)	120	120
Balcones Heights	514	670	0	0	Municipal Water Conservation	4	37
Bexar Metropolitan Water District	9,888	12,405	3,944	7,038	Municipal Water Conservation		293
					Purchase from WWP (BMWD)	3,944	7,038
Castle Hills	820	771	96	47	Municipal Water Conservation	61	166
					Drought Management	41	
					Purchase from WWP (BMWD)	96	47
China Grove	376	695	0	0	Municipal Water Conservation	28	217
Converse	1,907	3,564	0	969	Municipal Water Conservation		110
					Purchase from WWP (BMWD)	0	969
East Central SUD	1,523	2,793	0	942	Municipal Water Conservation		104
					Purchase from WWP (CRWA)	0	942
Elmendorf	112	156	0	0	Municipal Water Conservation		6
Fair Oaks Ranch	1,434	1,479	0	0	Municipal Water Conservation	125	509
Helotes	1,537	4,047	0	0	Municipal Water Conservation	115	993
Hill Country Village	838	826	730	718	Municipal Water Conservation	77	365
					Purchase from WWP (BMWD)	730	718
					Drought Management	42	
Hollywood Park	2,314	2,616	1,969	2,271	Municipal Water Conservation	212	1,154
					Purchase from WWP (BMWD)	1,969	2,271
					Drought Management	116	
Kirby	1,005	1,034	335	364	Edwards Transfers	335	364
					Drought Management	50	
Lackland AFB (CDP)	3,104	3,016	0	0	Municipal Water Conservation	268	1300
Leon Valley	1,091	1,036	0	0	Municipal Water Conservation		12
Live Oak	1,145	1,284	0	0	Municipal Water Conservation		
Olmos Park	403	484	0	0	Municipal Water Conservation	9	33
San Antonio	216,945	317,727	77,783	194,228	Municipal Water Conservation	5,752	23,711
					Purchase from WWP (SAWS)	68,760	169,752
					Purchase from WWP (BMWD)	9,023	24,476
					Drought Management (SAWS)	37,622	
					Drought Management (BMWD)	1,233	

Appendix D, Table 3 (Continued)

County/Water User Group	Demand 2010 (acft)	Demand 2060 (acft)	Need (Shortage) 2010 (acft)	Need (Shortage) 2060 (acft)	Recommended Management Strategies to Meet Needs (Shortages)	Amount from WMS 2010 (acft)	Amount from WMS 2060 (acft)
Selma	1,667	2,605	0	749	Municipal Water Conservation	135	1,122
					Purchase from WWP (SSLGC)	0	749
Shavano Park	819	880	320	381	Municipal Water Conservation	73	382
					Drought Management	41	
					Purchase from WWP (SAWS)	320	381
Somerset	405	709	0	0	Municipal Water Conservation	29	177
St. Hedwig	310	501	0	0	Municipal Water Conservation		14
Terrell Hills	863	1,057	0	0	Municipal Water Conservation	14	65
Universal City	2,608	3,101	113	606	Municipal Water Conservation		148
					Edwards Transfers	113	606
					Drought Management	130	
Water Service Inc. (Apex Water Ser.)	951	2,058	911	2,018	Municipal Water Conservation		105
					Edwards Transfers	587	1,116
					Purchase from WWP (TWA)		1,000
					Purchase from WWP (SSLGC)	324	324
Windcrest	1,204	1,182	235	214	Municipal Water Conservation	99	385
					Edwards Transfer	235	235
Rural	6,624	7,496	0	655	Municipal Water Conservation	49	505
					Purchase from WWP (SAWS)	0	655
Industrial	25,951	42,112	1,340	17,588	Purchase from WWP (SAWS)	12,000	30,000
					Recycled Water	1,340	17,588
Steam-Electric	20,395	39,614	0	0			
Mining	3,582	4,766	0	1,216	Mining Water Conservation		1,216
Irrigation	15,273	12,306	0	0			
Livestock	1,319	1,319	0	0			
Caldwell County	**Table 2-12**		**Table 4A-1**		**Section 4B.2.3**		
Aqua WSC	267	580	49	362	Municipal Water Conservation		19
					Local Carrizo Aquifer	403	403
					Drought Management	13	
Creedmoor-Maha WSC	244	583	108	447	Municipal Water Conservation		11
					Purchase from WWP (GBRA)	108	447
Lockhart	2,451	5,285	0	2,512	Municipal Water Conservation		333
					Local Carrizo Aquifer		2823
					Purchase from WWP (GBRA)		1,120
					Drought Management	123	
Luling	1,067	1,594	0	506	Municipal Water Conservation	70	192
					Local Carrizo Aquifer		807
					Purchase from WWP (GBRA)		1,680
					Drought Management	53	
Martindale	125	158	0	0	Purchase from WWP (CRWA)	0	0
					Drought Management	6	
Martindale WSC	189	329	42	182	Purchase from WWP (CRWA)	396	896
					Drought Management	9	
Maxwell WSC	660	1,733	0	689	Municipal Water Conservation		55
					Purchase from WWP (CRWA)	0	2,000
Mustang Ridge	135	329	19	213	Municipal Water Conservation	10	116
					Purchase from WWP (GBRA)	19	213
					Drought Management	6	
Polonia WSC	668	1,656	0	265	Local Wilcox		323
Rural	237	143	0	0	Municipal Water Conservation	21	29
Industrial	15	29	0	0			
Steam-Electric	0	0	0	0			
Mining	14	18	0	0			
Irrigation	1,044	578	0	0			
Livestock	918	918	0	0			
Calhoun County	**Table 2-12**		**Table 4A-1**		**Section 4B.2.4**		
Calhoun County WSC	436	632	0	0			
Point Comfort	224	667	46	489	Municipal Water Conservation	18	98
					Purchase from WWP (LNRA)	46	489
					Drought Management	11	
Port Lavaca	1,769	2,345	0	0	Municipal Water Conservation		89
Seadrift	252	258	0	0	Municipal Water Conservation	20	41
Rural (Port O'Conner MUD)	267	269	0	0	Municipal Water Conservation		11
Industrial	49,784	72,238	0	209	Purchase from WWP (LNRA)	10,000	10,000
Steam-Electric	0	0	0	0			
Mining	32	38	0	0			
Irrigation	15,568	9,581	0	0			
Livestock	342	342	0	0			
Comal County	**Table 2-12**		**Table 4A-1**		**Section 4B.2.5**		
Bulverde City	1,053	4,995	653	4,595	Municipal Water Conservation		430
					Purchase from WWP (GBRA)	653	4,595
					Drought Management	53	

Appendix D, Table 3 (Continued)

County/Water User Group	Demand 2010 (acft)	Demand 2060 (acft)	Need (Shortage) 2010 (acft)	Need (Shortage) 2060 (acft)	Recommended Management Strategies to Meet Needs (Shortages)	Amount from WMS 2010 (acft)	Amount from WMS 2060 (acft)
Canyon Lake WSC	2,928	13,331	0	6,769	Municipal Water Conservation		1,414
					Purchase from WWP (GBRA)		6,769
					Drought Management[1]		
					Purchase from WWP (TWA)		12,000
Garden Ridge	565	1,360	257	1,052	Municipal Water Conservation	42	460
					Purchase from WWP (SSLGC)	257	1052
					Drought Management	28	
New Braunfels	10,509	26,226	0	13,920	Municipal Water Conservation	815	8,152
					Drought Management	525	
					Purchase from WWP (GBRA)		13,920
Rural	2,721	3,998	1,782	2,960	Municipal Water Conservation		85
					Purchase from WWP (GBRA)	891	1,480
					Purchase from NBU (term)	891	
					Purchase from WWP (TWA)		1,480
Industrial	7,729	11,553	5,199	9,022	Recycled Water	5,199	9,022
Steam-Electric	0	0	0	0			
Mining	2,678	3,401	439	1,173	Mining Water Conservation	439	1,173
Irrigation	204	119	0	0			
Livestock	298	298	0	0			
DeWitt County	**Table 2-12**		**Table 4A-1**		**Section 4B.2.6**		
Cuero	1,249	1,177	0	0	Municipal Water Conservation	99	218
Yoakum	352	328	0	0	Municipal Water Conservation	14	27
Yorktown	343	318	0	0	Municipal Water Conservation		13
Rural	1,013	912	0	0	Municipal Water Conservation		6
Industrial	184	254	0	0			
Steam-Electric	0	0	0	0			
Mining	64	71	0	0			
Irrigation	159	54	0	0			
Livestock	1,689	1,689	0	0			
Dimmit County	**Table 2-12**		**Table 4A-1**		**Section 4B.2.7**		
Asherton	286	279	0	0	Municipal Water Conservation	20	64
Big Wells	149	145	0	0	Municipal Water Conservation	11	33
Carrizo Springs	1,842	1,836	0	0	Municipal Water Conservation	152	777
Rural	284	263	0	0			
Industrial	0	0	0	0			
Steam-Electric	0	0	0	0			
Mining	1,003	1,095	0	0			
Irrigation	10,611	8,987	0	0			
Livestock	552	552	0	0			
Frio County	**Table 2-12**		**Table 4A-1**		**Section 4B.2.8**		
Dilley	1,229	1,825	0	0	Municipal Water Conservation	104	772
Pearsall	1,443	1,449	0	0	Municipal Water Conservation	116	324
Rural	727	1,007	0	0	Municipal Water Conservation		18
Industrial	0	0	0	0			
Steam-Electric	289	91	0	0			
Mining	109	96	0	0			
Irrigation	82,017	68,592	0	0			
Livestock	1,209	1,209	0	0			
Goliad County	**Table 2-12**		**Table 4A-1**		**Section 4B.2.9**		
Goliad	416	594	0	0	Municipal Water Conservation	30	100
Rural	608	848	0	0	Municipal Water Conservation		16
Industrial	4	24	0	0			
Steam-Electric	9,027	16,643	0	0			
Mining	398	46	0	0			
Irrigation	309	149	0	0			
Livestock	920	920	0	0	Livestock Water Conservation		
Gonzales County	**Table 2-12**		**Table 4-10**		**Section 4B.2.10**		
Gonzales	1,545	1,759	0	0	Municipal Water Conservation	116	414
Gonzales County WSC	1,748	2,360	0	0	Municipal Water Conservation	143	1,002
					Purchase from WWP (TWA)		1,000
Nixon	438	488	0	0	Municipal Water Conservation	35	93
Waelder	154	203	0	0	Municipal Water Conservation		11
Rural	393	204	0	0	Municipal Water Conservation	6	3
Industrial	2,400	3,402	0	0			
Steam-Electric	0	0	0	0			
Mining	28	24	0	0			
Irrigation	1,304	621	0	0			
Livestock	5,453	5,453	0	0			
Guadalupe County	**Table 2-12**		**Table 4A-1**		**Section 4B.2.11**		
Cibolo	866	2,730	0	0	Municipal Water Conservation	65	645
					Purchase from WWP (CRWA)	700	7,180
					Purchase from WWP (BMWD)	500	500

Appendix D, Table 3 (Continued)

County/Water User Group	Demand 2010 (acft)	Demand 2060 (acft)	Need (Shortage) 2010 (acft)	Need (Shortage) 2060 (acft)	Recommended Management Strategies to Meet Needs (Shortages)	Amount from WMS 2010 (acft)	Amount from WMS 2060 (acft)
Crystal Clear WSC	2,041	5,551	0	2,716	Municipal Water Conservation		184
					Local Wilcox Aquifer		2,823
					Purchase from WWP (CRWA)	1,300	5,185
					Purchase from WWP (SSLGC)		900
					Purchase from WWP (SHWSC)	0	0
Green Valley SUD	3,039	7,826	0	547	Municipal Water Conservation		20
					Purchase from WWP (CRWA)	700	9,500
					Purchase from NBU	552	552
Marion	164	251	0	75	Municipal Water Conservation		10
					Purchase from WWP (CRWA)	100	400
City of New Berlin	70	180	0	0			
Santa Clara	220	954	76	810	Municipal Water Conservation		79
					Purchase from WWP (CRWA)	100	900
					Drought Management	11	
Schertz	1,451	12,059	0	2,420	Municipal Water Conservation	22	1,088
					Purchase from WWP (SSLGC)	0	5,923
Seguin	5,018	9,047	0	0	Municipal Water Conservation	377	2,131
					Purchase from WWP (SSLGC)		
Springs Hill WSC	2,349	4,330	0	0	Municipal Water Conservation	174	877
					Purchase from WWP (TWA)		3,000
					Brackish Wilcox Groundwater for RWA		1,500
					Facilities Expansions		
Rural	270	13	0	0	Municipal Water Conservation	2	
Industrial	2,638	4,097	0	0			
Steam-Electric	4,788	7,515	0	0			
Mining	306	353	0	0			
Irrigation	1,070	705	0	0			
Livestock	1,057	1,057	0	0			
Hays (Part) County	**Table 2-12**		**Table 4A-1**		**Section 4B.2.12**		
County Line WSC	1,151	3,677	0	2,386	Municipal Water Conservation	43	473
					Local Trinity Aquifer		2,420
					Purchase from WWP (CRWA)	0	570
					Drought Management	58	
					Recycled Water		
Goforth WSC	1,156	3,485	0	1,872	Municipal Water Conservation		111
					Hays/Caldwell PUA Project		1639
					Purchase from WWP (GBRA)		300
Kyle	2,740	5,203	0	1,699	Municipal Water Conservation		443
					Hays/Caldwell PUA Project		9,355
					Drought Management	137	
Mountain City	45	183	0	134	Municipal Water Conservation	1	22
					Hays/Caldwell PUA Project		150
Niederwald	130	449	58	377	Municipal Water Conservation		42
					Purchase from WWP (GBRA)	58	377
					Drought Management	7	
Plum Creek Water Company	566	1,630	0	657	Municipal Water Conservation		54
					Purchase from WWP (GBRA)		657
San Marcos	8,038	24,439	0	11,387	Municipal Water Conservation	417	2,656
					Hays/Caldwell PUA Project		11,910
Wimberley WSC	776	1,966	219	1,409	Municipal Water Conservation		70
					Wimberley and Woodcreek Water Supply	320	1,480
					Drought Management	39	
Woodcreek	246	610	23	387	Municipal Water Conservation		37
					Wimberley and Woodcreek Water Supply	100	400
					Drought Management	12	
Woodcreek Utilities	748	2,873	455	2,580	Municipal Water Conservation	56	771
					Wimberley and Woodcreek Water Supply	700	2,600
Rural	1,444	2,584	0	0	Municipal Water Conservation		184
Industrial	212	386	0	0			
Steam-Electric	1,009	3,627	0	0			
Mining	142	163	82	103	Mining Water Conservation	82	103
Irrigation	353	338	0	0			
Livestock	280	280	0	0			
Karnes County	**Table 2-12**		**Table 4A-1**		**Section 4B.2.13**		
El Oso WSC	555	728	0	0	Municipal Water Conservation	41	139
Falls City	113	145	0	0	Municipal Water Conservation	8	23
Karnes City	432	512	182	262	Municipal Water Conservation		11
					Local Carrizo	323	323
Kenedy	763	993	0	118	Municipal Water Conservation	58	268
					Local Gulf Coast Aquifer		161
Runge	195	247	0	0	Municipal Water Conservation	15	37
Rural (TDCJ)	500	500	0	0			
Rural	372	822	0	0	Municipal Water Conservation	68	258
Industrial	118	137	0	0			

Appendix D, Table 3 (Continued)

County/Water User Group	Demand 2010 (acft)	Demand 2060 (acft)	Need (Shortage) 2010 (acft)	Need (Shortage) 2060 (acft)	Recommended Management Strategies to Meet Needs (Shortages)	Amount from WMS 2010 (acft)	Amount from WMS 2060 (acft)
Steam-Electric	0	0	0	0			
Mining	106	100	0	0			
Irrigation	1,382	836	0	0			
Livestock	1,185	1,185	0	0			
Kendall County	**Table 2-12**		**Table 4A-1**		**Section 4B.2.14**		
Boerne	1,570	4,282	0	276	Municipal Water Conservation	98	816
					Western Canyon WTP Expansion		276
Rural	2,750	7,460	0	3,514	Municipal Water Conservation		264
					Purchase from WWP (GBRA)		3,140
					Western Canyon WTP Expansion		374
Industrial	0	0	0	0			
Steam-Electric	0	0	0	0			
Mining	6	6	0	0			
Irrigation	714	646	0	0			
Livestock	446	446	0	0			
LaSalle County	**Table 2-12**		**Table 4A-1**		**Section 4B.2.15**		
Cotulla	1,407	1,743	0	0	Municipal Water Conservation	118	745
Encinal	110	107	0	0	Municipal Water Conservation	9	14
Rural	282	500	0	0	Municipal Water Conservation	3	42
Industrial	0	0	0	0			
Steam-Electric	0	0	0	0			
Mining	0	0	0	0			
Irrigation	4,791	4,097	0	0			
Livestock	1,687	1,687	0	0			
Medina County	**Table 2-12**		**Table 4A-1**		**Section 4B.2.16**		
Castroville	680	961	294	575	Municipal Water Conservation	53	302
					Edwards Transfers	294	575
					Drought Management	34	
					Purchase from WWP (BMWD)		
Devine	837	896	0	0	Municipal Water Conservation	63	196
East Medina SUD	881	1,385	0	491	Municipal Water Conservation		54
					Edwards Transfers		491
					Drought Management	44	
Hondo	1,784	2,717	319	1,252	Municipal Water Conservation	125	640
					Edwards Transfers	319	1,252
					Drought Management	89	
La Coste	205	281	92	168	Municipal Water Conservation		11
					Edwards Transfers	92	168
					Drought Management	10	
Natalia	330	519	194	383	Municipal Water Conservation	24	73
					Edwards Transfers	194	383
					Drought Management	17	
Yancey WSC	832	1,603	214	985	Municipal Water Conservation	61	316
					Edwards Transfers	214	985
Rural	1,527	2,949	0	1,296	Municipal Water Conservation		244
					Edwards Transfers		1,296
Industrial	67	103	0	0			
Steam-Electric	0	0	0	0			
Mining	130	143	0	0			
Irrigation	54,450	44,015	7,770	0	Irrigation Water Conservation	7,770	
Livestock	1,298	1,298	0	0			
Refugio County	**Table 2-12**		**Table 4A-1**		**Section 4B.2.17**		
Refugio	645	777	0	0	Municipal Water Conservation	44	144
Woodsboro	283	293	0	0	Municipal Water Conservation	5	20
Rural	321	232	0	0			
Industrial	0	0	0	0			
Steam-Electric	0	0	0	0			
Mining	7	8	0	0			
Irrigation	69	69	0	0			
Livestock	623	623	0	0			
Uvalde County	**Table 2-12**		**Table 4A-1**		**Section 4B.2.18**		
Sabinal	407	389	127	109	Municipal Water Conservation	34	145
					Edwards Transfers	127	109
					Drought Management	20	
Uvalde	6,087	6,178	3,172	3,263	Municipal Water Conservation	521	2,652
					Edwards Transfers	3,172	3,263
					Drought Management	304	
Rural	1,572	2,532	0	0	Municipal Water Conservation		137
Industrial	432	538	0	0			
Steam-Electric	0	0	0	0			
Mining	313	418	0	0			
Irrigation	55,791	45,703	0	0			
Livestock	1,284	1,284	0	0			

Appendix D, Table 3 (Continued)

County/Water User Group	Demand 2010 (acft)	Demand 2060 (acft)	Need (Shortage) 2010 (acft)	Need (Shortage) 2060 (acft)	Recommended Management Strategies to Meet Needs (Shortages)	Amount from WMS 2010 (acft)	Amount from WMS 2060 (acft)
Victoria County	**Table 2-12**		**Table 4A-1**		**Section 4B.2.19**		
Victoria	11,924	14,360	0	0	Municipal Water Conservation	874	2,485
Rural	2,666	3,674	0	310	Municipal Water Conservation		32
					Purchase from WWP (GBRA)		310
Industrial	28,726	43,520	0	14,441	Purchase from WWP (GBRA)		14,441
Steam-Electric	4,052	53,178	1,791	51,076	Purchase from WWP (GBRA - Exelon)		49,126
					Purchase from WWP (GBRA)	1,791	1,950
					Steam Electric Water Conservation	500	500
Mining	3,944	6,041	0	0			
Irrigation	9,936	4,759	0	0			
Livestock	1,085	1,085	0	0			
Wilson County	**Table 2-12**		**Table 4A-1**		**Section 4B.2.20**		
Floresville	1,805	3,000	0	433	Municipal Water Conservation	136	714
					Local Carrizo Aquifer		484
La Vernia	278	764	0	0	Municipal Water Conservation	21	227
					Purchase from WWP (CRWA)	400	400
Oak Hills WSC	693	2,160	0	298	Municipal Water Conservation		136
					Local Carrizo Aquifer		323
Poth	348	585	0	0	Municipal Water Conservation	20	64
SS WSC	1,563	5,030	223	3,690	Municipal Water Conservation		221
					Local Carrizo Aquifer	807	4,033
					Purchase from WWP (CRWA)		690
					Brackish Wilcox Groundwater for SS WSC		1120
					Drought Management	78	
Stockdale	350	558	0	0	Municipal Water Conservation	27	171
Sunko WSC	613	1,326	0	16	Municipal Water Conservation	3	92
					Local Carrizo Aquifer		161
Rural	609	2,006	0	33	Municipal Water Conservation		116
Industrial	1	1	0	0			
Steam-Electric	0	0	0	0			
Mining	242	218	0	0			
Irrigation	11,296	6,330	0	0			
Livestock	1,808	1,808	0	0			
Zavala County	**Table 2-12**		**Table 4A-1**		**Section 4B.2.21**		
Crystal City	2,247	2,370	0	0	Municipal Water Conservation	192	1,002
Rural	864	1,371	0	0	Municipal Water Conservation	42	149
Industrial	1,043	1,315	0	0			
Steam-Electric	0	0	0	0			
Mining	122	130	0	0			
Irrigation	71,800	58,692	54,600	41,492	Irrigation Water Conservation	6,948	6,948
Livestock	756	756	0	0			
Wholesale Water Providers	**Tables 2-13 through 2-19**		**Table 4A-3**		**Section 4B.3**		
San Antonio Water System	217,954	328,442	73,600	193,264	Municipal Water Conservation[2]		
					Drought Management	37,622	0
					Edwards Transfers	35,935	35,935
					ASR Project and Phased Expansion	3,800	16,000
					Recycled Water Program Expansion	15,127	15,127
					Regional Carrizo for Bexar County		11,687
					Edwards Aquifer Recharge – Type 2 Projects		21,577
					Brackish Groundwater Desalination (Wilcox)		26,400
					LCRA/SAWS Water Project		90,000
					Seawater Desalination		84,012
Guadalupe-Blanco River Authority	137,065	279,484	0	67,580	Municipal Water Conservation[2]		
					Wimberley and Woodcreek Water Supply Project	4,480	
					Simsboro Groundwater Project		49,777
					GBRA Mid-Basin/Gonzales Project (Surface Water)		25,000
					Storage Above Canyon Reservoir (ASR)		3,140
					GBRA/Exelon Project		49,126
					GBRA Lower Basin Storage		28,369
					GBRA New Appropriation (Lower Basin)		11,500
					Western Canyon WTP Expansion		5,600
Bexar Met	43,439	57,954	16,638	35,418	Municipal Water Conservation[2]		
					Edwards Transfers	3,000	3,000
					Local Trinity	2,016	2,016
					Local Carrizo	4,030	16,129
					Medina Lake Firm-Up (ASR – 15 wells)	9,933	9,933
					Purchase from WWP (CRWA)	2,800	8,250

Appendix D, Table 3 (Concluded)

County/Water User Group	Demand 2010 (acft)	Demand 2060 (acft)	Need (Shortage) 2010 (acft)	Need (Shortage) 2060 (acft)	Recommended Management Strategies to Meet Needs (Shortages)	Amount from WMS 2010 (acft)	Amount from WMS 2060 (acft)
Canyon Regional Water Authority	21,054	53,534	7,920	40,400	Municipal Water Conservation[2]		
					Wells Ranch Project Phase I	5,200	5,200
					Wells Ranch Project Phase II	5,800	5,800
					Purchase from WWP (GBRA)		5,000
					Brackish Wilcox Groundwater for RWA		11,200
					Siesta Project		5,042
					Hays/Caldwell PUA Project		10,260
Lavaca-Navidad River Authority			10,046	10,489	Municipal Water Conservation[2]		
					Lavaca River Off-Channel Reservoir	26,242	26,242
Schertz-Seguin Local Government Corp.	12,704	21,071	0	4,935	Municipal Water Conservation[2]		
					Regional Carrizo for SSLGC Project Expansion		10,364
					Brackish Wilcox Groundwater for RWA		2,000
Springs Hill WSC	3,384	5,365	0	0	Municipal Water Conservation[2]		
					Purchase from WWP (TWA)		3,000
					Brackish Wilcox Groundwater for RWA		1,500
Texas Water Alliance	0	18,480	0	18,480	Municipal Water Conservation[2]		
					TWA Regional Carrizo	0	27,000

[1] Historical per capita water use data unavailable or insufficient for calculation of yield.
[2] Municipal Water Conservation

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EXHIBIT I

U.S. Fish & Wildlife Service

International Recovery Plan

Whooping Crane

(Grus americana)

Third Revision

March 2007

International Recovery Plan for the

WHOOPING CRANE

(*Grus americana*)

(Third Revision)

U.S. RECOVERY PLAN

(Original Approved, January 23, 1980)

(First Revision Approved, December 23, 1986)

(Second Revision Approved, February 11, 1994)

CANADIAN RECOVERY PLAN

(Original Approved, December 4, 1987)

(First Revision Approved, June, 1993)

2006

Approved: _____

Regional Director, U.S. Fish and Wildlife Service, Southwest Region

Date: 7/21/06

Concurrence: _____

Executive Director, Texas Parks and Wildlife Department, Austin, Texas

Date: March 30, 2007

DISCLAIMER

Recovery plans delineate reasonable actions believed necessary to recover and/or protect listed species. Plans are published by the Environment Canada in Canada and by the U.S. Fish and Wildlife Service in the United States, sometimes prepared with the assistance of recovery teams, contractors, State or Provincial Agencies, and others. Objectives will be attained and any necessary funds made available subject to budgetary constraints affecting the parties involved, as well as the need to address other priorities. Recovery plans do not necessarily represent the views nor the official position or approval of any individuals or agencies involved in the plan formulation, other than Environment Canada and United States Fish and Wildlife Service. They represent the official position of the agencies mentioned only after they have been signed as approved by appropriate personnel and posted on the public registry. Approved recovery plans are subject to modification as dictated by new findings, changes in species status, and the completion of recovery actions. This International Recovery Plan, while approved by Environment Canada, does not constitute a Recovery Strategy under Canada's Species at Risk Act (SARA). A separate document derived from this International Recovery Plan and published on Environment Canada's SARA Public Registry will be prepared.

LITERATURE CITATION

The Literature Citation should read as follows:

Canadian Wildlife Service and U.S. Fish and Wildlife Service. 2007. International recovery plan for the whooping crane. Ottawa: Recovery of Nationally Endangered Wildlife (RENEW), and U.S. Fish and Wildlife Service, Albuquerque, New Mexico. 162 pp.

In the U.S., copies may be obtained on-line (Species Search, whooping crane):

http://www.fws.gov/endangered

In Canada, additional copies may be obtained from:

Recovery Secretariat
c/o Canadian Wildlife Service
4th Floor PVM, 351 Joseph Blvd
Hull, QC K1A 0H3
Tel: 1-819-953-1410
On-line: http://www.speciesatrisk.gc.ca/publications/plans/whocra_e.cfm

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The 5 Canadian and 5 U.S. members currently serving on the Recovery Team provided overall recovery objectives and strategies. Members in March, 2006, were Dr. George Archibald, Sandie Black DVM, Stuart Macmillan, Anne Riemer, Dr. John French, Brian Johns, Deborah Johnson, Marty Folk, Dr. Felipe Chavez-Ramirez, and Tom Stehn.

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GLOSSARY OF ACRONYMS

A	Alberta
AFLP	Amplified Fragment Length Polymorphisms
ANWR	Aransas National Wildlife Refuge
APLIC	Avian Power Line Interaction Committee
AWBP	Aransas Wood Buffalo Population
BR	Bureau of Reclamation
CCWHC	Canadian Cooperative Wildlife Health Centre
CNWR	Chassahowitzka National Wildlife Refuge
CG	Coast Guard
CH	Critical Habitat
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CWS	Canadian Wildlife Service
CZ	Calgary Zoo
DVC	Disseminated Visceral Coccidiosis
EEE	Eastern Equine Encephalitis
EMP	Eastern Migratory Population
ES	Ecological Services (USFWS)
ESA	United States Endangered Species Act
FAA	Federal Aviation Authority
FCC	Federal Communications Commission
FERC	Federal Energy Regulatory Commission
FL	Florida Fish and Wildlife Conservation Commission
FP	Florida Population
GIS	Geographical Information System
GIWW	Gulf Intracoastal Waterway
GL	Grays Lake National Wildlife Refuge
IBD	Infectious Bursal Disease
ICF	International Crane Foundation
IFIM	Instream Flow Incremental Methodology
LDWF	Louisiana Department of Wildlife and Fisheries
LE	Law Enforcement (USFWS)
M	Manitoba
MOU	Memorandum of Understanding
MVP	Minimum Viable Population
NAS	National Audubon Society
N_e	Effective Population Size
NEPA	National Environmental Policy Act
NNWR	Necedah National Wildlife Refuge

NGO	Non-Government Organization
NWA	National Wildlife Area
NWF	National Wildlife Federation
NWHC	National Wildlife Health Center (USGS)
NWI	National Wetland Inventory
NWR	National Wildlife Refuge
OM	Operation Migration
PA	Public Affairs (USFWS)
PCA	Parks Canada Agency
PWRC	Patuxent Wildlife Research Center (USGS)
PRT	Platte River Whooping Crane Habitat Maintenance Trust
RMP	Rocky Mountain Population
RW	Refuges and Wildlife (USFWS)
S	Saskatchewan
SARA	Canadian Species at Risk Act
SAZ	San Antonio Zoo
SSC	Audubon Species Survival Center
TC	Transport Canada
TNRCC	Texas Natural Resources Conservation Commission
TPWD	Texas Parks and Wildlife Department
USACE	U. S. Army Corps of Engineers
USFWS	U. S. Fish and Wildlife Service
USGS	U. S. Geological Survey
WBNP	Wood Buffalo National Park
WCCA	Whooping Crane Conservation Association
WCCMT	Whooping Crane Captive Management Team
WCEP	Whooping Crane Eastern Partnership
WCHAT	Whooping Crane Health Advisory Team
WCRT	Whooping Crane Recovery Team
WI	Wisconsin Department of Natural Resources
WNV	West Nile Virus

PREFACE

The Whooping Crane Recovery Plan (Plan) was prepared under the authorities of the U.S. Endangered Species Act (ESA) of 1973, as amended, the Canada Wildlife Act of 1974, and the Canadian Species at Risk Act of 2003. Decision-makers are provided with an orderly set of events that, if carried to successful completion, will change the status of this species from the Endangered to the Threatened level. The Plan describes management and research actions that are underway and proposes additional actions needed to ensure the recovery of the whooping crane. Funding levels and time schedules are estimated, and priorities have been set for each management and research action. This revision of the Whooping Crane Recovery Plan describes recovery actions and costs required for the birds and habitat in both Canada and the United States. Part I covers basic biology of the species, historical and present distribution, habitat requirements, numbers and rate of growth, biological factors limiting the population, human threats, and conservation measures. Part II states the recovery goals, strategy, objectives and criteria, provides a step-down outline of specific actions needed for recovery, and describes protective actions to alleviate threats. Part III provides an implementation schedule for recovery. Parts IV and V provide contact information and key references. Appendices C and D, respectively, address recovery actions completed or underway, and summarize responses to public comments on the draft plan.

The recovery program for the whooping crane is an excellent example of international cooperation to save a species. Cooperative recovery actions of the 2 nations are outlined in a *Memorandum of Understanding on the Conservation of the Whooping Crane* approved in 1991 and updated at 5-year intervals. Development of this Plan by a joint Canada/U.S. Recovery Team is appropriate because the whooping crane's recovery is dependent upon conservation and management of the species in both countries.

As an international document, the Plan has a unique format to satisfy the requirements of both Canada and the United States. It was written in conjunction with 2 Canadian documents; *National Recovery Strategy for the Whooping Crane* (*Grus americana*) and *Action Plan for the Whooping Crane* (Johns and Stehn 2005a,b).

EXECUTIVE SUMMARY

Current Status and Distribution: In the United States, the whooping crane (*Grus americana*) was listed as threatened with extinction in 1967 and endangered in 1970 – both listings were "grandfathered" into the Endangered Species Act of 1973. Critical habitat was designated in 1978. In Canada the whooping crane was designated as endangered in 1978 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and listed as endangered under the Species at Risk Act (SARA) in 2003. Critical habitat in Canada is officially designated upon publication of a final SARA Recovery Strategy or Action Plan on the SARA Public Registry.

Whooping cranes occur only in North America. They currently exist in the wild at 3 locations and in captivity at 9 sites. The February 2006 total wild population was estimated at 338. This includes: 215 individuals in the only self-sustaining Aransas-Wood Buffalo National Park Population (AWBP) that nests in Wood Buffalo National Park (WBNP) and adjacent areas in Canada and winters in coastal marshes in Texas; 59 captive-raised individuals released in an effort to establish a non-migratory Florida Population (FP) in central Florida; and 64 individuals introduced between 2001 and 2005 that migrate between Wisconsin and Florida in an eastern migratory population (EMP). The last remaining wild bird in the reintroduced Rocky Mountain Population (RMP) died in the spring, 2002. The captive population contained 135 birds in February, 2006, with annual production from the Calgary Zoo (CZ), International Crane Foundation (ICF), Patuxent Wildlife Research Center (PWRC), Species Survival Center (SSC), and the San Antonio Zoo (SAZ). The total population of wild and captive whooping cranes in February, 2006, was 473.

Habitat Requirements: The whooping crane breeds, migrates, winters, and forages in a variety of habitats, including coastal marshes and estuaries, inland marshes, lakes, ponds, wet meadows and rivers, and agricultural fields.

Reasons for Listing and Limiting Factors: Historic population declines resulted from habitat destruction, shooting, and displacement by activities of man. Current threats include limited genetics of the population, loss and degradation of migration stopover habitat, construction of additional power lines, degradation of coastal ecosystems, and threat of chemical spills in Texas.

Recovery Goal**:** The recovery goal is to establish multiple self-sustaining populations of whooping cranes in the wild in North America, allowing initially for reclassification to threatened status and, ultimately, removal from the List of Threatened and Endangered Species (delisting). Populations may be migratory or non-migratory.

Recovery Strategy: The wild whooping crane population is characterized by low numbers, slow reproductive potential, and limited genetic diversity. A stochastic, catastrophic event could eliminate the wild, self-sustaining Aransas-Wood Buffalo population (AWBP). Therefore, the recovery strategy involves: protection and enhancement of the breeding, migration, and wintering habitat for the AWBP to allow the wild flock to grow and reach ecological and genetic stability; reintroduction and establishment of self-sustaining wild flocks within the species' historic range and that are geographically separate from the AWBP to ensure resilience to catastrophic events; and maintenance of a captive breeding flock to protect against extinction. Offspring from the captive breeding population will be released into the wild to establish these

populations. Production by released birds and their offspring will ultimately result in self-sustaining wild populations. The continued growth of the AWBP, establishment of additional populations, and maintenance of the captive flock will also address the loss of genetic diversity.

RECOVERY OBJECTIVES AND CRITERIA:

This plan sets forth 2 primary objectives and measurable criteria that will allow the species to be reclassified to threatened (downlisted). The numerical population criteria can only be achieved if threats to the species are sufficiently reduced or removed, i.e., the population criteria are a benchmark for threat reduction.

Objective 1 – Establish and maintain self-sustaining populations of whooping cranes in the wild that are genetically stable and resilient to stochastic environmental events.

> **Criterion 1 –** Maintain a minimum of 40 productive pairs in the AWBP for at least 10 years, while managing for continued increase of the population. Establish a minimum of 25 productive pairs in self-sustaining populations at each of 2 other discrete locations. A productive pair is defined as a pair that nests regularly and has fledged offspring. The two additional populations may be migratory or non-migratory. Population targets are 160 in the AWBP, and 100 each in the Florida non-migratory population and the eastern migratory population. All 3 populations must be self-sustaining for a decade at the designated levels before downlisting could occur.
>
> **Alternative Criterion 1A** – If only one additional wild self-sustaining population is re-established, then the AWBP must reach 400 individuals (i.e. 100 productive pairs), and the new population must remain above 120 individuals (i.e. 30 productive pairs). Both populations must be self-sustaining for a decade at the designated levels before downlisting could occur. This alternative is based on the principle that with the re-establishment of only one additional population separate from the AWBP, then crane numbers must be higher in both populations than if there are three distinct populations.
>
> **Alternative Criterion 1B -** If establishment of second and third wild self-sustaining populations is not successful, then the AWBP must be self-sustaining and remain above 1,000 individuals (i.e. 250 productive pairs) for downlisting to occur. The *Memorandum of Understanding on Conservation of Whooping Cranes*, approved by Canadian and U.S. federal officials, recognizes a goal of 1,000 individuals in the AWBP population. This higher number ensures a better chance for survival of the AWBP in the event of a catastrophic event within its extremely limited range. The target of 1,000 is reasonable for downlisting given the historical growth of the AWBP and theoretical considerations of minimum population viability. To ensure sufficient genetic variability, the AWBP must increase to the level where the creation of new alleles through genetic mutation will offset the loss of genetic diversity. After reaching the goal of 250 pairs, the population should gain genetic variation faster than the population loses genetic material.

Objective 2 – Maintain a genetically stable captive population to ensure against extinction of the species.

Criterion 2 - Maintain 153 whooping cranes in captivity (21 productive pairs). Genetic analysis suggests that 90% of the genetic material of the species can be sustained for 100 years at this population size (Jones and Lacy 2003). To achieve this, this Plan recommends having 50 captive breeder pairs of whooping cranes by 2010, including 15 pairs at PWRC, 12 at ICF, 10 at CZ, 10 at SSC, and 3 at SAZ. A breeder pair (as differentiated from a productive pair) is defined as a pair that breeds or is intended to breed in the future. Production from PWRC, ICF, CZ, SSC and SAZ will be the principal source of birds for release to the wild for reintroduced populations. However, sources of release birds should be based on the optimal genetic mix to ensure long-term population viability.

Delisting Criteria

Delisting criteria have not yet been established because the status and biology of the species dictate that considerable time is needed to reach downlisting goals. In addition, new threats are expected to arise and will have to be overcome before downlisting occurs. Additional information is also needed on the conservation biology of small populations, including a determination of effective population size (N_e) for whooping cranes to maintain genetic viability over the long-term, and impacts of stochastic and catastrophic events on population survival.

Actions Needed:

1. Continue to build the AWBP and protect and manage its habitat to minimize the probability that a catastrophic event will eradicate this population.

2. Attain breeder pair and productivity goals at 4 captive facilities in the United States and 1 in Canada to produce the birds required for reintroductions. Continue research to improve production of captive flocks.

3. Establish 2 additional self-sustaining wild populations. Continue research to identify appropriate reintroduction sites and improve reintroduction techniques. Protect and manage habitat of reintroduced populations.

4. Continue to use genetic information and advances in conservation biology to conserve flock genetics, and determine N_e and revise criteria as warranted.

5. Maintain an outreach program.

Date of Recovery: The estimated time to achieve downlisting is the year 2035. At current rates of reintroduction it takes over 10 years to build a population of more than 100 individuals. These individuals must then reach breeding age (3-5 years) and produce enough young to become self-sustaining for a decade to meet criteria for downlisting. This is expected to take a minimum of 30 years. New information gathered through recovery actions will be incorporated into additional population viability analyses as the population approaches its downlisting goals. Delisting criteria will be established at that time, and the overall recovery strategy and actions will be revised as appropriate.

Total Estimated Cost of Recovery ($000s):

The current budget expenditures needed annually for recovery are $6.1 million (US). The cost through 2010 is estimated at just over $30 million (US) and nearly $126 million (US) through 2035.

Year	Action 1	Action 2	Action 3	Action 4	Action 5	Total $ (000's)
2006	1394	1705	3030	0	15	6144
2007	1388.25	1705	3042.5	30	15	6180.75
2008	1388.25	1705	3042.5	0	15	6150.75
2009	1388.25	1705	3042.5	0	15	6150.75
2010	1388.25	1705	3042.5	0	15	6150.75
2011	1419.8	1609	3045	0	15	6088.8
2012	1419.8	1609	3045	5	15	6093.8
2013	1419.8	1609	3045	0	15	6088.8
2014	1419.8	1609	3045	0	15	6088.8
2015	1419.8	1609	3045	5	15	6093.8
2016	1009	188	2025	0	6	3228
2017	1009	188	2025	0	6	3228
2018	1009	188	2025	0	6	3228
2019	1009	188	2025	0	6	3228
2020	1009	188	2025	0	6	3228
2021	1009	188	2025	0	6	3228
2022	1009	188	2025	5	6	3233
2023	1009	188	2025	0	6	3228
2024	1009	188	2025	0	6	3228
2025	1009	188	2025	0	6	3228
2026	1009	188	2025	0	6	3228
2027	1009	188	2025	0	6	3228
2028	1009	188	2025	0	6	3228
2029	1009	188	2025	0	6	3228
2030	1009	188	2025	0	6	3228
2031	1009	188	2025	0	6	3228
2032	1009	188	2025	5	6	3233
2033	1009	188	2025	0	6	3228
2034	1009	188	2025	0	6	3228
2035	1009	188	2025	0	6	3228
Total	34,226	20,330	70,925	50	270	125,801

PART I. BACKGROUND INFORMATION

INTRODUCTION

The whooping crane is a flagship species for the North American wildlife conservation movement, symbolizing the struggle for survival that characterizes endangered species worldwide. It is a large, distinctive, and photogenic bird, popular with the public and the media, and it is often used to illustrate endangered species literature.

Canadian Wildlife Service (CWS), Parks Canada Agency (PCA), U.S. Fish and Wildlife Service (USFWS), U.S. Geological Survey (USGS)-Biological Resources Division, Provincial Wildlife Agencies, the Florida Fish and Wildlife Conservation Commission (FL), Texas Parks and Wildlife Department (TPWD), Wisconsin Department of Natural Resources (WI), and other State Wildlife Agencies implement recovery with the support of many non-profit groups and private individuals (Lewis 1991). The Audubon Species Survival Center (SSC), Calgary Zoo (CZ), International Crane Foundation (ICF), National Audubon Society (NAS), National Fish and Wildlife Foundation, National Wildlife Federation (NWF), Operation Migration Ltd., San Antonio Zoo (SAZ), World Wildlife Fund, and the Whooping Crane Conservation Association (WCCA) are among the primary groups that have been or currently are active in promoting recovery.

The important role of the private citizen and private landowner in saving the whooping crane needs to be emphasized. Many migration stopovers occur on private lands. Sportsmen and other conservationists have helped protect wetlands throughout North America that cranes depend on during migration. In winter, a little over one-third of the flock is found on private lands (Tom Stehn, ANWR, pers. comm.). Many actions to protect the species have been carried out by private citizens, conservation organizations, sportsmen, and governments. Many people today can remember just how close the species was to extinction - there were fewer than 50 whooping cranes in North America prior to 1968, with an all-time low of 21 as recently as 1954.

Historically, population declines were caused by shooting and destruction of nesting habitat in the prairies from agricultural development. The species was listed because of low population numbers, slow reproductive potential (sexual maturity is delayed and pairs average less than 1 chick annually), cyclic nesting and wintering habitat suitability, a hazardous 4,000 km migration route that is traversed twice annually, and many human pressures on the wintering grounds. Current threats to wild cranes include collisions with manmade objects such as power lines and fences, shooting, predators, disease, habitat destruction, severe weather, and a loss of two thirds of the original genetic material. Threats to the captive flock include disease, accidents, and limited genetic material.

Whooping cranes in Canada nest in and near WBNP, migrate through Alberta, Saskatchewan, and occasionally Manitoba in spring and fall, and stage in fall in southern Saskatchewan. Spring and fall migration occurs in the central Great Plains of the U.S. The cranes winter on the central Gulf Coast of Texas at Aransas National Wildlife Refuge (ANWR) and vicinity. No individuals remain from reintroduction attempts in the Rocky Mountains that took place from 1975 to 1989, and in 1997, except for one male in captivity at ICF. In 1993, introduction of a non-migratory flock was initiated in the Kissimmee Prairie and surrounding area in central Florida south of Orlando. An attempt to establish a migratory flock between central Wisconsin and the central

Gulf Coast of Florida began in 2001. Captive whooping cranes are maintained at PWRC, Laurel, Maryland; ICF, Baraboo, Wisconsin; SSC, Belle Chasse, Louisiana; the Devonian Wildlife Conservation Center, Calgary Zoo, Calgary, Alberta; the SAZ, San Antonio, Texas; the New Orleans Zoo, New Orleans, Louisiana; the Lowry Park Zoo, Tampa, Florida; and Homosassa Springs State Wildlife Park in Homosassa, Florida.

SPECIES INFORMATION

Status

The whooping crane was listed as Endangered in 1970 in the United States by the USFWS, and in 1978 in Canada by the Committee on the Status of Endangered Wildlife (COSEWIC).

In the U.S., under Section 4(a)(2) of the ESA, the USFWS is charged with periodically reviewing the status of listed species to determine whether any species warrants reclassification. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) reviewed the status of the Whooping Crane in 1978 and again in 2000. The whooping crane was listed as an endangered species in Canada under the Species at Risk Act in 2003. COSEWIC must review the classification at least once every ten years. In both countries, the whooping crane remains endangered due to its low population size and the limited range of the single self-sustaining wild population.

Description

The whooping crane is in the Family *Gruidae*, Order *Gruiformes* (Krajewski 1989, Meine and Archibald 1996). The closest taxonomic relatives in continental North America are 5 races of sandhill crane (*G. canadensis*): the lesser (*G. c. canadensis*); Canadian (*G. c. rowani*); greater (*G. c. tabida*); Florida (*G. c. pratensis*); and Mississippi (*G. c. pulla*) (the last also listed as endangered by the USFWS (Meine and Archibald 1996). The common name "whooping crane" probably originated from the loud, single-note vocalization given repeatedly by the birds when they are alarmed.

Figure 1. Whooping crane pair with young.

Photo by Marty Folk, Florida Fish and Wildlife Conservation Commission.

As the tallest North American bird, males approach 1.5 m (5 ft) when standing erect, and exceed the greater sandhill crane in height by 12 to 20 cm (5 to 8 in) (Fig. 1). Males are generally larger than females. Captive males average 7.3 kg (16 lbs), and females average 6.4 kg (14 lbs). Seasonal weight variation in captivity is considerable, with a maximum in December and January and a minimum in July and August. Whooping cranes are sexually monomorphic

(Walkinshaw 1973). However, the guard call vocalization is sexually distinct (98.8% accurate, Carlson 1991) and the vocalization and visual components of the unison call are sexually distinct (Archibald 1975).

Adult plumage is snowy white except for black primaries, black or grayish alula (specialized feathers attached to the upper leading end of the wing), sparse black bristly feathers on the carmine crown and malar region (side of the head from the bill to the angle of the jaw), and a dark gray-black wedge-shaped patch on the nape. The size of the post-occipital patch located on the posterior portion of the crown varies considerably between individuals. The black primaries and alula are not visible when the wings are folded back, and the plumed, decurved tertials (type of wing feather located close to the body) ordinarily conceal the short tail. The strong bill is a dark olive-gray which becomes lighter during the breeding season. The area at the base of the bill is pink or rosaceous. The iris of the eye is blue at hatching, gradually turns gray in chicks, and by one year of age is yellow (Jane Chandler, PWRC, pers. comm.). The legs and feet are gray-black.

The juvenile plumage is a reddish cinnamon color. At age 80-100 days, the chick is capable of sustained flight. At age 120 days, white feathers begin to appear on the neck and back. Juvenile plumage is replaced through the winter months. The plumage is predominantly white by the following spring and the dark red crown, lores (area between eye and bill), and malar areas are apparent. Rusty juvenile plumage remains only on the head, the upper neck, secondary wing coverts (smaller feathers covering middle of wing), and scapulars (wing feathers arising from the shoulder) (Stephenson 1971). Yearlings achieve typically adult plumage late in their second summer.

Life Span

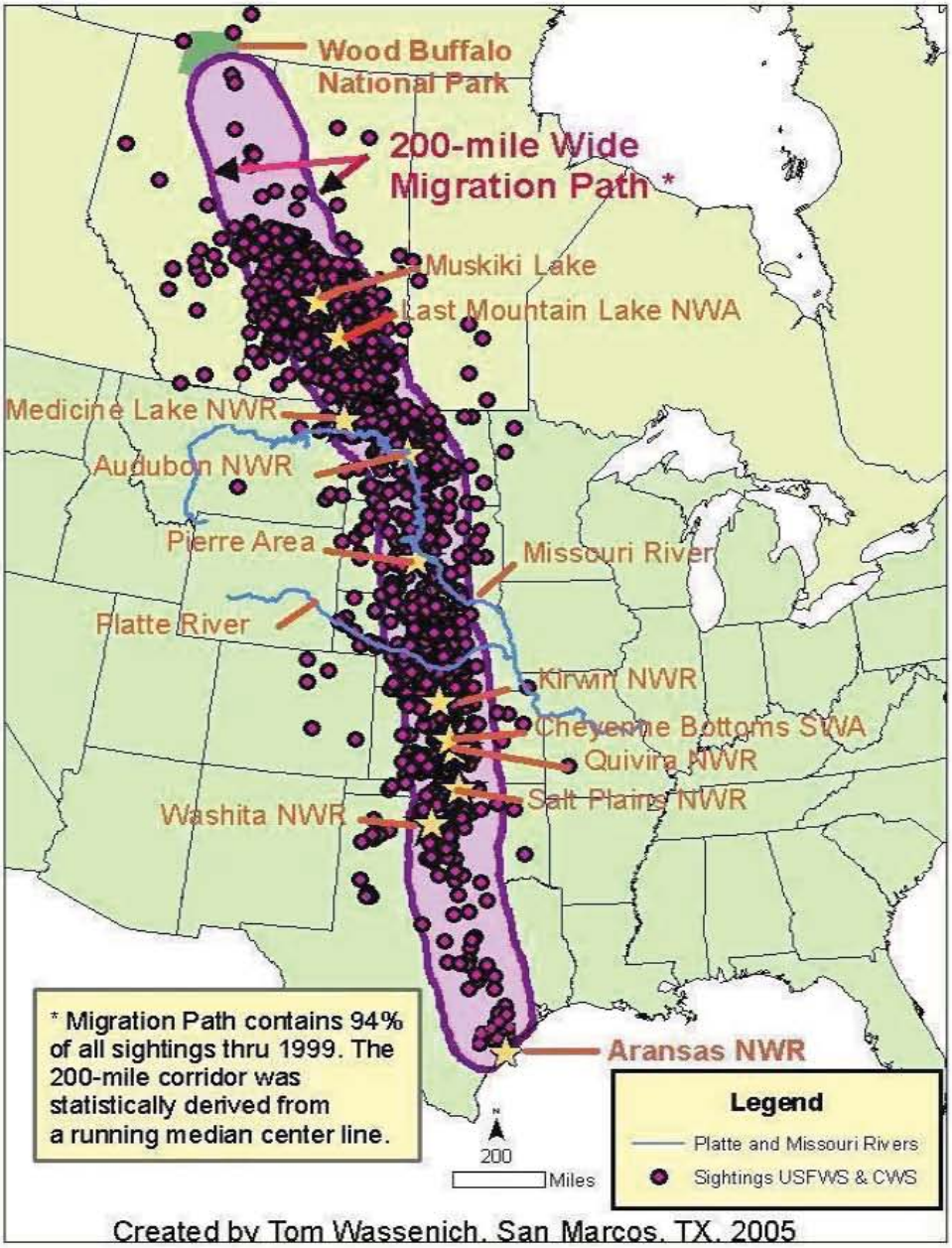
Whooping cranes are a long-lived species. Wild whooping cranes were not individually marked until 1975 (Drewien and Bizeau 1978, Kuyt 1978a, 1979a); consequently, some aspects of their life history and population biology remain uncertain. Current estimates suggest a maximum longevity in the wild of at least 30 years (Mirande et al. 1993).

