ANNUAL RECORD OF METABOLISM OF ESTUARINE ECOSYSTEMS AT CRYSTAL RIVER, FLORIDA

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SUMMARY

This is a report on the first year of a multi-year project of measurements of metabolism of estuarine ecosystems affected by power plants near Crystal River, Florida, made on contract with Florida Power Corporation. Included are measurements of the inner bay, the adjacent outer bays, the marshes, and the canals, all of which receive cooling water discharges, and similar areas not affected by cooling water discharge which are used as comparisons. The stations and sequence of sampling were selected to satisfy the Environmental Technical Specifications (ETS). Comparisons were made between the new conditions developing since a third power plant (unit #3) went on line January, 1977, and the pattern which had developed in 1974-75 after two plants had been in operation for 7 years.

Both stimulation and depression of community metabolism were observed in the bays affected by increased discharge. In the preoperational study, the productivity of the inner discharge bay was approximately 50% of the productivity measured in the control bay (Smith, 1976). In the present study (1977), productivity in the inner discharge bay was 10% of the productivity measured in the control bay. However, the current (1977) measurements contain only three quarters of data (two with a sufficient number of data points for statistical analyses).

Since measurements of plankton productivity levels in this bay made with bottles did not decline significantly from preoperational levels, the decrease in metabolism is attributed to a reduction in the benthic production.

There were no discernable differences in turbidity between the preoperational and present study in the inner discharge bay. However, Secchi measurements in the inner bay were not as reliable as in other areas because the bottom is sometimes visible. The range of turbidity was larger in the present study, indicating that at times more turbid water was present.

During the spring, fall, and winter seasons, the outer discharge bay ecosystem increased productivity as compared to the control bay. There was a delay in the peak of summer productivity in the discharge bay which corresponded to a decrease in plankton productivity. Considering both bays together, the discharge bay productivities were higher than control values. In the outer bays, changes in turbidity were small and in only two seasons.

Increased flows in the intake canal as a result of the pumping of the nuclear plant appeared to have no consistent effect on community metabolism. Measurements of community respiration and gross production were higher in the present study in the discharge canal with less net production as compared to values in the intake canal and discharge canal prior to operation of unit 3.

Measurements of marsh biomass and metabolism were similar to those before operation of unit 3.

The decrease in ecosystem functions in the inner bay may be temporary as self organizational processes adapt the estuarine ecosystem to new conditions. Future measurements should indicate if there is partial or complete return to earlier metabolic levels, and whether or not the ecosystem metabolic levels stabilize.

INTRODUCTION

Ecological systems are continually reorganizing so as to be adapted to the changing conditions in their natural environment. The addition of power plants with once through cooling also changes the biotope (environmental factors and energy flows) of estuarine ecosystems. Currents are increased, thermal energies added, circulations are modified and temporary changes are induced such as turbidity. New conditions may cause ecosystems to reorganize with changes in biota and processes. Like a giant oyster, a power plant recirculates waters, consumes some organisms, and recirculates nutrients and some energy services, becoming an integral part of a new ecosystem that develops.

Indices of total ecosystem function may be used to monitor the performance and order of estuarine ecosystems as they reorganize under new energies available to them. This is a report of indices of metabolism used to monitor estuarine ecosystems at Crystal River, Florida, in 1977, in the period just after a third power plant began its operation. Measurements were made with methods and at stations which are comparable to those before the new plant went on line. Previous studies were comprehensively summarized in dissertations, theses and reports (Kemp, 1977; McKellar, 1975; Smith, 1976; Lehman, 1974; Young, 1974).

The flows of energy through ecological systems in estuaries develops a complex organization of life in food webs and organismal controlling interactions which serves to maximize utilization of the combinations of resources available. The living system generates its order and values from total photosynthetic productivity and the inflow of organic matter produced elsewhere. The total work of the system in maintaining a viable system is measured by the total community metabolism. The total resident production measures the rate of generation of values from the interaction of light, nutrients, current, temperature, etc. Thus, measures of total metabolism provide some overview of the effectiveness of the ecosystem and the amount of order being developed. Measurement of the total metabolism from the diurnal swings in oxygen and other variables of a number of stations is used to estimate the overall production and respiratory metabolism. In the underwater ecosystems, oxygen was used; in the marshes, carbon dioxide exchange in chambers over the grasses was used.

Of the existing plants, unit 1 began operation in 1966 and unit 2 in 1969, with a combined thermal discharge of approximately 640,000 gal/min and a $\Delta T°$ of 5-6°C (McKellar, 1975). Estimates on the nuclear unit which was brought on line in 1977 included an approximate doubling of the thermal discharge volume (total of units 1, 2 and 3: 1.3 million gal/min) and a $\Delta T°$ increase of 1-2°C. (McKellar, 1975)

The Crystal River ecosystem was divided initially into five subsystems: inner discharge bay and control, outer discharge bay and control, canals (intake and discharge), the marshes (intake and discharge) and oyster reefs. Documentation of existing conditions as well as a model depicting the interactions of these flows on the various storages, producers, and consumers in the system were developed. In addition, some of the models were used to simulate predicted conditions with the addition of the nuclear unit (McKellar, 1975; Smith, 1976). Finally, the subsystem models were combined to form a model of the entire ecosystem and an energy cost-benefit analysis was made to compare estuary cooling with cooling towers (Kemp, 1977). This final analysis showed that when all energy inputs and outputs are accounted for (net energy principle), the estuary cooling was more productive and protective of U.S. environments (energetically and cost-effective) than the building and maintenance of cooling towers.

With the bringing on-line of the nuclear unit in January, 1977, the first year of a multi-year project monitoring the surrounding estuary was initiated in April of 1977 to measure community metabolism in selected areas (similar to those studied previously) in the Crystal River estuary. The current research effort involves the unique experience of going back to the same area to document new conditions as influenced by the nuclear plant and to compare these with prior conditions. It also compares existing data with predicted conditions developed through the earlier (pre-unit 3) models. In additions, the present study enables us to monitor both the diminished metabolism of the inner discharge as it is influenced initially by the increased temperatures and flows and the expected partial recovery of the bay due to the self organizing properties of estuaries to substitute varieties and organisms to fit the new conditions. Finally, the present study provides additional data which can be used to update the previous energy analysis concerning cooling tower versus estuary cooling.

Study Site and Sampling Plan

Florida Power Corporation's Crystal River power plants are located on the Gulf of Mexico coastline in Citrus County approximately 5 km north of the Crystal River and about 5 km south of the Cross Florida Barge Canal and Withlacoochee River (Fig. 1). The coastline in this area is characterized by low wave energies and the drowned karst topography typical of this part of Florida's west coast. Tidal marshes are dominated by the black rush, *Juncus roemarianus*, with a narrow band of *Spartina alterniflora* fronting the *Juncus* on the seaward side. Numerous oyster bars occur which run roughly parallel to the coastline extending 3 to 4 km seaward.