Binkley and Miller (1983) suggested a maximum life span of 22-24 years of age, however at present, 1 wild female died at age 28 and 1 male is currently 28 years old (Tom Stehn, ANWR, pers. comm.). Captive individuals live 35-40 years (Moody 1931, McNulty 1966). A 38-year-old male was still reproductively active in the captive flock at PWRC in 2002; he died in January 2003.

Mortality – Documented Losses

A complete census of the Aransas-Wood Buffalo population can only be done during the 5-6 months the flock is on the wintering grounds. A total census has never been attempted in WBNP because the area occupied by whooping cranes, and particularly by subadults, is too extensive for such counts (Lewis et al. 1992a). Aerial counts have provided an annual estimate starting in 1950 of how many whooping cranes arrive at Aransas in the fall and how many depart in the spring. Lewis et al. (1992a) analyzed data on mortality of fledged whooping cranes. Prior to fledging, chick mortality is high and usually occurs during the first 2 weeks of life (Kuyt 1981b). Between 1950 and 1986, a total of 26 whooping cranes were lost on the wintering grounds

Figure 2. Breeding and wintering areas and primary migration pathway of the AWBP.



(Lewis et al. 1992a). This represents 1.4% of 1,893 wintering cranes. About 15% of the annual losses occurred during the 5 to 6 months the cranes spent on the wintering grounds (Lewis et al. 1992a). During these same years, birds that started migration in the spring and failed to return in the fall (e.g., April to November mortality) numbered 131, or 83.4% of the total losses (157). Mortality during April through November was 5 times greater than mortality on the wintering grounds. Data has not been analyzed subsequent to 1987. Aerial surveys in summer in WBNP indicate that summer losses are infrequent (Brian Johns, CWS, pers. comm.). Two losses

occurred among cranes summering on ANWR. Sixty to 80% of losses occur during migration, a period comprising only about 9 weeks (17%) of the bird's year, but a time when loses are high because the cranes are exposed to new hazards as they travel through unfamiliar environments (Lewis et al. 1992a).

Few carcasses are ever found, thus no known causes of mortality can be attributed to a high percentage of losses. As previously noted, the principal known cause of loss during migration is collision with utility lines. Probable cause of death has been identified for 8 whooping cranes, including 2 radio-tagged birds, which died on the wintering grounds from 1950 to 1987 (Lewis et al. 1992a). Known losses were due to: shooting (2 known and a third suspected); avian tuberculosis (1); shooting injuries that were likely sustained during fall migration (2) (i.e. birds arrived injured at Aransas NWR and later died), avian predation (1), and non-shooting trauma injury following fall migration (1) (Lewis et al. 1992a). Carcasses of 13 birds in migration have been recovered. Five of the 13 losses were due to collision with power lines, 4 others suffered trauma injuries due to collisions or gunshot injuries, 1 was shot, 1 died in a muskrat trap, 1 may have had a heart muscle disease and 1 may have had a viral infection (Lewis et al. 1992a).

Breeding Ecology

Whooping cranes may start nesting, defined as laying eggs, as early as 3 years of age (Kuyt and Goossen 1987, Brian Johns, CWS, pers. comm.). However the average age of first egg production is 5 years (Kuyt and Goossen 1987). From the results of color-banding studies in the AWBP, 3-year-old whooping cranes have been documented nesting 10 times (5 males and 5 females), including one instance where both members of the pair were 3 years old (Kuyt and Goossen 1987, Brian Johns, CWS, pers. comm.). In the FP, 3-year-olds have nested on 4 occasions, including 1 pair with both cranes that were 3-years-old. The first two nesting attempts documented for the EMP included one female that was 3-years-old and a pair with both cranes that were 3-years-old.

Pair formation can occur rapidly or be a lengthy process. Bishop (1984) observed pair bonds that developed over 1 to 3 winters from associations in subadult flocks on the wintering grounds. Stehn (1997) observed that 27.7% of pair bonds formed during spring migration or on the breeding grounds without any prior association at Aransas. Bishop and Blankinship (1982) documented several instances in which 2- and 3-year-old color-banded birds paired with unmarked birds. Whooping cranes are monogamous, but will re-pair, sometimes within only a few days, following the death of their mate (Blankinship 1976, Stehn 1992c, 1997).

Experienced pairs arrive at WBNP in late April and begin nest construction. They show considerable fidelity to their breeding territories, and normally nest in the same general vicinity each year. Several pairs have nested in the same areas for 22 consecutive years. These nesting territories, termed "composite nesting areas", vary considerably in size, ranging from about 1.3 to 47.1 km^2 (0.8 to 29 mi^2) but averaging 4.1 km^2 (2.5 mi^2) (Kuyt 1976a, 1976b, 1981a, 1993a). Adjoining pairs usually nest at least 1 km (0.6 mi) apart; however, nests have been recorded as close as 400 m (435 yds) from each other (Brian Johns, CWS, pers. comm.). From the initiation of egg laying until chicks are a few months of age, the activities of pairs and family groups are restricted to the breeding territory.

Eggs are normally laid in late April to mid-May, and hatching occurs about 1 month later. The incubation period is from 29 to 31 days (Kuyt 1982). Kuyt (1995) reported that "Among 514 clutches observed between 1966 and 1991, 454 (90.8%) contained 2 eggs, 43 (8.6%) only 1 egg, and 3 (0.6%) 3 eggs." Eggs are light brown or olive-buff overlaid with dark, purplish-brown blotches concentrated primarily at the blunt end. Eggs average 100 mm in length and 63 mm in width (Bent 1926, Allen 1952, Stephenson and Smart 1972, Kuyt 1995). Whooping cranes may re-nest if their first clutch is destroyed or lost before mid-incubation (Erickson and Derrickson 1981, Kuyt 1981b, Derrickson and Carpenter 1982). However, egg predation is uncommon, and re-nesting by whooping cranes has only been documented a few times (Kuyt 1981b). Whooping cranes generally nest annually, but may skip a season when nesting habitat conditions are unsuitable, if they are nutritionally stressed (Chavez-Ramirez et al. 1997, Johns 1998b), or for other (not apparent) reasons. In 2005, 12 out of 70 known adult pairs (17.1%) failed to nest in WBNP.

Whooping cranes usually produce clutches of 2 eggs laid 48-60 hours apart. Incubation begins with the first egg laid, resulting in asynchronous hatching of the eggs. This asynchrony may follow the insurance hypothesis, as discussed by Forbes and Mock (2000), where parents add marginal offspring to their clutch/brood as a hedge against early failure of core brood members. Hatching asynchrony may be an adaptation to the availability of food resources or a means of ensuring that the adults do not expend an inordinate amount of time attending to 2 young if they are in marginal habitat. In whooping cranes, eggs laid after incubation has begun usually only produce fledged young if the earlier laid egg fails to hatch or the chick dies soon after hatching. Not attempting to breed in a particular year may be a time and energy saving adaptation to prepare for a future breeding season (Stenning 1996).

Erickson (1975) noted that although whooping cranes may lay 2 eggs, only about 10% of families arriving on the winter range have 2 chicks. About 90% of nests therefore contain 1 egg that is unlikely to result in a fledged chick. However, the second egg plays an unknown role in providing insurance that at least one chick survives. Boyce et al. (2005) suggest that removal of the second egg could actually increase the likelihood that one chick fledges. In nests with 2 eggs, the first hatched has the greater chance of survival in the wild. Habitat conditions, including food availability and predator abundance, affect survival. In years with suitable habitat conditions crane pairs may raise 2 young (Johns 1998a). For example, during the 1958-59 winter, 8 of the 9 young that arrived at Aransas were from twin pairs. In 1997 and 1998, at least 9% of second hatched whooping crane young survived to fledging age (Bergeson et al. 2001a).

During the years from 1938-l964, prior to egg-removal at WBNP, 101 single chicks and 15 pairs of "twin" siblings arrived at Aransas NWR from 230 nests or 213 2-egg clutches (Kuyt 1987). "Twins" arrived in 9 of the 29 years. No pairs brought 2 juveniles during the egg-pickup years 1965-1996 even though a few nests were left with 2 eggs in most years. Between 1997-2004, with no egg pickup, 8 pairs successfully raised twin chicks to fledging age (Brian Johns, CWS, pers. comm.), however only 4 pairs brought twin chicks to Aransas NWR (Tom Stehn, ANWR, pers. comm.).

Whooping crane parents share incubation and brood-rearing duties. Except for brief intervals, 1 member of the pair remains on the nest at all times. Females tend to incubate at night (Allen 1952, Walkinshaw 1965, 1973) and take the primary role in feeding and caring for the young (Blankinship 1976). Chicks are capable of swimming shortly after hatching; however, parents

and young return to the nest each night during the first 3-4 days after hatching. Later, parents brood their young wherever they are at night or during foul weather. During the first 20 days after hatching, families generally remain within 1.8 km of the nest site (Ernie Kuyt, pers. comm.) with daily movements averaging 340 m (Doug Bergeson, pers. comm.).

Information on marked individuals suggests that most juveniles and subadults spend the summer near their natal area (Kuyt 1979b, 1981a). Sexually immature birds (up to 4-year-olds) spend the summer as singles, pairs or in small groups of 3 to 5 birds. These birds usually occur on the peripheries of territories of nesting pairs.

Migratory Behavior

As spring approaches, "dancing" behavior (running, leaping and bowing, unison calling, and flying) increases in frequency, and is indicative of pre-migratory restlessness (Allen 1952, Blankinship 1976, Stehn 1992b). Family groups and pairs are usually among the first to depart wintering grounds, often assisted by seasonal strong southeast winds. First departure dates are normally between March 25 and April 15, with the last birds usually leaving by May 1. Occasional stragglers may linger into mid-May, and in 19 years, between 1938-2005, 1 to 4 birds (34 birds total) have remained at ANWR throughout the summer. Some of these birds were ill or crippled or mates of birds that were crippled. The spring migration is usually completed in 2-4 weeks, more rapidly than the reverse trip in the fall, as there is no known spring staging area.

Parents separate from their young of the previous year upon departure from ANWR, in northward migration while in route to the breeding grounds or soon after arrival on the breeding grounds (Allen 1952, Stehn 1992a, B. Johns, CWS, pers. comm.).

Autumn migration normally begins in mid-September, with most birds arriving on the wintering grounds between late October and mid-November. Occasionally, stragglers may not arrive until late December. Whooping cranes migrate south as singles, pairs, in family groups, or as small flocks of 3 to 5 birds (Johns 1992). They are diurnal migrants and make regular stops to feed and rest. Large groups of up to 20 sometimes use the same stopover location. Pairs with young are among the last to leave the breeding range (Allen 1952, Archibald et al. 1976, Stephen 1979). The migration corridor (Fig. 2) was determined by mapping confirmed sightings reported by individuals (Stephen 1979, Johnson and Temple 1980, Austin and Richert 2001) and radio-tracking whooping cranes during the period 1981-1984 (Kuyt 1992). Their first stop often occurs in northeast Alberta or northwest Saskatchewan, about 500 km southeast of their departure area in WBNP. Local weather conditions influence distance and direction of travel, but whooping cranes generally are capable of reaching the autumn staging grounds in the north-central portion of the Saskatchewan agricultural area on the second day of migration. Most of the cranes remain for 2 to 4 weeks in the large triangle between Regina, Swift Current, and Meadow Lake, where they feed on waste grain in barley and wheat stubble fields and roost in the many wetlands (Johns 1992). The remainder of the migration from Saskatchewan to the wintering grounds is usually rapid, probably weather-induced, and may be completed in a week (Kuyt 1992).

Winter Ecology

For almost half of the year, whooping cranes occupy winter areas on and adjacent to ANWR. Although close association with other whooping cranes is tolerated at times on the wintering

grounds, pairs and family groups typically occupy and defend relatively discrete territories. Studies indicate a declining territory size as the population increases, with territories averaging 117 ha (Stehn and Johnson 1987). Limited expansion of the wintering area has occurred (Tom Stehn, pers. comm.). Subadult and unpaired adult whooping cranes form small flocks and use areas outside occupied territories (Blankinship 1976, Bishop and Blankinship 1982). Subadults tend to winter near the territories where they spent their first year (Bishop 1984). Paired cranes will often locate their first winter territory near the winter territory of one of their parents (Bishop 1984, Stehn and Johnson 1987).

Diet

Whooping cranes are omnivorous (Walkinshaw 1973), probing the soil subsurface with their bills and taking foods from the soil surface or vegetation. Young chicks are fed by their parents. They gradually become more independent in their feeding until they separate from the parents preceding the next breeding season. Summer foods include large nymphal or larval forms of insects, frogs, rodents, small birds, minnows, and berries (Allen 1956, Novakowski 1966, Bergeson et al. 2001b). Foods utilized during migration are poorly documented but include frogs, fish, plant tubers, crayfish, insects, and agricultural grains. The largest amount of time is spent feeding in harvested grain fields (Johns et al. 1997). The winter diet consists predominately of animal foods, especially blue crabs (*Callinectes sapidus*), clams (*Tagelus plebius, Ensis minor, Rangia cuneata, Cyrtopleura costada, Phacoides pectinata, Macoma constricta*), and the plant wolfberry (*Lycium carolinianum*)(Allen 1952, Uhler and Locke 1970, Blankinship 1976 and 1987, Hunt and Slack 1987, Chavez-Ramirez 1996). Most foraging occurs in the brackish bays, marshes, and salt flats on the edge of the mainland and on barrier islands. Occasionally, cranes fly to upland sites when attracted by fresh water to drink or by foods such as acorns, snails, crayfish and insects, and then return to the marshes to roost (Hunt 1987, Chavez-Ramirez et al. 1995). Uplands are particularly attractive when partially flooded by rainfall, burned to reduce plant cover or when food is less available in the salt flats and marshes (Bishop and Blankinship 1982). Some whooping cranes use upland sites frequently in most years, but agricultural croplands adjacent to ANWR are rarely visited.

High fall tides and heavy rains sometimes flood tidal flats. In these circumstances, the birds forage almost exclusively on blue crabs and wolfberry in flooded areas. In December and January, tidal flats typically drain as a result of lower tides, and the birds move into shallow bays and channels to forage primarily on clams, although blue crabs are occasionally captured while probing the bottom. Clams are a significant dietary item when water depths are low, temperatures cold, and following drought when the blue crab population is low. Most clams and small blue crabs (5 cm or less in width) are swallowed whole. Larger crabs are pecked into pieces before being swallowed (Blankinship 1976).

The AWBP whooping cranes spend their summers and winters in restricted locations. Therefore, their pressure on local invertebrate food species may cause depletions, especially of blue crabs at Aransas. However, the total whooping crane population is so small that it is unlikely to exert any ecological effects except in small areas.

DISTRIBUTION

Historical Distribution and Abundance

Fossilized whooping crane remains from the Upper Pliocene in Idaho (Miller 1944, Feduccia 1967), and from the Pleistocene in California, Kansas, and Florida (Wetmore 1931, 1956) appear indistinguishable from the present form. Current evidence indicates that the species' historical range extended from the Arctic coast south to central Mexico, and from Utah east to New Jersey, South Carolina, Georgia, and Florida (Allen 1952, Nesbitt 1982). Distribution of these fossil remains suggests a wider distribution during the Pleistocene.

The major nesting area during the 19th and 20th centuries extended from central Illinois, northwestern Iowa, northwestern Minnesota, and northeastern North Dakota northwesterly through southwestern Manitoba, southern Saskatchewan, and into east central Alberta (Allen 1952)(Fig. 3). Some nesting apparently occurred at other sites such as Wyoming in the 1900's, but documentation is limited (Kemsies 1930, Allen 1952). Allen (1952) believed the whooping crane's principal wintering range was the tall grass prairies, in southwestern Louisiana, along the Gulf Coast of Texas, and in northeastern Mexico near the Rio Grande Delta. Other significant wintering areas were the interior tablelands in western Texas and the high plateaus of central Mexico, where whooping cranes occurred among thousands of sandhill cranes. Cannon (1998), Hayes, M. A. and J. Barzen (*In press*) and Gomez et al. (*In press*) provide additional insight into the historical distribution of the species.

In the 19th century, there were several migration routes. The two most important ones (Allen 1952:103) were "... those between Louisiana and the nesting grounds in Illinois, Iowa, Minnesota, North Dakota, Manitoba, and the other from Texas and the Rio Grande Delta region of Mexico to nesting grounds in North Dakota, the Canadian Provinces, and Northwest Territories." A route through west Texas into Mexico apparently followed the route still used by sandhill cranes, and it is believed the whooping cranes regularly traveled with them to wintering areas in the central interior highlands region (Allen 1952).

Another migration route crossed the Appalachians to the Atlantic Coast. These birds apparently nested in the Hudson Bay area of Canada. Wintering grounds included coastal areas of New Jersey, South Carolina, and more southerly river deltas. The specimen record or sighting reports for some eastern and mid-western locations are Alabama 1899; Arkansas 1889; Florida 1927 or 1928; Georgia 1885; Illinois 1891; Indiana 1881; Kentucky 1886; Michigan 1882; Minnesota 1917; Mississippi 1902; Missouri 1884; New Jersey 1857; Ohio 1902; Ontario 1895; South Carolina 1850; and Wisconsin 1878 (Burleigh 1944, Sprunt and Chamberlain 1949, Allen 1952, Hallman 1965).

Prior to 1950, Atlantic Coast locations used by whooping cranes included the Cape May area and Beesley's Point at Great Egg Bay in New Jersey; the Waccamaw River in South Carolina; the deltas of the Savannah and Altamaha Rivers, and St. Simon's Island in Georgia; and the St. Augustine area of Florida. Gulf Coast locations included Mobile Bay, Alabama; Bay St. Louis in Mississippi; and numerous records from southwestern Louisiana where the last bird was captured in 1950. Coastal Louisiana contained both a non-migratory flock and wintering migrants (Allen 1952).

Nesbitt (1982) summarized the following evidence that whooping cranes occurred in Florida, perhaps well into the 20th century. 0. E. Baynard, a respected field naturalist, said the last flock of whooping cranes (14 birds) he saw in Florida was in 1911 near Micanopy, southern Alachua County. Two whooping cranes were reported east of the Kissimmee River on January 19, 1936, and a whooping crane was shot and photographed north of St. Augustine, St. Johns County, 1927 or 1928.

Records from interior areas of the southeast include: the Montgomery area, Alabama; Crocketts Bluff on the White River, and near Corning, Arkansas; Jackson County near Kansas City, near Corning, Lawrence County southwest of Springfield, Audrain County, and near St. Louis, Misourri; and near Louisville and Hickman, Kentucky. It is unknown whether these records represent wintering locations, remnants of a non-migratory population, or wandering birds.

Although whooping cranes may never have formed large flocks and were thus reported infrequently, they ranged widely and utilized the vast wetland acreages available prior to the influx of white settlers. The growth of the AWBP at the end of the 20th century may provide insight for densities that could have occurred prior to colonial times. At WBNP, Kuyt (1993a) reported 13 nesting pairs had a mean home range size of 4.1 km sq (414 ha) and Doug Bergeson (pers. comm.) reported the mean home range size for 14 pairs as 3.8 km sq (384 ha). At ANWR, Stehn and Johnson (1987) found 86 whooping cranes distributed over 8,175 ha with an average territory size of 117 ha on the refuge where the density was highest. If these densities are expanded to the known historical distribution of the species, it is reasonable to assume that more than 10,000 whooping cranes once roamed across North America (Tom Stehn, ANWR, pers. comm.). This analysis differs from previously published information that was not based on current crane densities. Within the wintering area at ANWR and the nesting area in WBNP, the cranes are found within a relatively small area. Expanded throughout the known historical nesting and wintering range, the species may have been more numerous than reported, and by 1870 may have already been greatly reduced in number. It is erroneous to think that the whooping crane is not well adapted to its environment, was never numerous, and was about to become extinct even before human actions threatened the species (Tom Stehn, ANWR, pers. comm.).

Allen (1952:83) estimated that the whooping crane population in "... 1860, or possibly 1870, totaled between 1300 and 1400 individuals." Banks (1978), using 2 independent techniques, derived estimates of 500 to 700 whooping cranes present in 1870. The whooping crane disappeared from the heart of its breeding range in the north-central United States by the 1890s. The last documented nesting in the aspen parklands of Canada occurred at Eagle Lake (now called Kiyiu Lake), Saskatchewan, in 1922 (Hjertaas 1994). By 1944 only 21 birds remained in 2 small breeding populations: a non-migratory population that inhabited the area around White Lake in southwestern Louisiana, and the migratory AWBP that wintered on ANWR in coastal Texas and nested in an unknown location (Table 1). The last reported reproduction in the non-migratory Louisiana population occurred in 1939 (Lynch 1956, Gomez 1992, Drewien et al. 2001). In March, 1950, the Louisiana population ceased to exist as the last individual was captured and turned loose at Aransas but did not survive the summer. The nesting area of AWBP was discovered in 1954 in WBNP, Northwest Territories, Canada (Fig. 3).

Figure 3. The principal known breeding and wintering areas of the whooping crane (*Grus americana*) (adapted from Meine and Archibald 1996).

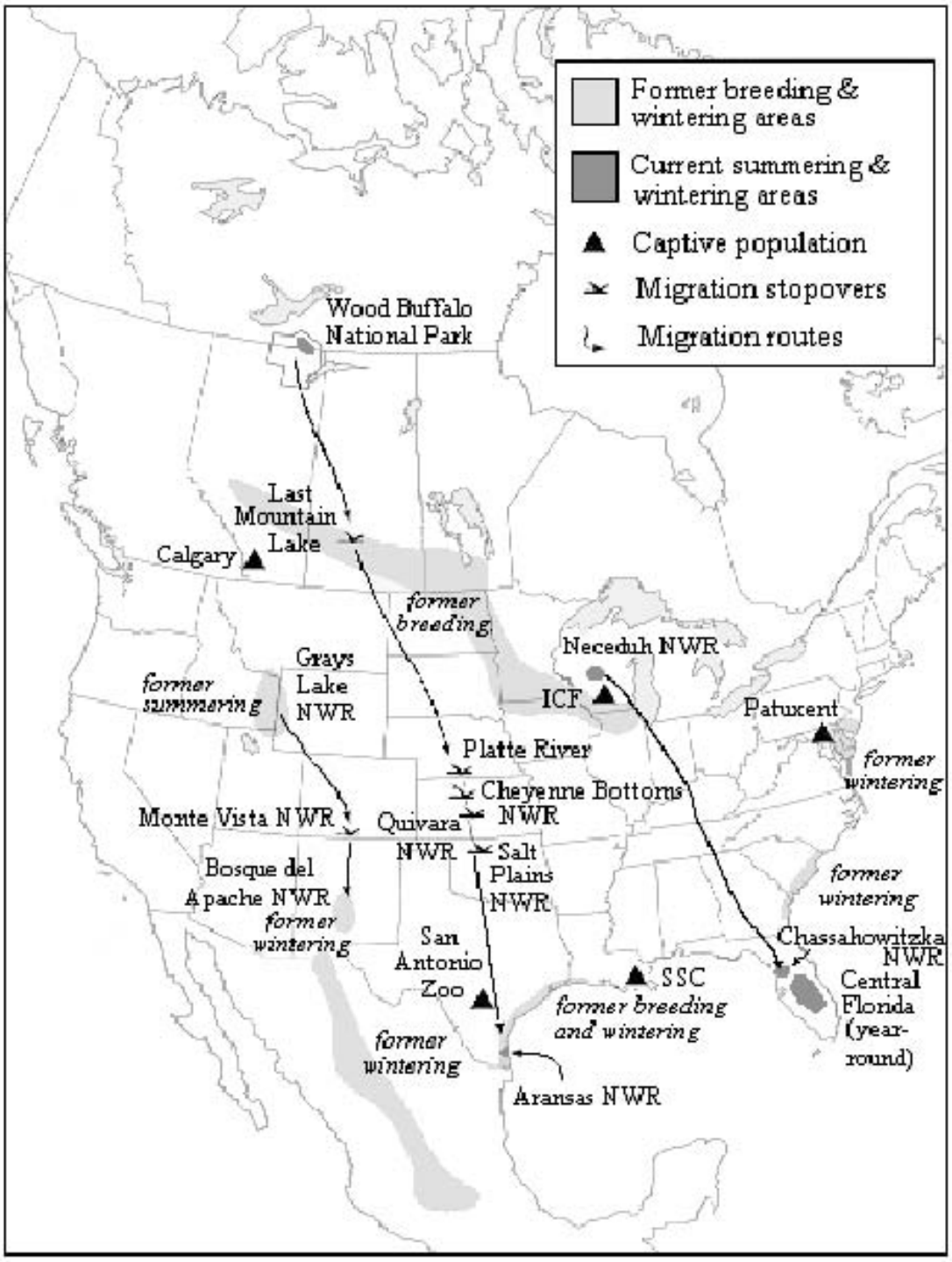


Table 1. Whooping crane peak winter numbers in North America 1938-2005.

AWBP					Louisiana	
Winter	**Adult[a]**	**Young[a]**				**Total**
1938-39	14	4			11	29
1939-40	15	7			13	35
1940-41	21	5			6	32
1941-42	14(13)	2			6	22
1942-43	15	4			5	24
1943-44	16	5			4	25
1944-45	15	3			3	21
1945-46	18(14)	4(3)			2	24
1946-47	22	3			2	27
1947-48	25	6			1	32
1948-49	27	3			1	31
1949-50	30	4			1	35
1950-51	26	5			0	31
1951-52	20	5				25
1952-53	19	2				21
1953-54	21	3				24
1954-55	21	0				21
1955-56	20	8				28
1956-57	22	2				24
1957-58	22	4				26
1958-59	23	9				32
1959-60	31	2				33
1960-61	30	6				36
1961-62	34	5				39
1962-63	32	0				32
1963-64	26(28)	7				33
1964-65	32	10				42
1965-66	36	8				44
1966-67	38	5				43
1967-68	39	9				48
1968-69	44	6				50
1969-70	48	8				56
1970-71	51	6				57
1971-72	54	5				59
1972-73	46	5				51
1973-74	47	2	**Rocky Mountain**			49
1974-75	47	2	**Adult**	**Young**		49
1975-76	49	8		4		61
1976-77	57	12	3	3		75
1977-78	62	10	6	2		80
1978-79	68	7	6	3		84
1979-80	70	6	8	7		91
1980-81	72	6	15	5		98
1981-82	71	2	13	0		86
1982-83	67	6	10	4		87
1983-84	68	7	13	17		105

Table 1, continued

AWBP			Rocky Mountain					Total
Winter	Adult	Young	Adult	Young				
1985-86	81	16	27	4				128
1986-87	89	21	20	1				131
1987-88	109	25	16	0				150
1988-89	119	19	14	0				152
1989-90	126	20	13	0				159
1990-91	133	13	13	0				159
1991-92	124	8	12	0	Florida[b]			144
1992-93	121	15	9	0	Adult	Young		145
1993-94	127	16	8	1	8			152
1994-95	125	8	4	0	16			153
1995-96	130	28	3	0	25			186
1996-97	144	16	3	0	56			219
1997-98	152	30	3	3	60			248
1998-99	165	18	4	0	57			244
1999-00	171	17	2	0	65		Eastern[b]	255
2000-01	171	9	2	0	74		Migratory[b]	256
2001-02	161	15	1	0	87		6	270
2002-03	169	16	0	0	85	1	21	292
2003-04	169	25	0	0	85	2	36	317
2004-05	183	34	0	0	66	5	47	335
2005-06	190	30	0	0	59	0	64	343

[a] Where two numbers occur in a column, the one in parentheses is the original count and the other is the adjusted number as explained in Boyce (1987). The 1945 count at ANWR and vicinity was 14 and 3, but 22 adult-plumaged birds returned to the refuge in the winter of 1946. Consequently, it is evident that some birds were not counted in 1945. The all-time low for the AWBP was either 15 or 16 in 1941.

[b] Number of birds present on December 31.

Current Distribution and Abundance

Whooping cranes occur only in North America within Canada and the United States. Approximately 83% of the wild nesting sites occur in Canada and 17% occur in Florida and Wisconsin. Sixty-four percent of the February, 2006, wild population (215 of 338 individuals) had summered in Canada, with 59 in Florida and 64 in the Wisconsin – Florida population. Currently, 16% of the captive individuals (22) remain in Canada and the balance (113) is housed in the United States.

The AWBP contained 215 individuals in February, 2006, and is the only self-sustaining wild population. This population nests in the Northwest Territories and adjacent areas of Alberta, Canada, primarily within the boundary of WBNP (Johns 1998b). In 2005, 58 of the 72 known adult pairs nested (Brian Johns, CWS, pers. comm.). These cranes migrate southeasterly through Alberta, Saskatchewan, and eastern Manitoba, stopping in southern Saskatchewan for several weeks in fall migration before continuing migration into the United States (Fig. 2). They migrate through the Great Plains states of eastern Montana, North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas. Their spring migration is more rapid and they simply reverse the route followed in fall. They winter along the Gulf of Mexico coast at ANWR and adjacent areas

(Fig. 4). The winter habitat extends 48-56 km along the coast from San Jose Island and Lamar Peninsula on the south to Welder Point and Matagorda Island on the north (Tom Stehn, ANWR, pers. comm.), and consists of estuarine marshes, shallow bays, and tidal flats (Allen 1952, Blankinship 1976). Some individuals occur occasionally on nearby privately owned pasture or croplands.

The second population of wild whooping cranes is non-migratory (Nesbitt et al. 1997) and occurs in central Florida. This population, known as the Florida Population (FP), has been designated experimental nonessential in the United States by the USFWS. First reintroduced in 1993, approximately 59 birds survived in February, 2006, from 289 captive-reared whooping cranes released over a 13-year period (Table 9). Two pairs first produced eggs in 1999 and the first chick fledged in 2002, the first chick in the U.S. to do so since 1939. In 2005, 8 pairs nested, 1 chick hatched, and none fledged. In summary, 41 pairs laid eggs between 1999 and 2005, 17 chicks hatched, and 4 fledged (Table 9). The FP is found primarily on the Kissimmee Prairie and surrounding areas. The Kissimmee Prairie is south of Orlando and consists of 500,000 ha of freshwater marsh and open grasslands in Osceola and Polk Counties associated with the flood plain of the Kissimmee River. Most grasslands are improved pasture used for livestock grazing and are heavily used by the cranes for foraging.

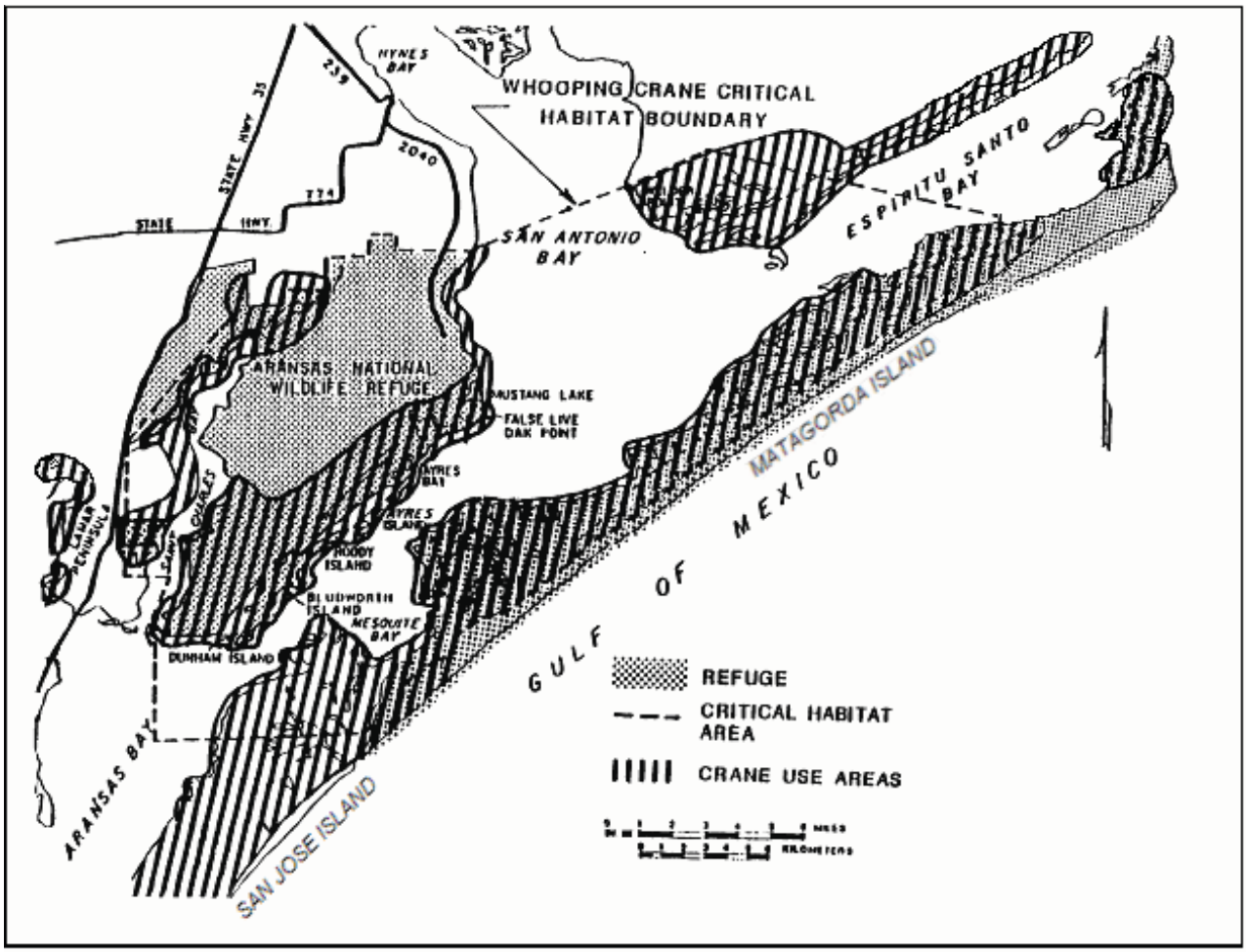
A third population of wild whooping cranes is migratory and was reintroduced starting in 2001. This population is referred to as the Eastern Migratory Population (EMP). Captive whooping cranes reared at PWRC are brought to the Wisconsin summering area, trained to fly behind ultralight aircraft, and led to Florida. This population migrates from the Necedah NWR (NNWR) in central Wisconsin to Chassahowitzka NWR (CNWR), a 12,500 ha expanse of salt marsh on the Gulf Coast of Florida. All 5 whooping cranes led south in 2001 survived the winter, returned to summer in central Wisconsin on their own, and returned to western Florida the subsequent winter. Additional birds are released directly into groups of older whooping cranes in central Wisconsin. As of February, 2006, this population numbered 64 birds.

No whooping cranes remain in the Rocky Mountains. The last bird from the cross-fostering experiment disappeared during migration from the winter grounds in 2002 at the age of 19. These birds had summered in Idaho, Montana, Utah, and Wyoming and wintered in New Mexico, staging in spring and fall near the Monte Vista NWR, Colorado. In 1989, because of the lack of breeding attempts and high mortality (Garton et al. 1989), the Recovery Team recommended to discontinue the reintroduction attempt. Additional guide bird and ultralight experiments were carried out through 1997, but not with an expectation of establishing a population in the Rocky Mountains.

As of February, 2006, 135 whooping cranes occur in captivity at 9 North American locations. The U.S. Geological Survey (USGS) maintains 55 adults at PWRC in Laurel, Maryland. The USFWS funds, cooperatively with ICF, 36 adult cranes at the Foundation facility in Baraboo, Wisconsin. Twenty adult birds are kept at the Devonian Wildlife Conservation Center operated by CZ. Eight whooping cranes are present at SSC, Belle Chasse, Louisiana. Their first egg was produced in 2003. Nine adult whooping cranes are at SAZ in San Antonio. The captive flocks at PWRC, ICF, CZ, SSC, and SAZ are the sources for captive-reared cranes used in the FP and EMP wild flocks. Since 1993, 14 to 48 young have been released annually into the wild in Florida with a total of 289. Between 2001 and 2004, a total of 54 young started the fall migration in Wisconsin behind ultralight aircraft. Whooping cranes are on public display at 6

locations, all in North America. Two birds each are present on display at CZ, Calgary, Alberta, Lowry Park Zoo, Tampa, Florida, SAZ in Texas, ICF in Baraboo, Wisconsin, and Audubon Zoo in New Orleans, Louisiana. One bird is at Homosassa Springs Wildlife State Park in Homosassa, Florida.

Figure 4. Wintering area of the Aransas Wood Buffalo Population, Aransas National Wildlife Refuge and Critical Habitat boundary on the Gulf of Mexico coast of Texas.



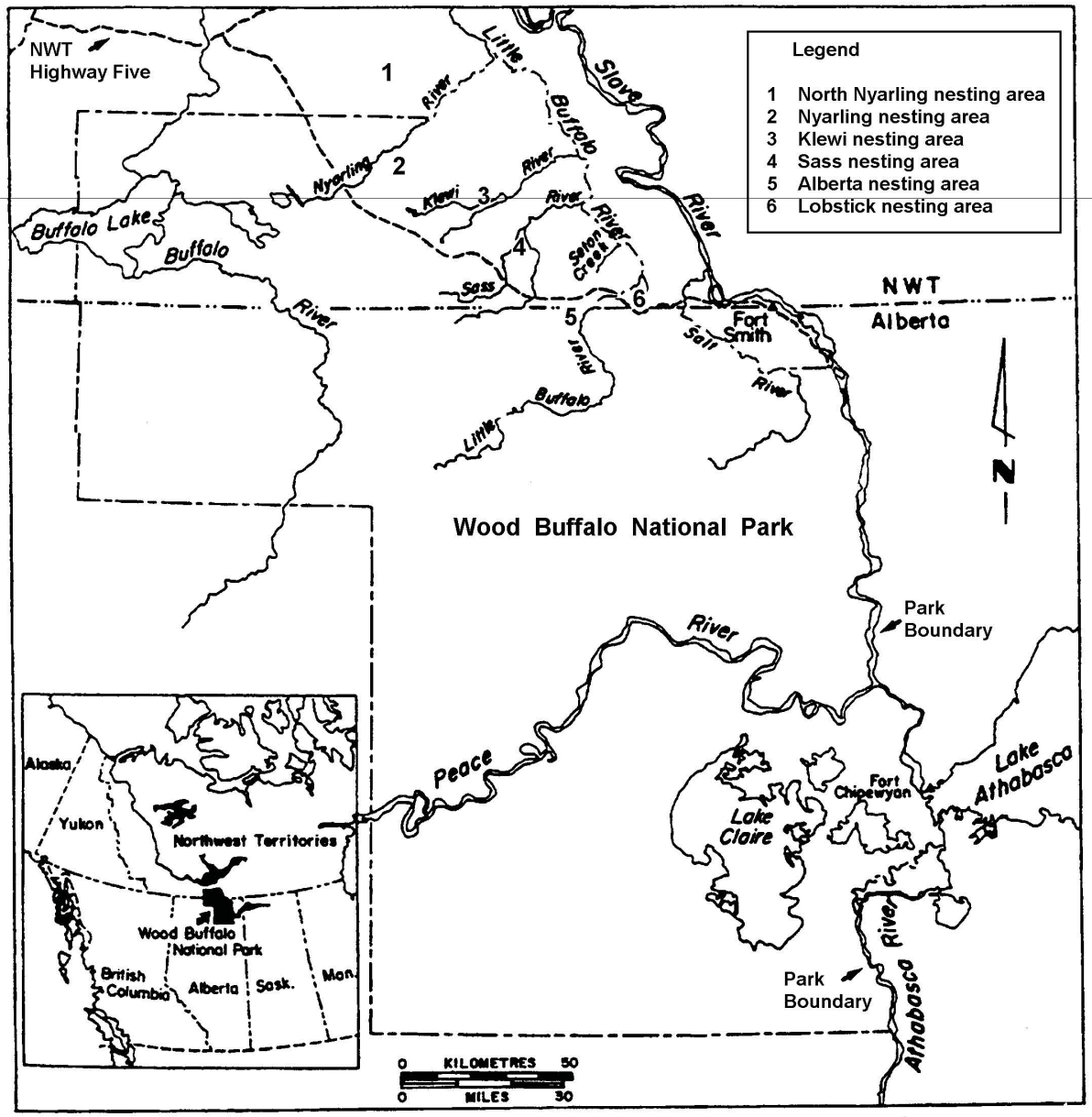
HABITAT REQUIREMENTS

Breeding Habitat

Whooping Cranes formerly bred in isolated marshes on the prairies and in aspen parkland. The current nesting area within WBNP lies between the headwaters of the Nyarling, Sass, Klewi, and Little Buffalo rivers (Fig. 5). The area is poorly drained and interspersed with numerous potholes. Wetlands vary considerably in size, shape and depth, and most possess soft marl bottoms (Timoney et al. 1997). Wetlands are separated by narrow ridges which support an over-story of white spruce (*Picea alauca*), black spruce (*P. mariana*), tamarack (*Larix laricina*),

willows (*Salix* spp.), and an understory of dwarf birch (*Betula glandulosa*), Labrador tea (*Ledum groenlandicum*), bearberry (*Arctosta phylos uva-ursi*), and several species of lichen, underlain by sphagnum moss (Novakowski 1966). Bulrush (*Scirpus validus*) is the dominant emergent in the potholes used for nesting, although cattail (*Typha* sp.), sedge (*Carex* aquatilis), musk-grass (*Chara* sp.), and other aquatic plants are common (Allen 1956, Novakowski 1965, 1966, Kuyt 1976a, 1976b, 1981a). Nest sites are primarily located in shallow diatom ponds that contain bulrush (Timoney 1997).

Figure 5. Breeding area of the Aransas Wood Buffalo Population, Wood Buffalo National Park.



Wildfires, caused primarily by lightning, are generally thought to have beneficial effects on crane habitat by recycling nutrients and removing and thinning vegetation on the forested ridges between nesting ponds, making the area more accessible to cranes. Fires have burned large portions of the nesting area during drought (e.g., 1981); however, wildfires do not appear to have influenced whooping cranes' choice of nest sites (Timoney 1999). Although molting adults or flightless young are vulnerable to fire, losses of eggs, chicks, or adults have not been confirmed. Due to the potential negative effects of a major fire control operation in the nesting area, it was advised that the area be classified as a modified response area where fire suppression activities are limited (Timoney 1997).

There is little competition by other species for nesting territories in WBNP (Kuyt 1989). Sandhill cranes are present on the nesting grounds; however, it is unlikely they would out-compete the larger whooping cranes for preferred nest sites and territories. Most territory overlap would probably occur on the drier sedge nest areas.

Although the quality of nesting habitat can be debated, there is no evidence that growth of the AWBP is limited by availability of summer habitat. Hatching success is high in most years (Kuyt 1976c, 198la, 1981b) and the area is remote from human activities. Thousands of hectares of unoccupied, apparently similar habitat are available in the area. Some new pairs have pioneered unoccupied nesting habitat adjacent to occupied range as the population has increased (Kuyt 1978b, Johns 1998a, Johns et al. *In press*). Wetlands suitable for breeding may still exist in the historical range on the Canadian prairies, although dry conditions in recent years and agricultural practices have greatly decreased the number and extent of these wetlands. A project of the CWS and Parks Canada was completed to identify suitable unoccupied nesting habitat within WBNP and adjacent areas (Olson and Olson 2003).

In 2005, 6 pairs nested just outside of WBNP. Additional expansion of the flock out of WBNP into adjacent areas of the Northwest Territories would occur on land with no formal protection. Land uses such as forestry, agriculture, and activities such as hunting could cause disturbance or change the quality of habitat available for cranes.

Migration Habitat

Whooping cranes use a variety of habitats during migration (Howe 1987, 1989, Lingle 1987, Lingle et al. 1991, Johns et al. 1997). Nine radio-tagged whooping cranes monitored for one or more seasons and others that associated with them fed primarily in a variety of croplands and roosted in palustrine (marshy) wetlands (Howe 1987, 1989). Seventy-five percent of the roosting wetlands were less than 4 ha and within 1 km of a suitable feeding site. More than 40% of the roosting wetlands were smaller than 0.5 ha. Johns et al. (1997) found that on average, wetlands were larger than those of Howe (1987, 1989), with spring sites averaging 36 ha and fall sites averaging 508 ha in size. The majority (94.9% spring; 72.9% fall) of these roost sites were also within 1 km of a suitable feeding site. Heavily vegetated wetlands were generally not used, but family groups appeared to select more heavily vegetated areas than non-families (Howe 1987, 1989). Cropland accounted for 70% of the feeding sites of non-families, but wetlands accounted for 67% of the feeding sites of families.

Clusters of migratory observations suggested relationships with large-scale spatial patterns in land cover (Richert et al. 1999, Richert and Church 2001). Areas characterized by wetland mosaics appear to provide the most suitable stopover habitat (Johns et al. 1997, Richert et al. *In press*). In states and provinces, excluding Nebraska, whooping cranes primarily used shallow, seasonally and semipermanently flooded palustrine wetlands for roosting, and various cropland and emergent wetlands for feeding (Johns et al. 1997, Austin and Richert 2001). Large palustrine wetlands included in this category (and the number of confirmed sightings through spring 2005) are those at Quivira NWR in Kansas (126), Salt Plains NWR in Oklahoma (84), Cheyenne Bottoms State Wildlife Area in Kansas (56), Last Mountain Lake NWA in Saskatchewan (58), and large reservoir margins in the Dakotas (Wally Jobman, USFWS files, Brian Johns, CWS files). Known staging areas and potential breeding wetlands on the prairies could be negatively impacted by drought, drainage, cattle grazing, contaminated runoff, or other disturbances associated with agricultural activities. Since fall staging habitat in Saskatchewan is primarily on private lands, conservation activities should include stewardship actions (Johns et al. 1997).

During migration, whooping cranes often are recorded in riverine habitats, especially in Nebraska. Frequently used riverine habitats (and the number of confirmed sightings through spring 2005) include: the South Saskatchewan River in Saskatchewan (42)(Brian Johns, CWS files); the Platte River (66), North and Middle Loup Rivers (18), and Niobrara River (14) in Nebraska; the Missouri River in North Dakota (8); and the Red River (3) in Texas (Wally Jobman, USFWS files). Cranes roost on submerged sandbars in wide, unobstructed channels that are isolated from human disturbance (Armbruster 1990).

Wintering Habitat

About 9,000 ha of salt flats on ANWR and adjacent islands comprise the principal wintering grounds of the whooping crane (Fig. 4). Marshes are dominated by salt grass (*Distichlis spicata*), saltwort (*Batis maritima*), smooth cordgrass (*Spartina alterniflora*), glasswort (*Salicornia* sp.), and sea ox-eye (*Borrichia frutescens*). Inland margins of the flats are dominated by Gulf cordgrass (*Spartina spartinae*). Interior portions of the refuge are gently rolling and sandy and are characterized by oak brush, grassland, swales, and ponds. Typical plants include live oak (*Quercus virginiana*), redbay (*Persea borbonia*), and bluestem (*Andropogon* spp.) (Stevenson and Griffith 1946, Allen 1952, Labuda and Butts 1979). In the last 30 years, many upland sites have been grazed, mowed, or burned under controlled conditions (Labuda and Butts 1979) to maintain oak savannah habitat. The refuge maintains as many as 3,300 ha of grassland for cranes, waterfowl, and other wildlife. Human visitation is carefully controlled, and other potentially conflicting uses of the refuge, such as activities associated with oil and gas exploration, are reduced when whooping cranes are present.

RATE OF POPULATION GROWTH

The whooping crane has a long-term recruitment rate of 13.9%, the highest of any North American crane population (Drewien et al. 1995). Annual growth of the population during the past 65 years has averaged 4.5% per year. Population studies indicate a 10-year cycle of unknown cause in survivorship (Boyce and Miller 1985, Boyce 1987, Nedelman et al. 1987). M. Boyce (pers. comm.) has correlated the crane cycle with that of boreal forest predator cycles. From 1983 to 1989, the AWBP population increased from 75 to a high of 146 birds, chiefly

because of suitable nesting habitat conditions during that period, then dropped to the anticipated 10-year low of 132 by the 1991-92 winter (Table 1). The AWBP then increased to a record high of 188 in the 1999-00 winter. Again, with the expected 10-year cycle, the population declined to 180 in 2000-01 and 176 in 2001-02, then rebounded to 185 in 2002-03, 194 in 2003-04 and 217 in 2004-05.

The growth of the AWBP up to the year 2000 seems to have resulted primarily from a decline in the mortality rate rather than an increase in recruitment. Between 1938-2000, 341 whooping cranes disappeared from the wild population. Annual mortality averages 9.8% (12.1% prior to 1970 and 7.6% since that time). In addition, recruitment has also declined from the pre-1970 average of 15.9% to 10.8%. If recruitment can be increased and if losses of white-plumaged birds can be reduced, population growth will accelerate. The factors causing the decline in recruitment are unknown, but identifying these sources and implementing remedial actions where feasible should be a high priority.

A Population Viability Assessment Workshop held in 1991 for the whooping crane was funded by the USFWS as a cooperative endeavor with CWS, U. S. Whooping Crane Recovery Team, Canadian Whooping Crane Recovery Team, ICF, The Captive Breeding Specialist Group, and Species Survival Commission of the International Union for Conservation of Nature. The final report included priorities for research and management of the wild and captive populations as a meta-population to maximize retention of genetic heterozygosity and minimize the risk of extinction (Mirande et al. 1993).

Several population viability analysis packages have been tested using whooping crane data from the AWBP (Mirande et al. 1997a, Brook et al. 1999). Annual growth of the population during the past 65 years has averaged 4.5% per year. If this rate continues, starting with a peak population of 185 birds in 2002, the population will reach 500 birds by 2025 and 1,000 birds by 2041 (John Cannon, pers. comm.). However, the standard deviation of the annual growth rates over the past 65 years has been 12.9%, almost triple the average annual growth rate. For example, the growth rate was as high as 33% in 1954-55 and as low as -38% in 1940-41. In the last 15 years, with a total population of >100 birds, the annual growth rate has varied from a high of 19% in 1994-95 to a low of -10% in 1990-91. This variation makes it difficult to predict the future population size for any given year. However, it is likely that the AWBP will continue to grow with a low probability (<1.0%) of extinction over the next 100 years (Mirande et al. 1997a).

Mirande et al. (1993) modeled the captive population from its establishment to 1991 and found a growth rate of 1.1% (SD+-0.114). At that rate a population of 127 birds would retain only 89% of the initial heterozygosity at the end of 100 years. However, many of the captively bred cranes were released during the cross-fostering experiment in the Rocky Mountains between 1975 and 1989. Expansion and major improvements in production occurred in the 1990s and the program now demonstrates the capacity to support the non-migratory reintroduction program in Florida. The captive flocks have contributed 289 young to the Florida introduction between 1993-2005, with 250 from captive-produced eggs, and 39 from WBNP eggs hatched in captivity.

THREATS AND REASONS FOR LISTING

The 1967 Federal document that first listed the whooping crane as in danger of extinction did not address the five factor threats analysis later required by Section 4 of the 1973 ESA. However, we address these factors in the summary below to organize threats to the species in a manner consistent with current listing and recovery analyses under the ESA. The five factor analysis is also utilized in Part II to address how threats are minimized by proposed recovery actions (see *Reduction or Alleviation of Threats to Whooping Cranes through Implementation of Recovery Actions*).

<u>Listing Factor A: The present or threatened destruction, modification, or curtailment of habitat or range.</u>

Human Settlement: The growth of the human population in North America has resulted in significant whooping crane habitat alteration and destruction. Historically, whooping cranes declined or disappeared as agriculture claimed the northern Great Plains of the U.S. and Canada (Allen 1952). By the mid-1900s, only one small population survived. Ironically, the steadfast use of a traditional summer area that appears to have saved the whooping crane as a small, relict breeding population in WBNP, prevents its voluntary return to what was once its principal nesting range. Re-colonization of these historic breeding areas remains unlikely unless humans assist with reintroductions or habitat restoration.

Conversion of pothole and prairie to hay and grain production made much of the historic nesting habitat unsuitable for whooping cranes. Disruptive practices included draining, fencing, sowing, and the human activity associated with these actions. Settlement of the mid-continent and coastal prairies and associated disturbance, in addition to alteration of habitat, may have interfered with continued use of prairie and wetlands by breeding whooping cranes. The extensive drainage of wetlands in the prairie pothole region of Canada and the United States also resulted in a tremendous loss of migration habitat available to whooping cranes. Water diversions on major river systems, such as the Platte River, have degraded migration habitat.

Freshwater Inflows: Currently, expanding human populations throughout the range of the whooping cranes continue to threaten survival and recovery of the birds. Impacts are particularly severe on the winter grounds. Freshwater inflows starting hundreds of kilometers inland, primarily from the Guadalupe and San Antonio rivers, flow into whooping crane critical habitat at Aransas; these inflows are needed to maintain proper salinity gradients, nutrient loadings, and sediments that produce an ecologically healthy estuary (TPWD 1998). Spring flows originating from the Edwards Aquifer are also crucial, especially in times of drought when they can make up 70% of Guadalupe River water. Inflows are essential to maintain the productivity of coastal waters and produce foods used by the whooping cranes. Coastal waters with low saline levels are maintained by these in-stream flows, providing drinking water for cranes that would otherwise fly inland for freshwater.

TPWD has recommended target inflow levels needed to maintain the unique biological communities of the Guadalupe Estuary (TPWD 1998), which includes whooping crane critical habitat. Unfortunately, mechanisms to guarantee these flows are not provided by Texas water law, and critics have challenged the size of the target inflows. In 2000, the San Marcos River Foundation applied for a water right that would leave 1.15 million acre-feet in the river, in

accordance with the flows recommended by TPWD for the Guadalupe estuary. The application was denied in 2003 but has been appealed and in February, 2005, was sent back by the court to the Texas Council on Environmental Quality for a re-hearing. Conservation flows were proposed in Senate Bill 3 in the Texas Legislature in 2005, but the bill was not acted upon in the House.

Upstream reservoir construction and water diversions for agriculture and human use reduce freshwater inflows. Many existing water rights are currently only partially utilized, but greater utilization is expected over time. Water rights continue to be granted on the Guadalupe, and some sections of the river are already over-appropriated. A proposal included in the state water plan proposes a diversion at the mouth of the Guadalupe River, pumping at least 94,500 acre-feet annually back to San Antonio for municipal use. As the San Antonio region grows, with population expected to double in the next 50 years (SAWS 2003), pumping from the Edwards Aquifer in times of drought threatens spring flows.

Projections indicate the river will be significantly threatened during periods of low flow and could cease to flow into the bay if all currently authorized water-use permits are utilized (National Wildlife Federation 2004). In 2002, American Rivers named the Guadalupe on their annual list of the 10 most endangered rivers in the U.S. because of the inflow issue. In a report entitled *Bays in Peril,* a "Danger" ranking was given to San Antonio Bay because drought periods were predicted to increase by 250%, and years with low freshwater pulses in the spring were calculated to increase 26% from naturalized levels (National Wildlife Federation 2004). Texas Water Development Board data indicate natural droughts already threaten the Guadalupe ecosystem. Withdrawals of surface and groundwater for municipal and industrial growth are predicted to leave insufficient inflows to sustain the ecosystem in less than 50 years. Modeling indicates that if all existing water rights were exercised during a repeat of the 1950-1956 drought, estuary inflows would be reduced by 17% to 43% below current levels and by 36% to 72% below historic levels, depending on the year (Norman Johns, National Wildlife Federation, Austin, TX, pers. comm., in Fitzhugh and Richter, 2004). Additionally, there are pending water right applications for much of the remaining unappropriated water in the Guadalupe.

A simple inverse relationship exists between blue crab catch rates and mean salinity within an estuary (Longley 1994). Inflows are already at times insufficient and reduced over historic levels, leading to increases in mean salinity and decreases in blue crabs, the primary food of the whooping cranes. Long before ecosystem collapse, due to lack of inflows, significant adverse impacts to blue crab populations would occur (Kretzschmar 1990). By 2040, due to constructed diversions, a decrease of freshwater inflows into the crane's winter range is projected in an average year to cause an 8% decline in blue crab populations (Texas Department of Water Resources 1980), but could have a much larger impact in drought years (Norman Johns, National Wildlife Federation, Austin, Texas, pers. comm.).

<u>Listing Factor B: Overutilization for commercial, recreational, scientific, or educational purposes.</u>

Shooting: Hunting was one of the primary reasons for the whooping crane's historical decline. Allen (1952:75) recorded 389 whooping cranes known to have died from gunshot or other causes from colonial times to 1948. The majority of documented mortalities (274 cranes) occurred between 1870 and 1930. Most losses (about 66%) occurred during migration, especially

between the 1880s and 1920s (Allen 1952). Allen (1956) reported that nearly 200 taxidermy mounts, study skins, skeletons, and an undetermined number of eggs were in museums in the United States and Canada. Hahn (1963) indicated that 309 mounts and 9 skeletons existed in museums throughout the world. The lack of records associated with most of these specimens suggests few were collected by museum employees. Considering the low reproductive potential of the species, the shooting mortality possibly exceeded annual reproduction by the early 1900s.

Human-caused mortality of cranes declined following enactment of protective legislation. Although hunting whooping cranes is now illegal, shootings occasionally occur (Lewis et al. 1992a). Four documented shootings of AWBP whooping cranes occurred during migration or on the wintering grounds between 1968-1991. One whooping crane was shot by a snow goose hunter in 1968 just north of the ANWR boundary; another was shot reportedly mistaken for a snow goose (*Anser caerulescens*) along the bay edge of San Jose Island in January 1989. A vandal shot a whooping crane in Saskatchewan in April 1990, and another vandal shot one in April, 1991 as it migrated through Texas. Vandals shot 3 whooping cranes in Florida in 1999 and 2000. The most recently documented losses associated with hunting were an adult shot in migration near Ennis, Texas in November, 2003 and 2 (possibly 3) birds killed by sandhill crane hunters in central Kansas in November, 2004. A total of 12 documented shootings of whooping cranes in North America has occurred in the last 17 years (1989-2005). It is not known what percentage of shootings go undetected, nor what percentage of unexplained losses can be attributed to shootings. Although examinations of retrieved carcasses rarely have revealed the presence of shotgun pellets, 3 lead pellets were found during the post-mortem examination of a male from the Rocky Mountain population in January, 1984, that had died from disease (Snyder et al. 1992), and a pellet was found in the foot of a dead whooping crane in Michigan in 2004.

Whooping cranes of the AWBP occasionally associate with sandhill cranes during migration and RMP birds frequently associated with sandhill cranes. Hunting of sandhill cranes and snow geese occurs in and adjacent to areas used by migrating and wintering AWBP whooping cranes. Hunters may misidentify and shoot whooping cranes as these species. Sandhill crane hunting seasons in Canada and the United States in the migration corridor were originally seasonally timed or geographically limited to protect whooping cranes (Buller 1967, Archibald et al. 1976, Thompson and George 1987). Recent expansions of sandhill crane hunting seasons offer an increased potential for overlap with whooping crane migration periods and increased risks to whooping cranes (Konrad 1987, Brian Johns, CWS, pers. comm.). In some instances, large land units have been closed to sandhill crane or waterfowl hunting due to the presence of a flock or flocks of whooping cranes. Quivira NWR in Kansas is closed during most fall migrations whenever whooping cranes stop-over (David Hilley, Quivira NWR, pers. comm.). Tundra swan hunts recently initiated in the northern Great Plains (Montana, 1983; North Dakota, 1988; South Dakota, 1990) also present opportunities for misidentification and accidental shooting of whooping cranes.

Although occasional shootings do occur, some of these shootings are strictly acts of vandalism. Sportsmen and other conservationists have played crucial roles in helping whooping cranes (see Conservation Measures – page 31).

Disturbance: The whooping crane is sensitive to disturbance on the breeding grounds and will not remain near human activity. However, the egg transfer and banding programs have demonstrated that cranes will tolerate human intrusion for short intervals. Some disturbances

cause the birds to leave an area; the effects of others may be more subtle. The public does not have access to most of the whooping crane nesting habitat, but does have significant access to whooping crane winter habitat, as these water areas are public domain.

The accessibility of the cranes to humans at Aransas has led to a great number of people coming specifically to see the cranes. Up to 10,000 people ride whooping crane tour boats and in excess of 70,000 people visit the refuge annually, many hoping to see the cranes. These interactions build support for the species both locally and nationally, create awareness of existing threats to the cranes, and provide educational opportunities. Other human activities in the wintering area including waterfowl hunting and sport and commercial fishing are undertaken regardless of the presence of whooping cranes.

Increasing disturbance to whooping cranes on the wintering grounds has been a concern for many years (T. Lewis *In prep*.). As the Texas coast is developed, whooping cranes will have more interactions with people. Cranes are somewhat tolerant of people in carefully operated boats and land vehicles (Mabie et al. 1989). On the Aransas NWR, whooping cranes responded negatively to 40% of all disturbances (T. Lewis *In prep.*). Whooping cranes disturbed for 17 minutes for each hour observed, moved an average of 525 m from human disturbances and were displaced most often from open bay and wet marsh habitats (T. Lewis *In prep*.). Airboats, low-altitude aircraft, and especially helicopters cause disturbance, and cranes are particularly sensitive to humans on foot (Lewis and Slack 1992). Crane displacement results in short-term or long-term loss of habitat and social disruption of the flock (T. Lewis *In prep.*). Furthermore, disturbance to cranes limits their ability to obtain food resources and thus impacts fitness (T. Lewis *In prep.*). Although whooping cranes sometimes may be found close to humans in familiar situations, it is unknown what levels of stress may be associated with these encounters.

<u>Listing Factor C: Disease or Predation.</u>

Disease/Parasites: Little is known about the importance of diseases or parasites as mortality factors for wild whooping cranes. Loss of wetlands has concentrated birds using aquatic habitat, thereby increasing the risk of disease exposure and transmission. For example, avian cholera epizootics occur fairly regularly in several areas used by cranes; this disease has been confirmed in one whooping crane. Avian tuberculosis is known to impact the species, and infectious bursal disease (IBD) has had a major impact on reintroduction programs in Florida in some years. Additionally, human impacts on the environment and movements around the globe are resulting in emerging disease problems of possible significance to whooping cranes. For example, West Nile virus appeared for the first time in North America in 1999 and is now spreading rapidly. The H5N1 strain of avian influenza that has surfaced globally in 2005 is an emerging threat to both captive and wild flocks. Coccidia have been found in a whooping crane with an injured wing captured in WBNP and in whooping crane droppings collected on the Texas wintering grounds (Forrester et al. 1978), are common in cranes in the Florida release population (Spalding et al. 1996), and have caused deaths of several whooping crane chicks at PWRC (Carpenter et al. 1980). The defense of large territories and small brood size ensures low density use of the WBNP natal area, and thereby reduces the likelihood of coccidia oocysts being ingested in quantities sufficient to cause significant disease. However, the disseminated form of coccidiosis (DVC) is believed to have contributed to the mortality of 2 released whooping cranes in Florida (Marilyn Spalding, U. of Florida, pers. comm.) A variety of other parasites has been documented in released whooping cranes in Florida, but none have been proven to cause

significant disease (Spalding et al. 1996).

Although wild whooping cranes are presumably susceptible to a variety of infectious and toxicological diseases, evidence of disease-related mortality is infrequently documented. From 1976 to 1989, the USFWS necropsied or examined 25 whooping crane carcasses found dead in the field or removed from the wild because of sickness or debility. Of these, nine were diseased. Seven had avian tuberculosis (Snyder et al. 1997), a subadult crane captured in New Mexico was suffering from avian cholera (Snyder et al. 1987), and an adult died from acute lead poisoning (Brand et al. 1992, Snyder et al. 1992). The high incidence of avian tuberculosis indicates that whooping cranes may be particularly susceptible to this disease.

Predation: Adult whooping cranes generally are not susceptible to predation unless they are weakened by disease or injury, or are flightless during feather molt. However, eggs and chicks are predated (Bergeson et al. 2001a). Potential predators in the WBNP nesting ground include the black bear (*Ursus americanus*), wolverine (*Gulo luscus*), gray wolf (*Canis lupus*), red fox (*Vulpes fulva*), mink (*Mustela vison*), lynx (*Lynx canadensis*), and raven (*Corvus corax*). Black bears and other mammals destroy eggs, and wolves, foxes, and ravens kill chicks (Kuyt 198la, 198lb, Bergeson et al. 2001a). The overall impact of predation on AWBP recruitment remains uncertain but may be a factor in the 10 year population cycle (Boyce et al. 2005). Predator control is not considered an appropriate management technique within Canadian National Parks. Whooping cranes are also exposed to predators during migration (Lewis et al. 1992a). On numerous occasions, golden eagles disrupted human-led sandhill crane migrations behind trucks and ultralights. In the west, two attacks on juvenile whooping cranes were documented during migration. In 2002, a bald eagle killed a whooping crane hatchling in Florida. Bobcats (*Lynx rufus*) and alligators (*Alligator mississippiensis*) are significant predators of reintroduced whooping cranes in Florida. Bobcat predation appears most severe on individuals that do not show proper roosting behaviors or use habitat with heavy cover. Bobcats and coyotes also take cranes that are sick or injured at ANWR. Predation rates are significant in Florida, but appear to be very low in wild birds in Texas where cranes spend more time in coastal wetlands.

<u>Listing Factor D: The inadequacy of existing regulatory mechanisms.</u>

The whooping crane became endangered primarily from shooting and habitat loss prior to the enactment of major conservation legislation. The current legal framework (ESA, Migratory Bird Treaty Act, SARA, and NEPA) should provide for adequate protection and conservation of the whooping crane and its habitat.

<u>Listing Factor E: Other natural or anthropogenic factors affecting its continued existence.</u>

Multiple factors limit the growth of the AWBP. Some are related to the biological environment of the whooping crane, others are human-related.

Life History: Delayed sexual maturity, small clutch size, and low recruitment rate preclude rapid population recovery. Nesting can occur as early as age 3 (Brian Johns, pers. comm.), with the average age of first egg production at age 5 and the first fertile eggs at 5.4 years (Kuyt and Goossen 1987). The climate of the current northern breeding grounds may be another handicap to productivity as the ice-free season is only 4 months long (and may be getting shorter). During that time, pairs must incubate their eggs for 29-31 days and rear their chicks to flight age in 3

months. Consequently, unless nest loss occurs early in incubation, there is rarely time to lay a second clutch and fledge young if the first clutch fails.

Food Availability/Sibling Aggression: About 734 crane chicks were observed to hatch at WBNP during 1976-2001, and 381 (59% survival) arrived at Aransas the following winter (Brian Johns, CWS, pers. comm). Factors limiting chick survival are only partially known. Most mortality occurs soon after hatching, and chicks that fledge have a high probability of successfully completing their first migration (Kuyt 1976a). Most immediate post-hatching mortality may be related to sibling aggression and short-term food shortage because eggs hatch asynchronously and the precocial young are extremely aggressive toward each other. The dominant chick apparently obtains principal access to food made available by the parents; consequently brood-size is rapidly reduced during periods of food shortage (Drewien 1973, Miller 1973, Bergeson et al. 2001b). Prolonged food shortage, possibly related to drought, and drought-increased predation (Kuyt 1981b), may account for additional mortality.

Climatic Factors: Cold weather and precipitation soon after hatching may lead to loss of chicks; in particular, pairs with two young often lose one during these periods of adverse weather (Brian Johns, CWS, pers. comm.). While flooding of nests in WBNP is thought to be rare, drought is a far greater hazard. During drought, the attractiveness of traditional nest sites is reduced, food supplies are diminished, and newly-hatched chicks are forced to travel long distances between wetlands. Drought conditions also increase exposure of eggs and chicks to terrestrial predators. Whooping cranes are exposed to various natural obstacles and threats during migration. Snow and hailstorms, low temperatures, and drought can present navigational handicaps or reduce food and habitat availability. Hurricanes and drought can create problems on the wintering grounds. A late-season hurricane could place cranes at risk due to high wind velocities and flooding. Fortunately, the hurricane season ends (November 30) just after most whooping cranes arrive. Drought at Aransas influences availability and abundance of the natural food supply by altering salinity of tidal basins and estuaries (Blankinship 1976).

Global warming and associated climate changes constitute a potential threat to whooping crane recovery. Based on climate records and calculated rates of rises in greenhouse gas concentration from human activities, models of global climate change suggest that average global surface temperatures will increase by 1.4 and 5.8ºC (2.5 and 10.4ºF) by the end of this century (National Academy of Sciences 2005 website: http://www4.nas.edu/onpi/webextra.nsf/web/climate?OpenDocument). In the Northern Hemisphere, from 1951 to 1990, average minimum winter temperature rose 2.9ºC, while average summer maximum temperature rose 1.3ºC (Crozier 2003). In addition to rising temperatures, other climate factors such as the rising of sea level, flooding of coastal wetlands, drying of interior wetlands, and intensifying of precipitation events may impact the whooping crane. Although the frequency of future hurricanes is uncertain, hurricanes are expected to become stronger and bring more intense rainfall than hurricanes at present, due to increases in sea surface temperatures (NOAA website: http://www.gfdl.noaa.gov/~tk/glob_warm_hurr.html, updated March 23, 2006). Coastal wetlands are particularly vulnerable to erosion, changes in salinity and microclimate conditions, changes in groundwater tables, and habitat loss from expected rises in sea level and hurricane damage (EPA Global Warming Impacts Coastal Zones website: http://yosemite.epa.gov/OAR/globalwarming.nsf/content/ImpactsCoastalZones.html).

Climate change is expected to alter the physiology, distribution, phenology, and adaptation of organisms (Hughes 2000, Menzel et al. 2001, Stenseth et al. 2002, Peterson 2003, Parmesan and Yohe 2003). In turn, these processes may affect growth rates, individual size, individual mobility, overall fitness, reproductive success, and population demographics (Stenseth et al. 2002). Changes in ecosystem functioning, such as cycling of nutrients, and interactions among whooping cranes and their biotic resources, such as food species, plant communities, predators, parasites, competitors, and mutualists, are difficult to predict and involve an understanding of an ecosystem's resistance and resiliency to interference (Chapin et al. 2000). Habitat specialization of birds has been associated with sharper declines in population abundance (Julliard et al. 2003, Peterson 2003, Thomas C. et al. 2004, Thomas J. et al. 2004). Warming temperatures have caused a northward shift in bird species' ranges, hastened the timing of winter and summer activities, and are predicted to decrease biodiversity world-wide (Thomas and Lennon 1999, McCarty 2001, Thomas C. et al. 2004). For the whooping crane, this could affect current wintering areas, summering locations, and the timing of breeding and migration. These changes may alter the extent to which a bird's life cycle is synchronized with its food supply and nest site availability.

If climate change results in drier conditions either on the summer or wintering grounds, whooping cranes would face great difficulties from disruptions to the ecology of those areas. Any changes that adversely affect the water regime of WBNP could have severe impacts on whooping crane reproduction. Permanently lowered water tables, for example, would shrink wetlands, reduce the availability of quality nesting sites, reduce invertebrate food availability, and allow predators to access nests and young. Chick survival is reduced during dry years in WBNP (Kuyt et al. 1992). On the winter area, a reduction in rainfall would reduce inflows and reduce the blue crab population that the cranes rely on for food. Global warming and associated sea level rise, combined with land subsidence, is projected to be about 17 inches on the Texas coast over the next 100 years (Twilley et al. 2001). This would reduce suitability of salt marsh and open water areas, making much of the present acreage too deep for use by whooping cranes (Tom Stehn, ANWR, pers. comm.).

Loss of Genetic Diversity: As a consequence of the 1941 population bottleneck, the current population is derived from an estimated 6 to 8 founders, with a loss of 66% of all genetic material (Mirande et al. 1993, Glenn et al. 1999). Subsequently, the captive population, which is derived solely from the AWBP, has received this legacy of a reduced gene pool. This high level loss of genetic diversity may have serious implications for this population.

Genetic theories suggest that small populations can continue to lose genetic diversity with each generation, and that continued loss of genetic material leads to inbreeding depression and declining productivity (Jimenez et al. 1994, Frankham 1995, Lacy 1997, Brook et al. 2002, Woodworth et al. 2002). There is concern that the limited genetic material of the whooping crane may lead to reduced productivity in WBNP, and may contribute to increasing difficulty in captive propagation. Limited genetic diversity is a detriment to a population currently threatened with unprecedented global ecosystem change as well as introduced diseases. The AWBP is challenged to grow to a level where the creation of new alleles through mutation will offset its past, current, and future losses in genetic diversity. [A detailed discussion on genetic issues is presented in Appendix A.]

Red Tide: Red tide is a bloom of phytoplankton (*Gymnodinum breve*), a microscopic algae that

historically occurred infrequently on the Texas Coast. In recent years, it has occurred nearly annually during late summer and fall, lasting for several months. It is not known what factors are causing the increased number of outbreaks of red tide. A toxin produced by the algae can concentrate in filter-feeding mollusks, including clams. It has been known to cause bird die-offs and could pose a significant threat to whooping cranes that feed heavily on clams in mid-winter. Although red tide has been documented in critical habitat in recent years, no severe outbreaks have occurred.

Chemical Spills: The only self-sustaining wild population remains vulnerable to extirpation from a contaminant spill due to its limited wintering distribution along the Gulf Intracoastal Waterway (GIWW) on the Texas coast. Numerous oil and gas wells and connecting pipelines are located in bay and upland sites near the cranes winter habitat. Many barges carrying toxic chemicals travel the GIWW daily through the core of whooping crane winter habitat. A spill or leak of these substances could contaminate or kill the cranes' food supply, or poison the cranes (Robertson et al. 1993). Spills that occur in summer, when whooping cranes are absent, could adversely affect survival by reducing productivity of the environment or leaving a toxic residue.

Gulf Engineers and Consultants, Inc. (1992) assessed threats to the whooping crane and its habitat from spills of vessel fuels and cargoes. They concluded that the hazard of spill exists, but the probability of occurrence is low. Catastrophic events such as a large spill are infrequent, and therefore, difficult to predict. Ratification of the 1993 North American Free Trade Agreement and industrial growth in South Texas makes increased traffic likely on the GIWW, with a greater potential for accidents. Thus, the probabilities of occurrence of the most likely spill (1 per 1,075 years) and worst spill (1 per 7,982 years) predicted by Gulf Engineers and Consultants, Inc. (1992) are likely conservative and may increase over time. The worst spill estimated by the Environmental Protection Agency (1992) would involve approximately 33,000 barrels of liquids.

During July 1974, 25 to 50 barrels of # 6 crude petroleum leaked from a barge at ANWR. Nothing could be done to keep the oil from washing into canal banks and emergent vegetation along 16 km of shoreline between Mustang Lake and Sundown Bay. A barge-loaded dragline, marsh buggy, and hand labor removed contaminated soil and vegetation over an 18-day cleanup period. No losses of wildlife were noted, and fortunately the spill was small and occurred during summer when no whooping cranes were present.

The U.S. Coast Guard (CG) has the lead responsibility for spill response and containment. The USFWS has response plans for the Gulf of Mexico (USFWS 1979) and specifically for Aransas NWR (Robertson et al. 1993). It is impossible to provide full protection for the cranes as long as chemicals are transported on the GIWW through the heart of the winter range. Spills of hazardous chemicals may limit human approach to only those personnel wearing special protective suits and breathing apparatus. Spill of gaseous materials could directly kill all cranes downwind. The Aransas oil spill plan emphasizes rapid response time to limit the amount of habitat impacted. Minimum response time by refuge staff is 1-2 hours, and 3-4 hours for spill control specialists. An event occurring at night or in bad weather (the most probable times) would further slow response. High winds greatly reduce the effectiveness of containment booms for products floating on the surface.

If crane habitat becomes contaminated, the Aransas oil spill plan calls for hazing cranes away from the spill area and capturing individuals that become seriously contaminated.

The response of whooping cranes to spilled materials, and to humans trying to haze the cranes away, is currently unknown. Since adult cranes are territorial, it is likely not possible to haze them from their large territories. Food supplies such as grain or milo could be placed on the edges of crane territories, but the cranes would still return to salt marsh ponds at night for required safe roosting habitat. Oiled cranes would be captured when possible and cleaned, although wild cranes are very difficult to capture and susceptible to death from capture myopathy, especially when young (Tom Stehn, ANWR, pers. comm.).

Whooping cranes on the winter range also are exposed to contaminants associated with runoff from agricultural and industrial activities and subjected to risks associated with offshore and onshore gas and oil operations. Nearby Lavaca Bay was closed for multiple years to the harvesting of fish and crabs because of industrial pollution including high levels of mercury (Lewis et al. 1992b).

Collisions with Power Lines, Fences and Other Structures: Human settlement in the prairies brought rural electrification and the fencing of open lands. Currently, the number of power lines, communication towers, and wind turbines is increasing in the U.S. and may kill as many as 225 million birds annually (Manville 2005).

Collisions with power lines are a substantial cause of whooping crane mortality in migration (Brown et al. 1987, Lewis et al. 1992a). Collisions with power lines are responsible for the death or serious injury of at least 44 whooping cranes since 1956. In the 1980s, 2 of 9 radio-marked whooping cranes from AWBP died within the first 18 months of life as a result of power line collisions (Kuyt 1992). Of 27 documented mortalities in the RMP, almost 2/3 were due to collisions with power lines (40.1%) and wire fences (22.2%) (Brown et al. 1987). Twenty individuals within the Florida populations and 2 individuals in the migratory Wisconsin population have died hitting power lines.

Currently, an estimated 804,500 km of bulk transmission lines and millions of km of distribution lines exist in the U.S. (Manville 2005). Whooping cranes can collide with both types of lines (Stehn, and Wassenich *In prep*). Additional power line construction throughout the principal migration corridor will increase the potential for collision mortalities. An Avian Power Line Interaction Committee (APLIC) composed of 9 investor-owned electric utilities and the USFWS was established in 1989 to address the issue of whooping crane collisions (Lewis 1997). In 1994, APLIC provided voluntary guidelines to the industry on avoiding power line strikes (APLIC 1994). At present, the USFWS is working on MOUs that call for the development of avian protection plans by participating companies to reduce bird strikes (Manville 2005). Tests of line marking devices, using sandhill cranes as surrogate research species, have identified techniques effective in reducing collisions by up to 61% (Morkill 1990, Morkill and Anderson 1991, 1993, Brown and Drewien 1995). Techniques recommended include marking lines in areas frequently used by cranes and avoiding placement of new line corridors around wetlands or other crane use areas.

Guy wires associated with telecommunication towers (radio, television, cellular, and microwave) present another collision obstacle to cranes. Such towers have been increasing at an estimated 6 to 8% annually. The USFWS Office at Grand Island, Nebraska, reviewed 260 tower site actions for Nebraska in fiscal year 2000. The Federal Communication Commission's (FCC) 1999 Antenna Structure Registry (November 1, 1999) listed 48,000 lighted towers over 60.7 m above

ground level and over 68,000 towers total in the United States. They estimated 24 to 38% of the towers were not properly registered with FCC. In the future, all television stations must be digitized, adding potentially 1,000 new towers exceeding 305 m height.

An estimated 16,000 new wind turbines may be constructed in the U.S. in the next decade, adding to the existing 15,000 turbines (Manville 2005). The development of wind farms in the whooping crane migration corridor has the potential to cause significant mortality. Cranes could be killed directly by wind turbines or from colliding with new power lines associated with wind farm development. Management and research are needed to reduce this new threat.

Collisions with Aircraft: One whooping crane was killed in June 1982 during a KC-135 tanker takeoff from Minot Air Force Base, North Dakota (Harrison 1983). Feather remains were identified by the Smithsonian Institute. Whooping crane collisions with aircraft are anticipated to be rare because of the small number of whooping cranes.

Pesticides: There is no evidence that pesticide contamination is a significant threat to whooping cranes. Whooping crane egg and tissue specimens examined for pesticide residues at PWRC have shown concentrations well below those encountered in most other migratory birds (Robinson et al. 1965, Lamont and Reichel 1970, Anderson and Kreitzer 1971, Lewis et al. 1992b). Eggshell thickness, a measure of contaminant exposure, has been measured in eggs taken from the wild and those in captivity from the 1970s to the present; no evidence of shell thinning has been detected. However, our knowledge of potential indirect or sublethal effects of pesticides on whooping cranes is inadequate and poorly understood. The baseline contaminant impacts research comes from research on other birds including sandhill cranes, but has never been done on whooping cranes. Contaminants could be impacting the FP, especially since some of the females in Florida have been found with improperly developed reproductive organs.

CONSERVATION MEASURES

Before the mid-1950s, a few significant events helped protect whooping cranes. The most important pieces of early protective legislation for whooping cranes were the Migratory Bird Treaty Act in the United States and the Migratory Birds Convention Act in Canada. These acts were ratified by the U.S. Congress on December 8, 1916, and by the Canadian Parliament on August 29, 1917. The Acts assured legal protection for migratory bird species in Canada and the United States and provided a basis for preventing the hunting of species requiring complete protection.

The significance of the establishment of WBNP in the Northwest Territories in December, 1922, was not realized until three decades later when the whooping crane nesting grounds were discovered there (Allen 1956). WBNP is a vast boreal forest and muskeg area (4,288,542 ha) designated by the Canadian government (Raup 1933) as a preserve and management area for the wood bison (*Bison bison athabascae*). The portion of the Park occupied by nesting whooping cranes is primarily located northwest of the intersection of the boundaries of Saskatchewan, Alberta and the Northwest Territories (Kuyt 1978b). The location of the crane summering grounds allows them to be protected by provincial and territorial wildlife acts as well as the National Parks Act. The breeding grounds also are designated as a Wetland of International Importance by the RAMSAR Convention and are an Important Bird Area in Canada. Some of the Canadian prairie wetlands used regularly by migrating whooping cranes have received

protection as Migratory Bird Sanctuaries, National Wildlife Areas (NWA), or under the Saskatchewan Wildlife Habitat Protection Act. Also, several stopover areas are designated as Important Bird Areas in Canada.

ANWR, purchased for $463,500 for the Bureau of Biological Survey's refuge program, was established in 1937 to protect the whooping crane and other wildlife of coastal Texas (Stevenson and Griffith 1946, Howard 1954). Leroy Denman (San Antonio Loan and Trust) retained mineral rights. These rights included a clause that used oil and gas royalties to refund to the government the entire purchase price of the refuge. The Refuge includes 22,148 ha of Blackjack Peninsula and adjacent properties, and provides essential wintering habitat for whooping cranes. Matagorda Island (44,606 ha of State and Federal ownership) is managed in conjunction with ANWR. Adjoining bay waters (5,236 ha) surrounding the Blackjack Peninsula, known as the Proclamation Boundary, were closed to hunting of migratory birds by Presidential Proclamation in 1938 for additional protection.

In the U.S., the whooping crane was listed as threatened with extinction in 1967 (Fed. Reg. Vol. 32, Number 48, March 11), and as endangered in 1970 (Fed. Reg. Vol. 35, Number 199, October 13). Both of these listings were "grandfathered" into the Endangered Species Act of 1973 (U.S.C., 1531-1 543; 87 Stat. 884), which resulted in establishing the U.S. Whooping Crane Recovery Team and facilitated further conservation actions on behalf of the species.

In 1974, the Canada Wildlife Act authorized the federal government to conduct research on endangered species. In 1976 the Committee on the Status of Endangered Wildlife was established and the whooping crane was designated as endangered in 1978 (Edwards et al. 1994). The Species at Risk Act was proclaimed in Canada in 2003, which designated the whooping crane as endangered and provided for additional protection for cranes and their habitat.

In April, 1985, Bert Tetreault, Director General of the CWS, and Robert A. Jantzen, Director of the USFWS, signed an MOU entitled *Conservation of the Whooping Crane Relating to Coordinated Management Activities* (Lewis 1991). The MOU provides a more formal structure to the cooperative working relationships that have characterized these 2 nations' joint efforts in management and research of whooping cranes. Under the new agreement, each Service appointed an employee to be responsible for inter- and intra-national coordination of whooping crane management and research. The MOU discusses disposition of birds and eggs, postmortem analysis, population restoration and objectives, new population sites, international management, recovery team, recovery plans, and consultation and coordination. The MOU was renewed in April, 1990, again in October, 1995, and August, 2001. The current MOU was signed by the USFWS, USGS, CWS, and Parks Canada.

A plan for *Federal-State Cooperative Protection of Whooping Cranes* was approved in 1985 and is updated periodically by the USFWS and 13 States where whooping cranes occurred (Lewis 1992). The CWS and 3 Canadian provinces approved the *Federal-Provincial Cooperative Protection of Whooping Cranes* in 1987 (Cooch et al. 1988). The plan describes response options when whooping cranes are observed in hazardous situations due to avian disease outbreaks, environmental contaminants, or hunting activities, or when whooping cranes are found injured, sick, or dead. Plan objectives are to provide added protection to whooping cranes, especially during migration, and to increase the opportunities to recover and rehabilitate birds found injured or sick.

Sportsmen and other conservationists have played a crucial role in protecting wetlands used by whooping cranes throughout the whooping crane migration corridor crossing 2,500 miles of North America. Duck Stamp funds have helped protect numerous acres of wetlands used by the cranes. Many sportsmen turn in whooping crane sighting reports to the monitoring network. Sport hunting programs help disperse waterfowl concentrations, reducing the threat of waterfowl disease outbreaks that can affect whooping cranes, and reducing instances of waterfowl crop depredation problems that arise. State hunting programs cooperate to protect whooping cranes by providing educational materials to hunters to help them identify whooping cranes, and by implementing hunting closures where necessary. (For more information on conservation measures, see Appendix C).

Critical Habitat – United States

Critical habitat is defined in the U.S. Endangered Species Act as habitat that contains those physical or biological features, essential to the conservation of the species, which may require special management considerations or protection. Critical habitat in the U.S. was designated in 1978 (43 FR 20938-942). Critical habitat is in effect for 5 sites in 4 states. A proposal for additional areas in the Central Flyway to be listed as critical habitat published in March, 1979, (44 FR 12382-384) was later withdrawn.

Wintering Grounds: ANWR and vicinity, Texas (Fig. 4), has been designated as critical to the conservation of the species. At ANWR, the listing of critical habitat has been extremely important in protecting habitat along the GIWW.

Migration – United States: Cheyenne Bottoms State Waterfowl Management Area and Quivira NWR, Kansas; the Platte River bottoms between Lexington and Denman, Nebraska; and Salt Plains NWR, Oklahoma, have been designated as critical to the conservation of the species.

Potential Critical Habitat - Canada

Critical habitat is defined in the Species at Risk Act as "…the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in a recovery strategy or in an action plan for the species." Critical habitat in Canada is officially designated upon publication of a final SARA Recovery Strategy or Action Plan on the SARA Public Registry**.** The location and extent of critical habitat is subject to change pending new information as identified in the National Recovery Strategy for the Whooping Crane in Canada.

Breeding Grounds: Potential critical habitat in WBNP includes suitable marshes within the northeast corner of the park bounded by the Little Buffalo River to the east and south; the north boundary of the park from the Little Buffalo River to Territorial Highway #5; south along Highway #5 to 1140 West Latitude; and south at 1140 West Latitude to 600 North Longitude then southeast to the Little Buffalo River closest to Conibear Lake.

Potential critical habitat outside of WBNP includes suitable marshes adjacent to the northeast corner of WBNP bounded by the Buffalo River to the west, Highway 6 to the north, and the

Canadian Shield to the east. Additional habitat for recovery includes wetlands available for re-introductions in other areas and jurisdictions.

The majority of breeding habitat is located in WBNP (Olson and Olson 2003) and is protected under the Canada National Parks Act. The breeding grounds also were designated as a Wetland of International Importance by the Ramsar Convention and an Important Bird Area by BirdLife International. Because of these designations, the potential critical habitat is protected from a number of anthropogenic threats. It may be threatened however, by climate change that could result in more severe weather events including drought. Also, increasing atmospheric pollution may be a concern.

Expansion of the AWBP has led to breeding of whooping cranes outside of WBNP as predicted by Olsen and Olsen (2003), into adjacent areas of the Northwest Territories without formal protection. Land uses, such as forestry and agriculture, and activities, such as hunting, could cause disturbance or change the quality of habitat available for cranes. In these instances stewardship opportunities will be pursued with the appropriate land managers (DeWandel 2003). CWS and Parks Canada are currently investigating suitable unoccupied nesting habitat within WBNP and adjacent areas that may be necessary for the recovery of whooping cranes.

Migration – Saskatchewan Staging Area: During fall migration whooping cranes typically stop in south central Saskatchewan for several days or weeks. This area of Saskatchewan, which forms a diamond between Meadow Lake, Swift Current, Estevan, and the Quill Lakes, can be described as a staging area for whooping cranes. The cranes spend their evenings roosting in shallow wetlands, while their days are occupied with feeding in harvested agricultural fields, chiefly wheat and barley (Johns et al. 1997). Fall staging wetlands are primarily on private lands (85%) (Johns et al.1997). Few wetlands are used repeatedly from one year to the next since most staging wetlands are ephemeral and their availability to cranes fluctuates annually due to variations in precipitation. Preferred staging wetlands have the following characteristics: permanent (32%) or semi-permanent (53%) flooding; soft mud bottoms (83%); sizes from less than ½ ha to several thousand hectares; average roost site water depths of 13 cm (SD 7.5); and roost site locations within 2 km of suitable feeding areas (agricultural fields), and over 1 km from human habitation (Johns et al. 1997). Large wetlands with a secure water supply are extremely important as staging sites since they provide refuge when ephemeral wetlands are dry. Threats to the migration/staging habitat include land use changes such as drainage of wetlands.

The Last Mountain Lake and Stalwart National Wildlife Areas and the Last Mountain Lake Migratory Bird Sanctuary are used repeatedly by cranes and are potential critical habitat for the survival and recovery of the species. These habitats are already protected under the Canada Wildlife Act and the Migratory Birds Convention Act.

The South Saskatchewan River and its sandbars between Outlook and Saskatoon and the North Saskatchewan River between the Maymont and Petrofka Bridges are potential critical habitat for the survival and recovery of the species. Currently there is no formal protection for this habitat; however, it is under the jurisdiction of the Province of Saskatchewan and stewardship agreements with the Saskatchewan Watershed Authority will be investigated.

Several wetland areas exhibit repeated use by whooping cranes and may be considered as potential critical habitat as well. These specific wetlands and adjacent smaller wetlands in the vicinity are: Midnight Lake, Witchekan Lake, Blaine Lakes, Radisson Lake, Buffer Lake,

Muskiki Lake, Quill Lakes, Kutawagan Lake, Luck Lake, Creelman Marsh, and wetlands near Tribune and Bromhead. Upland areas on provincial crown land associated with some of these and other known roosting sites for whooping cranes have already been protected under the Saskatchewan Wildlife Habitat Protection Act.

Due to the ephemeral nature of most prairie wetlands and their use by whooping cranes, it is difficult to predict which wetlands may be used by whooping cranes at any particular time. However, wetlands in the migration corridor that meet the criteria listed in Johns et al. (1997) may be used by whooping cranes at any time. Each of these wetlands may be critical to the survival and recovery of the species. At the present time these wetlands (including the bed, the bank, and the boundary) are under the jurisdiction of the Province of Saskatchewan and stewardship agreements with the Saskatchewan Watershed Authority will be investigated. Exceptions include wetlands that are wholly surrounded by a single land owner's property. In these instances separate stewardship agreements with individual landowners will be investigated.

Summary

Protective legislation, such as the Migratory Bird Treaty Act (US) and the Migratory Birds Convention Act (Canada) of the early 1900s, followed by the National Parks Act, Canada Wildlife Act, and Species at Risk Act in Canada and the Endangered Species Act in the US, has played a crucial role in raising awareness of the whooping crane's predicament and establishing the authority to implement conservation measures. As a species with particular breeding, wintering, staging, and migrating territories, the whooping crane has benefited directly from the designation of preserved areas, like the WBNP and ANWR, which provide habitat and wetland resources critical to supporting the whooping crane's complex life cycle. Critical habitat continues to be extremely important for the recovery of this species.

Research focusing on understanding whooping crane ecology, building whooping crane populations, and minimizing threats to the whooping crane has been an integral part of the whooping crane's recent history. In the 1970s and 1980s, efforts were focused on building and improving the productivity of the captive flocks, doing research on the AWBP and maintaining its growth, and trying to reintroduce an additional population into the wild. Second eggs were picked up from WBNP and used to increase captive populations and carry out a reintroduction in the western U.S. In 1993 and 2001, efforts began to reintroduce a non-migratory population in Florida and a migratory flock in the eastern U.S. Actions already completed or underway are covered in Appendix C. Continued work is needed to protect the AWBP from increasing threats from human population growth, development, and climate change, make the reintroductions a success, increase the size of the captive breeding flock, and maximize genetic diversity of all populations. Future actions needed to reach recovery are presented in Part II.

RECOVERY TEAM

The Canada/United States Whooping Crane Recovery Team consists of 5 representatives from Canada and 5 from the U.S. appointed by the CWS and the USFWS, respectively. The team, co-chaired by the whooping crane coordinators of the two countries, is responsible for making recommendations on actions needed to recover the species.

Whooping crane recovery teams were initially formed in 1975 in the U.S. and 1985 in Canada,

although ad hoc committees were in existence before that. Whooping crane coordinators were appointed in 1981 in Canada and 1984 in the U.S. In 1995, the separate recovery teams from both countries were joined as an international team. A Memorandum of Understanding (MOU) on the conservation of the whooping crane signed in 1985 and renewed periodically governs recovery actions that are outlined in a recovery plan written by the team.

In the 1970s and 1980s, efforts were focused on building and improving the productivity of the captive flocks, doing research on the AWBP and maintaining its growth, and trying to reintroduce an additional population into the wild. Second eggs were picked up from WBNP and used to increase captive populations and carry out a reintroduction in the western U.S. Actions already completed or underway are covered in Appendix C. Future actions needed to reach recovery are presented in Part II.

PART II. RECOVERY

The following section presents a strategy to recover the species, including objective and measurable recovery criteria and site-specific management actions to monitor and reduce or remove threats to the whooping crane, as required under section 4 of the ESA and under section 41 of the SARA. The Recovery Plan also addresses the five statutory listing/recovery factors (section 4(a)(1) of the ESA) and the short and long term goals of the SARA (section 41(1)(d)) to the current extent practicable, to demonstrate how the recovery criteria and actions will lead to removal of the whooping crane from the lists of Threatened and Endangered Species.

RECOVERY GOAL

The goal of this plan is to protect the whooping crane and its habitat, and allow the overall population to reach a level of ecological and genetic stability so that it can be reclassified to threatened status (downlisted). The ultimate goal is to recover the whooping crane and remove it from the lists of Threatened and Endangered Species (delist).

RECOVERY STRATEGY

The recovery strategy involves: protection and enhancement of the breeding, migration, and wintering habitat for the AWBP to allow the wild flock to grow and reach ecological and genetic stability; reintroduction and establishment of self-sustaining wild flocks geographically separate from the AWBP to ensure resilience of the species to catastrophic events; and maintenance of a captive breeding flock to protect against extinction.

Implementation of recovery actions will continue to reduce existing threats (habitat loss and degradation, disease, mortality from power lines, loss of genetic diversity), as well as new threats that may arise. Because of the limited range of the AWBP in both summer and winter (i.e., pioneering new habitat is limited to areas adjacent to existing use areas), efforts have been initiated to reintroduce a second population in Florida and a third population in eastern North America. These additional populations provide protection against extinction of the species in the wild, in the event that a catastrophic event impacts the AWBP, or if that flock begins to decline in size. These reintroduced populations must be geographically isolated from the AWBP so that potential negative influences of the captive-raised birds do not impact the AWBP. Negative factors could include disease transmission and behavioral differences, including vocalizations. Further, reintroduced populations listed as experimental nonessential under Section 10(j) of the ESA are required to be geographically distinct from existing wild populations.

In order to be genetically viable over the long-term, the whooping crane population must be large enough so that creation of new alleles through genetic mutation will offset the loss of genetic material in a small population. Growth of the AWBP and the two reintroduced populations is expected to increase numbers to a level at which the population should not lose any more genetic material. However, the effective population size (N_e) required to maintain genetic viability over the long term needs to be calculated.

RECOVERY POTENTIAL AND RATIONALE

The inherent capacity of whooping cranes to rebound demographically is low due to delayed sexual maturity (age 3-4 years) and a low reproductive rate (2 eggs in the annual nesting attempt

with only 1 chick typically fledging). Furthermore, given the many threats to breeding, migration, and wintering habitat, it is unlikely the whooping crane will ever become abundant. Nevertheless, if breeding pairs are protected from excessive mortality, a breeding pair's breeding experience and longevity can compensate for low reproductive rate. As nesting pairs gain experience, they become more successful in rearing chicks. At the same time, cranes can reproduce over a relatively long lifetime: 3 to 5% are predicted to live and remain productive beyond age 30 years (Mirande et al. 1993).

Threats to whooping cranes have been alleviated to a degree sufficient to allow an average annual growth of 4.5% for a half century in the AWBP. Some power lines are being marked to make them more visible, a technique shown to reduce sandhill crane collisions with power lines (Morkill 1990, Morkill and Anderson 1991, Brown and Drewien 1995), which would also help reduce whooping crane mortality. The Cooperative Protection Plans implemented by provincial, state, and federal agencies are believed to reduce losses to shooting and disease (Lewis 1992). Erosion losses of critical winter habitat along the Gulf Intracoastal Water Way have been reduced significantly through the use of concrete matting (Zang et al. 1993, Evans and Stehn 1997). Dredged material has been used to create winter habitat (Evans and Stehn 1997). Thus the whooping crane has responded positively to some conservation efforts.

The present nesting habitat at WBNP may not be as productive as the major historical nesting wetlands in the prairie grasslands (Brian Johns, CWS, pers. comm.). However, WBNP provides suitable protected nesting habitats that have supported population recovery from 3 or 4 adult pairs in 1941 to 73 adult pairs in 2005. Sufficient migratory stopover habitat is available to support the present population and numbers likely to be attained in the near future. Winter habitats at Aransas are presently sufficient to support at least 500 individuals (Tom Stehn, ANWR, pers. comm.). Uncertainty remains concerning possible long-term declines in ecosystems used by the cranes as a consequence of expanding human populations and their demands for fresh water, housing, recreation, agricultural production, and industrial products. Some of the prime historical grassland nesting habitat could be restored in southern Canada and the northern United States. However, such actions would be costly and would require purchase of large land blocks and restoration of wetlands.

Based upon overall habitat availability, a positive growth rate, success in captive breeding, and effective conservation measures, the potential for continued survival of the species and ultimate recovery is good. Average annual population growth in the AWBP was 4.5% from 1938-1991. Based on this growth rate, Mirande et al. (1993) projected the AWBP population to reach 500 individuals within 17 years, with no measurable probability of extinction over 100 years. Currently, 5 captive flocks, those at CZ, ICF, PWRC, SSC, and SAZ are producing offspring. Captive production has been sufficient to provide 289 birds for the non-migratory reintroduction experiment in Florida since 1993. In 2001, another reintroduction using captive-produced young was initiated in the eastern U.S with Wisconsin as the proposed nesting area and western Florida the wintering site. Continued conservation of this species will require vigilant management and the interest and concern of an informed public. Therefore, an important component of this Plan is its focus on outreach and education.

DOWNLISTING RECOVERY OBJECTIVES AND CRITERIA

This plan sets forth 2 primary objectives and measurable criteria that will allow the species to be reclassified to threatened (downlisted). These numerical population criteria can only be achieved if threats to the species are sufficiently reduced or removed, i.e., the population criteria are a benchmark for threat reduction. Specific actions to reduce these threats are addressed in the narrative outline (page 55) and are cross-referenced with the listing factors (page 53). Due to the length of time expected to reach downlisting goals and current information gaps in our knowledge of the species, it is not feasible to establish delisting objectives and criteria at this time. Recovery plans undergo periodic revisions, and if appropriate, delisting criteria will be added at that time. This recovery plan provides recovery actions that will enable us to fill information gaps and determine delisting criteria in the future.

Objective 1 – Establish and maintain self-sustaining populations of whooping cranes in the wild that are genetically stable and resilient to stochastic environmental events.

> **Criterion 1 –** Maintain a minimum of 40 productive pairs in the AWBP for at least 10 years, while managing for continued increase of the population. Establish a minimum of 25 productive pairs in self-sustaining populations at each of 2 other discrete locations.
>
> A productive pair is defined as a pair that nests regularly and has fledged offspring. The two additional populations may be migratory or non-migratory. Multiple populations provide protection against stochastic, catastrophic events in nature. A single wild population remains vulnerable to extinction during singular, or a series of, adverse events, regardless of its size.
>
> Population targets are 160 in the AWBP, and 100 each in the Florida non-migratory population and the eastern migratory population. These targets are consistent with a population viability assessment of what is needed to maintain genetic variability for the population (see Appendix A). All 3 populations must be self-sustaining for a decade at the designated levels before downlisting could occur. A self-sustaining population is defined as a stable or growing population that is not supplemented with any additional reintroductions from captivity.
>
> The AWBP has been maintained at above 40 productive pairs since 1992; however, additional populations are not yet self-sustaining. An alternative criterion may be applied for downlisting in the event that attempts to establish additional self-sustaining populations do not succeed.
>
> **Alternative Criterion 1A** – If only one additional wild self-sustaining population is re-established, then the AWBP must reach 400 individuals (i.e. 100 productive pairs), and the new population must remain above 120 individuals (i.e. 30 productive pairs). Both populations must be self-sustaining for a decade at the designated levels before downlisting could occur. This alternative is based on the principle that with the re-establishment of only one additional population separate from the AWBP, then crane numbers must be higher in both populations than if there are three distinct populations.

Alternative Criterion 1B - If establishment of second and third wild self-sustaining populations is not successful, then the AWBP must be self-sustaining and remain above 1,000 individuals (i.e. 250 productive pairs) for downlisting to occur. The *Memorandum of Understanding on Conservation of Whooping Cranes*, approved by Canadian and U.S. federal officials, recognizes a goal of 1,000 individuals in the AWBP population. This higher number ensures a better chance for survival of the AWBP in the event of a catastrophic event within its extremely limited range. The target of 1,000 is reasonable for downlisting given the historical growth of the AWBP and theoretical considerations of minimum population viability. To ensure sufficient genetic variability, the AWBP must increase to the level where the creation of new alleles through genetic mutation will offset the loss of genetic diversity. After reaching the goal of 250 pairs, the population should gain genetic variation faster than the population loses genetic material.

Objective 2 – Maintain a genetically stable captive population to ensure against extinction of the species.

Criterion 2 - Maintain 153 whooping cranes in captivity (21 productive pairs). Genetic analysis suggests that 90% of the genetic material of the species can be maintained for 100 years at this population size (Jones and Lacy 2003). To achieve this, this Plan recommends having 50 captive breeder pairs of whooping cranes by 2010, including 15 pairs at PWRC, 12 at ICF, 10 at CZ, 10 at SSC, and 3 at SAZ. A breeder pair (as differentiated from a productive pair) is defined as a pair that breeds or is intended to breed in the future. Production from CZ, ICF, PWRC, SAZ, and SSC will be the principal source of birds for release to the wild for reintroduced populations. However, sources of release birds should be based on the optimal genetic mix to ensure long-term population viability.

DELISTING CRITERIA

It is not feasible to establish well-defined objectives and criteria for delisting at this time. The extremely endangered status and the slow reproductive rate of the species dictate that considerable time will be needed to reach downlisting goals. Considering the historic slow growth of the AWBP and the challenges of reintroducing populations, downlisting is unlikely to be reached before year 2035. It is unrealistic to predict the environmental conditions and threats to the species that will prevail at that time. New threats are expected to manifest and will have to be overcome before downlisting occurs. Additional information is also needed regarding the conservation biology of small populations, including impacts of stochastic and catastrophic events on survival. For whooping cranes, the effective population size (N_e) required to maintain genetic viability over the long-term needs to be calculated. Appendix A provides detailed information on genetic issues and conservation of small populations.

De-listing criteria will require the establishment of a population target with a high level of confidence. Without knowledge of a minimum population size needed to ensure species survival, it would be unreasonable to provide delisting criteria. Current estimates of the population needed to ensure survival range widely between 1,000 and 7,000 and would provide little confidence if a specific numerical target for delisting were set at this time. With additional knowledge regarding the dynamics and long-term survival of small populations, numerical population targets can be set to remove the whooping crane from the List of Threatened and Endangered Species. Recovery action 4.0 addresses the need for this information.

New information gathered through recovery actions will be incorporated into additional population viability analysis as the population approaches its downlisting goals. Delisting criteria will be established at that time, and the overall recovery strategy and actions will be revised as appropriate. Future revisions of this recovery plan are anticipated, and a delisting goal for the species will be set prior to downlisting anticipated in 2035.

2003 SARA RECOVERY OBJECTIVES

In Canada, the 1978 COSEWIC designation of the whooping crane as endangered did not include a formal list of recovery objectives and actions later required under section 41(1)(d) of the 2003 SARA. The section below describes the recovery objectives and actions proposed and/or underway.

SHORT-TERM RECOVERY OBJECTIVES

Objective 1: The short-term recovery objective of 40 productive pairs in the AWBP for 10 consecutive years has been met. To reach the long-term recovery goal of 1000 birds in North America by the year 2035 the AWBP needs to increase to 240 individuals and 70 productive pairs by 2010.

Objective 2: Increase the captive populations to 45 breeding pairs by 2010.

Objective 3: Increase FP to 100 individuals and 10 productive pairs by 2010. Establish a third population containing 80 adults by 2010.

Objective 4: Analyze banding data and determine the N_e/N ratio for the AWBP.

Objective 5: Promote education of whooping crane recovery through innovative media technologies.

LONG-TERM ACTIONS NEEDED

1. Continue to build the AWBP and protect and manage its habitat to minimize the probability that a catastrophic event will eradicate this population.

2. Attain breeder pair and productivity goals at 4 captive facilities in the United States and 1 in Canada to produce the birds required for reintroductions. Continue research to improve production of captive flocks.

3. Establish 2 additional self-sustaining wild populations separate from the AWBP. Continue research to identify appropriate reintroduction sites and improve reintroduction techniques. Protect and manage habitat of reintroduced populations.

4. Continue to use genetic information and advances in conservation biology to effectively manage flock genetics and determine N_e and revise criteria as warranted.

5. Maintain an information/education program.

REDUCTION OR ALLEVIATION OF THREATS TO WHOOPING CRANES THROUGH IMPLEMENTATION OF RECOVERY ACTIONS

The following section describes recovery actions proposed or underway for recovery of the whooping crane and identifies the tasks in the Recovery Outline in Part III that specifically address threats to the whooping crane as they relate to the 5 listing factors.

Listing Factor A: The present or threatened destruction, modification, or curtailment of a species habitat or range

Habitat destruction and curtailment of the species' range are addressed in Tasks 1.1 – 1.54 through: population and habitat monitoring on the breeding, migration, and winter grounds; reduction of collision and disease mortality; public education to prevent accidental shooting; habitat protection and management; and monitoring and regulation of specific threats and impacts such as chemical spill, coastal erosion, dredging, changing salinity from water withdrawal, and changes in in-stream flows. Establishment of two additional wild populations (Tasks 3–3.4) also addresses this threat through augmentation of the current population and expansion of whooping crane range in historical habitats. Development and maintenance of a captive population (Tasks 2–2.4) provides protection against extinction in the wild and produces birds for reintroduction to the wild.

Listing factor B: Overutilization for commercial, recreational, scientific, or educational purposes

Task 1.3.1 addresses prevention of accidental shooting of whooping cranes. Tasks 1.4–1.4.2 address protection from disturbance. Tasks 5.1-5.3 address public education regarding whooping cranes.

Listing Factor C: Disease and predation

Disease and predation are important factors in population dynamics of whooping cranes. Diseases such as avian tuberculosis have been documented in the AWBP, and both West Nile virus and H5N1 avian influenza virus are emerging new threats of unknown proportion to both captive and wild populations. Disease research and management are needed to reduce this risk (Tasks 1.3.2, 2.3.4).

Predation is a significant source of mortality of flightless chicks in WBNP and of reintroduced populations in Florida. Efforts must be taken to reduce predation where practical, especially in the reintroduced populations (Tasks 1.3, 3.1).

Listing Factor D: The inadequacy of existing regulatory mechanisms

The CWS and the USFWS believe that the ESA, Migratory Bird Treaty Act, SARA, and NEPA provide an adequate legal framework for protection and conservation of the whooping crane and its habitat. However, as the human population continues to grow and development potentially impinges on whooping crane habitat, governments and their partners must not only fully utilize these regulatory tools, but continue to develop innovative and voluntary partnerships to protect whooping cranes throughout their 2,400-mile range (Tasks 1.3 -1.3.3; 1.4 – 1.4.3; 1.5 – 1.5.5).

Listing/Recovery Factor E: Other natural or human-caused factors affecting its continued existence

The primary source of mortality for fledged AWBP whooping cranes is collision with power lines. This threat needs to be analyzed and actions developed to minimize losses (Task 1.3.3). Collisions with fences and other man-made objects such as towers also need to be reduced (Task 1.3.3).

Although accidental shootings are believed to cause a low percentage of whooping crane mortality, Federal and State agencies need to continue to educate hunters to minimize and/or eliminate all such take (Tasks 1.3.1, 5, 5.1). "Take" in the form of harassment is a threat primarily in winter as human uses of salt marshes increase (fishing, hunting, bird watching, nature photography) as the human population continues to grow (Tasks 1.4, 1.4.1, 1.4.2). Current restriction of aircraft flights over summer and winter habitat is successfully reducing disturbance (Task 1.4.2). The loss of genetic diversity can only be overcome as population numbers increase to the level where the creation of new alleles through mutation will offset its past, current, and future losses in genetic diversity (Tasks 2-2.2, 3-4.1).

RECOMMENDED SCALE FOR RECOVERY ACTIONS

Recovery plans are usually produced for individual species. However, habitat management recommendations in recovery plans often affect numerous wildlife species. Recommendations in this plan range from specific objectives for crane management to larger scale habitat objectives. For example, habitat restoration in the Platte River Valley of Nebraska benefits other endangered species as well as other water birds. Consequently, recovery activities described within this plan are integrated with larger-scale recovery efforts wherever possible.

ANTICIPATED CONFLICTS OR LOGISTICAL DIFFICULTIES

There are no unique conflicts or logistical difficulties that can be identified at the present time. There will continue to be challenges of the type that impede new research and untested recovery techniques. Funding is always a potential constraint in implementing recovery actions. Competition for government and private sources of funding is increasing at the same time as are some threats to whooping cranes, including human population growth, development, and climate change. In addition, the large size and opportunistic use of the migration corridor used by whooping cranes precludes providing full protection during migration. Because recovery plans are advisory rather than regulatory in nature, implementation of the recovery actions will depend upon the commitment of governments and many dedicated partners on both sides of the border.

POTENTIAL IMPACTS FOR OTHER SPECIES/ECOLOGICAL PROCESSES

In general, preservation and management of crane habitats will benefit those species that already inhabit such sites. For example, protecting freshwater inflow into coastal areas will benefit all native coastal species. A possible exception may be predator control (e.g., alligator, bobcat, wolf, fox, raven, and coyote) if it should become necessary in nesting or winter habitats in the initial stages of reintroduction. A few bobcats and alligators have been removed from reintroduction sites in Florida. Hunting seasons for whooping crane look-alike species may be affected by the presence of whooping cranes. These issues are discussed in THREATS AND REASONS FOR LISTING – Shooting.

OUTLINE OF RECOVERY ACTIONS TO ACHIEVE OBJECTIVES

1. Increase the AWBP

1.1. Monitor population numbers, including annual recruitment and mortality.

1.1.1. Conduct aerial surveys in WBNP to determine distribution, productivity, recruitment and mortality.

1.1.2. Analyze data on egg management and develop a strategy to maximize size of the AWBP. Develop management options regarding egg manipulation.

1.1.3. Conduct aerial surveys at ANWR to determine total population numbers, movements, territories, habitat use, and mortality.

1.2. Monitor movements in migration.

1.3. Reduce mortality.

1.3.1. Prevent shooting.

1.3.2. Diminish losses to disease.

1.3.3. Reduce collisions/mortality.

1.4. Restrict detrimental human activities.

1.4.1. Restrict construction periods.

1.4.2. Restrict aircraft altitude.

1.4.3. Restrict other disturbance.

1.5. Identify, protect, manage, and create habitat.

1.5.1. Identify essential habitat.

1.5.2. Measure food resources in summer, winter, and during migration.

1.5.2.1. Monitor habitat in WBNP, including water levels and crane foods. Expand the surface-water monitoring network to measure water level fluctuations and their effect on nesting success. Define specific factors that impact cranes in relation to water levels in WBNP.

1.5.2.2. Monitor food resources and salinities at ANWR and relate these to energy budgets of the cranes and winter mortality. Hire a technician to carry out this task.

1.5.2.3. Complete measurement of availability of migration stopover habitat and monitor changes over time.

1.5.3. Protect habitat.

1.5.3.1. Maintain WBNP.

1.5.3.2. Ensure long-term protection of migration stopover sites.

1.5.3.3. Maintain ANWR and other NWRs.

1.5.3.4. Prevent contamination of habitat.

1.5.3.5. Prevent erosion of winter habitat at Aransas.

1.5.3.6. Better manage deposition of dredge material.

1.5.3.7. Maintain freshwater inflows.

1.5.3.8. Maintain appropriate in-stream flow.

1.5.3.9. Monitor global warming.

1.5.4. Manage habitat.

1.5.4.1. Manage fire.

1.5.4.2. Maintain upland water sources.

1.5.4.3. Manage vegetation.

1.5.5. Create wetland habitat.

2. Develop and maintain captive populations.

2.1. Develop more sensitive measures of genetic diversity.

2.2. Increase captive breeders.

2.3. Refine aviculture methods and productivity.

2.3.1. Refine breeding pair management.

2.3.2. Refine incubation procedures.

2.3.3. Refine rearing procedures for reintroductions.

2.3.4. Refine veterinary procedures.

2.3.5. Exchange aviculture information.

2.4. Maintain captive facilities.

3. Establish two additional wild populations.

3.1. Develop release techniques.

3.2. Evaluate and select release sites.

3.3. Establish a non-migratory population.

3.4. Establish a migratory population.

4. Determine N_e for species survival by analyzing banding data to determine the N_e/N ratio for the AWBP.

5. Maintain and expand information/education programs.

5.1. Develop media products.

5.2. Provide viewing opportunities.

5.3. Implement education programs.

NARRATIVE OUTLINE FOR RECOVERY ACTIONS TO ACHIEVE OBJECTIVES

1. Increase the AWBP

Reduce mortality and remove habitat constraints that might limit population recovery. The nesting and winter habitats appear to have potential to support substantially more than the 58 nesting pairs and the associated subadults and young-of-the-year present in 2005 (Johns 1998a, Brian Johns, CWS, pers. comm., Tom Stehn, ANWR, pers. comm.).

For those birds still identifiable by color marking, determine longevity and record movements in response to habitat changes. Identify pairs on summer and winter territories to determine adult survivorship and productivity by recording unison calls and analyzing sonograms as developed by Dr. Bernard Wessling. Measure chick survival in WBNP in relation to food supply, water levels, predation, and weather conditions. Analyze data to estimate population size, amount of habitat, and recruitment needed to achieve recovery goals. Develop management options by comparing mean annual population growth rates with and without egg manipulation practices. Periodically update the Population Viability Assessment as new data and improved models become available.

For the Central Flyway, develop a working group to address issues in the migration corridor. Issues would primarily include migration monitoring, collisions, shootings and other mortality factors, loss of habitat, or any needed recovery actions.

1.1. Monitor population numbers, including annual recruitment and mortality.

Conduct aerial population censuses on nesting and wintering areas to determine status and distribution. Nesting ground surveys will include: numbers of nests, location of territories, and clutch size (May); habitat conditions, nesting success, and chick survival (June); and habitat conditions and fledging (August). Weekly winter surveys will determine population size and number of juveniles, delineate territories, and detect mortality. Annual surveys of nesting and wintering areas should provide a record of each pair's annual productivity.

1.1.1. Conduct aerial surveys in WBNP to determine distribution, productivity, recruitment, and mortality.

Aerial surveys are currently conducted in May to find nests and determine number of eggs laid, in June to find out the number of chicks that hatched, and in August to count chicks that fledge.

1.1.2. Analyze data on egg management and develop a strategy to maximize size of the AWBP. Develop management options regarding egg manipulation.

Controlled scientific studies are needed on the effects of removing one egg from nests in WBNP.

1.1.3. Conduct aerial surveys at ANWR to determine total population numbers, movements, territories, habitat use, and mortality.

Flights are generally conducted weekly, fall to spring, at Aransas.

1.2. Monitor movements in migration.

Continue spring and fall migration monitoring to identify and map migration stopover habitat, and provide opportunities to protect birds from collisions with power lines, disease outbreaks, shooting, and to protect traditional migration stopover sites. Continue the whooping crane reporting network to document sightings. Develop a GIS database depicting all confirmed sightings categorized by state and by county that can be readily distributed to those whose management actions may affect migratory whooping cranes.

1.3. Reduce mortality.

Whooping cranes disappear due to unknown causes during most years. Spring and fall migration periods should receive emphasis to further diminish mortality of fledged birds (Lewis et al. 1992a). However, management actions need to be taken wherever they can effectively reduce mortality, regardless of relative rates of losses. Determine mortality factors, measure impacts, and carry out strategies to reduce losses. Aerial surveys on the nesting and wintering areas help detect losses and their causes. Determine mortality factors in WBNP and ANWR on adults and chicks and develop strategies to increase survival. Utilize satellite telemetry to determine causes of most mortality occurring during migration. Develop methods to address mortality factors not considered in subtasks below.

1.3.1. Prevent shooting.

Federal, provincial, and state wildlife agencies should continue to follow and update contingency plans for protection of whooping cranes that appear in hunt areas or other hazardous situations. Continue to work with provincial and state agencies to minimize conflicts between sport hunting and whooping cranes. Continue education programs, including identification brochures, videos, and DVDs, to increase competency of the public (e.g. hunters) for identifying whooping cranes and their protected status. Create a web site that offers an identification guide for whooping cranes and look-alike species. Continue public outreach programs to prevent shootings and inform the public of the need to report sightings.

1.3.2. Diminish losses to disease.

Develop methods of disease prevention, detection, and treatment for avian tuberculosis, infectious bursal disease (IBD), West Nile virus (WNV), Eastern Equine Encephalitis (EEE), and parasites. When possible, prevent whooping crane use of areas where waterfowl disease outbreaks are underway or have recently occurred. The Contingency Plan for Cooperative Protection of Whooping Cranes updated in 2006 covers response to disease incidents. Response will be directed by the Canadian Cooperative Wildlife Health Centre (CCWHC) in Canada and the National Wildlife Health Center (NWHC) in the United States. Disease research will determine where prevention and control methods should be directed, and whether control will involve site modification, inter-specific separation, individual prophylaxis, or a combination of responses. The Whooping Crane Health Advisory Team (WCHAT) will continue to provide advice and recommendations to the Recovery Team on all health issues. Captive breeding centers should formulate contingency plans using professional standards including quarantines to deal with an

outbreak of H5N1 avian influenza in their nearby vicinity that has spread exponentially in recent years.

1.3.3. Reduce collisions/mortality.

Collisions with power lines and fences are a frequent cause of death or injury. Use telemetry to locate areas receiving high crane use where power lines are a significant problem.

Monitor the placement and design of all new power lines in areas of known crane use. When possible, bury new power lines or route around areas frequently used by whooping cranes making low-level flights. Mark existing problem lines or modify fences to reduce collisions. Remove unnecessary fences and power lines from traditional stopover sites, Critical Habitat, National Wildlife Areas, National Wildlife Refuges, and National Wetland Areas used by cranes. Barbed wire fences should be of no more than 3-strand design. Visibility should be maximized on any existing structures or those, which of necessity, must be constructed in whooping crane use areas or flight routes by following USFWS and/or CWS guidelines to reduce bird strikes.

The USFWS has issued interim guidelines for recommendations on communication tower siting, construction, operation, and decommissioning. If communication equipment cannot be co-located on existing towers and a new tall tower is built requiring guy wires, the wires should have visual markers in place to reduce bird strikes. If possible, towers should be kept less than 61 m in height with a larger tower base and no guy wires. Tower lights for aviation safety should have flashing white strobe lights rather than continuous lighting. If guy wires are unavoidable, the wires should be marked. The Recovery Team should stay in contact with the Avian Power Line Interaction Committee to stay appraised of new developments in collision reduction.

The USFWS proactively should engage with the utility industry to address the potential threat from construction of wind turbines. Until more research is done to assess bird mortality, wind farms should not be constructed within the primary whooping crane migration corridor due to the unknown threat they pose.

1.4. Minimize disturbance from human activities.

Cranes need to be protected from disturbance, especially in migration and on wintering areas. Disturbance can result from activities such as petroleum exploration, mining, hunting, fishing, bird watching, and boat and airplane traffic. The cumulative effect on cranes should be evaluated. Sources and intensity of disturbance are expected to increase in the future. Human activities should be monitored and regulated wherever they cause problems for the cranes.

1.4.1. Coordinate construction projects with periods when cranes are absent.

Conduct seismic exploration, drilling, pipeline activity, dredging, and other development or construction activities within or near migration and wintering habitat only when cranes are absent. Accomplish scheduling through federal, provincial, and state permitting procedures and by agreement with the company or agency involved.

1.4.2. Restrict aircraft altitude in sensitive areas.

An altitude restriction of 610 m minimum, required by Canadian and U.S. regulations over nesting and winter habitat, is particularly important in regulating helicopter flights. Biological survey flights, research, and emergency situations, including unusual weather conditions, should be the only exceptions to these restrictions.

1.4.3. Restrict other disturbance.

Human activities in crane areas on the wintering grounds include bird watching, hunting fishing, commercial crabbing, and boat traffic. Levels of activity need to be monitored and controlled when found to be detrimental to the cranes.

1.5. Identify, protect, manage, and create habitat.

Determine availability of suitable habitat for breeding, staging, migrating, and wintering, including spatial needs and territories of an expanding population.

1.5.1. Identify essential habitat.

Suitable breeding habitat that is currently unoccupied by whooping cranes should be identified. Complete the mapping of these habitats using available satellite imagery. Evaluate the potential of Northwest Territories and Alberta summer habitats to support a population of 1,000 birds.

Additional study is needed to delineate areas that are important to migrating whooping cranes. Utilize satellite telemetry to identify additional stopover sites. Describe the unique characteristics of such habitat. Solicit reports and record sightings of whooping cranes by qualified observers. Identify food and water requirements of an expanding crane population in nesting, migration, and winter habitats. Investigate spatial needs of nesting and wintering adult pairs, family groups, and subadult groups to understand territorial defense behaviors that influence habitat requirements.

1.5.2. Measure food resources in summer, winter, and during migration.

The food base for cranes on sites utilized by cranes and areas not utilized should be sampled. Describe the food complex that seems attractive and supports crane needs. Relate this information to the evaluation of the ability of summer and winter habitats to support 1,000 whooping cranes. Obtain more information on blue crab populations in the crane marshes at Aransas. The food needs and energetics of whooping cranes during migration should be studied.

1.5.2.1. Monitor habitat in WBNP, including water levels and crane foods.

Expand the surface-water monitoring network to measure water level fluctuations and their effect on nesting success. Define specific factors that impact cranes in relation to water levels in WBNP.

1.5.2.2. Monitor food resources and salinities at Aransas and relate to energy budgets of the cranes and winter mortality.

Availability of food should be studied and related to crane behavior and energetics at Aransas. Hire a technician to carry out this task.

1.5.2.3 Complete studies of availability of migration stopover habitat and monitor changes over time.

A project to quantify suitable stopover habitat needs to be completed for the entire migration corridor and changes monitored over time.

1.5.3. Protect habitat.

The majority (90%) of the whooping crane population nests within WBNP. In 2005 six pairs of whooping cranes nested outside the boundaries of WBNP. As the population grows, more birds will begin to nest outside the park. Identify, map, and protect additional breeding habitat adjacent to WBNP.

Ensure long-term protection of migration stopovers sites, including staging areas in southern Saskatchewan and traditional stopovers along the Platte River, Nebraska. Ninety-five percent of the stopover sites in Canada are in private ownership (Johns et al. 1997). Work with landowners to ensure that habitat remains suitable for cranes. Several traditional stopover areas along the migration route in the United States have been designated as critical habitat. Identify, map, and protect additional important migration stopover areas. Pursue needed protection of stopover sites, including obtaining stewardship agreements and/or conservation easements. Conservation of stopover habitat should primarily focus on providing wetland mosaics (Richert et al. *In press*). Complete analysis of whooping crane habitat availability in Kansas and Texas.

Protection is also needed for winter habitat required to accommodate an expanding crane population on public and private lands. The threat of increasing human population growth, activities, and development that may be detrimental to the cranes and their habitat should be lessened or alleviated in these areas. In most instances, protection would not significantly alter current uses. Where non-refuge lands are involved, work with landowners/managers to ensure that habitat remains suitable for cranes. When necessary purchase fee title or conservation easements from voluntary sellers all essential marshes used by whooping cranes during winter. Study range expansion at ANWR and provide protection, including conservation easements, on areas that a larger whooping crane population will occupy. Complete protection for 100 hectares of salt marsh and adjacent uplands on the Johnson Ranch located on Lamar Peninsula. The area used historically for wintering along the Texas coast, including ANWR and Matagorda Island, has been declared critical habitat under the ESA. With the population wintering in a larger area, 8 crane territories were located outside critical habitat in the 2004-05 winter. With full public input, evaluate the need to expand critical habitat boundaries at ANWR and in the migration corridor to ensure protection of all important U.S. whooping crane habitats.

1.5.3.1. Maintain WBNP.

Effective management and research is needed on the wintering grounds to maintain the quality of crane habitat at WBNP. Long-term studies are needed to detect and address any detrimental changes from climate change or other causes.

1.5.3.2. Ensure long-term protection of migration stopover sites.

Work with landowners to ensure migration habitat remains suitable for cranes. Pursue stewardship agreements and conservation easements when needed, focusing on providing wetland mosaics.

1.5.3.3. Maintain ANWR.

Effective management and research is needed on the wintering grounds to maintain the quality of crane habitat at Aransas. Issues including freshwater inflows, development, and sea level rise all threaten the long-term suitability of coastal ecosystems.

1.5.3.4. Prevent contamination of habitat.

Preventive measures range from efforts to minimize existing damage to the long-range efforts to reduce the potential for contamination of habitat. Work with resource agencies in Texas to ensure that pollution is minimized during the rapid population and industrial growth that is occurring. Work with the Coast Guard and marine transportation industry to reduce the risk of chemical spills. Whooping crane protection should be specified explicitly in contaminant spill contingency plans which involve state, federal, and provincial agencies, along with local oil spill control groups, in efforts to contain and clean up leaks and spills which could impact whooping crane habitat. Ensure that response personnel are sufficiently trained and equipped.

The USFWS should coordinate with the appropriate regulatory agencies in all aspects of the oil and gas industry within whooping crane habitat. Encourage responsible agencies to inspect facilities to see that they conform to regulations and, if needed, to modify regulations to provide protection for cranes. For example, Quivira NWR is an important stopover site for migrating whooping cranes. The refuge contains numerous oil and gas wells where spills could occur. However, each production site is surrounded by a containment levee to ensure site protection if an accident occurs.

Screening for the presence of contaminants in habitats used by whooping cranes including known food items should be carried out periodically. More research is needed on the potential indirect or sublethal effects of pesticides on whooping cranes.

1.5.3.5. Prevent erosion of winter habitat at Aransas.

Erosion structures need to be monitored and maintained to remain effective. Other winter crane use areas need to be monitored for erosion.

1.5.3.6. Better manage deposition of dredge material.

Permit applications for dredging projects should be reviewed carefully and modified if they are incompatible with whooping crane management objectives. Solutions include

re-use of existing disposal sites, by removal of dredged material after it dries, and barging or pumping of dredged material to sites away from the marsh. Continue experiments to create new crane marsh habitat with dredged materials. Implement the USACE 50-year Dredge Material Plan, which calls for creation of 654 ha of marsh at 11 sites. Continue research as part of the plan and modify as needed to maximize benefits to whooping cranes.

1.5.3.7. Maintain freshwater inflows.

Human withdrawal of water from the Guadalupe and San Antonio Rivers and the Edwards Aquifer threatens productivity of marshes and bays at Aransas. Through consultation and management, agencies must ensure that stream flows are maintained to continue productivity of the Texas bay systems used by whooping cranes. Inflows on the Mission/Aransas watershed also potentially affect critical habitat. Future expansion of the flock northwards could make inflows critical on the Lavaca/Navidad Rivers.

1.5.3.8. Maintain appropriate in-stream flow.

Maintain suitable stopover habitat on the Platte River, Nebraska, and the South Saskatchewan River, Saskatchewan, and on other rivers used by migrating cranes, by ensuring adequate flows that provide quality roosting riverine and wet meadow habitats. These flows are necessary for scouring invading cottonwoods and willow from the riverbed. Purchase or lease of lands bordering key roosts may be necessary to protect the sites from human disturbance and to provide wet meadow habitat that supplies an important source of protein for whooping cranes.

1.5.3.9. Monitor global warming.

The potential for sea level rise and climate change related to global warming should be monitored to address possible impacts to whooping crane habitat. Research and appropriate management response will be needed to protect coastal ecosystems and nesting habitat.

1.5.4. Manage habitat.

First priority should be given to habitats designated as critical or essential. Essential habitat is that used by and important to an endangered species, but not given any special protection or designation by law. Evaluate and improve management practices on NWR, NWA, Waterfowl Production Area, federal, provincial, and state wildlife areas important to whooping cranes to develop and maintain habitat. Acquire or develop cooperative agreements on private lands. Review management practices systematically to determine benefit or detriment to whooping cranes.

1.5.4.1. Fire management

The effect of fire on nesting and wintering habitat is thought to be beneficial. Parks Canada Agency should continue to review fire management in WBNP and carefully manage fire suppression activities that would be detrimental to the crane summering area (Timoney 1999). Better define the role of fire in maintaining suitable nesting habitat. Maintain upland prairie savannah habitat used by the cranes at ANWR using prescribed fire and attract cranes to the uplands by making additional foods available.

1.5.4.2. Maintain upland water sources.

Maintain freshwater ponds and/or create new ponds on the wintering grounds to ensure a supply of freshwater for the cranes and to optimize distribution of upland use by cranes. Human activities on upland areas need to be controlled to minimize disturbance to cranes at freshwater sources.

1.5.4.3. Manage vegetation.

Manage vegetation in essential or critical roosting habitat on the migration route. This may require mechanical or chemical removal of established trees or other vegetation that may be discouraging use by cranes (i.e., the degraded Platte River, Nebraska). Cranes make significant use of uplands in winter when relatively open feeding conditions are maintained. Mowing, roller chopping, and prescribed burning can provide such areas. Control the exotic Chinese tallow tree (*Sapium sebiferum*) that invades wetland swales at ANWR with an aggressive herbicide application program. Continue to develop other habitat management practices that increase the habitat base available in wintering areas. These techniques should emphasize use in areas that are most protected from human encroachment.

1.5.5. Create wetland habitat.

On the migration route, wetland restoration may be needed in areas where there has been extensive loss of crane habitat. On and near the ANWR wintering grounds, enhance the whooping crane wintering habitat to provide for an expanding crane population. Increase management activities to provide better use of existing protected areas. Create new habitat to help compensate for habitat losses and increase the carrying capacity of the wintering area. Saltwater marsh can be created in open water areas using dredged material. Lowering of some areas mechanically, to allow flooding by high tides and collection of runoff, should promote development of salt or brackish marsh areas.

2. Develop and maintain captive populations.

Maintain 45 breeder pairs of whooping cranes at PWRC (15), ICF (12), CZ (10), SSC (5), and SAZ (3). Birds unable to reproduce can be used for parent-rearing, role models, or education programs.

2.1. Develop appropriate measures of genetic diversity.

Develop a thorough pedigree history for each producing pair in the captive flocks, outlining production histories and difficulties encountered, and analyze for genetic inheritance of deficiencies. Enter data annually into the flock studbook. Identify ways to separate family lines by exploring the use of anonymous fragment length polymorphisms (AFLP) or other techniques. Convene a genetics workshop to develop specific genetic plans for the FP and EMP.

Based on the above actions, research would extend to captive crane populations to: (1) obtain genetic representatives of as many wild pairs as possible; (2) retain in captivity those birds that are especially valuable because of their genetic background; and (3) give careful attention to genetic and demographic considerations to ensure health of the captive population. The

genetics flock manager(s) of the captive population should make annual analyses of the genetics and demographics of captive and reintroduced populations. Results of these analyses could be used to guide selection of eggs for transfer from the wild, selection of individuals for pairing and maintenance of appropriate population demography. Before additional eggs are picked up from the wild, a large-scale genetic study is needed in WBNP since information on the composition of nesting pairs has been lost with the cessation of color-banding in 1988. Frozen semen banks should be maintained to prevent loss of founder lines. A national serum bank should be set up to serve as a repository of genetic material for the species.

2.2. Increase the number of captive breeders.

The small captive population of the past placed constraints on productivity and reduced the potential to form socially and genetically compatible pairs. As more pairs begin egg production, there will be an increase in offspring available for reintroduction efforts and an opportunity to enhance the behavioral, demographic, and genetic management of the captive population.

2.3 Refine aviculture methods and productivity.

Captive breeding centers should optimize the production of whooping cranes in captivity through the application of proven aviculture techniques described in the Crane Propagation Manual (Ellis et al. 1996). Research is needed in the fields of reproductive physiology, genetics, behavior, and veterinary science.

2.3.1. Refine breeding pair management.

Develop and/or refine various procedures used in captive propagation of whooping cranes, particularly behavioral and physiological management, to maximize productivity of captive populations. Use research surrogates to accomplish biological research and develop techniques. Determine optimum techniques for handling, pairing, and inducing crane reproduction at captive breeding centers. Foster whooping crane production at an earlier age comparable to that of wild cranes.

2.3.2. Refine incubation procedures.

Whooping crane eggs have greater hatching success when incubated naturally for at least two weeks. Determine conditions involved in successful artificial and natural incubation to enhance overall egg hatchability and flock productivity. Sandhill cranes and other cranes are available and desirable for natural incubation. Improve mechanical incubation to allow reduction in the numbers of captive cranes used for incubation, resulting in a savings in costs and pen space.

2.3.3. Refine rearing procedures for reintroductions.

Focus captive rearing techniques and procedures on conditioning the birds for release into the wild. Birds destined for release into the wild should either be parent-reared by whooping cranes or isolation-reared using live whooping cranes as models. Whooping cranes should not be reared by other species. Birds reared for captive breeding would initially be parent-reared or exposed to proper imprint cues to assure reproduction. When

possible, expose captive-reared birds to conditions and situations in captivity that they will encounter in the wild.

2.3.4. Refine veterinary procedures.

Long-term survival and productivity of the captive populations will require healthy flocks. Proposed protocols are described in the report entitled *Whooping Crane Health Management Workshop* (Anonymous 1992). Another workshop is needed and tentatively planned for 2006. Conduct research at the captive centers, the NWHC, and other partner centers on the diagnosis, treatment, and prophylaxis of ailments in whooping cranes and other cranes in order to ensure flock health and minimize mortality. Monitor routine health practices at all times, and modify as necessary. Record health and provide postmortem findings and the long-term storage of preserved tissues in a centralized facility. Captive health research needs include investigation of orthopedic problems, chick developmental problems, parasite control, drug and vaccine use, emerging infectious diseases such as WNV, and salmonella pathogenicity.

2.3.5. Exchange aviculture information.

Staff of captive centers should exchange information including annual progress reports on propagation activities. Propagation and veterinary personnel should meet periodically to exchange information, jointly address similar problems, and develop implementation plans and protocols. Cooperation and exchange between captive centers is needed to train new staff.

2.4. Maintain captive facilities.

All aspects of Task 2 require adequate facilities for the captive whooping crane populations and surrogate species. All facilities should be maintained in conditions suitable for the cranes' health, safety, and productivity so that recovery and research objectives can be achieved. Captive sites will conform to national animal care guidelines. Once established at a site, captive pairs should not be moved to another captive facility, as transporting can cause stress and mortality, and disrupt and/or permanently hinder production (Mirande et al. 1997b).

3. Establish two additional wild populations.

The USFWS and CWS should coordinate their research and management efforts to establish at least two discrete, self-sustaining populations, each consisting of a minimum of 25 nesting pairs by year 2035. As long as they meet recovery criteria, these new populations can be either migratory or non-migratory. Plans call for all releases to be in the eastern U.S., at least through 2010.

It is important to note that much of what is known about the life history, behavior, and ecology of whooping cranes is based on the small, remnant AWBP. New behaviors or selection of new habitats may be exhibited by new populations, depending on reintroduction techniques employed, and/or changes to the current environment, which differs drastically from that of historical times. These ecological nuances should become evident through time and research.

3.1. Develop release techniques.

Test techniques for establishing migratory and non-migratory populations. Research and establish protocols for age of released birds, rearing methods, time of year, pre-release conditioning procedures, methods for teaching suitable migration behavior, and predator avoidance training. The number of released birds and post-release monitoring should be adequate to ensure proper evaluation.

3.2. Evaluate and select release sites.

Evaluate proposed potential release sites based on the biological needs of the whooping crane, the likelihood of establishing discrete, self-sustaining populations, and the impact of such an introduction on other resources and programs. Select proposed sites and rank them according to their biological suitability. Examine proposed release sites and other habitats to be used by released cranes to determine potential conflicting management problems, e.g., land and water resource development, habitat degradation, impact on other wildlife species, distribution of power lines, towers, and fences, disease, predators, and hunting of look-alike species. Conduct research studies on the suitability of release sites at Marsh Island and White Lake, Louisiana.

3.3. Establish a non-migratory population.

Continue to test the soft release of whooping cranes, isolation-reared or parent-reared in captivity, as a means of establishing a non-migratory population in Florida or elsewhere. Monitor the released birds to gather data on habitat use, movements, mortality factors, nesting success, and other data crucial to success of a reintroduction. Conduct an ongoing evaluation of release success. Implement management techniques throughout the range of the new wild population to increase project success. Management should be designed to minimize unnecessary conflict with other land and resource uses. If survival and productivity data indicate a reasonable chance for attaining a self-sustaining population, supplement the Florida population until it attains 25 nesting pairs.

3.4. Establish a migratory population.

Continue to test various means of teaching captive-produced birds to migrate and survive in the wild. Supplement this population until 25 nesting pairs are reached. Monitor the released birds to gather data on habitat use, movements, mortality factors, nesting success, and other data crucial to success of the reintroduction. Conduct an ongoing evaluation of release success. Techniques worth investigating include leading birds behind an ultralight or model aircraft, stage-by-stage migration by truck, or allowing released cranes to follow wild cranes in migration. Write a management plan for the EMP. Implement management techniques throughout the range of the new wild population to increase project success. Management should be designed to minimize unnecessary conflict with other land and resource uses.

4. Determine N_e for species survival by analyzing banding data to determine the N_e/N ratio for the AWBP.

Determine a minimum population size needed to ensure survival of the whooping crane through stochastic and catastrophic events while maintaining genetic diversity. Use knowledge from advances in the conservation biology of small populations, population viability theory, experience with long-term survival of endangered populations and genetic information to determine N_e and revise recovery criteria as warranted. An analysis of banding data collected

from the AWBP from 1977 – 1988 would provide an estimate of productive pairs vs. total population size.

5. Maintain and expand information/education programs.

Implement information and education programs to further recovery of the whooping crane. Issue press releases for December population counts at ANWR; spring departure from ANWR, arrival in Saskatchewan and requests for reports of migration sightings; number of nesting pairs in WBNP; number of chicks surviving to autumn in and near WBNP; and autumn arrival in Saskatchewan and other provinces. Events to publicize for reintroduced populations could include similar significant events including population census estimates, nesting successes, migration departures, arrivals, and general locations of birds, and requests for migration sightings. Provide outreach opportunistically at meetings and festivals.

5.1. Develop media products.

Develop and distribute printed and audio-visual media regarding recovery efforts. Target important segments of the public and specific needs of the recovery program. Encourage collaboration between the various agencies and organizations that have specific responsibilities or interests in whooping crane recovery.

5.2. Provide viewing opportunities.

Provide opportunities for the public to view whooping cranes near major use areas wherever such viewing does not interfere with recovery of the cranes. Provide live whooping cranes when available for educational displays at zoos. Provide specimen mounts for museums and educational institutions to further public education and research.

5.3 Implement education programs.

Work with educators to tell the story of whooping crane recovery and promote whooping crane conservation. Develop appropriate web sites and other methods for providing information.

INFORMATION NEEDS

Survey Requirements

Aerial population surveys on nesting and winter areas are a continuing need. There remains a need to identify unoccupied but potential nesting and winter habitat to identify any limitations on population growth. Some of these habitats may require protection by purchase, lease, or legal action. Water level surveys and monitoring of food resources are a necessity in WBNP to fully understand ecological changes and their impact on population trends. Surveys of coastal water salinity levels, freshwater inflows, and crane food resources will continue to be necessary on the winter area at Aransas to identify ecological trends. Migration activities must be monitored to ensure safety of the cranes and evaluate changes in conditions faced on the long semi-annual journey.

Biological/Ecological Research Requirements

Causes of mortality in wild and captive cranes should continue to be identified and addressed. Frequent monitoring of the birds will be required to detect losses. Such monitoring will require radio tracking or satellite tracking of wild birds in some instances. Further understanding of migration stopover habitat is needed to refine the effectiveness of habitat augmentation and management on the Platte River and elsewhere. Additional research is necessary to refine methods of creating marsh habitat with dredged sediments to ensure long-term benefits to whooping cranes. For captive populations, research needs include refining means of disease prevention, prevention of toe, leg, and wing injuries, gaining knowledge on pairing and promoting early breeding, improvements in use of artificial incubators, improving natural fertility, genetic management, nutrition of captive birds, and behavioral training to promote wildness in birds destined for release in the wild. Research is continuing to refine reintroduction techniques for establishing a second migratory population to promote appropriate migratory behavior and survival. In 2001 the Whooping Crane Health Advisory Team (WCHAT) identified the high priority research needs in captivity as: (1) the effect of West Nile virus on cranes and development of a vaccine; (2) developing a more effective TB test for screening whooping cranes; and (3) developing a fecal corticosterone test to compare levels of stress associated with various management techniques in captivity. Research is also needed on IBD in cranes.

Threat Clarification Research Requirements

Research already identified is needed to further define potential threats. For example, the impact that anticipated reduced freshwater inflows at ANWR will have on salinity, winter food resources, and population survival needs to be quantified. Continued research on mortality in reintroduced populations is another example. Such losses threaten the success of the reintroductions. Research is also needed to derive techniques to separate family lines so management of the captive flock can be improved to preserve and increase the genetic diversity of the flock.

FUTURE CONSIDERATIONS

Additional methodologies for re-establishing a migratory population need to be developed. Although the ultralight method appears to work well, it is labor intensive, expensive, and not practical for releasing hundreds of cranes. Also, it is unknown if cranes trained to follow an ultralight will have subsequent normal breeding behavior. Techniques for releasing juvenile captive-bred whooping cranes into migratory flocks of whooping or sandhill cranes should be explored.

The suitability of habitat in Florida is an area of concern. High mortality continues to hinder the reintroduction of non-migratory whooping cranes in Florida. Two of the 7 ultralight whooping cranes that followed an ultralight during migration were later killed by bobcats at CNWR in Florida in the 2001-02 winter. In 2002, the remaining 5 completed a successful migration in both the spring and fall and summered in the core release area of central Wisconsin. The 5 cranes returned to Florida but most did not remain in salt marsh habitat. Apparently the ultralight-trained whooping cranes will prefer other habitats over salt marsh habitat in Florida and may possibly associate with the non-migratory whooping cranes in central Florida.

Several sites, within the former range of the species, have been evaluated for their potential as reintroduction sites, including areas in Saskatchewan (Lyon et al. 2005a,b) and Manitoba (Sommerfeld and Scarth 1998, de Sobrino 1998), and the eastern United States (Cannon 1998, 1999). In 1999, the Canada/United States Whooping Crane Recovery Team agreed that further refinement of reintroduction techniques is needed prior to placing an experimental flock in proximity to the existing AWBP. With that in mind, the recovery team made a recommendation to release whooping cranes in central Wisconsin, with the birds wintering at CNWR in Florida, with future potential expansion into Manitoba and Louisiana.

Current plans call for all whooping crane releases to take place in the eastern U.S., at least through 2010. If either of the two eastern populations is not successful, and/or if the habitat in Florida is not suitable for whooping cranes, then the Recovery Team recommends consideration of reintroduction sites in Louisiana. In 2001, a committee was formed in Louisiana to investigate the potential for reintroducing whooping cranes to that state. At least two possible sites have been identified. Studies done by Cannon (1998) found winter habitat at Marsh Island, Louisiana, to be highly suitable for whooping cranes. There is also interest in restoring non-migratory whooping cranes to the vicinity of White Lake, Louisiana, where until 1950, a non-migratory flock existed. In July, 2002, BP American Production Company donated the 71,130-acre White Lake Preserve to the State of Louisiana. It is currently being managed by the Louisiana Department of Wildlife and Fisheries (LDWF). Returning whooping cranes to this site has been discussed with LDWF. Based on their historical presence in the state, Louisiana seems to be a good site for whooping crane reintroduction.

Although the Recovery Team is interested in the idea of establishing a Louisiana population, there are currently not enough whooping cranes produced annually in captivity to support a reintroduction effort in that state. Additionally, much planning and coordination with state and local agencies and other interested parties in Louisiana is required to further these preliminary discussions.

PART III. IMPLEMENTATION SCHEDULE

The implementation schedule outlines and prioritizes recovery tasks over the recovery period. It will be used in the ongoing monitoring of all recovery tasks and will provide the basis for funding of recovery actions. Tasks are identified under general categories, and all headings are derived from Part II's Narrative Outline for Recovery Actions to Achieve Objectives. The schedule ranks objectives and tasks, identifies respective responsible agencies, defines schedules, and estimates costs in terms of financial resources and person-years for the recovery period. Tasks must be continually revised as plans move from implementation to completion as a result of monitoring results and updating information. Each revision will identify additional actions and studies that will be needed during the recovery period.

Recovery priorities are defined as follows:

Priority 1: An action that must be taken to prevent extinction or prevent the species from declining irreversibly in the foreseeable future.

Priority 2: An action that must be taken to prevent a significant decline in species population or habitat quality or some other significant negative impact short of extinction.

Priority 3: All other actions necessary to provide for full recovery (or reclassification) of the species.

- IMPLEMENTATION SCHEDULE -

Action	Task #	Priority	Responsible Party	Program	Cooperator	Duration	Cost ($ x 1000) Year 1	Year 2-5	Year 6-10	Year 11-30
Conduct Aerial Surveys in WBNP	111	1	CWS, WBNP	CWS	WBNP	Continuous	25	100	125	600
Analyze Data on Egg Management	112	3	CWS	CWS	WCRT	Continuous	5	-	-	-
Conduct Aerial Surveys at ANWR	113	1	USFWS-2	ES, RW	-	Continuous	20	80	100	400
Monitor Movements in Migration	12	2	CWS, USFWS-2,6	CWS, ES	RW, A, M, S	Continuous	125	500	625	2500
Prevent Shooting	131	2	CWS, USFWS	CWS, USFWS-2,3,4,6	ES, RW, A, M, S	Continuous	5	25	32	150
Diminish Disease Losses	132	2	CWS, USFWS	NWHC	WCRT, PWRC, CCWHC	Continuous	20	90	115	450
Diminish Collisions	133	1	CWS, USFWS	CWS, ES	FCC	Continuous	2	13	180*	60
Restrict Construction Periods	141	2	CWS, USFWS-2	ES	A, M, S, RW, WBNP	Continuous	5	20	25	100
Restrict Aircraft Altitude	142	2	CWS, PCA, USFWS-2	WBNP, RW	FAA, TC	Continuous	2	5	5	10
Restrict other disturbance	143	2	CWS, PCA, USFWS-2	WBNP, RW	FAA, TC	Continuous	18	75	95	490
Identify Essential Habitat	151	2	CWS, PCA	CWS, USFWS-2,6	WBNP	Continuous	30	140	312*	100
Monitor Habitat in WBNP	1521	2	WBNP	WBNP	CWS	Continuous	40	160	75	250
Monitor Foods and Salinities at ANWR	1522	2	USFWS-2	RW, ES	-	Continuous	30	110	125	450
Measure stopover habitat	1523	3	CWS, USFWS	USFWS-2,6	PRT	Continuous	10	50	-	-
Maintain WBNP	1531	2	WBNP	WBNP	CWS	Continuous	100	380	485	25
Protect migration habitat	1532	2	CWS, USFWS	CWS, USFWS-2,6	States	Continuous	100	400	500	2000
Maintain ANWR and other NWR	1533	2	USFWS	USFWS-2,6	PRT	Continuous	290	1140	1465	75
Prevent Contamination	1534	2	CWS, USFWS-2	ES, CG	TNRCC,USACE	Continuous	1	4	5	20

Prevent Erosion of Habitat	1535	2	USFWS-2	USACE	RW, ES	Continuous	1	4	5	20
Manage Dredge Material	1536	2	USFWS-2	USACE	ES, RW	Continuous	1	4	5	20
Maintain Freshwater Inflows	1537	1	USFWS-2,6	ES, RW	TNRCC,TPWD, USACE	Continuous	40	160	200	2000
Maintain Instream Flows	1538	2	USFWS-6	ES, PRT	NAS	Continuous	100	400	500	2000
Monitor Global Warming	1539	2	CWS, PCA, USFWS-2,	RW, ES	CWS, WBNP,ES	Continuous	2	5	10	20
Fire Management	1541	2	PCA, USFWS	RW, ES	PRT, NAS WBNP	Continuous	20	80	100	400
Maintain Upland Water Sources	1542	2	USFWS-2	RW		Continuous	2	8	10	40
Manage Vegetation	1543	2	USFWS-2,6	RW	PRT, NAS	Continuous	300	1200	1500	6000
Create Wetland Habitat	155	2	USFWS-2,6	ES, USACE	RW	Continuous	200	800	1000	4000
Develop More Sensitive Measures of Genetic Diversity	21	2	USGS	-	ICF, PWRC, NGO, NWHC	Continuous	60	240	60	100
Increase Captive Breeders	22	1	CWS, USGS, USFWS-2,9	ES	all captive centers	Continuous	1400	5600	7000	300
Refine Breeding Pair Management	231	2	USGS, all captive centers	-	all captive centers	Continuous	50	200	50	100
Refine Incubation Procedures	232	3	ICF, PWRC	-	all captive centers	5 years	10	40	40	20
Refine Rearing Procedures for Reintroductions	233	2	PWRC, ICF, OM	-	all captive centers	10 years	10	40	40	100
Refine Veterinary Procedures	234	3	all captive centers, NWHC	-	-	Continuous	20	80	80	100
Exchange Avicultural Information	235	3	WCCMT	-	all captive centers	Continuous	5	20	25	40
Maintain Captive Facilities	24	3	USGS, USFWS-9	-	all captive centers	Continuous	150	600	750	3000
Develop Release Techniques	31	2	PWRC, ICF, USFWS-3,4	-	FL, OM, WCRT	10 years	750	3000	3750	400

Select Release Sites	32	2	CWS, USFWS-2,3,4	-	WCRT	Do when needed	-	50	75	100
Establish a Non-Migratory Population	33	2	USFWS-4,9, FL	-	-	10 years	280	1120	1400	-
Establish Migratory Population	34	2	USFWS-3,4, WI, PWRC,ICF, OM	-	States	20 years	2000	8000	10000	40000
Determine *Ne* for Species Survival	4	3	CWS, USFWS, PWRC	-	-	Continuous	-	30	10	10
Develop Media Products	51	3	CWS, USFWS-2,3,4,6,9	PA	ICF,PRT PWRC, WCCA	Continuous	5	20	25	40
Provide Viewing Opportunities	52	3	CWS, FL, WI USFWS-2,3,4,6	ES, RW	OM	Continuous	5	20	25	40
Implement Education Programs	53	3	CWS,USFWS-2,3,4,6,9		WCEP,WCCA	Continuous	5	20	25	40

* Includes 162K for satellite telemetry

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Canadian migration staging/stopover areas; contact Brian Johns, Canadian Wildlife Service, address listed above.

U.S. migration staging/stopover areas; contact Martha Tacha, USFWS, Grand Island Field Office, Federal Building, 2nd Floor, 203 West Second Street, Grand Island, Nebraska 68801

AWBP wintering area along the Texas Gulf Coast; contact Tom Stehn, Aransas NWR, address listed above.

Florida non-migratory population; contact Marty Folk, address listed above.

Eastern migratory experimental reintroduction; contact Beth Goodman, Wisconsin DNR, PO Box 7921, Madison, WI 53707. beth.goodman@dnr.state.wi.us

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PART V. REFERENCES

Allen, R. P. 1952. The whooping crane. Natl. Audubon Soc. Resource Rept. 3. 246 pp.

_____. 1956. A report on the whooping cranes' northern breeding grounds. Natl. Audubon Soc. Supplemental Resource Rept. 3. 60 pp.

Anderson, D. W., and J. F. Kreitzer. 1971. Thickness of 1967-69 whooping crane eggshells compared to that of pre-1910 specimens. Auk 88:433-434.

Anonymous. 1992. Whooping crane health management workshop. USFWS, Madison, Wisconsin. 47 pp.

Archibald, G. W. 1975. The evolutionary and taxonomic relationships of cranes as revealed by their unison calls. Ph.D. Dissertation, Cornell Univ., Ithaca, New York. 151 pp.

Archibald, G.W., J. Baldwin, and P. Konrad. 1976. Is sandhill hunting a threat to the whooping crane? Pages 207-221 in J. C. Lewis, ed. Proc. International Crane Workshop. Oklahoma State Univ. Press, Stillwater, Oklahoma.

Archibald, K., and G. W. Archibald. 1992. Releasing puppet-reared sandhill cranes in the wild: A progress Report. Pages 251-254 in D. A. Wood, ed. Proc. 1988 N. Am. Crane Workshop. State of Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

Armbruster, M. J. 1990. Characterization of habitat used by whooping cranes during migration. Biological Rept. 90(4):1-16.

Asherin, D., and R. Drewien. 1987. Computerized management and display of whooping crane observation data. Pages 276-282, in J. C. Lewis and J. W. Ziewitz, eds. Proc. 1985 Crane Workshop. Platte River Whooping Crane Habitat Maintenance Trust and USFWS, Grand Island, Nebraska.

Asherin, D. A., D. B. Hamilton, W. M. Brown, and R. C. Drewien. 1992. A microcomputer data base for managing whooping crane observation records. Pages 270-273 in D. Wood, ed. Proc. 1988 Crane Workshop. Florida Game and Freshwater Fish Commission, Nongame Tech. Rep. # 12.

Austin, J. E., and A. L. Richert. 2001. A comprehensive review of the observational and site evaluation data of migrant whooping cranes in the United States, 1943-99. U.S. Geological Survey, Northern Prairie Wildlife Research Center, Jamestown, North Dakota, and State Museum, University of Nebraska, Lincoln, Nebraska. 157 pp.

Avian Power Line Interaction Committee. 1994. Mitigating bird collisions with power lines: The state of the art in 1994. Edison Electric Institute, Washington, D.C. 78 pp.

Bakst, M. R. 1988. Turkey hen fertility and egg production by artificial insemination and multiple eversion during the pre-lay period. J. Reproduction and Fertility 83:1-5.

Ballou, J. D., M. Gilpin, and T. J. Foose. 1995. Population management for survival and recovery. In M. C. Pearl, ed. Methods and cases in conservation science. Columbia Univ. Press, New York. 375 pp.

Banks, R. 1978. The size of the early whooping crane populations. Unpubl. Rept. USFWS files. 10 pp.

Bennett, A. J., and L. A. Bennett. 1987. Evaluation of the Okefenokee Swamp as a site for developing a nonmigratory flock of whooping cranes. Final Rept., Georgia Cooperative Fish and Wildl. Research Unit, Athens. 112 pp.

Bent, A. C. 1926. Life histories of North American marsh birds. U.S. Natl. Museum Bull. 135:219-231.

Bergeson, D. G., B. W. Johns, and G. Holroyd. 2001a. Mortality of whooping crane colts at Wood Buffalo National Park, Canada. Proc. N. Am. Crane Workshop 8:6-10.

_____, M. Bradley, and G. Holroyd. 2001b. Food items and feeding rates for wild whooping crane colts in Wood Buffalo National Park. Proc. N. Am. Crane Workshop 8:36-39.

Binkley, C. S., and R. S. Miller. 1983. Population characteristics of the whooping crane, *Grus Americana*. Can J. Zool. 61:2768-2776.

Bird, D. M., W. Burnham, and R. W. Fyfe. 1985. A review of cross-fostering in birds of prey. ICBP Tech. Publ. 5:433-438.

Bishop, M. A. 1984. The dynamics of subadult flocks of whooping cranes wintering in Texas 1978-l979 through 1982-1983. MS Thesis, Texas A & M Univ., College Station. 128 pp.

_____. 1988. An evaluation of three areas in central Florida as potential reintroduction areas for a nonmigratory flock of whooping cranes. Univ. Florida, Gainesville. 63 pp.

_____, and D. R. Blankinship. 1982. Dynamics of subadult flocks of whooping cranes at Aransas National Wildlife Refuge, Texas, 1978-1981. Pages 180-189, in J. C. Lewis, ed. Proc. 1981 International Crane Workshop. Natl. Audubon Soc., Tavernier, Florida.

Bizeau, E., T. Schumacher, R. Drewien, and W. Brown. 1987. An experimental release of captive-reared greater sandhill cranes. Pages 78-89 in J. C. Lewis and J. W. Ziewitz, eds. Proc. 1985 Crane Workshop. Platte River Whooping Crane Habitat Maintenance Trust and USFWS, Grand Island, Nebraska.

Blankinship, D. R. 1976. Studies of whooping cranes on the wintering grounds. Pages 197-206 in J. C. Lewis, ed. Proc. International Crane Workshop, Oklahoma State Univ. Press, Stillwater.

_____. 1987. Research and management programs for wintering whooping cranes. Pages 381-386 in G. W. Archibald and R. F. Pasquier, eds. Proc. 1983 Crane Workshop,

International Crane Foundation, Baraboo, Wisconsin.

Bonds, C. J. 2000. Characterization of banded whooping crane territories from 1992-93 to 1996-97 using GIS and remote sensing. Ph.D. thesis. Texas A and M Univ.-College Station. 106 pp.

Bowman, M. R., J. Waldoch, J. M. Pittman and B. K. Hartup. 2002. Enrofloxacin plasma concentrations in sandhill cranes (*Grus Canadensis*) after administration in drinking water: A preliminary study. Proc. Am. Assoc. of Zoo Veterinarians Ann. Conf., Milwaukee, Wisconsin. Pages 389-390.

Boyce, M. S. 1987. Time-series analysis and forecasting of the Aransas-Wood Buffalo whooping crane population. Pages 1-9, in J. C. Lewis and J. W. Ziewitz, eds. Proc. 1985 Crane Workshop. Platte River Whooping Crane Habitat Maintenance Trust and USFWS, Grand Island, Nebraska.

_____, and R. S. Miller. 1985. Ten year periodicity in whooping crane census. Auk 102(3):658-660.

_____, S. R. Lele and B. W. Johns. 2005. Whooping crane recruitment enhanced by egg removal. Biological Conservation 126:395-401.

Brand, C. J., J. Langenberg, and J.W. Carpenter. 1992. Summary of diseases and disease recommendations in whooping cranes. In Mirande, R. Lacy, and U. Seal (compilers), *Grus americana* Whooping Crane Conservation Viability Assessment Workshop Rept., Fossil Rim Wildl. Center, 6-8 August 1991. Captive Breeding Specialist Group (CBSG/SSC/IUCN).

Brook, B. W., J. R. Cannon, R. C. Lacy, C. Mirande, and R. Frankham. 1999. A comparison of the population viability analysis packages GAPPS, INMAT, RAMAS, and VORTEX for the whooping crane *Grus americana*. Animal Conservation 2(1):23-31.

Brook, B. W., D. W. Tonkyn, J. J. O'Grady, and R. Frankham. 2002. Contribution of inbreeding to extinction risk in threatened species. Conservation Ecology 6(1):art. no. 16.

Brown, W. M., R. C. Drewien, and E. G. Bizeau. 1987. Mortality of cranes and waterfowl from powerline collisions in the San Luis Valley-Colorado. Pages 128-136, in J. C. Lewis and J. W. Ziewitz, eds. Proc. 1985 Crane Workshop. Platte River Whooping Crane Habitat Maintenance Trust and USFWS, Grand Island, Nebraska.

_____, and R. C. Drewien. 1995. Evaluation of two powerline markers to reduce crane and waterfowl collision mortality. Wildl. Soc. Bull. 23(2):217-227.

Buller, R. J. 1967. Sandhill crane study in the Central Flyway. USFWS Special Scientific Rept. Wildl. 113, Washington, D.C. 17 pp.

Burke, A. M. 1996. Habitat use and breeding biology of sandhill cranes in the Yorkton Region, Saskatchewan, Canada. Unpubl. Rept. College of Natural Resources. Univ. Wisconsin-

Stevens Point.

Burleigh, T. D. 1944. The bird life of the Gulf Coast Region of Mississippi. Louisiana State Univ., Occas. Pap. Mus. Zoology 20:329-490.

Cannon, J. R. 1998. Whooping crane wintering sites study: Final Rept. to Canadian-United States Whooping Crane Recovery Team, Calgary, Alberta, Canada. 19pp + appendices.

_____. 1999. Wisconsin whooping crane breeding site assessment. Final Rept. to Canadian-United States Whooping Crane Recovery Team. 38 pp.

_____, B. W. Johns, and T. V. Stehn. 2001. Egg collection and recruitment of young of the year in the Aransas/Wood Buffalo population of whooping cranes. Proc. N. Am. Crane Workshop 8:11-16.

Carlson, G. 1991. The feasibility of individual identification and sex determination of whooping cranes (*Grus americana*) by analysis of vocalizations. M.S. Thesis, Idaho State Univ., Pocatello. 60 pp.

Carpenter, J. W., and S. R. Derrickson. 1982. Whooping crane mortality at the Patuxent Wildlife Research Center, 1966-1981. Pages 175-179 in J. C. Lewis, ed. Proc. 1981 International Crane Workshop. Natl. Audubon Soc., Tavernier, Florida.

_____,T. R. Spraker, and M. N. Novilla. 1980. Disseminated visceral coccidiosis in whooping cranes. J. Am. Veterinary Medical Association 177:845-848.

_____, F. Dien, and G. Clark. 1987. An outbreak of eastern equine encephalitis virus in captive whooping cranes. Pages 123-127, in J. C. Lewis and J. W. Ziewitz, eds. Proc. 1985 Crane Workshop. Platte River Whooping Crane Habitat Maintenance Trust and USFWS, Grand Island, Nebraska.

Chapin, F. S. III, E. E. Zavaleta, V. T. Eviner, R.L. Naylor, P. M. Vitousek, H. L. Reynolds, D. U. Hooper, S. Lavorel, O. E. Sala, S .E. Hobbie, M. C. Mack, and S. Diaz. 2000. Consequences of changing biodiversity. Nature 405:234-242.

Chavez-Ramirez, F. 1996. Food availability, foraging ecology, and energetics of whooping cranes wintering in Texas. Ph.D. dissertation, Texas A & M Univ. 103 pp.

_____, F., H. E. Hunt, R. D. Slack, and T. V. Stehn. 1995. Ecological correlates of whooping crane use of fire-treated upland habitats. Cons. Biol. 10(1):217-223.

_____, F., J. T. Nelson, and R. D. Slack. 1997. Food and energy intake rates of wintering whooping cranes foraging on two selected food items. Proc. N. Am. Crane Workshop 7:259.

Clegg, K. R., J. C. Lewis, and D. H. Ellis. 1997. Use of ultralight aircraft for introducing migratory crane populations. Proc. N. Am. Crane Workshop 7:105-113.

_____ and J. C. Lewis. 2001. Continuing studies of ultralight aircraft applications for introducing migratory populations of endangered species. Proc. N. Am. Crane Workshop 8:96-108.

Cooch, F.G. (ed.), W. Dolan, J.P. Goossen, G. L. Holroyd, B.W. Johns, E. Kuyt, and G. H. Townsend. 1988. Canadian Whooping Crane Recovery Plan. Canadian Wildl. Service, Ottawa. 56pp.

Currier, P. J. 1997. Woody vegetation expansion and continuing declines in open channel habitat on the Platte River in Nebraska. Proc. N. Am. Crane Workshop 7:141-152.

_____, G. R. Lingle, and J. G. Van Derwalker. 1985. Migratory bird habitat on the Platte and North Platte Rivers in Nebraska. The Platte River Whooping Crane Habitat Maintenance Trust, Grand Island, Nebraska. 177 pp.

Darnell, T. M., E. H. Smith, J. W. Tunnell, Jr., K. Withers, and E. R. Jones. 1997. The influence of landscape features on bird use of marsh habitat created for whooping cranes through beneficial use of dredged material: Final report. Center for Coastal Studies, Texas A & M Univ., Corpus Christi. 93 pp.

Derby, C. and D. Strickland. 2001. Platte River Cooperative Agreement and proposed program: Efforts to protect, restore, and manage habitat for whooping crane, least terns, and piping plovers. Abstract in Proc. N. Am. Crane Workshop 8:224.

_____, E. Lack, and D. Strickland. 2000. Habitat management methods for least terns, piping plovers, and whooping cranes. Western Ecosystem Technology, Inc., Cheyenne, Wyoming. 92pp.

Derrickson, S. R., and J. W. Carpenter. 1982. Whooping crane production at the Patuxent Wildlife Research Center, 1967-1981. Pages 190-198 in J. C. Lewis, eds. Proc. 1981 International Crane Workshop. Natl. Audubon Soc., Tavernier, Florida.

de Sobrino, C. 1998. Evaluation of the Interlake region of Manitoba as a reintroduction site for whooping cranes: Food item evaluation. Unpubl. Rept. of the Delta Waterfowl and Wetlands Research Station, Portage la Prairie, Manitoba.

Dessauer, H.C., G. F. Gee, and J. S. Rogers. 1992. Allozyme evidence for crane systematics and polymorphisms within populations of sandhill, sarus, siberian and whooping cranes. Molecular Phylogenetics and Evolution 1:279-288.

DeWandel, M. 2003. Socio-economic considerations and protection options for whooping crane habitat in the Northwest Territories. Report prepared for Canadian Wildl. Serv., Saskatoon, Saskatchewan.

Doughty, R. W. 1989. Return of the whooping crane. Univ. Texas Press, Austin. 182 pp.

Drewien, R. C. 1973. Ecology of Rocky Mountain greater sandhill cranes. Ph.D. Dissertation, Univ. Idaho, Moscow, Idaho. 152 pp.

_____, and E. G. Bizeau. 1974. Status and distribution of greater sandhill cranes in the Rocky Mountains. J. Wildl. Management 38:720-742.

_____, and_____. 1978. Cross-fostering whooping cranes to sandhill crane foster parents. Pages 201-222, in S. A. Temple, ed. Endangered Birds - Management Techniques for Preserving Threatened Species. Univ. Wisconsin, Madison.

_____, and_____. 1981. Use of radiotelemetry to study the movements of juvenile whooping cranes. Pages 130-134, in J. C. Lewis and H. Masatomi, eds. Crane Research Around the World. International Crane Foundation, Baraboo, Wisconsin.

_____, and K. R. Clegg. 1992. Capturing whooping cranes and sandhill cranes by night-lighting. Proc. N. Am. Crane Workshop 6:43-49.

_____, and E. Kuyt. 1979. Teamwork helps the whooping crane. Natl. Geographic 155:680-693.

_____, S. R. Derrickson, and E. G. Bizeau. 1981. Experimental release of captive parent-reared greater sandhill cranes at Grays Lake Refuge, Idaho. Pages 99-111, in J. C. Lewis, ed. Proc. 1981 International Crane Workshop. Natl. Audubon Soc., Tavernier, Florida.

_____, S. H. Bouffard, D. D. Call, and R. A. Wonacott. 1985. The whooping crane cross-fostering experiment: The role of animal damage control. Pages 7-13, in P. T. Bromley, ed. Proc. Second Eastern Wildl. Damage Control Conf. N. Carolina State Univ., Raleigh.

_____, W. Brown, and E. Bizeau. 1989. Whooping crane cross-fostering experiment. Unpubl. Rept. to U.S. Whooping Crane Recovery Team. 10 pp.

_____, W. M. Brown, and W. L. Kendall. 1995. Recruitment in Rocky Mountain greater sandhill cranes and comparison with other N. Am. crane populations. J. Wildl. Management 59(2):339-356.

_____, W. L. Munroe, K. R. Clegg, and W. M. Brown. 1997. Use of cross-fostered whooping cranes as guide birds. Proc. N. Am. Crane Workshop 7:86-95.

_____, J. Tautin, M. L. Courville, and G. M. Gomez. 2001. Whooping cranes breeding at White Lake, Louisiana, 1939: observations by John J. Lynch, U.S. Bureau of Biological Survey. Proc. N. Am. Crane Workshop 8:24-30.

Duff, J. W, W. A. Lishman, D. W. Clark, D. H. Ellis, G. F. Gee, and D. T. Sprague. 2001a. Promoting wildness in sandhill cranes conditioned to follow an ultralight aircraft. Proc. N. Am. Crane Workshop 8:115-121.

Duff, J. W, W. A. Lishman, D. W. Clark, G. F. Gee, and D. H. Ellis. 2001b. Results of the first ultralight-led sandhill crane migration in eastern North America. Proc. N. Am. Crane Workshop 8:109-114.

Edwards, R., S. Brechtel, R. Bromley, D. Hjertaas, B. Johns, E. Kuyt, J. C. Lewis, N. Manners, R. Stardom, and G. Tarry. 1994. National recovery plan for the whooping crane. Rept. 6, Ottawa: Recovery of Nationally Endangered Wildl. Comm., Canadian Wildl. Fed., Ontario. 39 pp.

Ellis, D. H., and F. J. Dein. 1991. Flight restraint techniques for captive cranes. Pages 447-452 in J. Harris, ed. Proc. 1987 International Crane Workshop. International Crane Foundation, Baraboo, Wisconsin.

_____, and G. F. Gee. 2001. Whooping crane egg management: Options and consequences. Proc. N. American Crane Workshop 8:17-23.

_____, G. H. Olsen, G. F. Gee, J. M. Nicolich, K. E. O'Malley, M. Nagendran, S.G. Hereford, P. Range, W. T. Harper, R. P. Ingram, and D. G. Smith. 1992a. Techniques for rearing and releasing nonmigratory cranes: Lessons from the Mississippi sandhill crane program. Proc. N. Am. Crane Workshop 6:135-141.

_____, J. C. Lewis, G. F. Gee, and D. G. Smith. 1992b. Population recovery of the whooping crane with emphasis on reintroduction efforts: Past and future. Proc. N. Am. Crane Workshop 6:142-150.

_____, G. F. Gee, and C. M. Mirande, eds. 1996. Cranes: Their biology, husbandry, and conservation. Natl. Biological Service and International Crane Foundation, Washington, D.C., 307 pp.

_____, B. Claus, T. Watanabe, R. C. Mykut, M. Kinloch, and C. H. Ellis. 1997. Results of an experiment to lead cranes on migration behind motorized ground vehicles. Proc. N. Am. Crane Workshop 7:114-122.

_____, K. R. Clegg, J. C. Lewis, and E. Spalding. 1999. Golden eagle predation on experimental sandhill and whooping cranes. Condor 101(3):664-667.

_____, and G. F. Gee. 2001. Whooping crane egg management: options and consequences. Proc. N. Am. Crane Workshop 8:17-23.

_____, C. Mellon, M. Kinloch, T. Dolbeare, and D. Ossi. 2001a. Results of the Utah-Arizona stage-by-stage migrations. Proc. N. Am. Crane Workshop 8:132-138.

_____, G. F. Gee, K. R. Clegg, J. W. Duff, W. A. Lishman, and W. J. L. Sladen. 2001b. Lessons from the motorized migrations. Proc. N. Am. Crane Workshop 8:139-144.

_____, D. P. Mummert, M. Kinloch, C. Mellon, T. Dolbeare, and D. Ossi. 2001c. The one-by-one method for releasing cranes. Abstract in Proc. N. Am. Crane Workshop 8:225.

Environmental Protection Agency. 1992. Supplemental assessment, Section 7 consultation, Formosa Point Comfort Expansion, Letter of October 28, 1992. Dallas, Texas.

Erickson, R. C. 1961. Production and survival of whooping cranes. USFWS, Unpubl. Admin.

Rept. 29 pp.

_____. 1968. A federal research program for endangered Wildlife. Trans. N. Am. Wildl. Conf. 33:418-433.

_____. 1975. Captive breeding of whooping cranes at the Patuxent Wildlife Research Center. Pages 99-114, in R. D. Martin, ed. Breeding Endangered Species in Captivity. Academic Press, New York.

_____. 1976. Whooping crane studies at the Patuxent Wildlife Research Center. Pages 166-176, in J. C. Lewis, ed. Proc. International Crane Workshop, Oklahoma State Univ. Press, Stillwater.

_____ and S. R. Derrickson. 1981. Whooping crane (*Grus americana*). Pages 104-118, in J. C. Lewis and H. Masatomi, eds. Crane Research Around the World. International Crane Foundation, Baraboo, Wisconsin.

Evans, D. E., and T. V. Stehn. 1997. Use of dredged material to construct winter whooping crane habitat. Proc. N. Am. Crane Workshop 7:67-71.

Farmer, A. H., B.S. Cade, J.W. Terrell, J.H. Henriksen, and J.T. Runge. 2004. Models and data for assessing whooping crane (*Grus americana*) habitat in the central Platte River, Nebraska. A Final Report to the U.S. Fish and Wildlife Service, Region 6 Grand Island, Nebraska and Denver, Colorado Contract # 1448-60181-99-N292.

Feduccia, J. A. 1967. *Ciconia maltha* and *Grus americana* from the Upper Pliocene of Idaho. Wilson Bull. 79:316-318.

Filion, F.L., A. Jacquemot, E. DuWors, R. Reid, P. Boxall, P. Bouchard, P.A. Gray and A. Bath. 1994. The importance of wildlife to Canadians: The economic significance of wildlife-related recreational activities in 1991. Environment Canada. Ottawa.

Fitzhugh, T.W. and B. D. Richter, 2004. Quenching urban thirst: Growing cities and their impacts on freshwater ecosystems. BioScience 54(8):741-754.

Folk, M. J., S. A. Nesbitt, and M. G. Spalding. 2001. Interactions of sandhill cranes and whooping cranes with foreign objects in Florida. Proc. N. Am. Crane Workshop 8:195-197.

Forrester, D. J., J. W. Carpenter, and D. R. Blankinship. 1978. Coccidia of whooping cranes. J. Wildl. Diseases 14:24-27.

Forbes, S. and D. Mock. 2000. A tale of two strategies: Life-history aspects of family strife. Condor 102:23-24.

Frankel, O. H., and M. E. Soule. 1981. Design criteria for nature reserves. Pages 98-122 in Conservation and Evolution. Cambridge Univ. Press, Cambridge, London. 327 pp.

Frankham, R. 1995. Conservation genetics. Annual Review of Genetics 29:305-327.

Garton, E. 0., R. C. Drewien, W. M. Brown, E. G. Bizeau, and P. H. Hayward. 1989. Survival rates and population prospects of whooping cranes at Grays Lake NWR. Final Rept. Fish and Wildl. Department, Univ. Idaho. in files Aransas Natl. Wildl. Refuge, Austwell, Texas. 47 pp.

Gee, G. F., and S. A. Temple. 1978. Artificial insemination for breeding non-domestic birds. Symposium Zoological Soc. London 43:51-72.

_____, and C. M. Mirande. 1996. Special techniques, Part A: Crane artificial insemination. Pages 205-217 in D. H. Ellis, G. F. Gee, and C. M. Mirande, eds. Cranes: Their biology, husbandry, and conservation. Natl. Biological Service, Washington, D.C., and International Crane Foundation, Baraboo, Wisconsin, and USFWS, Washington, D.C. 308 pp.

_____, J. Nicolich, S. A. Nesbitt, J. Hatfield, D. H. Ellis, and G. H. Olsen. 2001. Water conditioning and whooping crane survival after release in Florida. Proc. N. Am. Crane Workshop 8:160-165.

Gerencser, J. 1997. Evaluation of pair-bond strength in cranes at the International Crane Foundation. Avicultural Magazine 103(3):107-111.

_____. 1998. Managing crane pair formation at the International Crane Foundation. AFA Watchbird 25(3):56-61.

Glenn, T. C., W. Stephan, and M. J. Braun. 1999. Effects of a population bottleneck on mitochondrial DNA variation in whooping cranes. Conservation Biology 13(5):1097-1107.

Gomez, G. M. 1992. Whooping cranes in southwest Louisiana: History and human attitudes. Proc. N. Am. Crane Workshop 6:19-23.

Gomez, S. D., R. Lara, M. Putnam and A. Lacy. In press. The whooping crane (*Grus americana*) in Mexico: Past, present, and future? Proc. 2006 N. Am. Crane Workshop 10:0-00.

Gulf Engineers and Consultants, Inc. 1992. Spill contingency and prevention plan for the Gulf Intracoastal Waterway at the Aransas National Wildlife Refuge. Rept. to USACE, Contract No. DACW 64-91-D-0002, Baton Rouge, Louisiana, 93 pp.

Hahn, P. 1963. Where is that vanished bird? Royal Ontario Museum, Univ. Toronto, Canada.

Hallman, R. C. 1965. Whooping crane shot in St. Johns County, Florida. Fla. Nat. 38:22.

Harrison, M. 1983. Letter from Office of Airport Standards to R. Thorsell of Edison Electric Institute. USFWS file at Aransas NWR, Austwell, TX. 2 pp.

Hartup, B. K., K. A. Linn and J. A. Langenberg. 2001a. Patellar ligament rupture and tibiotarsal crest fractures in whooping crane (*Grus americana*) chicks: Potential risk factors and

treatment constraints. Proc. Am. Assoc. of Zoo Veterinarians Ann. Conf., Orlando, Florida. Pages 371-373.

_____, N. M. Czekala, G. H. Olsen and J. A. Langenberg. 2001b. Levels of fecal corticosterone in released sandhill cranes: An indicator of potential stress for reintroduced whooping cranes. Proc. Am. Assoc. of Zoo Veterinarians Ann. Conf., Orlando, Florida. Pages 222-223.

Hayes, M. A. and J. Barzen (In press). An ecological interpretation of historic location records for whooping cranes (Grus Americana). Abstract in Proc. 2003 N. Am. Crane Workshop 9:0-00.

Henszey, R. J., and T. A. Wesche. 1993. Hydrologic components influencing the condition of wet meadows along the central Platte River, Nebraska. Rept. to Nebraska Game and Parks Commission, Lincoln, Nebraska. HabiTech, Inc. Laramie, Wyoming. 84 pp.

Hjertaas, D. 1994. Summer and breeding records of the whooping crane in Saskatchewan. Blue Jay 52:99-115.

_____, B. W. Johns, and W. J. Lyon. 1997. Identification of potential reintroduction sites for whooping cranes in the prairie provinces of Canada. Proc. N. Am. Crane Workshop 7:256-257.

Horwich, R. H. 1986. Reintroduction of cranes to the wild. ICF Bugle 12(4):1-5.

_____. 1989. Use of surrogate parental models and age periods in a successful release of hand-reared sandhill cranes. Zoo. Biol. 8:379-390.

_____, J. Wood, and R. Anderson. 1992. Release of sandhill crane chicks hand-reared with artificial stimuli. Pages 255-262 in D. A. Wood, ed. Proc. 1988 N. Am. Crane Workshop. Florida Game and Fresh Water Fish Commission.

Howard, J. A. 1954. Aransas, a National Wildlife Refuge. U.S. Department of the Interior, USFWS. 12 pp.

Howe, M. A. 1987. Habitat use by migrating whooping cranes in the Aransas-Wood Buffalo corridor. Pages 303-311, in J. C. Lewis and J. W. Ziewitz, eds. Proc. 1985 Crane Workshop. Platte River Whooping Crane Habitat Maintenance Trust and USFWS, Grand Island, Nebraska.

_____. 1989. Migration of radio-marked whooping cranes from the Aransas-Wood Buffalo population: Patterns of habitat use, behavior, and survival. USFWS, Fish Wildl. Tech. Rept 21. 33pp.

Hughes, L. 2000. Biological consequences of global warming: is the signal already apparent? Tree 15:56-61.

Hunt, H. E. 1987. The effects of burning and grazing on habitat use by whooping cranes and

sandhill cranes on the Aransas Natl. Wildl. Refuge. Ph.D. Dissertation, Texas A & M Univ., College Station. 172 pp.

_____, and R. Slack. 1987. Winter foods of the whooping crane based on stomach content analyses. Pages 217-218, in J. C. Lewis and J. W. Ziewitz, eds. Proc. 1985 Crane Workshop. Platte River Whooping Crane Habitat Maintenance Trust and USFWS, Grand Island, Nebraska.

Hurr, R. T. 1983. Ground-water hydrology of the Mormon Island Crane Meadows Wildl. area near Grand Island, Hall County, Nebraska. Pages H1-H12, in Hydrologic and Geomorphical studies of the Platte River Basin, U.S. Geological Survey Professional Paper 1277.

Hyde, D. 0. 1968. Sandy, the sandhill crane. Dial Press, New York. 241 pp.

Immelmann, K. 1972. Sexual and other long-term aspects of imprinting in birds and other species. Pages 147-174 in D. S. Lehrman et al., eds. Advances in the study of behavior. Vol.4, Academic Press, New York.

Irby, H. D. 1990. Whooping crane/human interaction study. Welder Flats Coastal Preserves Baseline Studies Rept. Section III. Texas Parks and Wildl. Dept., Austin. 52 pp.

Jarvi, S. I., G. F. Gee, W. E. Briles, and M. M. Miller. 1992. Identification of segregating hapolotypes of the major histocompatibility complex in cranes. Proc. N. Am. Crane Workshop 6:171.

Jimenez, J. A., K. A. Hughes, G. Alaks, L. Graham, and R. C. Lacy. 1994. An experimental study of inbreeding depression in a natural habitat. Science 266(5183):271-273.

Johns, B. W. 1987. Whooping crane sightings in the prairie provinces 1979-1985. Canadian Wildl. Service Progress Note 169. 6 pp.

_____. 1992. Preliminary identification of whooping crane staging areas in prairie Canada. Pages 61-66 in D. A. Wood, ed. Proc. 1988 N. Am. Crane Workshop. Florida Game and Fresh Water Fish Commission, Tallahassee.

_____. 1998a. Whooping cranes nesting in Alberta. Blue Jay 56:31-33.

_____. 1998b. 1997: Year of the crane. Alberta Naturalist 28:3-4.

_____, E. J. Woodsworth, and E. A. Driver. 1997. Habitat use by migrant whooping cranes in Saskatchewan. Proc. N. Am. Crane Workshop 7:123-131.

_____ and T.V. Stehn. 2005a. National Recovery Strategy for the Whooping Crane (*Grus americana*). Government Report, Environment Canada, Ottawa. 27pp.

_____ and _____. 2005b. Action Plan for the Whooping Crane. Government Report,

Environment Canada, Ottawa. 22pp.

_____, P. Goossen, E. Kuyt and L. Craig-Moore In press. Philopatry and dispersal in whooping cranes (*Grus americana*). Proc. 2003 N. Am. Crane Workshop 9:0-00.

Johnson, E. F. 1976. Aransas whooping cranes. Blue Jay 34:220-228.

Johnson, K. A. and S. A. Temple. 1980. The migration ecology of the whooping crane. Unpublished report prepared under contract 14-16-0009-78-034 to USFWS. U. of Wisconsin, Madison. 87pp.

Jones, K. L. 2003. Genetic variation and structure in cranes: a comparison among species. Ph.D. dissertation. University of Illinois - Chicago.

Jones, K. L. and B. Lacy. 2003. Whooping crane master plan for 2003. Final report from workshop held at ICF in September, 2002. 119 pp.

_____, T. C. Glenn, R. C. Lacy, J. R. Pierce, N. Unruh, C. M. Mirande, and F. Chavez-Ramirez. 2002. Refining the whooping crane studbook by incorporating microsatellite DNA and leg-banding analyses. Conservation Biology 16(3):789-799.

_____, and J. M. Nicolich. 2001. Artificial insemination in captive whooping cranes: Results from genetic analyses. Zoo Biology 20(4):331-342.

_____, _____, and G. Gee. In prep. Investigation of fertility and artificial insemination timing in Florida sandhill cranes.

Julliard, R., F. Jiguet, and D. Couvet. 2003. Common birds facing global changes: what makes a species at risk? Global Change Biology 10:148-154.

Kemsies, E. 1930. Birds of the Yellowstone National Park, with some recent additions. Wilson Bull. 42:198-210.

Kepler, C. B. 1976. Dominance and dominance-related behavior in the whooping crane. Pages 177-196, in J. C. Lewis, eds. Proc. International Crane Workshop. Oklahoma State Univ. Press, Stillwater, Oklahoma.

_____. 1978. Captive propagation of whooping cranes: A behavioral approach. Pages 231-241, in S. A. Temple, ed. Endangered Birds - Management Techniques for Preserving Threatened Species. Univ. Wisconsin, Madison, Wisconsin.

Konrad, P. M. 1987. Expanded sandhill crane hunting in the Dakotas and Oklahoma threatens endangered whooping cranes. Pages 69-77 in Proc. 1985 Crane Workshop. Platte River Whooping Crane Habitat Maintenance Trust and USFWS, Grand Island, Nebraska.

Krajewski, C. 1989. Phylogenetic relationships among cranes (Gruiformes: Gruidae) based on DNA hybridization. Auk 106:603-618.

Kreger, M., J. Hatfield, G. Gee, D. Clugston, and I. Estevez. 2001. Behavioral profiles of the captive whooping crane as an indicator of reintroduction survival. Abstract presented to Society for Conservation Biology, August, 2001.

Kretzschmar, G. E. 1990. Executive administrator, Texas Water Development Board. Letter to T. Grahl, USFWS-Ecological Services, Corpus Christi, Texas. December 5, 1990.

Kuyt, E. 1976a. Whooping cranes: The long road back. Nature Canada 5:2-9.

_____. 1976b. The continuing story of the whooping crane. Pages 109-111, in T. Mosquin and C. Suchal, eds. Proc. Symposium on Canada's Threatened Species and Habitats. Canada Natl. Federal Special Publ. 6, Ottawa, Canada.

_____. 1976c. Recent clutch-size data for whooping cranes, including a three-egg clutch. Blue Jay 34:82-83.

_____. 1978a. Whooping crane color-marking. N. Am. Bird Bander 3:162.

_____. 1978b. A modern nesting record for whooping cranes in Alberta. Blue Jay 36:147-148.

_____. 1979a. Banding of juvenile whooping cranes on the breeding range in the Northwest Territories, Canada. N. Am. Bird Bander 4:24-25.

_____. 1979b. Banding of juvenile whooping cranes and discovery of the summer habitat use by non-breeders. Pages 109-111 in J. C. Lewis, eds. Proc. 1978 International Crane Workshop. Colorado State Univ. Printing Service, Fort Collins, Colorado.

_____. 1981a. Population status, nest site fidelity, and breeding habitat of whooping cranes. Pages 119-125, in J. C. Lewis and H. Masatomi, eds. Crane Research Around the World. Proc. International Crane Symposium, Sapporo, Japan, International Crane Foundation, Baraboo, Wisconsin.

_____. 1981b. Clutch size, hatching success, and survival of whooping crane chicks, Wood Buffalo National Park, Canada. Pages 126-129, in J. C. Lewis and H. Masatomi, eds. Crane Research Around the World. Proc. International Crane Symposium, Sapporo, Japan, International Crane Foundation, Baraboo, Wisconsin.

_____. 1982. Whooping crane. Hinterland Who's Who, Canadian Wildl. Service, Ottawa. 6pp.

_____. 1987. Management and research of whooping cranes, 1965-1982. Pages 365-369 in G. W. Archibald and R. F. Pasquier, eds. Proc. 1983 International Crane Workshop. International Crane Foundation, Baraboo, Wisconsin.

_____. 1989. Use of a whooping crane nest by a sandhill crane. Blue Jay 47(1):33-38.

_____. 1992. Aerial radio-tracking of whooping cranes migrating between Wood Buffalo

National Park and Aransas National Wildlife Refuge, 1981-84. Occas. Pap. 74, Canadian Wildl. Service, 53 pp.

_____. 1993a. Whooping crane, *Grus americana*, home range and breeding range expansion in Wood Buffalo Natl. Park, 1970-1991. Can. Field-Nat. 107:1-12.

_____. 1993b. Case study - whooping cranes. In A. W. Diamond and B. D. Bell, eds. The management of populations of endangered bird species. Chap. 4. Reproductive manipulation. International Council for Bird Preservation.

_____. 1995. The nest and eggs of the whooping crane, *Grus americana*. Canadian Field Naturalist 109:1-5.

_____, and J. P. Goossen. 1987. Survival, age composition, sex ratio, and age at first breeding of whooping cranes in Wood Buffalo National Park, Canada. Pages 230-244, in J.C. Lewis and J.W. Ziewitz, eds. Proc. 1985 Crane Workshop, Platte River Whooping Crane Habitat Maintenance Trust and USFWS, Grand Island, Nebraska.

_____, S. J. Barry, and B. W. Johns. 1992. Below average whooping crane production in Wood Buffalo National Park during drought years 1990 and 1991. Blue Jay 50(4):225-229.

_____, B. E. Johnson, and R. C. Drewien. 1981. A wolf kills a juvenile whooping crane. Blue Jay 39(2):116-119.

Labuda, S. E., and K. 0. Butts. 1979. Habitat use by wintering whooping cranes on the Aransas National Wildlife Refuge. Pages 152-157, in J. C. Lewis, ed. Proc. 1978 International Crane Workshop, Colorado State Univ., Printing Service, Fort Collins, Colorado.

Lacy, R. C. 1997. Importance of genetic variation to the viability of mammalian populations. Journal of Mammalogy 78(2):320-335.

Lamont, T., and W. Reichel. 1970. Organochlorine pesticide residues in whooping cranes and Everglade kites. Auk 87:158-159.

Lande, R. 1995. Breeding plans for small populations based on the dynamics of quantitative genetic variance. Pages 318-340 in J. D. Ballou, M. Gilpin and T. J. Foose, eds. Population Management for survival and recovery. Analytical methods and strategies in small population conservation. Columbia Univ. Press, New York.

Langenberg, J. A., and S. Donoghue. 1997. Clinical nutrition in a crane captive propagation program. Pages 52-61 in M. Gies, ed., Proc. 9th Dr. Scholl Conf. on Nutrition of Captive Wild Animals. Lincoln Park Zoological Soc., Chicago, Illinois.

_____, K. Maguire, and N. Businga. 1998. New techniques in incubation management: egg radiography and egg sex identification. 1998 Proc. Assoc. Avian Veterinarians.

Lamont, T., and W. Reichel. 1970. Organochlorine pesticide residues in whooping cranes and everglade kites. Auk 87:158-159.

Lauver, J. A. 1992. Whooping cranes at the San Antonio Zoo. Pages 239-244 in D. Wood, ed. Proc. 1988 Crane Workshop. Florida Game and Freshwater Fish Commission, Nongame Tech. Rep. # 12.

Leach, B. 1987. The sandhill crane recovery project in the Lower Fraser Valley, British Columbia. Pages 415-423 in G. W. Archibald and R. F. Pasquier, eds. Proc. 1983 International Crane Workshop. International Crane Foundation, Baraboo, Wisconsin.

Lewis, J. C. 1991. International cooperation in recovery of whooping cranes: A model for other nations. Pages 389-394 in. Proc. 1987 International Crane Workshop. International Crane Foundation, Baraboo, Wisconsin.

_____. 1992. The contingency plan for federal-state cooperative protection of whooping cranes. Pages 293-300 in D. A. Wood, ed. Proc. 1988 N. Am. Crane Workshop. Florida Game and Fresh Water Fish Commission, Tallahassee.

_____. 1997. Alerting the birds. Endangered Species Bulletin XXII:2.

_____. 1999. Population recovery techniques in North America using captive-reared cranes. Pages 2522-2532 in J. J. Adams and R. H. Slotow, eds. Proc. 22nd International Ornithological Congress, Durban, South Africa.

_____. 2001. Increased egg conservation – is it essential for recovery of the whooping crane in the Aransas-Wood Buffalo population? Proc. N. Am. Crane Workshop 8:1-5.

_____, and F.G. Cooch. 1992. Introduction of whooping cranes in eastern North America. Pages 301-305 in D. A. Wood, ed. Proc. 1988 N. Am. Crane Workshop. Florida Game and Fresh Water Fish Commission, Tallahassee.

_____, and L. Finger. 1993. Endangered and threatened wildlife and plants: Establishment of an experimental nonessential population of whooping cranes in Florida. Federal Register 58(13):5647-5658.

_____, E. Kuyt, K. E. Schwindt, and T. V. Stehn. 1992a. Mortality in fledged cranes of the Aransas-Wood Buffalo population. Pages 145-148 in D. A. Wood, ed. Proc. 1988 N. Am. Crane Workshop. Florida Game and Fresh Water Fish Commission, Tallahassee.

_____, R.C. Drewien, E. Kuyt, and C. S. Sanchez, Jr. 1992b. Contaminants in habitat, tissues, and eggs of whooping cranes. Proc. N. Am. Crane Workshop 6:159-165.

Lewis, T. E. In prep. Effects of disturbance on whooping cranes wintering at Aransas National Wildlife Refuge.

Lewis, T. E., and R. D. Slack. 1992. Whooping crane response to disturbances at the Aransas National Wildlife Refuge. Proc. N. Am. Crane Workshop 6:176.

Lingle, G. R. 1987. Status of whooping crane migration habitat within the Great Plains of North

America. Pages 331-340 in J. C. Lewis and J. Zewitz, eds. Proc. 1985. Crane Workshop. Platte River Whooping Crane Habitat Maintenance Trust and USFWS, Grand Island, Nebraska.

_____. 1992. History and economic impact of crane-watching in central Nebraska. Proc. N. Am. Crane Workshop 6:33-37.

_____, G. A. Wingfield, and J. W. Ziewitz. 1991. The migration ecology of whooping cranes in Nebraska, U.S.A. Pages 395-401 in J. Harris, ed. Proc. 1987 International Crane Workshop, International Crane Foundation, Baraboo, Wisconsin.

Lishman, W. J., T. L. Teets, J. W. Duff, W. J. Sladen, G. G. Shire, K. M. Goolsby, W. A. Bezner-Kerr, and R. P. Urbanek. 1997. A reintroduction technique for migratory birds: leading Canada geese and isolation-reared sandhill cranes with ultralight aircraft. Proc. N. Am. Crane Workshop 7:96-104.

Longley, W. H. 1970. Sandhill cranes at the Carlos Avery Wildl. Area. The Loon 4:124-128.

Longley, W. L., ed. 1994. Freshwater inflows to Texas bays and estuaries: ecological relationships and methods for determination of needs. Texas Water Development Board and Texas Parks and Wildl. Dept., Austin, Texas. 386 pp.

Longmire, J. L., G. F. Gee, C. L. Hardeknopf, and G. A. Mark. 1992. Establishing paternity in whooping cranes (*Grus americana*) by DNA analysis. Auk 109(3):522-529.

Love, J., and P. Deininger. 1992. Characterization and phylogenetic significance of a repetitive DNA sequence from whooping crane (*Grus americana*). Auk 109:73-79.

Lynch, J. 1956. The great white bird. Proc. Federal-Prov. Wildl. Conf. 20:287-301.

Lyon, W.J., D. Hjertaas, and B.W. Johns. 1995a. Development of screening criteria and identification of potential reintroduction sites for whooping cranes in prairie Canada. The Canadian Plains Research Center, Univ. Regina.

_____,_____,and _____. 1995b. Evaluation of three potential reintroduction sites for whooping cranes in Canada. The Canadian Plains Research Center, Univ. Regina, Regina, Saskatchewan, Canada.

Mabie, D. W., L. A. Johnson, B. C. Thompson, J. C. Barron, and R. B. Taylor. 1989. Responses of wintering whooping cranes to airboat and hunting activities on the Texas Coast. Wildl. Soc. Bull. 17(3):249-253.

Mahan, T. A., and B. S. Simmers. 1992. Social preference of four cross-foster reared sandhill cranes. Proc. N. Am. Crane Workshop 6:114-119.

Manville, A.M., II. 2005. Bird strikes and electrocutions at power lines, communication towers, and wind turbines: state of the art and state of the science – next steps toward mitigation. Bird Conservation Implementation in the Americas: Proceedings 3rd International

Partners in Flight Conference 2002, C.J. Ralph and T. D. Rich, Editors. U.S.D.A. Forest Service, GTR-PSW-191, Albany, CA. 25 pages (In press).

Maroldo, G. K. 1980. Crip: The constant dancer. Blue Jay 38:147-161.

May, P. L. 1992. The feasibility of establishing a breeding whooping crane (*Grus americana*) flock on the Canadian Prairies. MS Thesis, Univ. Calgary, Alberta.

McCarty, J. P. 2001. Ecological consequences of recent climate change. Conservation Biology 15(2):320-331.

McIlhenny, E. A. 1943. Major changes in the bird life of southern Louisiana during sixty years. Auk 60:541-547.

McMillen, J. L. 1987. Evaluation of the Seney National Wildl. Refuge as a reintroduction site for whooping cranes. Final Rept. Ohio Cooperative Fish and Wildl. Research Unit, Columbus, Ohio. 195 pp.

McNulty, F. 1966. The whooping crane. E. P. Dutton & Co., New York, New York. 88 pp.

Meine C. D., and G. W. Archibald. Compilers. 1996. The cranes: Status survey and conservation action plan. IUCN/SSC Crane Specialist Group, IUCN the World Conservation Union, Gland, Switzerland. 282 pp.

Melvin, S. M., and S. A. Temple. 1980. Migration ecology and wintering grounds of sandhill cranes from the Interlake of Manitoba. Unpubl. USFWS Rept., Washington, D.C.

_____, W.J.D. Stephen, and S. Temple. 1990. Population estimates, nesting biology, and habitat preferences of Interlake, Manitoba, sandhill cranes, *Grus canadensis*. Canadian Field Naturalist 104:354-361.

Menzel, A. N. Estrella, and P. Fabian. 2001. Spatial and temporal variability of the phonological season in Germany from 1951 to 1996. Global Change Biology 7:657-666.

Miller, L. 1944. Some Pliocene birds from Oregon and Idaho. Condor 46:25-32.

Miller, R. S. 1973. The brood sizes of cranes. Wilson Bull. 85:436-440.

Mirande, C., R. Lacy, and U. Seal. 1993. Whooping crane (*Grus americana*) conservation viability assessment workshop report. Captive Breeding Specialist Group, IUCN, Apple Valley, Minnesota. 115 pp.

_____, G. F. Gee, A. Burke, and P. Whitlock. 1996. Egg and semen production. Pages 45-57 in D. H. Ellis, G. F. Gee, and C. M. Mirande, eds. Cranes: Their biology, husbandry, and conservation. Natl. Biological Service, Washington, D.C., and International Crane Foundation, Baraboo, Wisconsin, and USFWS, Washington, D.C. 308 pp.

_____, J. R. Cannon, K. Agzigian, R. E. Bogart, S. Christiansen, J. Dubow, A. K.

Fernandez, D. K. Howarth, C. Jones, K. G. Munson, S. I. Pandya, G. Sedaghatkish, K. L. Skeri, S. A. Stenquist, and J. Wheeler. 1997a. Computer simulations of possible futures for two flocks of whooping cranes. Proc. N. Am. Crane Workshop 7:181-200.

_____, J. W. Carpenter, and A. M. Burke. 1997b. The effect of disturbance on the reproduction and management of captive cranes. Proc. N. Am. Crane Workshop 7:56-61.

Moody, A. F. 1931. Death of an American whooping crane. Aviculture Magazine 9:8-11.

Morkill, A. E. 1990. Effectiveness of markers in reducing sandhill crane collisions with powerlines. Univ. Wyoming MS Thesis, Laramie.

_____, and S. H. Anderson. 1991. Effectiveness of marking powerlines to reduce sandhill crane collisions. Wildl. Soc. Bull. 19:442-449.

_____, and _____. 1993. Effectiveness of yellow aviation balls in reducing sandhill cranes collisions with power lines. Pages 21-1 to 21-l7 in Proc. International Workshop On Avian Interactions With Utility Structures. Elect. Power Res. Institute, Pleasant Hill, California.

Mummert, D. P., D. H. Ellis, and C. L. Chambers. 2001. Fate of the survivors of the 1995 and 1996 trucking migrations of costume-reared sandhill cranes in Arizona. Proc. N. Am. Crane Workshop 8:127-131.

Nagendran, M. 1992. Winter release of isolation-reared greater sandhill cranes in south Texas. Proc. N. Am. Crane Workshop 6:131-134.

_____, R. P. Urbanek, and D. H. Ellis. 1996. Special techniques, Part D: Reintroduction techniques. Pages 231-240 in D. H. Ellis, G. F. Gee, and C. M. Mirande, eds. Cranes: their biology, husbandry, and conservation. Natl. Biological Service, Washington, D.C. and International Crane Foundation, Baraboo, Wisconsin.

National Research Council of the National Academies. 2005. Endangered and threatened species of the Platte River. The National Academies Press, Washington, D.C. 299 pp.

National Wildlife Federation. 2004. Bays in peril: A forecast for freshwater flows to Texas estuaries. Austin, Texas. 44 pp.

Nedelman, J., J. A. Thompson, and R. J. Taylor. 1987. The statistical demography of whooping cranes. Ecology 68(5):1401-1411.

Nelson, J. T. 1995. Nutritional quality and digestibility of foods eaten by whooping cranes on their Texas wintering ground. MS Thesis, Texas A and M Univ. 95pp.

Nesbitt, S. A. 1979. Notes on the suitability of captive-reared sandhill cranes for release into the wild. Pages 85-88, in J. C. Lewis, ed. Proc. 1978 International Crane Workshop, Colorado State Univ., Printing Service, Fort Collins, Colorado.

_____. 1982. The past, present, and future of the whooping crane in Florida. Pages 151-154 in J. C. Lewis, ed. Proc. 1981 International Crane Workshop. Natl. Audubon Soc., Tavernier, Florida.

_____. 1988. An evaluation of the Florida sandhill crane population of peninsular Florida and its potential to support a population of nonmigratory whooping cranes. Florida Game and Fresh Water Fish Commission, Tallahassee, Florida. 70 pp.

_____, and K. S. Williams. 1990. Home range and habitat use of Florida sandhill cranes. J. Wildl. Manage. 54:92-96.

_____, and J. W. Carpenter. 1993. Survival and movements of greater sandhill cranes experimentally released in Florida. J. Wildl. Management 57:673-679.

_____, M. J. Folk, M. G. Spalding, J. A. Schmidt, S. T. Schwikert, J. M. Nicolich, M. Wellington, J. C. Lewis, and T. H. Logan. 1997. An experimental release of whooping cranes in Florida – the first three years. Proc. N. Am. Crane Workshop 7:79-85.

_____, _____, K. A. Sullivan, S. T. Schwikert, and M. G. Spalding. 2001. An update of the Florida whooping crane release project through June 2000. Proc. N. Am. Crane Workshop 8:62-72.

Nicolich, J. M., G. F. Gee, and S. G. Hereford. 2001. Natural fertility in whooping cranes and Mississippi sandhill cranes at Patuxent Wildlife Research Center. Proc. N. Am. Crane Workshop 8:170-177.

Novakowski, N. 5. 1965. The day we rescued a whooping crane. Audubon Mag. 67:230-233.

_____. 1966. Whooping crane population dynamics on the nesting grounds, Wood Buffalo National Park, Northwest Territories, Canada. Canadian Wildl. Service, Res. Rept. Ser. 1, 20 pp.

Olsen, G. H., and M. Wise. 2001. Ingested metal in whooping cranes: An endoscopic technique for removal and implications for the release program. Proc. N. Am. Crane Workshop 8:198-202.

_____, J. A. Taylor, and G. F. Gee. 1997. Whooping crane mortality at Patuxent Wildlife Research Center, 1982-1995. Proc. N. Am. Crane Workshop 7:243-248.

_____, M. M. Hendricks, and L. E. Dressler. 2001. Hematological and serum chemistry norms for sandhill and whooping cranes. Proc. N. Am. Crane Workshop 8:178-184.

Olson and Olson Planning & Design Consultants, Inc. 2003. Whooping Crane potential habitat mapping project. Report prepared for Parks Canada and Canadian Wildlife Service. Ottawa, Ontario. 41pp.

Parmesan, C. and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421:37-42.

Peterson, A. T. 2003. Projected climate change effects on Rocky Mountain and Great Plains birds: generalities of biodiversity consequences. Global Change Biology 9:647-655.

Platte River Management Joint Study. 1990. Biology workgroup final report. USFWS and Bureau of Reclamation, Denver, Colorado. 131 pp.

Platte River Management Joint Study. 1993. Methods for calculating and displaying habitat target flows by species. Management Alternatives Work Group, Task 5a working document. USFWS, Grand Island, Nebraska. 34 pp.

Primack, R. B. 1993. Essentials of conservation biology. Sinauer Associates Inc., Sunderland, Massachusetts. 564 pp.

Randall, A., and J. R. Stoll. 1983. Existence value in a total valuation framework. In R. Rowe and L. Chestnut, eds. Managing Air Quality and Scenic Resources at National Parks. Westview Press, Boulder, Colorado.

Raup, H. M. 1933. Range conditions in the Wood Buffalo Natl. Park of western Canada with notes on the history of the wood bison. Am. Comm. International Wildl. Protection, Special Publ. 1:2-16.

Reed, D. H., J. J. O'Grady, B. W. Brook, J. D. Ballou and R. Frankham. 2003. Estimates of minimum population sizes for vertebrates and factors influencing those estimates. Biol. Cons. 113:23-34.

Richert, A. D. 1999. Multiple scale analyses of whooping crane habitat in Nebraska. Ph.D. Dissertation, Univ. Nebraska-Lincoln. 175 pp.

_____, K. E. Church, and S. E. Richert. 1999. Methods for multiple-scale analysis of crane habitat. Pages 2544-2551 in J.J. Adams and R. H. Slotow, eds. Proc. 22nd International Ornithological Congress, Durban, South Africa.

_____, and K. Church. 2001. Multiple spatial scale analysis of whooping crane habitat in Nebraska. Abstract in Proc. N. Am. Crane Workshop 8:217.

_____, J. S. Taylor, and S. E. Richert. In press. Stopover habitat selection by whooping cranes in Nebraska. Proc. Midwest Fish and Wildl. Conf. 2000.

Robertson, S., T. Stehn, and J. Magera. 1993. Oil spill contingency plan for Aransas National Wildlife Refuge, Texas. USFWS, Region 2. 25 pp.

Robinson, W. H., M. G. Sheldon, and R. A. Wilson. 1965. Whooping crane studies. Pages 35-36 in The effects of pesticides on fish and wildlife. USFWS Circulation 226.

Salwasser, H., S. P. Mealy, and K. Johnson. 1984. Wildlife population viability: A question of risk. Trans. N. Am. Wildl. Nat. Resour. Conf. 49:421-439.

{SAWS} San Antonio Water System. 2003. Quarterly Report on Water resources, July-September, 2003. San Antonio, Texas.

Shaffer, M. l. 1981. Minimum population sizes for species conservation. BioScience 31:131-134.

Sherrod, H. L., and R. Medina. 1992. Whooping crane habitat alteration analysis at Aransas National Wildlife Refuge, Texas. Pages 87-99 in D. A. Wood, ed. Proc. 1988 N. Am. Crane Workshop. Florida Game and Fresh Water Fish Commission, Tallahassee.

Shields, R. H., and E. L. Benham. 1969. Farm crops as food supplements for whooping cranes. J. Wildl. Management 33:811-817.

Snyder, S. B., M. Richard, R. Drewien, and J. C. Lewis. 1987. *Pasteurella multocida* infection in a whooping crane associated with an avian cholera outbreak. Pages 149-155 in J. C. Lewis and J. W. Ziewitz, eds. Proc. 1985 Crane Workshop. Platte River Habitat Maintenance Trust and USFWS, Grand Island, Nebraska.

_____, _____, J. P. Thilsted, R. C. Drewien, and J. C. Lewis. 1992. Lead poisoning in a whooping crane. Pages 207-210 in D. A. Wood, ed. Proc. 1988 N. Am. Crane Workshop. State of Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

_____, _____, and C. U. Meteyer. 1997. Avian tuberculosis in a whooping crane: Treatment and outcome. Proc. N. Am. Crane Workshop 7:253-255.

Sommerfeld, W. J., and J. Scarth. 1998. An evaluation of the Interlake region of Manitoba as a release site for the potential reintroduction of whooping cranes. Delta Waterfowl and Wetlands Research Station, Portage la Prairie, Manitoba. 44 pp.

Spalding, M. G., J. M. Kinsella, S. A. Nesbitt, M. J. Folk, and G. W. Foster. 1996. Helminth and arthropod parasites of experimentally introduced Whooping Cranes in Florida. J. Wildl. Dis. 32: 44-50.

_____, S. A. Nesbitt, M. J. Folk, L. R. McDowell, and M. S. Sepulveda. 1997. Metal consumption by whooping cranes and possible zinc toxicosis. Proc. N. Am. Crane Workshop 7:237-242.

Sprunt, A. Jr., and E. B. Chamberlain. 1949. South Carolina bird life. Univ. South Carolina Press, Columbia. 585 pp.

Stahlecker, D. A. 1988. An inventory of potential stopover roosting habitat for whooping cranes in the Wood Buffalo-Aransas migration corridor: A pilot study in the Clinton NE (1/100,000), Oklahoma map area. Eagle Ecological Services, Santa Fe, New Mexico. 17 pp.

_____. 1992. Using National wetlands inventory maps to quantify whooping crane stopover habitat in Oklahoma. Proc. N. Am. Crane Workshop 6:62-68.

_____. 1997a. Predicting availability of stopover roosting habitat for migrant whooping

cranes in the Northern Great Plains. Rept. by Eagle Ecological Services for USFWS. 21 pp.

_____. 1997b. Availability of stopover habitat for migrant whooping cranes in Nebraska. Proc. N. Am. Crane Workshop 7:132-140.

Stehn, T. V. 1987. Impacts of the Gulf Intracoastal Waterway on the endangered whooping crane. Unpubl. Rept. USFWS, Aransas NWR, Austwell, Texas. 13 pp.

_____. 1992a. Unusual movements and behaviors of color-banded whooping cranes during winter. Proc. N. Am. Crane Workshop 6:95-101.

_____. 1992b. Behavior of whooping cranes during initiation of migration. Proc. N. Am. Crane Workshop 6:102-105.

_____. 1992c. Re-pairing of whooping cranes at Aransas National Wildlife Refuge. Proc. N. Am. Crane Workshop 6:185-187.

_____. 1997. Pair formation by color-marked whooping cranes on the wintering grounds. Proc. N. Am. Crane Workshop 7:24-28.

_____, and E. F. Johnson. 1987. The distribution of winter territories of the whooping crane on the Texas coast. Pages 180-195 in J. C. Lewis and J. W. Ziewitz, eds. Proc. 1985 Crane Workshop. Platte River Whooping Crane Habitat Maintenance Trust and USFWS, Grand Island, Nebraska.

_____, and T. Wassenich. In prep. Whooping crane collisions with power lines: an issue paper. 2006 North American Crane Workshop.

Stenning, M. 1996. Hatching asynchrony, brood reduction and other rapidly reproducing hypothesis. Trends in Ecology & Evolution. Elsevier Trends Journals, Cambridge.

Stenseth, N. C., A. Mysterud, G. Ottersen, J. W. Hurrell, K. S. Chan, and M. Lima. 2002. Ecological effects of climate fluctuations. Science 297:1292-1296.

Stephen, W. J. D. 1979. Whooping crane sightings in prairie provinces, 1977 and 1978. Blue Jay 37:163-168.

Stephenson, J. D. 1971. Plumage development and growth of young whooping cranes. MS Thesis, Oregon State Univ., Corvalis. 56 pp.

_____, and G. Smart. 1972. Egg measurements for three endangered species. Auk 89:191-192.

Stevenson, J. 0., and R. E. Griffith. 1946. Winter life of the whooping crane. Condor 48:160-178.

Stoll, J. R. 1983. Recreational activities and nonmarket valuation: the conceptualization issue. South J. Agric. Econ. 15(2):119-125.

_____, and L. A. Johnson. 1984. Concepts of value, nonmarket valuation, and the case of the whooping crane. Trans. N. Am. Wildl. Natural Resources Conf. 49:382-393.

Strom, K. J. 1987. Lillian Annette Rowe - Managing migratory crane habitation the Platte River, Nebraska. Pages 326-330, in J. C. Lewis and J. W. Ziewitz, eds. Proc. 1985 Crane Workshop. Platte River Whooping Crane Habitat Maintenance Trust and USFWS, Grand Island, Nebraska.

Stroud, R. K., C. 0. Thoen, and R. M. Duncan. 1986. Avian tuberculosis and salmonellosis in a whooping crane (*Grus Americana*). J. Wildl. Diseases 22(1):106-110.

Sutton, G. M. 1967. Oklahoma birds. Univ. Oklahoma Press, Norman. 674 pp.

Texas Department of Water Resources. 1980. Guadalupe Estuary: A study of the influence of freshwater inflows. August 1980, Austin, Texas. 386 pp.

Texas Parks and Wildlife Department. 1998. Freshwater inflow recommendation for the Guadalupe Estuary of Texas. Coastal Studies Technical Report No. 98-1. Austin, Texas. 61 pp. + figures

Thomas, C. D. and J. J. Lennon. 1999. Birds extend their ranges northwards. Nature 399:213.

Thomas, C. D., A. Cameron, R. E. Green, M. Bakkenes, L. J. Beaumont, Y. C. Collingham, B. F. N. Erasmus, M. Ferreira de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A. S. van Jaarwveld, G. F. Midgley, L. Miles, M. A. Ortega-Huerta, A. T. Peterson, A. L. Phillips, and S. E. Williams. 2004. Extinction risk from climate change. Nature 427:145-148.

Thomas, J. A., M. G. Telfer, D. B. Roy, C. D. Preston, J. J. D. Greenwood, J. Asher, R. Fox, R T. Clarke, and J. H. Lawton. 2004. Comparative losses of British butterflies, birds, and plants and the global extinction crisis. Science 303:1879-1881.

Thompson, B. C. and R. R. George. 1987. Minimizing conflicts between migratory game bird hunters and whooping cranes in Texas. Pages 56-68, in J. C. Lewis and J. W. Ziewitz, eds. Proc. 1985 Crane Workshop. Platte River Whooping Crane Habitat Maintenance Trust and USFWS, Grand Island, Nebraska.

Timoney, K. P. 1997. The summer breeding habitat of whooping cranes in Wood Buffalo National Park, Canada. Parks Canada. WBNP, Ft. Smith, NT.

_____. 1999. The habitat of nesting whooping cranes. Biological Conservation 89:189-197.

_____, S. C. Zoltai, and L. Goldsborough. 1997. Boreal diatom ponds: a rare wetland associated with nesting whooping cranes. Wetlands 17(4):539-551.

Twilley, R. R., E. J. Barron, H. L. Gholz, M. A. Harwell, R. L. Miller, D. J. Reed, J. B. Rose, E. H. Siemann, R. G. Wetzel and R. J. Zimmerman. 2001. Confronting climate change in the Gulf Coast region: Prospects for sustaining our ecological heritage. Union of Concerned Scientists, Cambridge, Massachusetts, and Ecological Society of America, Washington, D.C. 2001. Published report.

Uhler, F. M., and L. M. Locke. 1970. A note on the stomach contents of two whooping cranes. Condor 72:246.

Urbanek, R. P., and T. A. Bookhout. 1992. Development of an isolation-rearing/gentle release procedure for reintroducing migratory cranes. Proc. N. Am. Crane Workshop 6:120-130.

_____, and _____. 1994. Performance of captive-reared cranes released into a migration route in eastern North America. Pages 1221-1329 in H. Higuchi and J. Minton, eds. The future of cranes and wetlands. Wild Bird Soc. Japan, Tokyo.

_____, J. Duff, and S. Swengel. In press{a}. Reintroduction techniques: Post release performance of sandhill cranes (1) released into wild flocks and (2) led on migration by ultralight aircraft. Proc. 2003 N. Am. Crane Workshop 9:0-00.

_____, L. Fondow, C. Satyshur, A. Lacy, S. Zimorski, and M. Wellington. In press{b}. Monitoring of first cohort of migratory whooping cranes reintroduced to eastern North America: The first two years after release. Proc. 2003 N. Am. Crane Workshop 9:0-00.

U.S. Army Corps of Engineers. 1988. Study of erosion along GIWW in the Aransas National Wildlife Refuge. USACE. 45 pp.

U.S. Fish and Wildlife Service. 1979. Contingency plan for the protection of whooping cranes during a major oil spill in the Gulf of Mexico. 23 pp.

_____.1981. The Platte River ecology study. Spec. Res. Rept., Northern Prairie Res. Cent., Jamestown, North Dakota. 187 pp.

_____. 1994. Whooping crane recovery plan. USFWS, Albuquerque, New Mexico. 92 pp.

_____. 2001. Endangered and Threatened Wildlife and Plants: Establishment of a Nonessential Experimental Population of Whooping Cranes in the Eastern United States. Final Rule. Federal Register 66:33903-33917, June 26, 2001.

Valente, K. F. 1992. The effects of T2 toxin on Northern bobwhite, MS Thesis, Univ. Maryland, College Park. 89 pp.

Walkinshaw, L. H. 1965. Attentiveness of cranes at their nests. Auk 82:465-476.

_____. 1973. Cranes of the world. Winchester Press, New York. 370 pp.

Ward, J., and S. Anderson. 1987. Roost site use versus preference by two migratory whooping cranes. Pages 283-288 in J. C. Lewis and J. W. Ziewitz, eds. Proc. 1985 Crane Workshop.

Platte River Whooping Crane Habitat Maintenance Trust and USFWS, Grand Island, Nebraska.

Wesche, T. A., Q. D. Skinner, and R. J. Henszey. 1990. Platte River wetland hydrology study: Draft report for the first 18 months. Wyoming Water Research Center, Univ. Wyoming, Laramie. 43 pp.

Wessling, B. 2000. Crane voice prints. The ICF Bugle 26(3):1-2.

Wetmore, A. 1931. The avifauna of the Pleistocene of Florida. Smithsonian Miscellaneous Collection 85:35-36.

_____. 1956. A check-list of the fossil and pre-historic birds of N. America and the West Indies. Smithsonian Misc. Collection 131. Washington, D.C. 105 pp.

Windingstad, R. M., H. E. Stiles, and R. C. Drewien. 1981. Whooping crane preyed upon by golden eagle. Auk 98:393-394.

Woodworth, L. M., Montgomery, M. E., Briscoe, D. A., and R. Frankham. 2002. Rapid genetic deterioration in captive populations: Causes and conservation implications. Conservation Genetics 3(3):277-288.

Zang, J., F. Ting, D. Hershberger, H. Yu, and C. A. Spell. 1993. Bank erosion of the Gulf Intracoastal Waterway at the Aransas National Wildlife Refuge. USACE Rept. 332, Vicksburg, Mississippi.

Ziewitz, J. W. 1992. Whooping crane riverine roosting habitat suitability model. Pages 71- 81 in D. A. Wood, ed. Proc. 1988 N. Am. Crane Workshop. Florida Game and Fresh Water Fish Commission, Tallahassee.

Zwank, P.J., and S. R. Derrickson. 1981. Gentle release of captive, parent-reared sandhill cranes into the wild. Pages 112-116 in J. C. Lewis, ed. Proc. 1981 Crane Workshop. Natl. Audubon Soc., Tavernier, Florida.

_____, and C. D. Wilson. 1987. Survival of captive, parent-reared Mississippi sandhill cranes released on a refuge. Conservation Biology 1:165-168.

APPENDICES

APPENDIX A: MINIMUM VIABLE POPULATION AND GENETICS

Minimum Viable Population

Extinction in small populations has led to the theory of minimum viable population size, defined as the smallest number of individuals necessary to give a population a high probability of surviving over a specified time (Primack 1993). Small populations are subject to rapid decline due to 3 main causes: (1) genetic fluctuations (e.g., genetic drift, inbreeding); (2) demographic fluctuations (e.g., variations in birth and death rates); (3) environmental fluctuations in predation, disease, competition, food supply, and natural catastrophes. As the population increases, the threat of extinction due to stochastic events diminishes, and loss of genetic diversity slows, thereby increasing species security.

Shaffer (1981) provided a specific technique for determining the minimum viable population (MVP):

> "A minimum viable population for any given species in any given habitat is the smallest isolated population having a 99% chance of remaining extant for 1,000 years despite the foreseeable effects of demographic, environmental, and genetic stochasticity, and natural catastrophes,"

(e.g., the smallest population size that can be predicted to have a very high chance of persisting for the next 1,000 years). In this case, the probability for remaining extant could be set at 95% or 99%, and the time frame could be adjusted to 100 or 500 years. The theory of MVP is simply a guide to aid in the preservation of a species.

Opinions vary widely as to the population sizes necessary to achieve a minimum viable population. One rule of thumb is to protect 1,000 individuals of a vertebrate species, because this number seems adequate to preserve genetic diversity (Shaffer 1981, Salwasser et al. 1984). Others suggest that an effective population size of 5,000 individuals is needed to retain evolutionary potential (Lande 1995). More recently, Reed et al. (2003) used population viability analysis to estimate MVP for a variety of vertebrate species. Their definition of MVP is a population that has a 99% probability of persistence for 40 generations. Their results indicate that the lack of long-term studies for endangered species may lead to an underestimation in the extinction rates for the species. They recommend that recovery/conservation programs should be designed to support a population of up to 7,000 adults to ensure long-term survival.

Downlisting Based on MVP Criteria

Population sizes sufficient to be referred to as a minimum viable population depend highly on the effective population size (N_e). The effective population size is the size of a population that maintains heterozygosity at the same rate of the entire species' population and is a function of mating behavior, mutation rate, gene flow, demographics, and population size, among other factors. As not all breeding adults pass on their genetic material equally and randomly, there is a difference between the number of breeders and effective population size. When defining the population size sufficient for downlisting, criteria must account for the difference between the total population and the breeding population size (i.e., the N_e/N ratio). For the wild whooping

crane population, breeders comprise approximately 50% of the population. However, as the effective population will always be less than the number of breeders, proper estimates for N_e will need to be obtained before the minimum viable population for whooping cranes can be determined.

Given the data to date, this plan recognizes growth of the AWBP to 1,000 individuals and 250 productive pairs as criteria for downlisting. The Memorandum of Understanding on Conservation of Whooping Cranes, approved by Canadian and U.S. federal officials, recognizes a goal of 1,000 individuals in the AWBP population. If two additional self-sustaining populations can be established in the wild, each with 25 nesting pairs, and with the AWBP projected to reach 125 nesting pairs by the year 2020, a figure approaching a population of 1,000 whooping cranes may be obtained from these three populations. However due to the uncertainty surrounding the exact figure required, with suggested values ranging between 1,000 and 7,000, this Plan does not set a delisting goal for the whooping crane. If additional research into the exact calculation of a *Ne*/*N* ratio for the wild whooping crane population and additional research with other conservation programs can provide more assurances of the N_e required, a delisting goal will be set prior to the anticipated downlisting in 2035.

Population Growth and Retention of Genetic Material

A Conservation Viability Assessment (CVA) workshop held in 1991 for the whooping crane was funded by the USFWS as a cooperative endeavor with CWS, U.S. Whooping Crane Recovery Team, Canadian Whooping Crane Recovery Team, ICF, The Captive Breeding Specialist Group, and Species Survival Commission of the International Union for Conservation of Nature. The final report includes priorities for research and management of the wild and captive populations as a meta-population to maximize retention of genetic heterozygosity and minimize the risk of extinction (Mirande et al. 1993). The CVA developed stochastic simulation models to estimate rates of genetic loss for the wild and captive whooping crane populations. As a consequence of the 1941 population bottleneck, the current population is derived from an estimated 6 or 8 founders (Mirande et al. 1993, Glenn et al. 1999), with an estimated genetic loss of 66% (Glenn et al. 1999). Mirande et al. (1993) showed that a loss of 6% to 8% of gene diversity would have resulted in the first generation following the bottleneck, where generation time is 12 years. It was estimated that about 87% of the gene diversity that survived the bottleneck has persisted from 1938 to 1990. In contrast, the captive-hatched descendants have retained about 96% of the gene diversity present in the post-bottleneck wild flock. As continued loss of genetic material could lead to inbreeding and declining productivity, the AWBP must increase to the level where creation of new alleles will offset the loss of genetic diversity.

Several other population viability analysis packages have been tested using whooping crane data (Mirande et al. 1997a, Brook et al. 1999). Modeling of the AWBP showed the population large enough to sustain a fairly steady annual growth rate of 0.046 (SD=0.081) over the last 50 years (Mirande et al. 1997a). The standard deviation is about double the mean growth rate so in many years the population will decline temporarily even though long-term growth may be good. If this rate continues, the population will reach 500 birds in 17 years (about 2020) and 1,000 in 33 years (2035). The population is projected to have a very low probability of extinction over the next 100 years (less than 1%).

Given the current genetic analyses based on captive pedigrees, an estimated 153 whooping cranes (21 productive pairs) are needed in captivity to retain 90% of genetic material for 100 years (Jones and Lacy 2003). This Plan recommends having 50 captive breeder pairs of whooping cranes by 2010, including 15 pairs at PWRC, 12 at ICF, 10 at CZ, 10 at SSC, and 3 at the SAZ. Production from these five facilities will be the principal source of birds for release to the wild. However, sources of release birds should be based on the optimal genetic mix to ensure long-term population viability.

Loss of Genetic Diversity and Estimates of Relatedness

For most of the 1940's, the AWBP teetered on the brink of extinction. Mitochondrial DNA from museum specimens collected before and after 1941, when the AWBP declined to 15 birds, showed a 66% reduction in haplotypes post-bottleneck, with the rarest haplotype before 1940 now the most common (Glenn et al. 1999). Although we lack pre-bottleneck diversity estimates for nuclear DNA, we realize that similar declines for this genome must have also occurred (Jones et al. 2002). This is evident from AWBP's lack of genetic diversity as compared to other cranes. Compared with a subset of other cranes, an electrophoretic study of blood proteins showed that whooping crane diversity was less than that known from out-bred populations of Sandhill Cranes, and greater than that of the Mississippi Sandhill which was known to have undergone a similar genetic bottleneck (Dessauer et al. 1992). When diversity was compared across other markers, the whooping cranes were shown to be below average in band sharing of DNA fingerprints (Longmire et al. 1992), average in polymorphism of the major histocompatibility complex (Jarvi et al. 1992), and less than average in microsatellite DNA diversity (Jones et al. 2002, Jones 2003). From these studies, it is evident that the extant whooping cranes show an overall reduction in genetic diversity compared to their pre-bottleneck ancestors and to that of out-bred cranes. This known diversity reduction, along with the fact that generations of captivity increase inbreeding and decrease genetic diversity (Woodworth et al. 2002), indicates that genetic changes within the population threaten to reduce vitality before the population is large enough for mutation to offset losses in diversity from genetic drift (Frankel and Soule 1981, Ballou et al. 1995).

In addition to the knowledge of genetic diversity, understanding relatedness among individuals within the captive whooping crane populations is important to adequately manage the captive population and to establish viable wild populations (Jones et al. 2002). In addition to pedigree management, there have been various molecular genetic techniques used in relatedness estimation. These studies have resolved unknown paternities (Longmire et al. 1992; Jones and Nicolich 2001), developed a species-specific probe for the whooping crane (Love and Deininger 1992), and identified inter-relatednesses within the captive founder lines (Jones et al. 2002). A recently developed technique that could provide additional insights into the whooping crane population is Amplified Fragment Length Polymorphisms (AFLP). Because of the relative paucity of information in birds in general, and cranes in particular, the usefulness of this technique in cranes is currently unknown. An AFLP study currently underway at PWRC will include samples from other crane populations with robust populations and those of reduced diversity. This comparison across crane species should provide additional understanding of crane diversity in general and the relative state of genetic diversity of the whooping crane.

APPENDIX B: SOCIAL AND ECONOMIC CONSIDERATIONS

Numerous books, magazine articles, television programs, and nature documentary films have been produced about this magnificent bird. Corporations have funded whooping crane research and recovery efforts and also have used whooping cranes in promoting their environmental concern. The WCCA, a nonprofit organization, was formed in 1961 to promote conservation of whooping cranes and to educate the public. Other organizations, such as the NAS and NWF, have participated in whooping crane research, conservation, and education. The Platte River Whooping Crane Habitat Maintenance Trust (PRT) was established in 1978 as a nonprofit conservation organization to protect and enhance habitat for migratory birds in Nebraska, along the Platte and North Platte rivers, and especially to protect and maintain whooping crane habitat.

Appreciation of whooping cranes also can be expressed in monetary terms. Each year 70,000 to 80,000 people visit ANWR, most during the winter, and spend significant amounts locally on lodging, gasoline, and supplies (Ellen Michaels, ANWR, pers. comm.). Starting in 1964, 1 tour boat named the "Whooping Crane" offered weekend day-trips from Rockport, Texas, to view the cranes along the Gulf Intracoastal Waterway that runs through ANWR. By 1990, 5 boats offered this opportunity, spanning every day of the week. During 1990-1991, approximately 17,000 people took these tours, paying an average of $20 per ticket, for total seasonal expenditures of $340,000 (Ellen Michaels, ANWR, pers. comm.). In 2004-05, an estimated 8,500 people rode commercial tour boats, paying an average of $35 per adult (Bernice Jackson, ANWR, pers. comm.). The Rockport Chamber of Commerce estimates that whooping crane-related activities result in annual gross economic benefits of $6 million to the local economy. Port Aransas, Texas, holds an annual event in February entitled "Festival of Whooping Cranes and Other Birds".

An understanding is needed of the secondary socio-economic benefits that Canadians derive from Canada's biological resources today while providing for the perpetuation of these resources for future generations. The $11.7 billion spent by Canadian residents and U.S. tourists on nature-related activities in Canada represents a significant outlay which has important impacts on the Canadian economy (Filion et al. 1994).

In Calgary, Alberta, in 2003, 1.2 million people visited the Calgary Zoo, where a whooping crane pair in a wetland exhibit is on display. Entry fees to the zoo are $15.00 for adults and $7.50 for children (in 2003). Operation Migration, an organization involved in the introduction of whooping cranes to eastern North America, has an annual budget of $420,000 entirely directed toward the recovery of the whooping crane. WBNP receives over 1,400 visitors each year, and many of them come there to see the habitat of whooping cranes and for a possible chance to see the birds themselves. A recent land transfer to the Salt River First Nation in Fort Smith has provided the First Nation with the unique opportunity of having Whooping Cranes nesting on their lands. The First Nation is entertaining the idea of establishing a remote viewing area that may provide an opportunity for visitors to view whooping cranes. In addition, each autumn, visitors descend on Saskatchewan in search of whooping cranes. Many of these visitors stay for several days and a large portion of them are with various tour groups.

In 2001, annual fall whooping crane festivals were started in Tennessee and in central Wisconsin. In Baraboo, Wisconsin in 2004, 25,092 people paid an entry fee of $8.50 for adults and $7.00 for seniors to visit ICF where a whooping crane breeding pair in a wetland exhibit is

among the crane species on display (ICF Education Department, pers. comm.). In several areas where large numbers of sandhill cranes are viewed by tourists, an additional attraction for observers is the possibility of sighting whooping cranes. Approximately 80,000 people visit the Platte River area of Nebraska each year during the peak of spring crane migrations, expending approximately $15 million (Lingle 1992).

Although whooping cranes no longer occur in the Rocky Mountains, interest in crane festivals that the whooping cranes played a role in starting remains high. Approximately 160,000 people annually pay a $3 per vehicle entrance fee to visit Bosque del Apache NWR, New Mexico, mostly in winter when the sandhill cranes are present (Maggie O'Connell, USFWS, pers. comm., 2005). The refuge and Socorro Chamber of Commerce also sponsor a 6-day "Festival of the Cranes" in the fall to promote tourism. The presence of whooping cranes in the past heightened interest in the crane migration at the Alamosa/Monte Vista NWR in Colorado. Approximately 10,000 people visit the refuge during the peak migration periods, many of these during the spring Monte Vista Crane Festival. This 4-day festival is estimated to generate about $10,000 per day in revenue to the local economies (Ann Morekill, Alamosa/Monte Vista NWR, pers. comm., 1993).

The total value for most endangered species is intangible and difficult to quantify; however, in recent years economists have developed methods to approximate the value of nonmarket resources such as endangered species. These methods measure: (1) the value people place on seeing an endangered species (use value); (2) the value they place on continued existence of the species for potential future observation value (option value); and (3) the value of simply knowing the species exists (existence value) (Randall and Stoll 1983). One method of estimating these values, the contingent valuation method, asks individuals to express their willingness to pay for nonmarket goods (Stoll 1983). Individuals are asked to estimate their willingness to pay for observing (use value) or preserving (option and existence value) the species.

Contingent valuation methodologies have been used to estimate the value of whooping cranes. In written surveys distributed in 1982-83 at ANWR, refuge visitors indicated willingness to pay an average of $4.47 for an annual permit to visit the refuge and an average of $16.33 per year to support a private foundation that would be responsible for conservation of whooping cranes. A mail survey to 4 metropolitan areas outside of Texas indicated that respondents were willing to contribute an average of $7.13 per year to the same hypothetical foundation. Allowing for sampling error and non-response bias, the total value of the whooping crane to United States' residents appears to range between 0.5 billion to 1.5 billion dollars per year (Stoll and Johnson 1984).

Three conclusions can be drawn from this evidence of the economic value of whooping cranes. First, local economies can realize significant economic benefit from the presence of an endangered species; these localities need assistance in identifying and capturing these economic benefits. Second, values for endangered species appear to be directly associated with the public's knowledge and awareness of the species. Value for the whooping crane derives not only from its aesthetic qualities and rarity, but probably more directly from its identity as a symbol of the effort to save species from extinction. This value would not have been realized without extensive education efforts. Finally, increasing interest in this endangered species, which brings economic benefits, has raised concerns about the effects of these appreciative uses upon the well being of the species. The issue of disturbance management is discussed elsewhere in this Plan.

APPENDIX C: ACTIONS ALREADY COMPLETED OR UNDERWAY

Breeding Grounds Management and Research

Management of Wood Buffalo National Park

Management of WBNP and the crane breeding grounds is not nearly as complex an operation as management of the increasingly active wintering grounds at ANWR in regards to whooping crane issues. The breeding range of the AWBP flock is secure from human-induced changes such as forestry or conversion to agricultural land, because approximately 90% of the nesting occurs within WBNP. To afford the highest level of protection, the breeding habitat is designated as a Zone 1 Special Preservation area. The Special Preservation designation establishes that within that area, there are to be no manmade facilities (except Hwy 5), and human access is prohibited from April 15 through October, except for park staff and scientists involved in whooping crane research. Under normal circumstances, habitat manipulation is not permitted in a Canadian national park. Policy would allow for manipulation of natural processes only if feasible, beneficial, and urgent to achieve recovery goals. Issues such as global warming, which may dry out the marshes, and acid rain, are external concerns that may affect the population and require habitat intervention.

Egg Collection

The management activity that has had the most profound effect on the recovery program has been the collection of eggs from the wild. These eggs when hatched would form a captive breeding and release program. The idea of a captive flock of whooping cranes dates back about 50 years (Lynch 1956). Lynch recommended capturing young cranes to serve as a nucleus of breeders, producing offspring to release back into the wild. This proposal, although passed by the participants of the Twentieth Federal-Provincial Wildlife Conference, was very controversial.

In an effort to move the captive propagation proposal along, Erickson (1961) analyzed the Aransas winter population counts from 1938-1960. This analysis revealed 3 important characteristics of the wild population that were later confirmed by Novakowski (1966): (1) principal production was apparently derived from a fairly stable cohort of long-lived adults; (2) among birds returning to Canada, mortality was highest in the subadult cohort; and (3) because subadult mortality was apparently limiting recruitment into the breeding population, the population would remain insecure until this mortality was reduced. Based on these findings, Erickson reiterated Lynch's proposal to bolster the wild population through captive propagation and the release of captive-produced stock. However, he cautioned that before stock was obtained from the wild, safe and effective procedures should be developed using sandhill cranes as research surrogates.

Research results indicated that egg collection was the best method of obtaining wild stock. These experiments also indicated that nest desertion was negligible and population productivity was relatively unaffected when single eggs were removed from 2-egg clutches. Others noted that cranes normally lay 2 eggs but rarely fledge 2 chicks. Observations on the breeding grounds by Novakowski (1966) confirmed that whooping cranes generally follow this pattern. It appeared that a single egg could be removed from each 2-egg clutch with the same favorable

results experienced with sandhill cranes.

The whooping crane population has been artificially augmented through translocation and captive rearing of wild eggs. The total number of cranes (wild plus captive) was increased by taking 1 egg from a clutch of 2 and rearing it in captivity (Erickson 1975).

The CWS and the USFWS obtained eggs from nests in WBNP from 1967 to 1971 and in 1974 to further augment the PWRC population, and in 1975 through 1988 to provide 215 eggs for the Grays Lake cross-fostering experiment (Table 2). Egg transfers to PWRC were resumed in 1982-1989 and 1991-1996. Egg transfers to ICF began in 1990 and resumed in 1992-1996. Eggs were shipped to Calgary in 1994 and 1998 and a chick was transferred from WBNP in 1999. The transfer of eggs between nests ended with the last scheduled pickup of eggs in 1996. Between 1967 and 1998, 242 eggs were taken from WBNP to the captive sites. The transfers in the 1990s were designed to increase the size and genetic diversity of the captive flock. Chicks raised from these eggs currently form the nucleus of the breeding flocks being maintained at PWRC, ICF, and CZ. Egg collections and subsequent propagation efforts have been described elsewhere (Ellis et al. 1996, Kepler 1976, Kuyt l976a).

Viability testing of eggs during collection was initiated in 1985 with the objective of leaving at least 1 viable egg in each nest visited. In nests with 2 viable eggs, 1 egg was removed and placed in nests that contained nonviable eggs or transported to the captive facilities. As a result of this procedure, the hatching success of tested known live eggs left in nests was 11.7-15.5% over those of undisturbed nests from 1985-1988 (Kuyt 1993b). However, some of the lower hatching success among undisturbed eggs/nests probably existed because they were primarily those of younger, less experienced pairs.

The results of egg collection on the growth rate and overall fitness of the wild AWBP population are unknown. Erickson (1976) and Kuyt (1976a, 198la, 198lb) noted that egg removals have not adversely affected the productivity of the wild population. Between 1967 and 1996, the era of egg pickups, the AWBP increased from 48 to 160, and the number of nesting pairs increased from 5 to 45. Cannon et al. (2001) agree that although total numbers of whooping cranes, both captive and wild, can be increased by egg pickup, total numbers of chicks reaching Aransas are less when eggs are picked up compared to when no eggs are removed. Ellis and Gee (2001) further noted the potential benefits of removing the second fertile egg from nests. After reviewing studies by Cannon et al. (2001) and Ellis and Gee (2001), Lewis (2001) concluded that the data as presented did not support the views of Cannon et al. (2001) and determined that a re-analysis of the existing egg collection data was warranted.

Because of these differing opinions, B. Johns reviewed the data pair by pair and extracted as much information as possible from original reports and solicited the expertise of Dr. Mark Boyce, University of Alberta, for the analysis. Mark Bradley (WBNP, pers. comm.) advises that the data set used has biases, including: non-random nest selection; lack of a control group; not testing eggs for viability in the early years of collection; limited samples in certain years; and potential inaccuracies in chick surveys.

Table 2. Known number of nesting pairs, productivity, and distribution of eggs removed from Aransas Wood Buffalo Population, 1966-2005.

Year	No. of known nesting pairs[a]	No. of juveniles[b]	Max. no. of nonbreeders[c] (including juveniles)	Destination of eggs removed from WBNP			
				PWRC[d]	Grays Lake	ICF[e]	CZ[f]
1966	5[g]	5	-[h]	0	0	0	0
1967	9[g]	9	-[h]	6	0	0	0
1968	10	6	30	10	0	0	0
1969	12	8	32	10(3)[i]	0	0	0
1970	15	6	27	0	0	0	0
1971	13	5	33	11(2)	0	0	0
1972	16	5	19	0	0	0	0
1973	14	2	21	0	0	0	0
1974	15	2	19	13	0	0	0
1975	16	8	25	0	14(3)	0	0
1976	16	12	37	0	15	0	0
1977	17	10	38	0	16	0	0
1978	15	7	45	0	13(2)	0	0
1979	19	6	38	0	19(3)	0	0
1980	19	6	40	0	12(2)	0	0
1981	17	2	39	0	12(2)	0	0
1982	17	6	39	2	14(1)	0	0
1983	24	7	27	2	16	0	0
1984	29	15	28	3(2)	22	0	0
1985	28	16	41	4(3)	23(3)	0	0
1986	29	21	52	12(10)	15(2)	0	0
1987	32	25	70	12(5)	12	0	0
1988	31	19	76	14[j](6)	12	0	0
1989	31	20	84	15(9)	0	0	0
1990	32	13	82	0	0	12(1)	0
1991	33	8	66	16(10)	0	0	0
1992	41	15	56	10(1)	0	11(1)	0
1993	45	16	57	16(1)	0	10(2)	0
1994	28	8	77	0	0	9	4
1995	49	28	60	14(2)	0	10	0
1996	45	16	70	8(1)	0	6	0
1997	51	30	84	0	0	0	0
1998	50	18	83	0	0	0	2[k]
1999	48	17	92	0	0	0	0
2000	50	9	80	0	0	0	0
2001	52	15	72	0	0	0	0
2002	50	16	73	0	0	0	0
2003	61	25	72	0	0	0	0
2004	54	34	109	0	0	0	0
2005	58	30		0	0	0	0
			TOTALS	178	215	58	6

[a] Nesting pairs. (Canadian Wildlife Service, Brian Johns, pers. comm.)
[b] Fall arrivals, ANWR and area (U.S. Fish & Wildlife Service 1994; Refuge Manager, ANWR, pers. comm.).
[c] Calculated as following winter's peak population minus number of breeding adults.
[d] Patuxent Wildlife Research Center, Laurel, Maryland.
[e] International Crane Foundation, Baraboo, Wisconsin.
[f] Calgary Zoo
[g] Data incomplete.
[h] Cannot be calculated, as data on number of known nesting pairs are incomplete.
[i] Numbers in parenthesis indicate nonviable eggs or eggs that failed as a result of embryonic death (1975-1988 data from R.C. Drewien).
[j] Excluding one sandhill crane egg.
[k] Two eggs from an abandoned nest were picked up opportunistically in May, 1998.

Boyce et al. (2005) analyzed colt recruitment in WBNP in relation to egg removal activities between 1987-1996. The egg collection was never intended to be established with an experimental design suitable for testing its effect on the population. As such there are inherent biases associated with the data set, including a bias towards experienced, productive pairs. The results of the analysis indicated that recruitment of young into the population was higher when eggs were removed than when eggs were not removed: theta=0.498$\pm$0.0012 with removal, theta=0.355$\pm$0.0013 without removal, showing a 25% reduction in survival of chicks without removal. This advantage of increased recruitment from 1-egg nests is counterbalanced by occasional survival of both chicks from 2-egg nests.

Boyce and Miller (1985) found a 10-year cycle in whooping crane counts, which held true through 2002 (Boyce et al 2005). This trend parallels counts of predators (based on lynx fur returns) in the area (Boyce et al. 2005). There was a strong negative effect between egg collection and lynx populations, such that collection of eggs during a crashing lynx population may not be detrimental to the AWBP. This would provide additional offspring for recovery efforts elsewhere. During years that egg removal did not occur, 10% of recruits were from sets of twins. One interpretation is that periodically there are very good years and the whooping cranes can actually raise twins. The analysis revealed that there were no negative consequences from egg removal, even with the twinning effect.

Boyce et al. (2005) also evaluated egg substitution effects and found that they did not improve nest success over nests that had no substitutions. This could be due to the nest being situated in a poor habitat or because the pair was inexperienced.

The recovery team recognizes that collection of eggs has benefited the whooping crane recovery program by providing stock to establish the captive flocks and providing offspring for release, thus increasing the total number of whooping cranes and helping to preserve the genetics of the species. The recovery team believes that data analyses to date do not indicate that egg collection would increase recruitment in the AWBP over the long term, but could increase recruitment in selected years. The recovery team would like to document the rate of twinning until 2006 without any egg collection in order to observe the population dynamics through a full 10-year cycle (1997-2006).

The genetic master plan indicates that the genetic diversity of the AWBP is well represented in the captive flocks, hence there would be little to be gained genetically in the captive flocks by removing additional eggs from WBNP at this time. However, certain pairs in captivity are not breeding, so it may become important to obtain additional genetic material from WBNP similar to those pairs. A large-scale study of the genetics of the nesting pairs may have to be undertaken first since information has been lost on the composition of nesting pairs with the cessation of the color-banding program in 1988. There may be demographic benefits to egg collections (i.e. more chicks available for reintroductions), but the recovery team believes that production from the captive flocks is sufficient to support reintroductions at the present time. The current captive facilities are at peak manpower and pen capacity for raising existing chicks and would be strained to handle additional eggs at present. The issue of egg collection should be reevaluated in 2006 at the completion of 10 years with no collection.

Color Banding

Flightless young whooping cranes were captured and marked with colored plastic leg bands in WBNP from 1977 through 1988 (Kuyt 1978a, 1979a, Drewien and Kuyt 1979). Banding whooping cranes in WBNP was halted after 1988, since much information had already been obtained and the objectives of the original banding program had been met. Also, capturing the chicks can cause some mortality. Over the 12 years of the banding program, 134 birds were captured and 2 chicks died (1.5%). As of winter, 2004-2005, 25 of the 217 birds (i.e. 11.5%) in the AWBP were still individually identifiable by their bands (Tom Stehn, ANWR, pers. comm.).

This marking program provided a wealth of information on whooping crane biology, including the summering locations of subadults, the dynamics and habitat use of wintering subadult flocks, age specific survivorship, the age of initial pairing and breeding, juvenile and adult philopatry and the identification of stopover sites, and wintering and breeding territories used by specific pairs (Kuyt 1979b, 1981a, 1981b, Bishop and Blankinship 1982, Bishop 1984, Stehn and Johnson 1987, Johns et al. *In press*). Other information gained from the banding studies included the ability to develop a studbook on a fairly large segment of the wild population, tracing the reproductive histories of many of the birds including mate switches and probable deaths. These data provide valuable insight into the relatedness and genetic diversity of the wild flock and may be of assistance in evaluating potential inbreeding effects in the future.

Migration Monitoring

Whooping cranes spend approximately 3 months annually in migration. Although a number of migration sightings have been reported and compiled over the years (Allen 1952, Sutton 1967, Walkinshaw 1973, Archibald et al. 1976, Stephen 1979, Asherin and Drewien 1987, Johns 1987, Asherin et al. 1992), few were confirmed. In order to protect migrating whooping cranes from disease outbreaks and other potential hazards, and to compile information on the characteristics and locations of stopover sites, the USFWS initiated the Cooperative Whooping Crane Tracking Project in 1975. The CWS started a similar program in 1977. This program alerts key personnel about sightings so that reports can be verified, stopover sites described, and the birds kept under protective surveillance by State, Provincial, and Federal personnel. This monitoring program is coordinated with reporting networks of wildlife agencies along the migration corridor. Whooping crane sightings compiled within the U.S. portion of the migration corridor by the USFWS (1,352 confirmed sightings, 1943-99) were summarized by Austin and Richert (2001).

Whooping crane sightings compiled within the Canadian portion of the migration corridor were summarized by Johns (1992) and Johns et al. (1997) The presence of marked birds from the banding program conducted in WBNP provided more precise information on migration chronology, and yielded information on several events that would have otherwise gone undetected (Stehn 1992a,c).

Radiotelemetry techniques were first tested on cross-fostered whooping cranes in the RMP (Drewien and Bizeau 1981). Beginning in 1979, flightless young were captured and marked with plastic leg bands to which miniature radio transmitters (45-60 g) were attached. Local movements of the radio-tagged birds were monitored on summering and wintering areas, and several individuals were followed during their fall migration between Grays Lake NWR in southeastern Idaho and Monte Vista NWR in south-central Colorado. No adverse effects were noted from capturing, banding, and radio-tagging young whooping cranes (Drewien and Bizeau 1981).

On the basis of these preliminary studies, a cooperative USFWS-CWS-NAS radio tracking program was initiated for birds in the AWBP to determine various aspects of migration ecology, including habitat characteristics, behavior, and sources of mortality. During each summer 1981-1983, small solar-powered transmitters were placed on several prefledged whooping cranes captured during the color-banding operation in WBNP (Kuyt 1979a, 1979b, 1992). Data were obtained on 3 southbound and 2 northbound migrations. Most information involved the individuals or family groups actually being followed, but data also were accumulated on other migrating whooping cranes encountered during the project.

This successful tracking project resulted in important information concerning migration routes, migration timing, flight methods and speed, stopover locations and staging areas, habitat use, social behavior, activity budgets, predator/disturbance reactions, and sources of mortality (Howe 1989, Kuyt 1992). Perhaps the most important result obtained from this tracking project has been documenting mortalities on the breeding grounds (wolf predation) (Kuyt et al. 1981), during migration (power line collisions), and on the wintering grounds (predation and disease). Similar valuable information has been acquired on migration and behavior of whooping cranes in the RMP (Drewien and Bizeau 1981, Asherin and Drewien 1987, Drewien et al. 1989) and the EMP (Urbanek et al. *In press*{b}).

Migration Habitat Management and Research

Suitable stopover habitat is necessary for the birds to complete their migration in good condition. There has been considerable alteration and destruction of natural wetlands, rivers, and streams, some of which had served as potential roosting and feeding sites for migrating cranes. There may be additional areas along the migration route that need to be delineated and protected.

South central Saskatchewan has been referred to as a traditional fall staging area for whooping cranes (Johns 1992). Habitats used by cranes, in the staging area, were characterized by Johns et al. (1997). Choice of wetland types for roosting was influenced by a variety of landscape features both natural and manmade. Roosting wetlands varied in size and type, depending on the season, in areas of higher than average wetland density. The staging area is in a highly modified environment with the majority of crane roosts (96% spring, 85% fall) being on private land. Foraging area use exhibited a similar trend (Johns et al. 1997). Once the cranes leave the fall

staging area, the remainder of their migration is rapid and stopovers are of shorter duration (Kuyt 1992). There is no equivalent spring staging area.

The USFWS has funded studies of availability of suitable migration stopover habitat within the AWBP migration pathway in the United States (Stahlecker 1988, 1992, 1997a, 1997b). National Wetland Inventory (NWI) maps, used in conjunction with aerial photo maps and suitability criteria (Armbruster 1990), were poor predictors (33% correct) of suitable roosts in Oklahoma, but good predictors (97% correct) of unsuitability (Stahlecker 1992). NWI map review in Nebraska was a good predictor of both suitability (63% correct) and unsuitability (73% correct). Wetlands suitable for overnight roost sites for migrating whooping cranes were available throughout the migration corridor in the Dakotas and Nebraska (Stahlecker 1997a, 1997b), but may be limited in Oklahoma (Stahlecker 1992). Similar sampling to evaluate roost availability in Kansas and Texas should be conducted.

Richert (1999) used Geographic Information Systems (GIS) and remote sensing technologies to evaluate whooping crane stopover habitat in Nebraska. Confirmed whooping crane sightings, when compared with habitat selection, suggest that whooping cranes select roost habitat by recognizing local and larger-scale land cover composition. Habitat selection was influenced by social group, season, and landscape pattern (Richert 1999).

Based upon recommendations from the Recovery Team, the USFWS initiated a project in 1977 to conduct site evaluations at sites in the U.S. used by whooping cranes during migration. The site evaluation data base, containing 1,060 evaluations completed between 1977 and 2000, was summarized by Austin and Richert (2001). Results revealed some new insight into whooping crane habitat use during migration (e.g., roosting and feeding site characterization).

Based on the large number of sightings along the central Platte River in Nebraska during 1820-1948, Allen (1952) believed that whooping cranes made that area a major stopover, remaining in the area for some days. In 1978, the USFWS designated an 88 km portion of the Platte River in central Nebraska as critical habitat. The National Research Council of the National Academies of Science (NRC) (2005) reviewed and affirmed the scientific validity of that critical habitat designation, and the importance of the Platte River to the survival and recovery of the whooping crane population.

Currently, an average of about 7% of the AWBP population use the central Platte River during migration, although there is substantial fluctuation in that percentage from year to year (NRC 2005). Additionally, the average duration of stopovers (as reflected by crane use-days) and the number of confirmed sightings along the central Platte River have increased more than can be explained by the increase in size of the AWBP (NRC 2005).

The NRC (2005) concluded that "…current habitat conditions along the central Platte River adversely affect the likelihood of survival and recovery of the whooping crane population." (p. 183). As a result of reduced channel width, loss of adjacent wet meadows, and encroachment of the channel by woody vegetation brought on by diversion and storage of water for irrigation and power generation (USFWS 1981), 128 km of Platte River channel habitat has been lost. In the remaining 120 km of the Platte River channel that crosses the breadth of the migration path, there has been a 58 to 87% reduction in channel area due to encroachment of woody vegetation and approximately 70% loss in the average annual flow since 1930. As much as 97% of suitable

crane roosting habitat has been lost in some river segments. Woody vegetation is still expanding and channel width declining on the Platte River (Currier 1997). Over 73% of native grasslands and wetlands adjacent to the river channel have been lost due to declines in river flows, construction of drainage systems, and conversion to cropland (Currier et al. 1985). The need to prevent further deterioration of habitat along the Platte River has been identified (USFWS 1981, NRC 2005).

A river management plan was prepared by the Biology Workgroup of the Platte River Management Joint Study, a group of representatives from the USFWS, Bureau of Reclamation, Corps of Engineers, States of Wyoming, Colorado, and Nebraska, water development interests, and environmental groups. The plan identified management alternatives that could be implemented in the Platte River basin as an aid to future management (Platte River Management Joint Study 1990). Currier et al. (1985) and Strom (1987) described management programs to preserve, rehabilitate, and restore river habitat. Other research conducted along the Platte River (Hurr 1983, Wesche et al. 1990, Henszey and Wesche 1993) indicates river discharge and stage are dominant factors affecting groundwater levels in wet meadow grasslands. Areas for whooping cranes should be managed to prevent further channel shrinkage and encroachment by woody vegetation. Reasonable in-stream flows are required to maintain the wet meadows used by cranes.

The USFWS recommended target flows for the central Platte River, Nebraska, to the Federal Energy Regulatory Commission (FERC). These recommendations are designed to rehabilitate and maintain the structure, patterns, processes, and habitat of the central Platte River ecosystem. Flow recommendations are generally prioritized by time period in the following order: a) pulse flows during late spring (May and June) and late winter (February and March); b) summer; c) spring migration; and d) fall migration.

Multiple organizations and agencies continue to be involved in habitat restoration and management for whooping cranes on the Platte. These include the USFWS, the Nebraska Game and Parks Commission, the Platte River Whooping Crane Habitat Maintenance Trust (PRT), the Platte River Bird Observatory at Crane Meadows, the Audubon Society's Rowe Sanctuary, the Nature Conservancy, and the National Wildlife Federation. Beginning in the 1980s, restoration activities have focused on clearing and maintaining river roost sites free of trees and shrubs and restoring and rehabilitating wetland meadows and marshes adjacent to the river channel. Other efforts include habitat management done by the Nebraska Public Power District and the Central Nebraska Public Power and Irrigation District pursuant to conditions of their FERC licenses. The Nebraska Game and Parks Commission and the Central Platte Natural Resource District hold instream flow rights that may help provide river roosting habitat during migration periods.

Additional actions intended to improve habitat conditions on the Platte River are currently being pursued by the states of Wyoming, Colorado, and Nebraska, and the U.S. Department of the Interior. In 1997 they signed a *Cooperative Agreement for Platte River Research and Other Efforts Relating to Endangered Species Habitats Along the Central Platte River, Nebraska* (Derby and Strickland 2001). The cooperators agreed to implement certain management activities for four target endangered or threatened species, including the whooping crane and its federally designated critical habitat. Currently, intensive aerial and ground monitoring for whooping crane use of the Platte River is being done pursuant to the Cooperative Agreement, at a cost of more than $100,000 per year.

The signatories of the Cooperative Agreement are planning to implement a basin-wide Platte River Recovery Implementation Program (Program) to restore the river to assist in the conservation and recovery of the target species. Although the signatories anticipated development and implementation of the Program by the year 2000, negotiation of Program details are ongoing. Program implementation currently is expected in 2006, following appropriate environmental reviews. One objective of the Program is to protect or restore 4,047 ha in the first 10-13 years and, ultimately, protect 11,736 ha of Platte River habitat for the whooping crane, least tern, and piping plover (Derby et al. 2000). It is important that actions taken reverse the ongoing degradation of the river and loss of crane habitat as described in the NAS report (National Research Council 2005).

Along the Platte River, roosting habitat suitability criteria (Ward and Anderson 1987, Armbruster 1990), combined with hydraulic simulations of Instream Flow Incremental Methodology (IFIM), have been used to identify the relationship between river discharge and roosting habitat (Platte River Management Joint Study 1990, Ziewitz 1992, Platte River Management Joint Study 1993). The IFIM consists of a collection of computer models, including the Physical Habitat Simulation Model and analytical procedures, designed to predict incremental changes of habitat resulting from incremental changes in river discharge.

Farmer et al. (2004) reviewed the C4R version of the Whooping Crane Habitat Suitability Model and suggested some improvements. Their suggestions will be considered by the USFWS, along with recommendations of the NRC (2005) regarding water management using normative flows, and information collected during the Program and from other sources, to evaluate current USFWS instream flow recommendations for the central Platte River.

Wintering Grounds Management and Research

Despite intensive studies of whooping cranes on the wintering grounds by Allen in the late 1940s, some important questions remained unanswered. More detailed information was needed on food habits, food availability in relation to climatic conditions, spatial requirements and territorial behavior in an expanding population, and on the effects of increasing human activities in and around the cranes' habitat. With more of this information available, better management planning and evaluation would be possible.

Potential whooping crane food organisms and related physical factors were studied in 1963 and 1964 by Bill Van Tries and Gordon Folzenlogen of the USFWS. In1970, the NAS assigned David Blankinship to conduct research on wintering whooping cranes at ANWR and adjacent areas. Findings on territorial behavior, subadult flocks, adult-young relationships, feeding ecology, parasites, and other aspects of wintering ecology have been published (Blankinship 1976, Forrester et al. 1978, Bishop and Blankinship 1982, Bishop 1984, Blankinship 1987).

Hunt (1987) studied upland habitats at ANWR to identify environmental conditions associated with crane use, the effect of management on uplands, and the importance of food items consumed there. Whooping cranes used portions of upland pastures that were open, close to the wetland edge, and away from sources of human disturbance. Periodic upland burning increased visual openness of habitat, oak stem density, and availability of acorns (Hunt 1987).

Winter territories of whooping cranes on the Texas coast place the birds in close proximity to several human-induced disturbance factors. These factors included whooping crane tour boats, boat and barge traffic along the GIWW, recreation and commercial traffic (including hunting, angling, crabbing, and oystering), photographers, and aerial overflights. In the winter of 1985-86, Mabie et al. (1989) examined the response of 4 whooping crane family groups on Matagorda Island to several staged hunting and boating activities. Cranes are somewhat tolerant of people in carefully operated boats and land vehicles. Direct harassment by airboat caused the only significant difference in behavior pattern (percent of time alert) when compared to control observations. The cranes responded to disturbances at distances ranging from 25 to 550 m. Response ranged from alert posture to walking away to flying away for a maximum distance of 2,150 m. Whooping crane response was generally short-term, with a return to normal behavior patterns by the second hour of observation. Irby (1990) observed whooping cranes on Welder Flats for 365 hours, using scan sampling and focal bird sampling techniques, and noted all events that caused disturbance. Of the 365 hours of observation, cranes spent 47 minutes responding to non-observer human-induced disturbance. Irby (1990) made several recommendations resulting from his observations. Barge mooring may represent a dangerous threat. A coordinated plan needs to be developed to protect the area from pollution, and to designate safe barge mooring areas. In a study done in the winters of 1989-90 and 1990-91, whooping cranes on the ANWR responded with a negative reaction to 40% of all disturbances, were disturbed for 17 minutes for each hour observed, and moved an average of 525 m from human disturbances, and were displaced most often from open bay and wet marsh habitats (T. Lewis In prep). Airboats, low-altitude aircraft, and especially helicopters were more disturbing, and cranes were particularly sensitive to humans on foot (Lewis and Slack 1992). The extent to which whooping cranes were exposed to disturbance varied among the different use localities. The most recent disturbance study being done by Kristen LaFever and Dr. Doug Slack of Texas A & M University is scheduled for completion in 2006.

It is difficult to assess the total impacts of disturbance upon whooping cranes in terms of fitness, productivity, and survival. Crane displacement results in short-term or long-term loss of habitat, social disruption of the flock, and limits the ability to obtain food resources and thus impacts fitness (T. Lewis In prep). Refuge and coastal wetland users should be encouraged to minimize disturbance to whooping cranes. Damage caused to submerged vegetation by boating activities should be reduced. Support of private landowners in minimizing disturbance and maximizing protection should be recognized and encouraged. As the AWBP continues to expand, a decrease in territory sizes and expansion into new wintering areas is likely to continue. The effects of increased population density and/or exposure to disturbances could be compounded by an increase in frequency or severity of disturbance. Levels of disturbance should be monitored on the wintering grounds and steps taken to minimize detrimental activities.

Management of ANWR is a sizeable and complex operation (Johnson 1976). Prime habitat is limited and natural foods may be in short supply at times. Two 40-ha fenced enclosures were developed during 1964-1968, in which various cereal and root crops were grown. Some whooping cranes used these fields but sandhill cranes and Canada geese (*Branta canadensis*) ate most of the food (Shields and Benham 1969). Another management strategy was the diking of a 28-ha impoundment equipped with a high volume, low-lift pump designed to bring large quantities of saline water and marine life into the basin; the exit of live food items was prevented by screens at spillway outlets. Limited use by whooping cranes was achieved during 1 winter

when they were attracted to the site by "bait" grains, but in subsequent years whooping cranes did not use the artificial impoundment.

During the mid-1960s, whooping cranes were attracted to grains spread for their use. Such supplemental food has since been avoided because concentrating the birds increases the potential for a disease outbreak or the spread of parasites, and changes the distribution of the cranes. Supplemental feeding could be attempted to attract cranes from the tidal areas in certain emergency situations, such as during oil or chemical spills, or periods of food scarcity.

Chavez-Ramirez (1996) analyzed whooping crane winter foods during the 1992-93 and 1993-94 winters. He evaluated standing biomass of blue crabs, clams, and wolfberries and human and wildlife competition for these principal foods. The nutritive composition of winter foods was compared to the commercial rations used for the captive flocks (Nelson 1995, Chavez-Ramirez et al. 1997).

Prescribed burning is used to reduce height and density of grasses, remove brush, and modify plant composition on uplands to make them more attractive to whooping cranes. Management in the past included mechanical cutting and grazing by livestock. Whooping cranes almost immediately use the burned areas (Hunt 1987). Currently, 15 prescribed burn units averaging 322 ha are located in the crane area at ANWR, with the units burned on a 3-year rotation. Additional burning is done on Matagorda Island, as well as on private lands on San Jose Island and Welder Flats.

About 30 freshwater ponds are present on ANWR and Matagorda Island near areas used by cranes. Cranes drink at upland freshwater ponds where surrounding vegetation is kept low to the ground and aquatic emergent or floating vegetation is sparse or absent. Such ponds provide a source of fresh water when coastal waters are highly saline above 23 parts per thousand and may encourage cranes to utilize upland food resources.

The most complete census of the AWBP is made during winter. Aerial censuses are made weekly from the time the first whooping cranes appear, approximately twice a month during mid-winter, and again weekly until the last cranes depart. Flights provide information on mortality, habitat use, pair formation, territory establishment, and population age structure by identifying all color-banded birds present. These flights serve to alert the refuge staff to hazards or harassment of cranes resulting from human activity. If a crane is determined to be "missing," then a ground search may be initiated to locate the carcass.

Whooping cranes use marshes bordering Matagorda Island, a barrier island 60.8 km long by 1.2 to 7.2 km wide. In 1942, the Federal government purchased approximately 7,700 ha of Island uplands, and leased 2,400 ha from the State of Texas, to establish an airbase and bombing range. In 1971, a Memorandum of Agreement with the USFWS established the Matagorda Island Unit of ANWR. The upland area was declared excess property by the Air Force in 1975. The property was transferred to the USFWS as part of the NWR system in 1978. In 1988, the USFWS and Texas General Land Office exchanged easements and signed a management agreement that established Matagorda Island State Park and Wildlife Management Area. In 1988, the USFWS purchased 2,232 ha on the south end of the Island. A new agreement between the USFWS and the State of Texas enabling joint management of the entire island was signed in 1994 and is reviewed every 5 years. It established the Matagorda Island NWR and State Park

and includes a separation of duties. The USFWS has the lead for wildlife and habitat management, and Texas Parks and Wildlife Department manage public use.

Additional protection of some winter habitat has been provided by NAS's leasing of Ayres, Roddy, and a portion of Rattlesnake islands from the State of Texas. The leasing arrangement substantially reduces the potential for disturbing or harassing cranes wintering in these areas.

Construction of the GIWW in the early 1940s through the heart of marshes on ANWR, subsequent erosion by wind and boat wakes, and deposition of dredged material, resulted in loss of 11% of wintering habitat (Sherrod and Medina 1992). In 1983-1984, shoreline erosion along the GIWW was measured at a loss of 1 m per year, amounting to destruction of 0.8 ha of whooping crane habitat along 13.6 km of critical habitat shoreline (Stehn 1987). In 1985, the USACE formed an interagency committee to study the impacts of the GIWW on critical habitat of whooping cranes. Boats and barges plying the GIWW create wakes and surges that erode marsh bordering the channel (U.S. Army Corps of Engineers 1988). Ponds and sloughs in the marsh are destroyed as erosion breaches their margins.

Between 1989-1992, volunteers built walls using more than 57,000 sacks of cement to protect 2,652 m of shoreline. In 1992, USACE used 610 m of interlocking cement mats to stop erosion. USACE agreed in 1993 to armor approximately 4.8 km of the most critically eroding shoreline, and to continue to armor 610 m annually until all areas were adequately protected. The USACE's Section 216 Study provided a permanent solution to the habitat erosion problem. In 1998-2000, the USACE used flexible cement mats to protect 25.6 km of shoreline at ANWR and 8.3 km at Welder Flats. They also protected 471 m at Welder Flats using geotubes, and purchased equipment stored on the refuge to respond to an oil spill. Total project costs were $15.43 million.

Deposition of dredged material from periodic maintenance dredging of the channel has destroyed additional marsh and, accidentally, created some new marsh. Dredged material disposal sites along the GIWW have been nearly fully utilized. The problem of future disposal of dredged material is critical.

In the summer of 1991, Mitchell Energy created a dike around 5 ha of open shallow bay and filled the area with dredge material. Vegetation was planted in the created shallows and the first whooping crane use was documented in January 1992. Mitchell Energy constructed additional marsh acreage in 1993 and 1995 totaling 8 ha. The USACE has evaluated beneficial uses of dredge material to create new coastal marsh habitat for whooping cranes. In 1995, the USACE created 2 wetland areas using dredged material totaling 18 ha (Evans and Stehn 1997). The USACE's new dredge material disposal plan calls for the creation of 654 ha of marsh habitat over the next 50 years. The USACE is working cooperatively with other agencies on the design and location of these new marshes.

Several studies have characterized whooping crane winter habitat. Darnell et al. (1997) studied influence of landscape features on bird use of marsh habitat created for whooping cranes. Although the created marshes were successful in providing avian habitat, design modifications were suggested to increase the similarity of created and natural marshes (Darnell et al. 1997). Bonds (2000), using GIS and remote sensing, characterized whooping crane territories from 1992-1997. Bonds (2000) recommended land-cover composition of whooping crane areas to be

50% salt marsh (5-6.5 patches/ha), 30-40% salt marsh open water (10-16 patches/ha), and up to 10% grasslands (8.9 patches/ha).

Vocalizations of whooping cranes have been studied by several researchers. Initial vocal analysis of alarm calls was not sufficiently accurate (64.4%) to identify individual birds (Carlson 1991), but recordings of unison calls allows for identification of individuals (Bernhard Wessling, pers. comm.). Wessling (2000) recorded the unison calls for 27 pairs on winter territories at ANWR in winter 1999-2000. In the summer of 2000, Brian Johns recorded unison calls of 9 pairs on the breeding grounds. Additional calls were recorded in subsequent summers and winters. From the comparisons, it was possible to identify several of the nesting pairs on their winter territories (Brian Johns, CWS, pers. comm.).

Health Management

A whooping crane health management workshop was organized in 1992 by the NWHC and ICF. Participants included the veterinary and wildlife disease specialists working with whooping cranes. Uniform health management protocols were established for disease monitoring of captive and wild flocks, and for pre-release and pre-transfer disease screening. Unpublished information was collated on disease research. Research needs were identified and prioritized including avian tuberculosis, EEE, and crane herpes. A centralized, computerized database on whooping crane mortality was initiated. WCHAT was established with clinical and research veterinarians identified to coordinate input and serve as official advisors to the recovery team. This Team continues to meet periodically to evaluate progress and address needs. It has regularly updated the health management protocols, developed plans for a centralized serum/tissue bank, and provided advice to the recovery team on issues such as new release site disease assessments, monitoring and control of emerging disease including EEE and West Nile virus, and selection of new captive facilities.

Captive Propagation

Whooping cranes are propagated to save the genetic material of the species and to establish additional wild populations. In 1998, the Recovery Team adopted the following allocation of captive-produced chicks listed in order of priority: maintenance of captive flocks; Florida releases; Wisconsin/Manitoba releases; off-corridor experiments considered essential to Florida, Wisconsin, or propagation; education; other approved populations; and other experiments.

<u>Research and Propagation at Patuxent Wildlife Research Center</u>

Before research was carried out at PWRC, successful attempts to propagate whooping cranes involved only 4 birds - 2 females (Josephine and Rosie) and 2 males (Crip and Pete) (McNulty 1966, Doughty 1989) (Fig. 6). Josephine, who in 1941 was captured and placed in captivity at Audubon Park Zoo in New Orleans, Louisiana, became the last survivor of the non-migratory, southwestern Louisiana population. Crip, Pete, and Rosie, flightless due to injuries, were from the migratory population (McNulty 1966, Maroldo 1980). Three other birds in poor health (1 from Louisiana and 2 from ANWR) were rescued from the wild but all died soon after capture.

Josephine, in captivity from 1941 to 1965, produced 13 chicks. Four lived for more than a decade but left no survivors and the genetics of the Louisiana non-migratory flock was lost. Pete

lived for 13 years in captivity but also left no survivors. In 1949, Pete and Josephine nested unsuccessfully in an enclosure at ANWR. After Pete died at ANWR in 1949, Josephine was re-paired with Crip. The pair hatched one chick in 1950 at ANWR but a predator took it a few days after hatch. After nesting unsuccessfully in 1951, Crip and Josephine were transferred to Audubon Park Zoo. Josephine died in 1965 and Rosie was paired with Crip. After an unsuccessful nesting attempt in 1966, they were moved to the San Antonio Zoo in Texas. Rosie, in captivity from 1956 to 1971, produced 1 line with Crip that survives today (Gee Whiz). Crip, in captivity from 1949 to 1979, produced 13 chicks with Josephine, 3 with Rosie, and 1 with Ektu. Ektu, hatched and reared at PWRC from an egg taken from WBNP in 1967, died in 1984, and produced 1 chick with Crip that died the same year (Fig. 6).

Experimentation with bringing sandhill cranes into captivity began in 1961. Immature lesser and greater sandhill cranes were captured in 1961 and 1962, respectively, and greater sandhill crane eggs and downy chicks were collected in 1962. These cranes were housed in temporary facilities at Monte Vista NWR, Colorado. Initial results of this research indicated that egg collecting was the safest and most convenient method of obtaining and transporting wild stock (McNulty 1966, Doughty 1989). In subsequent years, only eggs were taken from the wild at Malheur NWR, Oregon, and Grays Lake NWR, Idaho, several locations in peninsular Florida, Jackson County, Mississippi, and central Wisconsin.

A male whooping crane named CAN-US, captured as a chick in WBNP in 1964 with an injured wing (Novakowski 1965), was the only whooper in the flock. In 1966, U.S. Senator Karl Mundt sponsored a supplemental appropriation to establish the Endangered Wildlife Research Program and to develop permanent facilities at the PWRC in Laurel, Maryland. The WCCA was influential in acquiring the first project funding at PWRC (Erickson 1968). The single whooping crane, sandhill cranes, and Aleutian Canada geese were transferred to Maryland in spring 1966.

Although some propagation techniques developed for sandhill cranes can be applied to whooping cranes, the latter have required certain procedural modifications. Whooping cranes are more difficult to rear than sandhills, and most mortality has occurred within one month of hatching as a result of bacterial infections, coccidiosis, congenital abnormalities, and leg disorders resulting from rapid growth (Kepler 1978). All mortalities in the captive flock have been summarized from 1967 to 1981 (Carpenter and Derrickson 1982) and from 1982 to 1995 (Olsen et al. 1997).

Whooping crane eggs were first produced at PWRC in 1975 when 1 female laid 3 eggs. Although 2 females produced eggs when they were 5 years old, most captive females have not laid until they were 7-10 years old (Table 3). At CZ, 1 female produced eggs when she was 4 years old (Dwight Knapik, CZ, pers. comm.) and 2 females when 5 years old. ICF had 2 females produce eggs at 4 years of age (Mike Putnam, ICF, pers. comm.).

Possible factors responsible for delaying reproduction in the captive flock include photoperiod, rainfall, rearing conditions, dominance relationships, age of separation of potential pairs from a bachelor flock, sexual compatibility, inadequate pen size, lack of access to ponds, and stress associated with handling and disturbance (Kepler 1976, 1978, Derrickson and Carpenter 1982, Ellis et al. 1996, Mirande et al. 1996). Besides delayed sexual maturity, other factors reduce reproductive potential in the captive flock. Most birds, after they start, lay eggs every year. Some pairs lay every other year, some more occasionally, and some lay small or misshapen eggs. Between 1975 and 2005, the captive flock at PWRC produced 957 eggs (Table 4).

Figure 6. Whooping crane captive propagation, 1941-1979.

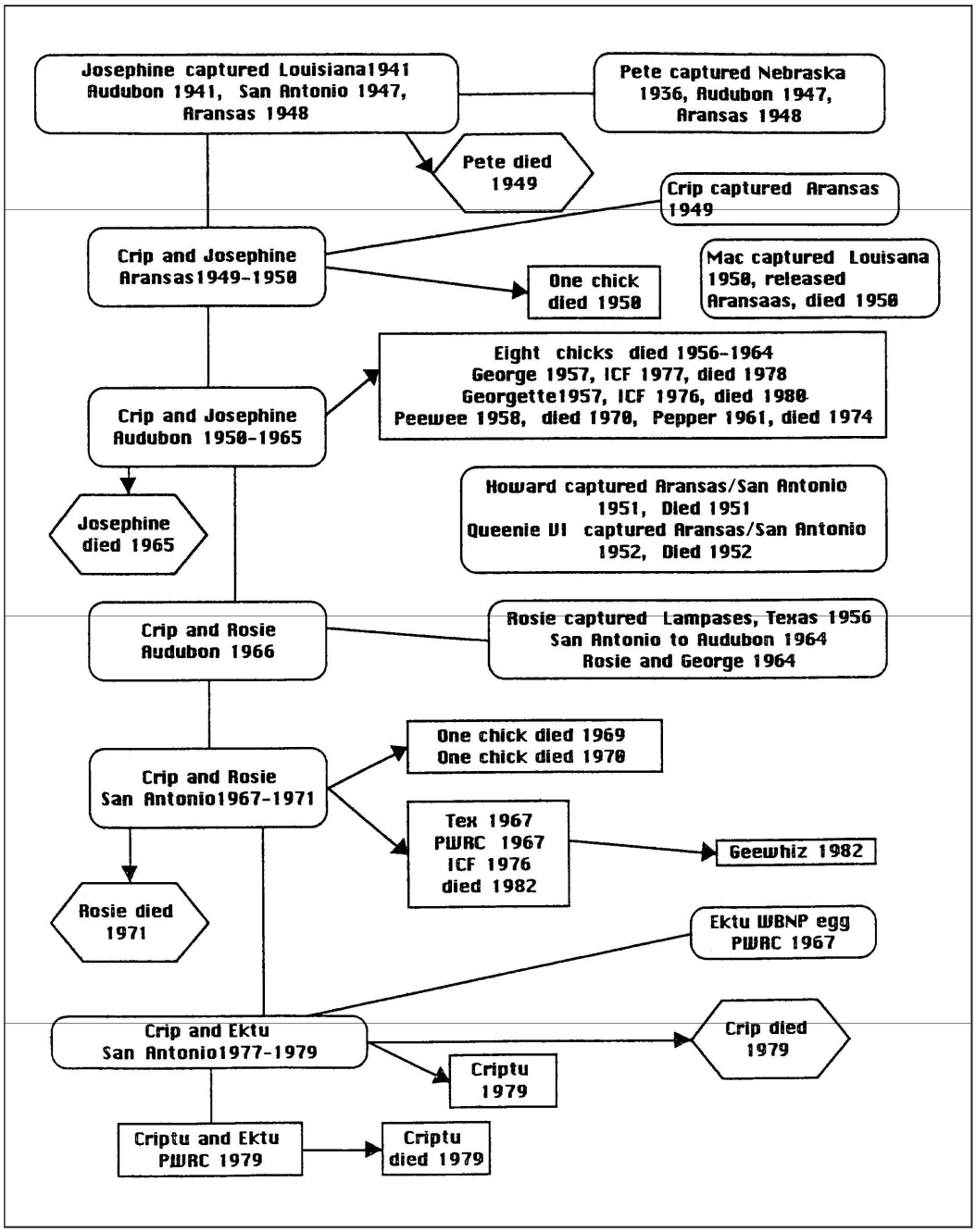


Table 3. Age of captive whooping cranes when they first produced eggs, Patuxent Wildlife Research Center, 1975-1993.

Age (years)	Females[ab]	Producing Females[c]	Percent Producing
5	28	5	17
6	22	8	36
7	15	8	53
8	13	10	76
9	10	9	90
10	9	9	100

[a] Does not include birds transferred between centers before maturation. Transfers delayed egg production.
[b] Females reaching or passing through that age class by 1993.
[c] Females producing eggs in that age class.

Breeding pair numbers and egg fertility have been the primary factors limiting annual production in captivity (Gee and Temple 1978). Successful natural copulations were not observed until 1991 when a full-winged pair laid a fertile egg (Nicolich et al. 2001).

There has been no difference in the number of eggs produced by naturally fertile pairs and artificially inseminated birds at PWRC. From 1991 to 1999, 8 pairs produced chicks by natural breeding, but egg fertility (54%) was less than from females artificially inseminated (76%). Natural fertility, which reduces the risk of injury due to handling, is good in some pairs but overall is less than in pairs artificially inseminated. Some pairs, although they copulate, fail to lay a high percentage of fertile eggs or do not reliably lay fertile eggs every year. In these pairs, artificial insemination before they lay the first egg may increase natural fertility and increase total fertile production in the captive flock (Bakst 1988). To get fertile eggs from badly imprinted or handicapped individuals, the females have been artificially inseminated using the massage technique (Gee and Mirande 1996). To condition pairs to this procedure, collection of semen from males and the handling of females begin well before laying. After their pubic bones begin to spread, females are inseminated 3 times weekly and after each oviposition until laying ceases.

From 1975 through 2005 at PWRC, fertility of eggs (256 of 376) from whooping cranes artificially inseminated averaged 68%. From 1991, when the whooping cranes began natural breeding, through 2005, fertility through natural breeding was 64% (268 of 421). In 1999, PWRC began doing supplemental artificial insemination on a few naturally breeding birds to increase their rate of fertility. Fertility of eggs produced by these pairs in 1999-2005 was 81% (43 of 53). From 1975 through 2005, the PWRC flock produced 967 eggs of which 503 were fertile (52%). Through 2005, from these 503 fertile eggs, PWRC fledged 350 birds (70%). In addition, between 1975 through 1996, PWRC received 90 fertile whooping crane eggs from WBNP and from those eggs, 61 chicks fledged (68%).

Table 4. Size and productivity of the captive whooping crane flock at Patuxent Wildlife Research Center, 1975-2005.

					Eggs retained at PWRC			
Year	AHY[a] Birds 31 Dec.	HY[b] Birds 31 Dec.	Females Laying	Total Eggs[c]	No.	Fertile	Hatched	Chicks Fledged
1975	20	0	1	3	3	2	1	0
1976	18	1	2	5	3	1	1	1
1977	19	2	4	22	8	4	3	2
1978[d]	19	3	3	23	8	8	7	3
1979[e]	22	4	4	21	16	10	8	4
1980	22	0	2	6	4	1	0	0
1981	19	1	2	11	11	5	3	1
1982	19	7	5	28	15	12	9	6
1983	25	10	5	34	22	18	14	8
1984	27	5	5	31	21	16	12	4
1985	31	7	3	13	13	8	7	6
1986[f]	36	2	0	0	0	0	0	0
1987	35	6	5	7	7	3	2	1
1988	37	9	6	15	15	8	7	3
1989	30	2	5	19	19	14	9	8
1990	32	3	4	14	14	5	4	3
1991	35	5	5	21	21	9	5	2
1992	36	13	8	48	48[g]	11	9	8
1993	37	19	8	35	35	16	15	10
1994	40	16	9	48	48	29	21	18
1995	37	35	8	48	48	35	31	26
1996	39	21	8	44	44	27	25	18
1997	42	18	8	55	55	30	29	18[h]
1998	40	27	10	55	55	35	30	27
1999	44	30	8	52	52	32	29	26
2000	47	25	8	51	51	35	35	32
2001	53	15	10	52	52	31	29	25[h]
2002	50	7	10	43	43	27	22	20[h]
2003	51	8	10	51	51	30	27	26[h]
2004	50	4	13	54	54	23	21	19[h]
2005	53	2	13	58	53	18	18	17[h]
			TOTALS	967	889	503	433	350

[a] AHY = After Hatch Year
[b] HY = Hatch Year
[c] Includes 73 eggs transferred to Grays Lake National Wildlife Refuge in 1976-1984. Fertility determined for unhatched eggs by examination of egg contents. Examination occurred after full-term incubation and eggs containing no detectable embryo were considered infertile, therefore, the number of fertile eggs listed is considered a minimum estimate.
[d] All eggs retained at PWRC were incubated and hatched under sandhill cranes and chicks were "foster-parent" reared. All eggs transferred to GL were artificially incubated until transfer.
[e] All eggs retained at PWRC were incubated under sandhill cranes and chicks were hand-reared or foster parent-reared by sandhill cranes. All eggs transferred to GL were incubated under captive pairs of sandhill cranes at Patuxent until transfer this year and subsequent years.
[f] No eggs were produced in 1986. Breeding birds were moved temporarily to pens in summer 1985 during construction of new pens. The birds were moved into the new pens in November 1985. These movements were believed to be the disturbance that disrupted the 1986 breeding cycle.
[g] Six new pairs broke the 19 eggs they produced.
[h] In 1997 and 2001-2005, the number of chicks fledged also includes chicks that were shipped to their release site prior to fledging.

From 1993 to 2005, 368 of 641 eggs (63%) from the PWRC flock were fertile. From these 368 eggs, 282 (77%) were fledged or were shipped prior to fledging. Of these, 177 (plus 14 produced from WBNP origin eggs) were sent to the Florida reintroduction. In addition, 7 chicks (plus 1 of ICF origin) were sent to Idaho and 75 (plus 13 eggs from other institutions) were sent to Wisconsin for release through ultralight migration reintroduction projects. PWRC avoids imprinting problems by parent-rearing chicks or hand-rearing them in visual and auditory contact with a subadult whooping crane imprint model.

Seventy-three whooping crane eggs were transferred from PWRC to Grays Lake between 1976 and 1984. PWRC shipped 22 birds to ICF in 1989 and 11 birds to Calgary in 1992 and 1993 to help establish other captive flocks. The flock was split several times to reduce the risk of disease outbreaks decimating the entire captive population.

Hatchability of whooping crane eggs incubated by cranes exceeds that of eggs placed in incubators, probably because of less than optimum incubation regimes. In 1978, hatchability of the 8 eggs retained at PWRC and incubated under sandhill cranes was 88%, while only 5 of 11 fertile eggs incubated artificially before their transfer to GL hatched. As a result, since 1979 all whooping crane eggs at PWRC have been incubated under sandhill cranes or whooping cranes. Since these modifications were undertaken, hatchability and chick survival (Table 4) has equaled that observed in eggs and chicks from the AWBP.

A study of the pedigree effect on survival in captivity and in Florida found that some families do not produce eggs or fertile eggs. Some produce many chicks but few survive well in captivity and after wild release, some fledge many chicks and they survive well in captivity and after wild release, and some families carry genetic defects (e.g. scoliosis) (George Gee, PWRC, pers. comm.).

Infection with coccidia (*Eimeria* spp.) has been a major morbidity and mortality factor for chicks at PWRC, in some years resulting in up to 20% mortality of the hatched chicks (Carpenter et. al 1980). Control programs, including better pen design, improved pen husbandry, pen rotation, and development and use of new coccidiostats in the feed, have now reduced the mortality to zero.

A disease outbreak can cause a serious setback to the captive breeding program. In the fall of 1984, 7 whooping cranes in the captive flock at PWRC died from EEE, of which 5 were females. The January 1985 sex ratio in the surviving adult captive population was 10 males to 4 females. Sandhill cranes at PWRC also were exposed to the virus, but no mortality occurred (Carpenter et al. 1987). Whooping cranes appear especially susceptible to EEE; consequently the potential impact of this disease will be considered when selecting any site for additional whooping crane populations.

Thirteen of the 32 whooping cranes at PWRC were exposed naturally to the EEE virus and all developed antibody titers. Ongoing unpublished research has shown that use of an EEE vaccine protects against infection and should reduce the risk of this disease in the future. Actions taken in 1985 and continued annually to prevent another outbreak of EEE at PWRC include: (1) a surveillance and control program for the principal mosquito (*Culiseta melanura*), vector of the disease; (2) testing EEE vaccines and developing a more effective vaccine for whooping cranes; and (3) continuing serological monitoring of the captive flock for antibody titers. Now that the etiology of the whooping crane deaths at PWRC is known, the disease threat can be minimized in captivity by initiating appropriate mosquito control measures and the use of EEE vaccines. However, the long-term efficacy of the vaccine is unknown and annual booster shots are required. The WCHAT recommended that the breeder cranes at all captive facilities in EEE geographic areas, including ICF and PWRC, be vaccinated. EEE vaccination research is also being done to test its usefulness when whooping cranes are released into EEE areas like Florida. As part of an experimental strategy, chicks transported from PWRC to Florida for release are vaccinated, but those coming from ICF and other northern captive centers are usually not vaccinated.

In September-October 1987, a mycotoxin in commercially prepared crane feed poisoned about 240 of the 300 captive cranes at PWRC. Fifteen cranes died (5% of the flock), including 3 whooping cranes. Laboratories found a trichothecene in the feed that may have been the toxic agent (Valente 1992). A small sample of each commercial food shipment is now fed to bobwhites (*Colinus virginianus*) before being offered to cranes. Food consumption, body weight changes, and mortality in the quail are used to detect toxins in the feed.

WNV, a form of encephalitis newly arrived from Africa and first detected in the New York area in 1999, has been spreading across the U.S. and Canada. An outbreak of WNV at SSC in August 2002 resulted in the death of 7 out of 18 sandhill crane chicks and the serious illness of one staff person. The adult whooping cranes were apparently not affected. WNV may pose a threat, which needs to be assessed, to the cranes at PWRC and to all the whooping crane populations (Robert McLean, NWHC, pers. comm.). Young chicks with undeveloped immune systems may be particularly vulnerable. Research on WNV and the efficacy of vaccination in sandhill cranes was carried out by PWRC and NWHC in 2002. Preliminary results show that sandhill cranes didn't die or develop obvious clinical signs when challenged with WNV, but they did have a

subclinical infection. Vaccination appears to be particularly effective in protecting sandhill cranes, reducing virus shedding.

Recent significant studies at PWRC include: use of monensin and vaccine as an improved treatment for disseminated visceral coccidiosis; estimates of diversity in the major histocompatibility complex; methods to establish migratory crane populations using trucks, ultralight aircraft, and other techniques; ingested metal treatment (Olsen and Wise 2001), blood studies (Olsen et al. 2001), experiments involving fertilization timing of artificially inseminated cranes (Jones and Nicolich 2001; Jones et al. *In prep*), and comparisons between individual crane behaviors and survival in Florida (Kreger et al. 2001, Gee et al. 2001). An adaptive management study of the Florida population is currently underway.

The pen facilities at PWRC were modernized in the early 1990s, but major maintenance and replacement needs exist at present. These new facilities should help establish breeder pairs on a territory without the disturbances associated with pen maintenance experienced in earlier complexes.

Propagation at International Crane Foundation

The ICF is a non-profit conservation organization that works worldwide to conserve cranes and the wetland, grassland, and other ecosystems on which they depend. The ICF is dedicated to providing experience, knowledge, and inspiration to involve people in resolving threats to these ecosystems.

Captive propagation expertise was developed during the 1970s with several crane species, including whooping cranes (Doughty 1989). ICF employs 30 full-time staff members and 10 additional people on project funding. The Crane Conservation Department, which manages the whooping crane flock and also assists with the eastern migratory reintroduction, consists of 6 employees. In addition, a veterinarian and veterinary technician provide clinical care to the captive flock.

In 1989, the U.S. Whooping Crane Recovery Team decided to split the captive flock to reduce the risk of disease. The ICF received 22 whooping cranes from PWRC and an injured adult male from the RMP. Two cranes died shortly after their arrival. Two experienced pairs failed to lay in 1990, probably due to the disruption caused by the move. Cranes, especially whooping cranes, are sensitive to disturbance and pen changes (Mirande et al. 1997b). Three females laid 9 eggs in 1991, and 1 chick was parent-reared, the start of captive whooping crane production at ICF. From 1991-2005, the flock at ICF has laid 349 eggs, of which 183 were fertile, 135 hatched, and 108 fledged (Table 5). Fifty-five have been sent to Florida for reintroduction. Twenty-three were kept at ICF to build the captive flock and for genetic management.

Eggs were also harvested from wild nests in Canada and shipped to ICF to build up the size of the captive flock or to support reintroductions. In May of 1990, 12 eggs were transferred from WBNP and 8 fledged to increase the size of the captive flock at ICF to 30. Between 1990 and 1996, 58 eggs from WBNP were transported to ICF, 49 hatched and 41 fledged (Table 6). Eighteen were sent to Florida for reintroduction, 4 to Idaho, 3 to Calgary, and 16 retained in captivity for genetic management.

Table 5. Size and productivity of the captive whooping crane flock at International Crane Foundation, 1989-2005.

Year	All Birds, Jan. 1	Females Laying	Eggs	Fertile Eggs	Chicks Hatched	Chicks Fledged	Chicks Sent to Florida
1989	23[a]	-	-	-	-	-	-
1990	21	0	0	0	0	0	0
1991	30	3	9	2	2	1	0
1992	28	3	16	8	6	6	1
1993	37	3	9	5	5	5	2
1994	28	5	14	6	6	6	4
1995	34	5	21	10	8	5	2
1996	34	6	23	15	12	10	10
1997	32	5	23[b]	13	8[c]	7	7
1998	30	6	22	13	11	7	6
1999	30	4	20	9	8	7	6
2000	28	7	26	12	5	5	4
2001	28	5	21	6	5	2	1
2002	28	7	33	16[b]	13[c]	11[d]	4
2003	32	8	31	17	14	12	8
2004	35	8	40	21	11	7	4
2005	35	8	41	30	21[e]	16	0
TOTALS			349	183 (52.4%)	135 (73.8%)	107 (79.2%)	59

[a] 22 birds arrived at ICF in fall of '89
[b] 3 of these eggs sent to PWRC.
[c] 3 eggs hatched at PWRC.
[d] 3 chicks hatched at PWRC and fledged at NNWR.
[e] 9 hatched at PWRC and 2 at SAZ

At ICF, chicks have been parent-reared, hand-reared, or costume-reared. In costume-rearing, cranes are exposed to the human form only during negative, stressful situations and remain wary of people. From the time of hatching, costume-reared whooping cranes are exposed to live whooping crane role models in adjacent pens to avoid imprinting problems.

Significant morbidity and mortality factors for captive whooping cranes at ICF have been orthopedic problems and metal foreign body ingestion (Langenberg, unpubl. reports to the Recovery Team). Developmental wing and leg deformities, and handling-associated leg fractures and joint injuries in chicks have contributed to low fledging or release rates at the ICF in some years, especially in the early 1990s when production first started (Hartup et al. 2001a). Changes in handling protocols, information exchange with PWRC and other centers, and increased experience have decreased the impacts of these chick problems. The ICF flock has been free of significant infectious disease problems, probably the result of intensive husbandry practices and regular health monitoring. As the captive whooping crane population ages, the

incidence of geriatric problems (such as leg joint arthritis) is increasing, and can be a particular problem in the captive facilities in colder regions, such as the ICF.

Beginning in 1990, closed circuit television proved to be an effective tool for monitoring and supervising the socialization of new pairs as well as for monitoring pairs that break their eggs. Through video monitoring, an egg could be retrieved within minutes of being laid. Currently the ICF has 17 cameras. At least 17 crane pens are wired and ready for cameras, allowing staff to move cameras as needed. The ICF has acquired software for analysis and storage-retrieval of its growing collection of video materials.

The number of laying females at the ICF has increased to 8 starting in 2003. The ICF has facilities to house 12 breeder pairs. Research is ongoing to improve reproduction, rearing procedures, behavioral management, health care, and other topics that may directly benefit management and recovery (Gerencser 1997, 1998, Langenberg and Donoghue 1997, Langenberg et al. 1998, Hartup et al. 2001b, Bowman et al. 2002).

Water and exposure to the wetland environment is incorporated into the rearing of the crane chicks for release. Pairs that raise young are provided with flooded areas. Isolation-reared chicks are also provided with pools and flooded areas in their exercise yard. When the cohorts are formed and the youngest crane is thermo-regulating well, they are moved to larger enclosures. These pens have ponds approximately 20 by 30 feet in size where the chicks are encouraged to roost in the ponds overnight.

As part of the ICF's efforts to improve crane management, work was started on a new isolation rearing facility on a secluded portion of the property. This new facility moves the cranes from an area adjacent to the main office complex where it is difficult to isolate chicks from human sounds, to a low disturbance area. Wetlands in the new facility will allow the cranes access to a larger area providing wide open vistas with fewer human artifacts. Currently the new isolation-rearing facility can house 10 chicks and will eventually house 20 chicks when completed. To enhance public education efforts, fiber optic cable delivers real time video images from a camera in the rearing facility to a public display screen.

Since 1989, the ICF has received support from Region 2 of the USFWS to cover costs of maintaining and breeding its captive whooping cranes. Beginning in 2001, these funds have been appropriated from the Washington Office of the USFWS. The ICF raises additional funds from the private sector to support whooping crane conservation, over $300,000 in each of the last two years. Aside from research and crane management efforts, the ICF emphasizes public education about cranes, their habitats, and conservation. Roughly 25,000 visitors come to the ICF each year, where they can see a pair of whooping cranes in a natural wetland setting. In 2005 for the first time, the pair on public exhibit was given a whooping crane chick to hatch and rear, providing great public viewing opportunities. ICF staff members engage in outreach activities along the Wisconsin-to-Florida flyway, in Texas, and in other key crane areas, involving use of crane posters, audio-visual presentations, and Crane Trunks (boxes shipped on temporary loan to schools and containing a variety of crane artifacts and educational activities). The ICF also has a school curriculum on crane migration available through registration on its website.

Table 6. Hatching and fledging rates of AWBP eggs transferred to International Crane Foundation, 1990-1996.

Year	Eggs Received	Eggs Fertile	Eggs Hatched	Chicks Fledged	Chicks Sent to Florida
1990	12	11	11	8	0
1991	0	0	0	0	0
1992	11	10	10	7	6
1993	10	9	8[a]	7	0
1994	9	5	5	5	4
1995	10	10	10	9[b]	8
1996	6[c]	5	5	5[d]	0
TOTALS	58	50	49	41	18

[a] Four chicks sent to Grays Lake, Idaho; 2 chicks sent to Calgary Zoo.
[b] One chick sent to the Calgary Zoo.
[c] One egg arrived with a hole in it, late dead embryo.
[d] All chicks retained at ICF for genetic management.

Propagation at Calgary Zoo

The Calgary Zoological Society is a non-profit, charitable organization that operates the Calgary Botanical Gardens and Prehistoric Park in Calgary, Alberta, Canada. The Society houses a wide variety of living animals and plants, and participates in many threatened and endangered species breeding programs. In 1988, the CWS called for bids from suitable organizations to manage a captive breeding flock of whooping cranes. In 1989, Calgary was chosen, and the Calgary Zoological Society signed an agreement with CWS to serve as the Canadian captive breeding center.

In 1991, zoo staff visited the ICF for training in captive husbandry. Funding was obtained from the Nat Christie Foundation in Calgary to build breeding enclosures, a chick-rearing building, and incubation facility. In November 1992, the first 2 whooping cranes arrived from ICF, with 11 sent from PWRC in 1993. In 1994, the first chick was hatched from a wild egg from WBNP. In 1995, Hope and Chinook produced the first eggs at Calgary. Chinook, at age 4 years and 14 days, was the youngest female to lay an egg in captivity. In 1996, the same pair produced the first fertile eggs laid at Calgary. Three chicks were reared to fledging, and were the first released to the wild at Kissimmee Prairie, Florida, from this facility (Table 7). Between 1996 and 2005, 17 chicks reared at Calgary, all from Hope and Chinook, were shipped to Florida.

From 1995 to 2005, 183 whooping crane eggs have been laid at Calgary; 56 were fertile, 32 hatched, and 24 fledged (Table 7). Four eggs were received from WBNP in 1994 and 2 in 1996, from which 2 chicks hatched in 1994 and 1 in 1996. From those AWBP eggs, 1 chick fledged each year. Through 2004, all fertile eggs have been produced by natural fertilization. Artificial

Table 7. Size and productivity of the captive whooping crane flock at Calgary Zoo, 1992-2005.

Year	All Birds	Females Laying	Eggs	Fertile Eggs	Chicks Hatched	Chicks Fledged	Chicks Sent to Florida
1992	2	0	0	0	0	0	0
1993	13	0	0	0	0	0	0
1994	16	0	0	0	0	0	0
1995	18	2	5	0	0	0	0
1996	18	1	5	5	5	3	3
1997	20	2	12	1	1	0	0
1998	21	2	10	2	2	2	2
1999	21	3	13	6	2	2	2
2000	20	4	21	11	6	3	2
2001	20	6	28	5	5	3	3
2002	19	6	24	6	2	2	2
2003	17	4	21	8	3	2	1
2004	19	6	22	7	3	3	2
2005	19	7	21	9	6	4	0
TOTAL			183	56	32	24	17

insemination methods were started in 2003 to increase production with successful fertilization first achieved in 2005. Eggs are incubated using a combination of natural and artificial methods. Chicks are reared by parents or by costumed caretakers.

Propagation at San Antonio Zoo

Since April 1956 when an injured whooping crane was received for rehabilitation, the SAZ has maintained this species in their collection and has successfully bred them in captivity (Lauver 1992). The SAZ is the closest facility to ANWR with expertise in cranes and has taken in cranes captured from the wild that have been sick or injured. The Recovery Plan calls for 3 breeder pairs to be kept at the SAZ. They currently hold 5 adult cranes that have produced off-spring for reintroduction programs. In 2005, SAZ hatched 3 genetically valuable eggs sent to them from other facilities. The public exhibit that holds one breeding pair was remodeled in 2000 and includes a stream running through the enclosure. The other whooping cranes are kept off-exhibit. The SAZ has worked in close cooperation with the Recovery Team and provides its own funding for whooping crane propagation activities.

Propagation at Freeport McMoran Audubon Species Survival Center

The Freeport McMoran Audubon Species Survival Center (SSC), a major propagation facility for the endangered Mississippi sandhill crane located in Belle Chasse, Louisiana, was approved by the Recovery Team in 1998 to propagate whooping cranes. The facility is needed primarily as a breeding facility to support ongoing whooping crane reintroduction programs, as well as

increase capacity of the captive flock to reach the objective of 153 birds, the size recommended for conservation of flock genetics. The Recovery Plan calls for 10 breeder pairs to be kept at the SSC.

The SSC received their first whooping cranes in 1998, had their first eggs laid in 2003, shipped fertile eggs to PWRC for the EMP reintroduction program in 2005, and in March, 2005 held 9 birds. In 2002, a review done to balance the needs of the Mississippi sandhill crane and whooping crane propagation programs recommended that a new facility be built for whooping crane propagation. Initial funding was received and land cleared in 2004 with construction getting underway in 2005. The new facility will have larger pens with ponds to promote breeding at an earlier age. More funding will have to be obtained to expand the facility to hold 10 breeder pairs. The facility hopes to eventually produce chicks for a whooping crane reintroduction in Louisiana and do research on propagation issues.

The Audubon Zoo in New Orleans had whooping cranes on exhibit from 1941-1975, including the female "Josephine" from the non-migratory Louisiana flock who hatched the first whooping crane chick in captivity in 1956. In November, 2001, a whooping crane shipped to the Audubon Zoo marked the historic return of the species to the zoo. A new whooping crane exhibit was dedicated in September, 2004, with a pair on display featured prominently near the zoo entrance. This is currently a genetically over-represented pair and is slated for display purposes only.

Cross-fostering, Translocation, and Guide-bird Studies at Grays Lake NWR, Idaho

Survival prospects for the whooping crane would be greatly enhanced by establishing additional, separate populations. The first technique tried was cross-fostering whooping cranes to sandhill crane foster parents. Whooping crane eggs from the wild or from captive breeders were placed in sandhill crane nests, and the sandhill cranes incubated, hatched, reared, and introduced the whooping crane chicks into the wild.

Cross-fostering was tested at Grays Lake NWR (GL) in Idaho, on the western edge of the recent historical range of the whooping crane, where studies on the greater sandhill crane had been in progress (Fig. 7)(Drewien 1973, Drewien and Bizeau 1974). From 1975 through 1988, 216 whooping crane eggs were transferred to GL from WBNP, and 73 from PWRC, and placed under pairs of sandhill cranes. Two hundred and ten eggs hatched and 84 chicks fledged (Table 8) (Drewien et al. 1989, Ellis et al. 1992b). The whooper chicks adapted to dietary and habitat differences and, in subsequent years, repeated the migration pattern of their foster parents.

High chick mortality was attributed to inclement weather at the time of hatching, poor habitat and food conditions during some years, and coyote predation (Drewien and Bizeau 1978, Drewien et al. 1985). Subadult and adult mortality rates were also high; birds were lost to fence and power line collisions (Brown et al. 1987, Brown and Drewien 1995), disease (Snyder et al. 1987, 1992, Stroud et al. 1986), predation (Windingstad et al. 1981, Drewien et al. 1989), and other causes. High mortality and the absence of breeding resulted in a relatively small population that peaked at 33 individuals in winter 1985.

Higher mortality rates among females apparently were the basis for unequal sex ratios among cross-fostered adults. In research in other locations, it had been documented that wild cranes can successfully pair with tame or captive individuals (Hyde 1968, Longley 1970, Nesbitt 1979).

Figure 7. Summer and winter ranges and migration route of the reintroduced Rocky Mountain whooping crane population. As of 2002, this population ceased to exist, except for 1 bird in captivity at ICF.

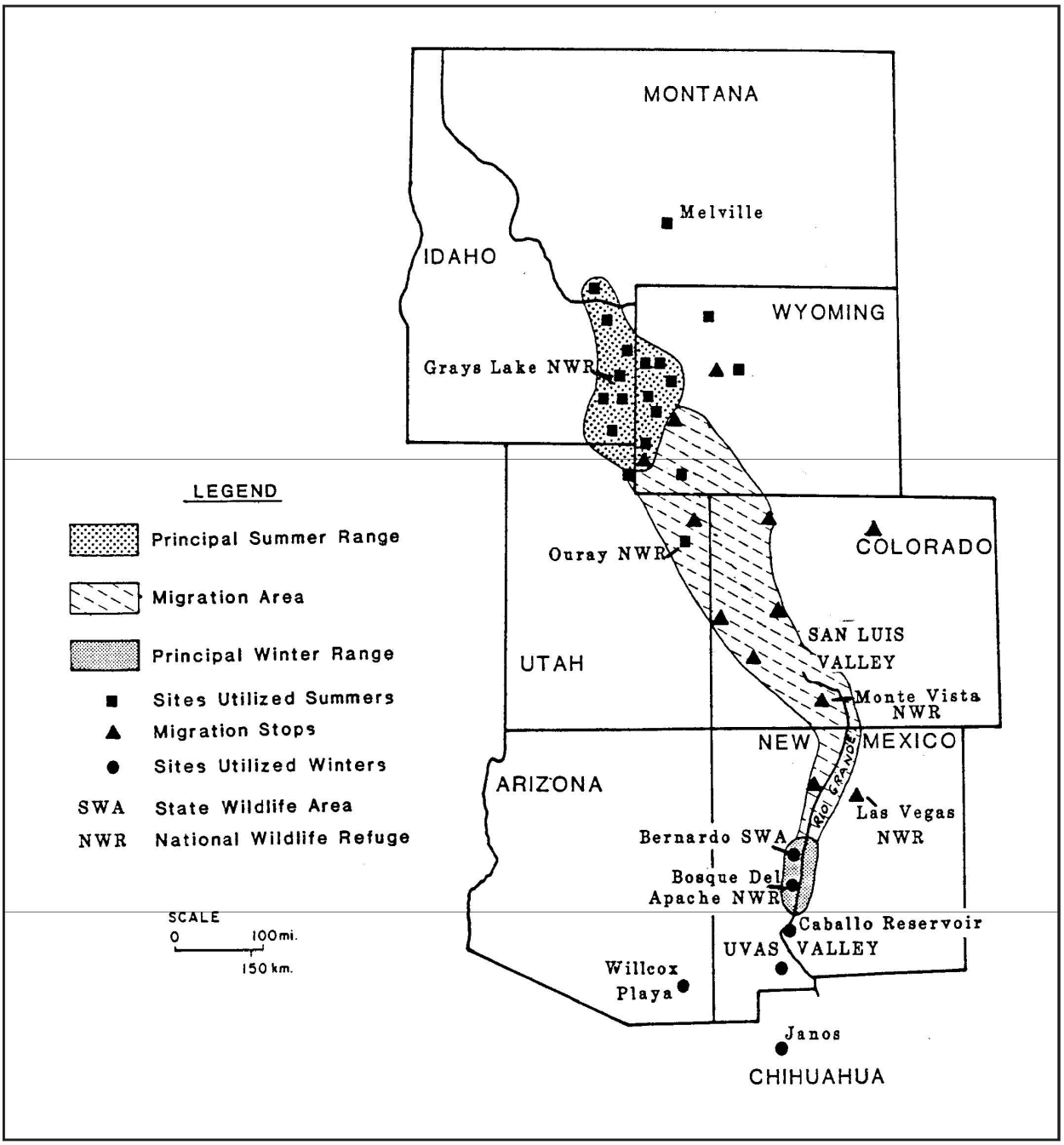


Table 8. Eggs transplanted, hatched and chicks fledged at Grays Lake, Idaho, 1975-1988.

Year	Origin of Eggs	No. eggs transplanted	No. eggs Hatched	No. chicks Fledged
1975	Canada	14[a]	9	5
1976	Canada	15[b]	11	4
	PWRC	2	0	0
1977	Canada	16	15	4
	PWRC	14[c]	5	0
1978	Canada	13	9	3
	PWRC	15[d]	5	0
1979	Canada	19	12	6
	PWRC[e]	5	4	2
1980	Canada	13	10	4
	PWRC	2	2	1
1981	Canada	12	5	0
1982	Canada	14	8	3
	PWRC	13	11	4
1983	Canada	16[f]	15	11
	PWRC	12[f]	11	8
1984	Canada	22[g]	19	10
	PWRC	10[f]	6	2
1985	Canada	23[h]	20	11
1986	Canada	15[i]	11	2
1987	Canada	12	12	2
1988	Canada	12	10	2
Subtotal	Canada	216	166	67
	PWRC	73	44	17
	Total	289	210	84

[a] Two of 14 eggs lost to predators.
[b] Four of 15 eggs lost to predators.
[c] Three eggs deserted after a snowstorm, one egg lost to a predator.
[d] Examination of 10 eggs that did not hatch revealed that 4 were infertile, 2 contained early-dead embryos, and 4 contained late-dead embryos.
[e] Poor hatchability of PWRC eggs during the period 1976-1978 was due largely to egg infertility (11 eggs) and artificial incubation (20 eggs). After 1978, only eggs containing viable embryos (as determined by flotation) were transferred and all eggs were incubated under sandhill cranes at PWRC before their transfer.
[f] One egg lost to a predator before hatching.
[g] Three eggs lost to predators before hatching.
[h] Three eggs believed to be infertile or to contain early dead embryos at the time of transfer.
[i] Two eggs were eaten by predators and two failed to hatch.

Experimentation was started to simultaneously augment the wild cross-fostered population at Grays Lake NWR with captive-reared individuals, rectify the male-skewed sex ratio, and hasten the onset of breeding in the wild population. In June 1981, a captive, 3-year-old, parent-reared female whooping crane was transferred from PWRC to GL and placed on a male whooper's territory (Drewien et al. 1989). Although the female rapidly adjusted to the wild and associated periodically with the male, a pair bond was never established. Successful migration seemed unlikely, so the female was captured and returned to PWRC in October (Drewien and Clegg 1992). The experiment was repeated in 1982. The same female quickly adapted to the wild and her presence stimulated increased territorial activities by the male (Drewien et al. 1989). Unfortunately, the male died after becoming entangled in a barbed wire fence. The female was recaptured and returned to PWRC.

The experiment was repeated in 1989, but in May rather than June. A captive 6-year-old female from PWRC was placed in a pen on a male's territory at GL. The male exhibited much interest in the female and after 1 week she was released from the pen. Pairing behavior included unison calling and copulations. No nesting attempt was made, perhaps because it was somewhat late in the season. The male molted his flight feathers and secluded himself in the marsh. In early June, the female abandoned the flightless male but was joined by another wild male. The new pair remained together for over 4 months. From October 5-15, the male was observed initiating migratory flights on 5 occasions with the female following. However, the female was unable to keep up with the male and she always returned to the territory with the male following.

On October 15 the male migrated alone. The only other whooper present, a male, immediately joined the female for 2 days until he migrated. Six years in captivity apparently made the female physically incapable of sustaining long flights. Attempts to capture her in late October were unsuccessful and she disappeared. The behavior of the males at GL demonstrated that they were highly responsive to the presence of a conspecific female during the breeding season.

During the 1980s it became apparent that during summer older females did not return to GL or other areas occupied by territorial males. Experiments to enhance pair formation were carried out from 1986 through 1990 whereby 20 whooping cranes (some females were recaptured several times) were moved from isolated summer sites and released at GL near male whooping

cranes (Drewien et al. 1989). Five (2 males, 3 females) were held for 1 to 4 months in a pen before being released. These experiments contributed to numerous associations and interactions between both sexes, but no permanent pair bonds developed. The longest associations lasted 2 to 4 months before males and females separated. The cross-fostered females exhibited minimal response to the presence of males. These results suggested that imprinting problems possibly existed in whooping cranes raised by sandhill cranes.

Dr. Edward 0. Garton, biometrician at the University of Idaho, modeled the cross-fostered population to predict when it might become self-sustaining. The model assumed (1) cross-fostered females would be breeding at the same rate as the females in Canada and (2) survival of birds in their first year would be similar to that of first year birds in Canada. Despite these optimistic and unrealized assumptions, with the future transfer of 30 eggs per year, the population would only reach 6 nesting pairs after 50 years (Garton et al. 1989). "It is obvious from all scenarios modeled that egg transplants of less than 30 eggs per year will not suffice to establish a self-sustaining population in a reasonable period of time. Natural breeding will be essential to establish a self-sustaining population" (Garton et al. 1989).

At the 1989 meeting of the U.S. WCRT, the team recommended the cross-fostering be discontinued. Other research continued at GL until 1992, but cross-fostered females appeared incapable of normal breeding behavior. The average whooping crane at WBNP begins egg production in its 4th year (Ernie Kuyt, CWS, pers. comm., 1991). By the fall of 1992, cross-fostered adult female whooping cranes of ages 4 through 12 years had passed through a nesting season on 34 occasions without pairing.

In 1992, a wild cross-fostered male whooping crane paired with a female sandhill crane to produce a hybrid chick. The hybrid wild chick provided additional evidence that cross-fostering may break down behavioral barriers that normally discourage pairing between the 2 species. However, isolated cranes from one species may hybridize with the more common species found in the same area. The hybrid summered in Yellowstone National Park. It never produced offspring and was believed sterile. It was last seen in spring 1999 and is believed dead.

Sexual imprinting of a foster-reared species on the foster-parent species had already been confirmed in foster-reared raptors, waterfowl, gulls, finches, and gallinaceous birds (Immelmann 1972, Bird et al. 1985). An investigation of the potential imprinting problem in cranes occurred at the ICF where sandhill cranes were foster-reared by red-crowned cranes (sample of 1), white-naped cranes (sample of 2), and Siberian cranes (sample of 1). When given a choice the cross-fostered sandhill cranes socialized more with the foster species than with conspecifics. The 2 foster-reared females showed a stronger preference for the foster species than did the 2 foster-reared males (Mahan and Simmers 1992) lending further support to the theory of improper sexual imprinting, particularly in female cranes, being the reason for failure of pairing in the cross-fostered whooping cranes at GL.

In 1993, 4 males (9-17 yr old) and 4 females (7-13 yr old) remained in the Rocky Mountains. A variety of observations suggested that these adults might adopt and rear whooping crane chicks. Cross-fostered males had built nests, intermittently incubated an empty nest and sandhill eggs placed in that nest, and assisted neighboring sandhill pairs in raising sandhill and whooper chicks. Penned male and female whoopers fed and temporarily reared sandhill crane chicks.

In 1993 and 1994, an experiment was designed to determine if the cross-fostered adults would adopt and raise whooping crane chicks and teach them migration (Drewien et al. 1997). If successful, this procedure would overcome the imprinting problems that had prevented appropriate pairing. Four whooping crane chicks or eggs were provided to the project each year. Although parent-chick bonds appeared to develop in captivity, adults did not remain with the chicks after release to the wild. The chicks did not permanently remain with any cranes nor migrate. Field research was ended after 1994.

In 1997, the remnant Rocky Mountain whooping crane population was designated experimental nonessential and 4 areas removed from designation as critical habitat to allow greater management flexibility and to permit crane research to be conducted using ultralight aircraft. In fall 1997, Kent Clegg flew a mixed flock of 8 sandhills and 4 whooping cranes behind an ultralight aircraft between Grace, Idaho, and Bosque del Apache NWR, New Mexico. The trip covered 1,140 km in 9 days. Two of the whooping cranes were lost to predators on the wintering grounds, and two migrated north in the spring. The cross-fostered population in the Rockies declined to a single survivor in year 2000 along with one crane from the ultralight experiment. Both were dead by spring 2002.

Reintroducing a Non-migratory Population in Florida

A November 21, 1975, letter to members of the WCRT from the Florida Game and Fresh Water Fish Commission suggested the possibility of re-establishing a non-migratory whooping crane population in the eastern United States. No pure genetic representative of the non-migratory Louisiana flock remained in captivity. The letter proposed that Florida sandhill cranes might be used as surrogate parents to instill non-migratory behavior into cross-fostered whooping cranes with the goal of restoring a non-migratory flock in the Southeast.

In 1977, John Allender (Audubon Park Zoological Garden) and George Archibald (ICF) submitted a proposal to reintroduce whooping cranes to Louisiana. The proposal was tabled by USFWS because they did not wish to endorse other reintroduction efforts until the cross-fostering project was fully evaluated (letter from Lynn Greenwalt, Director, USFWS, to Regional Directors, May 1978). Louisiana Wildlife agency personnel were concerned that critical habitat might be designated within the State as a consequence of a release, a designation that might place unfavorable constraints on land and hunting management (March 1978 letter of J. Burton Angelle, Secretary, Louisiana Wildlife and Fisheries Commission to George Archibald). Resource agency personnel in Louisiana were also concerned that restrictions on hunting of geese and ducks might be imposed as a consequence of the presence of an endangered species (Gomez 1992). Federal concerns included the belief that local residents might not be instilled with a conservation ethic sufficient to permit success of the reintroduction (letter from D. L. Hall, Special Agent In Charge, USFWS, April 1978).

In 1979, the U.S. Whooping Crane Recovery Team contacted the Florida Commission to ask if they were still interested in evaluating the feasibility of establishing a non-migratory flock of whooping cranes. Research was needed to determine whether a migratory crane species, when reared by non-migratory Florida sandhill crane foster parents, would also be non-migratory. Any cranes cross-fostered in Florida would potentially be in association with migratory greater sandhill cranes that nest in the Great Lakes region but winter in southern Georgia and Florida. Such an association at the time of spring migration might trigger some inherent tendency to

migrate. Research to address the question began in 1980. One member of each of several established pairs of Florida sandhill cranes was captured and instrumented with a radio transmitter. When nesting began, eggs of greater sandhill cranes, obtained from PWRC or from the wild in Wisconsin or Idaho, were substituted for the pair's natural clutch. Hatching and rearing of the young were monitored until the resultant chick/chicks were 55 to 60 days old. The young were then captured, radio-tagged, and plastic leg bands attached. Movements were monitored through 1 or 2 spring migrations following separation from their parents.

Thirty-four greater sandhill crane eggs were transferred into 23 Florida sandhill crane nests between 1982 and 1987. From these transfers, 5 young were produced which survived to the age at which they separated from their parents. Twenty-seven captive-reared young were released (4 cohorts) during 1986 and 1987. They were radio-instrumented and distinctly color banded. Eighteen survived through at least 1 spring migration and 2 fall migrations. Only southerly movements by some individuals (60 to 120 km) exceeded normal dispersal of subadult Florida sandhill cranes. In the 1 instance of the 120 km movement south, the birds returned within 6 weeks to the general vicinity of release. The movements of the dispersing experimental birds did not differ significantly ($P > 0.05$), either in direction or date of movement from that of a control group (Nesbitt and Carpenter 1993). Research results all indicated that migration in sandhill cranes was learned from their parents and not genetically programmed.

By the mid-1980s, questions began to arise concerning the lack of pairing behavior of whooping cranes cross-fostered by sandhill cranes. It was desirable to test an alternative reintroduction technique. Thus, in 1986, releases of captive-reared sandhill cranes began. Four cohorts of captive-reared greater sandhill cranes were soft-released in Florida during late winter or early spring (Nesbitt and Carpenter 1993). Concurrently a group of Florida sandhill cranes (1- or 2-year-olds) from known natal sites were captured, radio-instrumented, and monitored as a control to compare dispersal.

In 1983, the U.S. WCRT met to select sites to evaluate for another wild population. Eastern sites were proposed because they would be discrete from the other wild populations, a requirement of endangered species re-introductions in the United States. Coastal Louisiana, where whooping cranes survived as a non-migratory population in the 1940s (McIlhenny 1943), was not considered due to its proximity to Texas wintering sites and potential conflicts with Louisiana's extensive hunting of waterfowl.

Sites selected for evaluation were Seney NWR and adjacent areas in the Upper Peninsula of Michigan and Ontario, Okefenokee NWR in southern Georgia, and 3 sites in Florida (Lewis and Cooch 1992). Three-year research projects began in 1984 and final reports on the eastern study sites were submitted in 1987-88 (Bennett and Bennett 1987, McMillen 1987, Bishop 1988, Nesbitt 1988). In summer, 1988, the U.S. WCRT recommended that the next reintroduction establish a non-migratory population in the Kissimmee Prairie of Florida. Reasons the Team chose to establish a non-migratory population included (1) failure of the cross-fostering technique in Idaho and (2) lack of any proven technique to establish a migratory population. Some Florida habitats are similar to habitats historically used in Louisiana. Florida has no goose or crane hunting so hunting conflicts were unlikely. The Canadian Recovery Team endorsed the Kissimmee Prairie site in fall 1988. The Director of the USFWS and the Director General of CWS approved the project in 1989.

Considerable progress had been made in developing reliable methods for reintroducing captive-produced cranes to the wild. Releases of isolation-reared sandhill cranes resulted in high post-release survival both in migratory and non-migratory situations (Ellis et al. 1992a). Isolation-rearing refers to rearing the birds separated from visual contact with humans. Ethologist Dr. Robert Horwich at the ICF developed costume-rearing, and the release of such birds into flocks of wild cranes, in 1986. These first experimental releases used captive-reared sandhill cranes (Nesbitt 1979, Drewien et al. 1981, Zwank and Derrickson 1981, Horwich 1986, Bizeau et al. 1987, Leach 1987, Zwank and Wilson 1987, Nesbitt 1988, Horwich 1989, Archibald and Archibald 1992, Ellis et al. 1992b, Horwich et al. 1992, Urbanek and Bookhout 1992, 1994, Nesbitt and Carpenter 1993) to test the techniques. Some were soft or gentle releases involving a gradual transition from life in captivity to the wild. The cranes were placed in large predator-proof enclosures containing food and water. Their wings were brailed to prevent flight (Ellis and Dein 1991). After an acclimation period of 1-2 weeks, the brails were removed and the cranes could fly from the pen. Urbanek and Bookhout (1992) noted the need for similar studies on captive-reared whooping cranes.

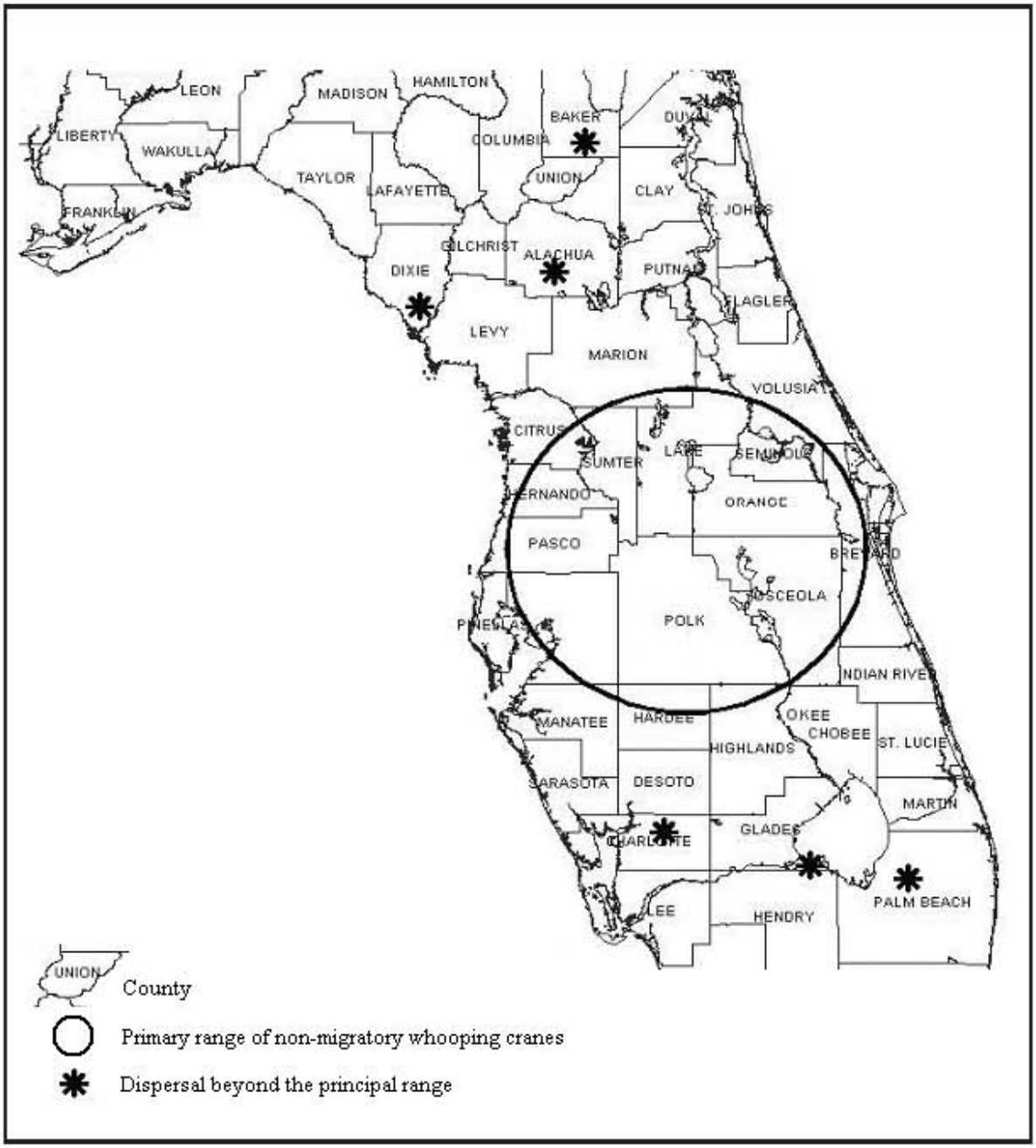
The Florida release site, Kissimmee Prairie, consists of approximately 2,000 square kilometers of flat, open palmetto prairie interspersed with shallow wetlands and lakes (Fig. 8). On private ranch lands, much of the prairie has been converted to improved pasture. Land ownership includes 8 large ranches totaling 82,200 ha. Large private holdings range from 2,700 ha to 42,500 ha. Public lands range from 2,955 ha to 43,300 ha. Three Lakes WMA (22,450 ha) was identified by Bishop (1988) as the preferred release site with the best habitat lying between lakes Jackson and Kissimmee.

The whooping crane population in Florida was designated experimental nonessential to increase flexibility of management (Lewis and Finger 1993). Release pens like those used successfully in releases of the endangered Mississippi sandhill crane (*Grus c. pulla*), at the Mississippi Sandhill Crane NWR, were built near Lake Jackson and Lake Marian. In January 1993, the first group of 14 juvenile whooping cranes was transferred to Florida in a soft-release, managed like previous sandhill crane releases in Mississippi (Ellis et al. 1992b) and Florida. The objective of the first release was to evaluate release techniques and response of whooping cranes to the Florida habitat. At regular intervals released birds were recaptured and samples taken to evaluate exposure to disease and parasites.

Whooping cranes were released in Florida habitats similar to those used by Florida sandhill cranes (Nesbitt and Williams 1990). Shallow palustrine wetlands were used for roosting, foraging, loafing, and nesting. They also frequented upland habitats for foraging. Open grassy fields, usually grazed by livestock and/or used for sod production, provided abundant invertebrate and vertebrate food items. Live oaks and laurel oaks (*Quercus spp.*) provided seasonally abundant acorns. Marsh/pasture ecotones and lake edges provided a diversity of aquatic, semiaquatic, and upland food resources.

Upon arrival and prior to release from the pens, whooping cranes were examined and treated with antihelmenthics to reduce the chance for introduction of exotic parasites. Most were vaccinated for eastern equine encephalitis (EEE) and provided feed containing a coccidiostat. Three exotic parasites were found in early releases (Spalding et al. 1996), but their occurrence declined with additional antihelmentic treatment in Florida of subsequent releases.

Figure 8. The Florida peninsula, showing the primary range of the Florida non-migratory population.



Two diseases, EEE and disseminated visceral coccidiosis (DVC) are of particular concern for the recovery of whooping cranes in Florida. Released whooping cranes are partly protected from these diseases by the current release protocol. DVC is caused by infection with a protozoan, *Eimeria* spp., transmitted by fecal contamination of food. This disease is very prevalent in local sandhill cranes but illness and mortality are rarely observed in this species. Whooping cranes are given feed containing a coccidiostat during the time that they are in the pens and while they continue to use the pen area. Although disseminated granulomatous lesions are frequently found in whooping cranes killed by bobcats, severe lesions have only been recorded a few times. In two cases, DVC may have caused mortality, or predisposed birds to predation. Exposure of chicks to DVC is expected to be high, and research to determine its impact on chicks is needed.

EEE virus is endemic in central Florida, although more common in the panhandle. Transmission is by mosquitoes but varies greatly from year to year, being more common in wet years. Most whooping cranes released in central Florida are vaccinated prior to release. The vaccine titer wanes after about 6 months. Several cranes are believed to have been temporarily ill from EEE virus and have recovered when given supportive care. Exposure of newly hatched chicks is likely in years with high transmission. Maternal antibodies may provide some protection in chicks but more research is needed to elucidate risk factors. The drought in Florida from 1998-2002 reduced transmission of the disease and also the ability to study it.

From 1993-2005, 289 whooping cranes were released in Florida, mostly as juveniles, and 60 have survived as of August, 2005 (Table 9). Predation by bobcats has been the primary mortality factor (Nesbitt et al. 1997). Other mortality factors, roughly in order of importance are: wasting syndrome associated with IBD virus infection (Julie Langenburg, Wisconsin DNR, pers. comm.), power line collision and electrocution, alligator predation, and ingestion of metal and other objects (Spalding et al. 1997, Folk et al. 2001).

Egg production started in 1999, with 41 pairs producing eggs through 2005. The first chick was fledged in 2002. Wetlands in Florida experienced a drought during 1998-2002, reducing the potential for suitable nesting conditions.

The drought is believed to have increased the dispersal range in recent years. The birds have ranged over much of peninsular Florida from near the Georgia border (Baker County) to the latitude of Lake Okeechobee (Palm Beach County) (Nesbitt et al. 2001) (Fig. 8). One pair spent the summer and fall of 2000 in Michigan, and 1 subadult spent nearly 2 months in Virginia in 2001. Eight other birds (in 2 groups) dispersed from the state in 2000 and 4 were never seen again. Five subadults were observed in South Carolina in May, 2005. Efforts to track them down shortly after the initial confirmed report were unsuccessful. One of the 5 was back in Florida in early September.

The Florida reintroduction has entered an assessment phase, with no additional introductions planned for 2005. Results of the adaptive management study being conducted by PWRC along with 2005 production and mortality data will be used in 2006 to determine goals and objectives for the FP. The WCRT will continue to evaluate the project's potential for establishing a self-sustaining population.

Table 9. Number of birds released and surviving in the Florida non-migratory population, 1993–2005.

Year	Number Released	Age	Year end Population	Number Pairs	Nesting Pairs	Chicks Hatched	Chicks Fledged
1993	14	all < 1year	8	0	0	0	0
1994	19	all < 1year	16	0	0	0	0
1995	19	all < 1year	25	0	0	0	0
1996	47	5=1.5y, 43=<1y	56	1	0	0	0
1997	28	all < 1year	60	1	0	0	0
1998	22	all < 1year	57	7	0	0	0
1999	28	all < 1year	65	10	2	0	0
2000	30	all < 1year	82	15	3	2	0
2001	21	all < 1year	86	15	2	0	0
2002	27	8=1.5y, 19=<1y	85	16	7	2	1[a]
2003	13	all < 1year	87	18	7	8	2
2004	16	all < 1year	71	15	12	4	1
2005	5	all < 1year	59	15	8	1	0
TOTAL	289				41	17	4

[a] First chick to fledge in the U.S. since 1939 in Louisiana.

Research on Reintroducing Migratory Populations

After cross-fostering proved unsuitable as a technique for reintroducing migratory populations of whooping cranes, the Whooping Crane Recovery Team identified the need for testing other techniques (U.S. Fish and Wildlife Service 1994). Since then, various modifications of leading captive-reared cranes with trucks and ultralight aircraft, and coordinated releases with migratory sandhill populations, have been tested (Nagendran 1992, Urbanek and Bookhout 1994, Nagendran et al. 1996, Ellis et al. 1997, 2001a, Lewis 1999, Duff et al. 2001a, Urbanek et al. *In press*{a}). Some projects utilized isolation-rearing with caretakers in crane costumes and another project (Clegg et al. 1997, Clegg and Lewis 2001) used group rearing of chicks to promote proper imprinting. Formerly, aggression was thought to be so severe as to prevent group rearing.

Cranes can be led long distances behind motorized craft (air and ground), and those led over most or the entire route will return north in spring and south in fall to and from the general area of training (Ellis et al. 1997, Ellis et al. 2001b, Duff et al. 2001b, Mummert et al. 2001). However, they may follow their own route. Groups transported south and only flown at intervals may not migrate. Trained birds will not home on a captive site where they hatched but rather will return to the site where they were flown free and began their migration. Cranes can also be expected to return to the same (or nearby) wintering area the following fall. All birds need not follow the entire route south to return north if flock mates know the route.

If cranes are field-reared and are to be introduced into a wild flock, costumes may not be necessary and cranes quickly learn to avoid humans (Clegg et al. 1997). Crane decoys can be used to hold cranes at roost sites before and during migration and at the release site after migration. The threat of losses to predators can be reduced with these decoys by influencing the cranes selection of roost sites and feeding locations (Clegg et al. 1997, Clegg and Lewis 2001).

If certain protocol restrictions are followed, it is possible to make the costume-reared cranes exhibit some wild behavior. The most efficient way to make trained cranes wild (e.g., not approach humans) is to release them after migration with wild cranes.

In the western United States, golden eagle (*Aquila chrysaetos*) attacks were a problem (Ellis et al. 1999) both for ultralight-led and for truck-led migrations. Collisions with power lines were a major problem in the trucking migrations. During the 2 trucking migrations, 3 cranes died and about 15 non-lethal collisions were observed. However, techniques were developed to diminish or eliminate these hazards (Ellis et al. 1997).

It appears possible to restore or supplement wild migratory populations of cranes by first leading small groups from chosen northern to southern sites. Abruptly releasing cranes after migration results in good survival if they are released individually or released as a group into a large wild flock (Ellis et al. 2001c, Clegg et al. 1997, Clegg and Lewis 2001).

Proposed Migratory Reintroductions

In 1996, the WCRT decided to investigate the potential for another reintroduction site in the eastern United States with the intent of establishing an additional migratory population. Separation between a new flock and the AWBP was an important safeguard against a catastrophic event impacting both populations, to avoid transmission of disease, crossbreeding between the 2 populations, and the behavioral influence that cranes reintroduced from captivity could have on the wild flock (U.S. Fish and Wildlife Service 2001). Also, under Section 10(j) of the ESA, reintroductions of experimental nonessential populations must essentially be kept separate from endangered populations.

After a study of potential wintering sites (Cannon 1998), the Team selected the CNWR/St. Martin's Marsh Aquatic Preserve near Crystal River, Florida, as the top wintering site for a new migratory flock. Although the habitat at Marsh Island, Louisiana, appeared to be excellent, its location closer to the AWBP migration corridor was a key negative factor resulting in the selection of a site in Florida.

Based on concerns that a reintroduced population in Saskatchewan or Manitoba might mix with the wild AWBP (Melvin and Temple 1980, Melvin et al. 1990, May 1992, Lyon et al. 1995a,b, Burke 1996, Hjertaas et al. 1997, deSobrino 1998, Sommerfeld and Scarth 1998), the Team considered summering areas further to the east of the AWBP migration corridor and requested the investigation of suitable sites in Wisconsin.

From the beginning, Wisconsin and other eastern flyway States have been and remain extremely supportive of establishing the EMP. After a list of potential areas was compiled, studies evaluated 3 potential release sites: Crex Meadows State Wildlife Management Area; central Wisconsin, including NNWR and several Wisconsin WMAs; and Horicon NWR (HNWR) (Cannon 1999). The WCRT in September, 1999, recommended that releases start in central

Wisconsin (Fig. 9). This recommendation was based on the presence of suitable habitat, food resources, and favorable local attitudes.

A partnership of 9 founder organizations comprised of public agencies and private nonprofit organizations was formed and referred to as the Whooping Crane Eastern Partnership (WCEP). Founding members (alphabetically) include:
* International Crane Foundation
* International Whooping Crane Recovery Team
* National Fish and Wildlife Foundation
* Natural Resources Foundation of Wisconsin
* Operation Migration, Inc.
* US Fish and Wildlife Service
* USGS National Wildlife Health Center
* USGS Patuxent Wildlife Research Center
* Wisconsin Department of Natural Resources

The partnership extends beyond the list above. The huge scope of this migration requires united efforts spanning twenty states, seven of which lie in the migration corridor. WCEP was divided into sub-teams of Bird, Budget, Outreach, Regulatory, and Flyway teams. A Project Direction team with key representatives from each agency serves as the final decision making body. Federal environmental documents were prepared and after publication in the Federal Register in June, 2001, the eastern migratory population of whooping cranes was declared experimental non-essential under section 10(j) of the ESA. This action provides for greater management flexibility and reduces the regulatory requirements.

The plan is to release annually 10 to 25 juvenile, captive-reared whooping cranes in central Wisconsin (U.S. Fish and Wildlife Service 2001). Cranes will be captive-reared to 20-40 days of age at PWRC or the ICF, before transfer to facilities at the Wisconsin release site, where they will be conditioned for wild release to increase post-release survival (Ellis et al. 1992b) and adaptability to wild foods. They will be radio-tagged at release and monitored to discern movements, habitat use, behavior, and survival. They will be released in the fall and taught to migrate. Several strategies may be used to teach migration including: (1) leading them by ultralight aircraft to the chosen wintering site in Florida (Clegg et al. 1997, Lishman et al. 1997, Clegg and Lewis 2001); (2) releasing them with migrating wild whooping cranes or sandhill cranes, or (3) some combining of these or other techniques. If initial results are favorable, the releases would continue for at least 10 years. Experience with the RMP and FP provides insight that a minimum of 20 years may be needed for attaining self-sustaining populations. Thus, a 20-year project duration is listed in the Implementation Schedule.

In fall 2001, 8 cranes started the migration behind an ultralight from NNWR in central Wisconsin (Table 10). One bird would not follow well enough and was placed daily in a crate and trucked to the next roost site. The migration included 26 stops, covered 1,987 kilometers, and took 50 days. The longest flight day covered 154 km, and the longest flight lasted 2.15 hours. The shortest migration leg only lasted 38 minutes. Total flight time of the birds between Wisconsin and Florida was 35.8 hours. One crane died in Wisconsin hitting a power line at night after a severe storm blew the pen down and the birds escaped. Bobcats killed two cranes during the winter at CNWR. The remaining five migrated back on their own to central Wisconsin in

Figure 9. Eastern United States experimental nonessential population area, with 2001 migration route.

spring, 2002. Four summered right at or near Necedah NWR, and one female summered about 80 miles to the southeast at HNWR.

In 2002, 17 whooping cranes raised at PWRC were shipped to Wisconsin and trained to follow ultralight aircraft. One of the young cranes died from injuries received colliding with the ultralight in migration; the remaining 16 were led to Florida (Table 10). In the fall of 2002, the 5 surviving whooping cranes reintroduced in 2001 migrated south on their own. One spent a considerable time at Hiwassee Wildlife Refuge in Tennessee before joining another ultralight whooping crane in Florida, whereas the other 4 returned initially to CNWR. In December 2002, one had joined the 16 juveniles wintering at the release pen at CNWR, 2 were together with sandhills about 125 miles northeast of CNWR, and 2 were about 30 miles southeast of the refuge.

In 2003, 17 whooping cranes raised at PWRC were shipped to Wisconsin and trained to follow ultralight aircraft. One of the young cranes died from injuries received colliding with the ultralight during a training flight. Sixteen were led 1,191 miles to Florida in a journey of 54 days, utilizing 20 stopovers. All 21 whooping cranes in the EMP migrated north on their own in the spring, 2003. One crane got off track but was captured in Ohio and released in Wisconsin. One crane stopped short and summered in Northern Illinois, and one crane summered in southeastern Minnesota. Three cranes moved through Wisconsin and just across the border into South Dakota where they by law stop being classified as experimental nonessential and become endangered. At the request of the Central Flyway Council, the trio was captured and returned to Wisconsin. One of the three suffered capture myopathy and was the only mortality of the summer.

In the spring of 2004, 6 cranes migrated too far to the east and summered in Michigan. Five were blocked from continuing by Lake Michigan. The other 30 cranes in the EMP returned to Wisconsin. In fall 2004, 14 juveniles migrated behind the ultralight to Florida, with 13 arriving safely. One bird died of EEE at the final migration stop. One bird in the fall was direct-released into a group of older whooping cranes in Wisconsin and successfully migrated to Florida. This reintroduction technique will be tried with a larger sample size in 2005. In the winter of 2004-05, the EMP whooping cranes were more scattered. Nineteen older birds wintered in Florida, but 3 wintered in North Carolina, 7 in South Carolina, and 4 in Tennessee. Two of the older cranes died in the fall migration, and 2 died at CNWR. Two pairs nested in central Wisconsin in spring of 2005, but eggs were predated. In fall 2005, 19 juveniles migrated behind the ultralight to Florida. Four birds in the fall were direct-released into a group of older whooping cranes in Wisconsin and successfully migrated, with 2 wintering in Tennessee and 2 making it to Florida. In the 2004-05 and 2005-06 winters, a total of 4 of the WCEP cranes spent time in the vicinity of or closely associated with non-migratory Florida whooping cranes. These associations broke up and some mixing between the two flocks is not considered to be a problem. In February, 2006, the EMP consisted of 64 whooping cranes. Releases are planned to continue through at least 2010 until the population reaches a minimum of 100.

Two unanticipated events have occurred during the EMP reintroduction. The release site selected by the WCRT at CNWR is apparently not suitable whooping crane habitat, but it is an excellent release site (Urbanek et al. *In press*{b}). Secondly, older birds returning to the CNWR

release site may stay if they find pelleted food being given to the juvenile ultralight cranes. These older birds will disrupt the juveniles which, if not intensively managed, can increase mortality. As expected, not every crane will summer in central Wisconsin and return to Florida to winter, although a high percentage has done so.

Table 10. Number of birds released and surviving in the eastern population, 2001–2005.

Year	# Eggs Hatched	# Young Sent to Wisconsin	# Fledged	# Starting Migration	# Finishing Migration	# Surviving Winter	Year End Total
2001	11	10	8	8	7	5	5
2002	18	17	17	17	16	16	21
2003	19	17	17	16	16	16	36
2004	21	17	16	15	14	13	47
2005	33	26	25	24	23	23	64
Total	102	87	83	80	76	73	

APPENDIX D. SUMMARY OF COMMENTS ON DRAFT RECOVERY PLAN AND USFWS RESPONSES

On January 11, 2005, the USFWS released the Draft Revised International Whooping Crane Recovery Plan for a 60-day review and comment period ending on March 11, 2005. Availability of the plan was announced in the Federal Register (70 FR:1902-1903) and via a news release to media contacts throughout the species' U.S. range. Electronic versions of the plan, notice of its availability, press release, fact sheet, and a questions and answers document were posted on the USFWS's national and Region 2 web sites.

In accordance with USFWS policy, an earlier draft was sent out for peer review, and comments were incorporated into the agency draft. Initial peer review was conducted by Dr. M. Bishop, Cordova, Alaska. Revisions made to the January, 2005, public draft were peer reviewed at a meeting held at the 10th North American Crane Workshop in February, 2006. Reviewers were LeeAnn Linam of TPWD, Walter Sturgeon of WCCA, Kelley Tucker of ICF, and Marty Folk of FL. Their comments are briefly described at the end of Appendix D, with many items incorporated into the final plan.

Nearly 600 people were notified via email about the availability of the draft plan. Additionally, approximately 30 copies and/or CDs of the Draft Recovery Plan were distributed to affected agencies, organizations, and interested individuals during the comment period.

Twenty-four comment letters and/or emails were received during the official comment period. All comments, including those of the peer reviewer are on file at the Aransas National Wildlife Refuge, P.O. Box 100, Austwell, TX 77950.

Some commenters raised similar issues. Most expressed strong support for the conservation of the species as described in the Recovery Plan. Four were quite critical of specific portions of the plan.

Many of the comments were incorporated into the approved recovery plan. Information and comments not incorporated into the approved plan were considered and noted. A synopsis of comments received is presented below.

COMMENTS AND USFWS RESPONSE

COMMENTS ON PART I – BACKGROUND INFORMATION

1. <u>Comments about updating crane numbers:</u>

Several reviewers wanted numbers to be up-to-date as possible.

<u>USFWS Response:</u> Numbers were not up-to-date because of time elapsed between writing the Draft Plan and receiving final approval of the document. Population numbers in the Final Plan were updated through February, 2006.

2. <u>Comment about variability in AWBP numbers over time:</u>

One reviewer analyzed recruitment rates and noted that although recruitment rates since 1970 are lower than those between 1938-69, rates have been relatively stable since 1970 and are much less variable than in earlier times. They noted that the AWBP continues to grow, but at a more constant, less stochastic rate, whereas the draft text on pp. 25-27 conveyed somewhat of a concern for population growth.

USFWS Response: The text referred to does not express concern about the continued growth of the population except for the unexplained drop in recruitment rates. The text states that the AWBP is likely to continue to grow with a low probability of extinction over the next 100 years. Other sections of the plan do express concern about the future population because of looming threats and unprecedented global changes and expanding human pressures on wildlife species throughout North America.

3. Comment that the impact of egg collection should be assessed:

USFWS Response: The Recovery Team has discussed a study to determine the impact of egg pickup on the growth rate of the AWBP, but is waiting to collect data through 2006 before making any decisions involving egg pickup (see p. C-6).

4. Comments about down-listing criteria and lack of de-listing criteria:

Two comments were made supporting the down-listing criteria, including specifically the level of 250 pairs in the AWBP. Two comments thought the down-listing criteria did not set levels high enough. One comment thought there should be more than 3 populations established. Four comments were received saying the species should not be downlisted at the present time. One comment specifically supported not having any delisting criteria at the present time.

USFWS Response: A misleading news story that ran in south Texas made people think the USFWS was contemplating downlisting the species in the near future. This definitely is not the case – the Draft Plan states that the expected date to reach downlisting criteria is approximately 2035. The downlisting criteria are primarily an indicator that the species is making significant progress towards recovery. Downlisting would not remove legal protections from the species, as it would then be listed as threatened. Thus, the population targets set to recommend downlisting seem reasonable.

5. Comments about Critical Habitat:

Three comments addressed Critical Habitat (CH). The Canadian Wildlife Service (CWS) modified the previous section on CH to reflect a refinement of their definition of CH that came out after the draft plan was distributed. Another reviewer asked if the areas listed that "may be considered critical at some time in the future" referred to areas in Canada only. A third comment cautioned that private landowners affected should be a part of any discussion involving changes in CH.

USFWS Response: All revisions from the CWS were incorporated. Areas that may be considered critical sometime in the future refer to Canadian areas only. This was clarified by separating the discussion of CH for Canada and the U.S. The Narrative Outline (Section 1.5.2)

calls for evaluation of the need to expand CH boundaries at ANWR and in the migration corridor to ensure protection of all important U.S. whooping crane habitats. It may seem logical to add additional CH areas in the U.S, especially at ANWR where multiple whooping crane territories are now located outside the CH boundary. However, in 30 years of implementing the Act, the USFWS has found that the designation of statutory CH provides little additional protection to most listed species, while consuming significant amounts of available conservation resources. The USFWS's present system for designating CH has evolved since its original statutory prescription into a process that provides little real conservation benefit, is driven by litigation and the courts rather than biology, limits our ability to fully evaluate the science involved, consumes enormous agency resources, and imposes huge social and economic costs. The USFWS believes that additional agency discretion would allow its focus to return to those actions that provide the greatest benefit to the species most in need of protection. If the USFWS receives a petition to amend CH for the whooping crane, it will go through a public rule-making process with full public involvement.

6. Comments about inadequate recovery cost estimates:

Two reviewers involved with Platte River issues commented on the inadequacy of the recovery costs in the Draft Plan. Expenditures for specific management programs along the Platte River alone exceed the Plan's anticipated costs for those same programs for the entire flyway.

USFWS Response: Costs in the Draft Plan were incorrectly based primarily on anticipated Federal dollar expenditures. Cost estimates were revised to reflect total estimated costs for recovery, including the amounts forecasted to be needed for recovery actions on the Platte River.

7. Comment about funding shortfalls for Recovery Actions that are needed.

One comment was received about the inadequacy of funding made available for recovery.

USFWS Response: Recovery actions implemented by federal agencies are dependent on budget appropriations. The USFWS can only accomplish its goals for recovery with the assistance and participation of its many partners.

COMMENTS ABOUT THREATS TO THE SPECIES

8. Comments about freshwater inflows in Texas:

Five comments mentioned the importance of freshwater inflows in Texas to wintering whooping cranes.

USFWS Response: Comments received were incorporated to provide more details on freshwater inflow and water rights issues in Texas (see p. 22-23). The Draft Plan was updated to include relevant issues that had occurred in the past two years that potentially impact Guadalupe River flows and spring flows that feed the Guadalupe. More emphasis was placed on the difficulties faced by the estuary during drought years, and information from a recent report (National Wildlife Federation) 2004 was incorporated.

9. Comments about shootings:

Three comments addressed the issue of hunting. Much input from the States was received on the issue of shootings (see pages 23-24). Although hunting was a major factor in the decline of the whooping crane in the 1800s and early 1900s, reviewers felt that losses today are mostly acts of vandalism and that the term "shooting" should be used instead. One comment was received stating that hunting was causing the demise of far too many species.

USFWS Response: The term "shooting" in many places was substituted for "hunting", including the heading in the Table of Contents. The USFWS agrees that the use of "shootings" is a more inclusive term since many of the shootings of whooping cranes that have taken place were separate from sport hunting programs, or were done illegally in connection with sport hunting actions. Shootings of whooping cranes only occur occasionally and many are acts of vandalism not connected with sport hunting. The final plan carefully tries to differentiate between the historical role of hunting in the decline in whooping crane numbers versus the occasional shootings that occur at present. More emphasis was placed on the crucial role that sportsmen and other conservationists have played in helping whooping cranes (see Conservation Measures – page 31).

10. Comments about the positive role in conservation of hunters and private landowners:

One comment mentioned the positive way hunters and private landowners help whooping cranes. Positive hunter actions include hunters turning in sighting reports, dispersing waterfowl concentrations, thus decreasing the threat of disease, and also reducing crop depredation.

USFWS Response: A paragraph was added to the first page of the Introduction to emphasize the role of private citizens, including sportsmen and sportswomen, in saving the whooping crane. A paragraph was added under the heading *Conservation Measures* referred to in the *Shootings* section to mention positive aspects of sports hunting for whooping crane recovery.

The sections on hunting were carefully edited to remove any unintended negative slant towards hunting. However, up to 4 whooping cranes have been shot in the last 2 years, an unacceptable level of take, so the Plan continues to address strongly the issue of shootings.

11. Comments about unexplained losses:

Two reviewers commented on statements in the draft made about mortality with no known cause. They cautioned about making implications about these unexplained losses, and especially attributing them to shooting.

USFWS Response: It is reasonable to take the known causes of mortality and hypothetically project them in an equal percentage for carcasses that are not recovered (unexplained losses). However, caution has to be exercised in doing so since there could be many other unknown factors affecting the population, and detectability of the various causes of mortality could vary greatly. Thus, wording was changed to reduce speculation involving shooting. A sentence was added on p. 24 (See Shooting) stating that it is not known what percentage of unexplained losses can be attributed to shooting.

12. Comments about genetic issues:

One comment questioned the evidence that limited genetic diversity is hurting the AWBP. Another pointed out an incorrect use of the term "genetic drift".

USFWS Response: It is well established that limited genetic diversity is likely to affect productivity of avian populations. Data are starting to show a trend towards reduced productivity in the AWBP, but other factors could be involved and the exact role that genetics is playing is unknown. The text was clarified on pages 27, 36, 38, and 42 and an explanation given in Appendix A to more clearly differentiate between "genetic drift" and "genetic mutations".

13. Comments about power line issues:

One reviewer mentioned that there was no consideration of the economic or technical feasibility of some of the recommendations made in the plan about reducing the threat of cranes colliding with power lines. They felt stakeholders were not involved enough in formulating recommended recovery actions in the Plan.

USFWS Response: The USFWS has worked extensively with electric utility companies on the issue of avian mortality. A product of this collaboration was the 1994 publication, *Mitigating Bird Collisions with Power Lines: The State of the Art in 1994*, which is referenced in the Plan. The USFWS agrees that more participation by the electric power industry in whooping crane recovery is needed and is welcomed, and that the USFWS should work hard to facilitate such interactions.

14. Comments about the threat of wind farms:

Two comments stated the expected growth of wind farms in the migration corridor could be a major threat to the species. Not only are there unknowns associated with cranes being able to avoid wind turbines, it is known that construction of transmission lines associated with wind farms will be hazardous.

USFWS Response: Material was added to the Plan about growing concerns about wind farms in the section dealing with Threats (See p. 29 - *Collisions with Power Lines, Fences and Other Structures*).

15. Comments about migration mortality and the need for another telemetry study:

Three comments dealt with the desire to learn more about mortality that occurs in migration and location of sites used in migration. A radiotelemetry study could provide data on both topics.

USFWS Response: The Recovery Team has discussed the need for a telemetry study similar to the one carried out from 1981-1985. The Recovery Team feels that much of the data obtained from a telemetry study would be very similar to the previous data set. Mortality of approximately 1% can be anticipated when capturing juveniles to put radios on them, so significant value would have to be expected from the study to justify expected losses. Without significant funding sources at present to conduct a telemetry study, there are currently no plans to

carry out such a study. However, the Recovery Plan leaves open the possibility of future telemetry studies. The Recovery Team has stated that more data on mortality is needed.

16. Comment about forming working groups to promote interactions among states within flyways to work on whooping crane issues (2 such comments):

USFWS Response: This comment is similar to an idea previously expressed by the Platte River Trust to form a working group for the AWBP to deal primarily with migration issues. The Recovery Team is supportive of such an action and it was added to the Plan's Task 1 in the *Narrative Outline of Recovery Actions to Achieve Objectives*.

17. Comments about the migration corridor map for the AWBP:

One reviewer thought the map depicting the migration corridor (Figure 2) should be re-drawn from the sighting database using a GIS system.

USFWS Response: This process utilizing a GIS data base has been completed for Texas and started for the state of Kansas, but has not been completed for the entire flyway. There is currently inadequate staff and funding to complete this task. An updated map showing confirmed sightings done by graduate student Tom Wassenich was incorporated as Figure 2 in the Final Plan.

18. Comments about treatment of Platte River issues:

Two critical comments stated that too much emphasis was put on Platte River issues in the draft plan since less than 3% of the AWBP stops on the Platte in any single migration. Both pointed out the apparent inconsistency with the Plan's mentioning the socioeconomic value of birdwatchers traveling to see whooping cranes, and yet human disturbance is an issue of concern to the species. Both mentioned that the Recovery Team should re-evaluate management actions for the Platte River to ensure they will benefit the population.

USFWS Response: The Platte River serves as a model of river flow requirements for the species throughout the flyway. Because of the long history of management disputes on the Platte and the documented degradation of crane critical habitat on the Platte, the plan cannot minimize treatment of these important issues. The Recovery Team believes that whooping crane use of the Platte will increase if more habitat is restored as has been documented by whooping cranes that have utilized cleared portions of the river channel. The recent National Academy of Science study of the Platte confirmed the general degradation of the riverine ecosystem and the importance of the Platte River to the species, and tied management efforts providing habitat along the river with helping the species. That study, which explains the importance of the Platte River to whooping cranes, was added as a key reference to the Recovery Plan. Bird watching can be compatible with whooping crane recovery if the public is educated to remain at an adequate distance from cranes.

19. Comments that the management efforts of many groups along the Platte River should be recognized:

USFWS Response: In response to the comments received, additional organizations involved with Platte River restoration efforts were mentioned in a new paragraph added on page C-9.

20. Comment about inadequate evaluation of impacts to other species along the Platte River:

Two comments mentioned that recovery actions on the Platte River to help whooping cranes can end up hurting other wildlife; specifically woodland obligate bird species along the Platte. They felt the Plan failed to adequately take into account the loss to other species that habitat modification and enhancement for the whooping crane will cause.

USFWS Response: All wildlife management practices impact species differently. The conservation of wetlands used by cranes throughout the Flyway, including the Platte River, will help numerous wetland obligate birds complete their annual migrations. Restoration of the Platte River ecosystem is consistent with sound ecological principles. The NAS study re-confirmed the importance of the Platte River to endangered species and the Cooperative Agreement needs to be carried out in good faith and in a timely fashion to meet obligations of the ESA. Members of the Platte River Cooperative agreement should assess impacts to all species of concern and formulate management plans accordingly to counterbalance negative impacts that may occur to other key species.

21. Comments about the value of whooping cranes:

Two comments expressed that the value of a whooping crane as described in Appendix B was overstated and failed the common sense test of what people are willing to pay to protect endangered species. They also felt the number of visitors that actually visit the Platte River to view sandhills is overstated.

USFWS Response: Information presented on species value is from published scientific literature based on accepted methodology of estimating values. What people perceive as the value of something and what they actually would pay are very different. The number of visitors to the Platte River that view sandhills is taken from peer-reviewed scientific literature. The option to write and publish a rebuttal or conduct a study challenging these results is open to anyone.

22. Comment about re-organizing Part II so that the section on *Reduction or Alleviation of Threats* either followed *Downlisting Criteria* or preceded *Recovery Actions*:

USFWS Response: Part II was re-organized extensively with the section on "*Reduction or Alleviation of Threats"* put before "*Recovery Actions"*.

COMMENTS ON REINTRODUCED POPULATIONS

23. Comments on Reintroduced Populations:

Three comments suggested putting more emphasis on and/or incorporating more information on reintroduced populations. One mentioned that life history information is based on the AWBP, but in the future may have to reflect differences of behavior and habitat use found in the reintroduced populations. One comment felt it desirable that recovery actions such as habitat

management and education efforts should specifically address those actions needed in reintroduced populations as well as the AWBP.

USFWS Response: Information on reintroduced populations is covered primarily in Appendix C. A statement that there may be nuances of behavior and habitat use for reintroduced populations different from the AWBP was added to the Narrative Outline (Section 3.0, p. 54). An effort to develop a Wisconsin management plan for the EMP is currently underway that will provide management guidelines for that reintroduced population. Portions of that management plan can be incorporated into future revisions of the Recovery Plan.

24. Comments about experimental nonessential whooping cranes that move into the central flyway should remain designated as "experimental nonessential":

One commenter strongly supported establishing populations distinct from the AWBP. However, they felt reintroduced whooping cranes designated as experimental nonessential should not automatically be re-classified as "endangered" if they stray into the central flyway.

USFWS Response: This issue is beyond the scope of the Recovery Plan. At the present time, legal interpretations of the ESA, including court rulings (January 31, 2005; U.S. District Court in Portland, Oregon), don't allow for the kind of flexibility discussed in the comment. The States could ask the USFWS to work on a more flexible approach. Reintroduced birds classified as experimental nonessential in some instances can be expected to stray long distances.

25. Comments about the Florida population (FP):

Two comments were made that high mortality rates and continued human development make it unlikely the non-migratory FP can be successfully reintroduced into Florida.

USFWS Response: The Recovery Team is currently assessing the future of the FP.

26. Several comments supporting the Eastern Migratory Population (EMP):

USFWS Response: The reintroduction of the EMP shows great promise and is currently receiving great emphasis.

27. Comments of final peer reviewers made February 7, 2006.

The 4 reviewers all felt the plan was very good, comprehensive, and well written. They felt that threats to the species were adequately portrayed and quite complete. However, their primary criticism was that in the Recovery Criteria for downlisting to occur, there was no alternative to growth of the AWBP to 1,000 individuals if two additional populations cannot be reintroduced. They felt a middle ground was needed, especially given the difficulties currently faced by the non-migratory population in Florida. In response to this, an additional alternative criterion (1A) was added to the plan. This alternative provides for downlisting if the AWBP grows to 100 pairs (400 individuals) and one reintroduced population reaches a goal of 30 nesting pairs (120 individuals). This criterion of 520 individuals in two populations is a middle ground between having 360 individuals in 3 populations and 1,000 individuals in only one population. The

numbers follow the principal that more individuals are needed for downlisting to occur if they are in fewer populations where a single threat may have a greater impact.

The reviewers mentioned numerous items they felt were not adequately covered in the plan. These included indirect and sublethal impacts of pesticides, positive benefits of human interactions with whooping cranes, the global spread of the H5N1 bird flu and potential threat particularly to captive crane populations, some inadequate regulatory mechanisms to protect the species and additional genetic reasons for egg collection. Corresponding sections of the plan were modified to meet these concerns. In addition, crane numbers were updated in the final draft to make them as current as possible.

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Front cover, Whooping crane.
Photgraph by Tiffany Smith, FWS
Rear Cover, Male and female whooping cranes at Aransas National Wildlife Refuge, Texas.
Photograph by Steve Sykes, FWS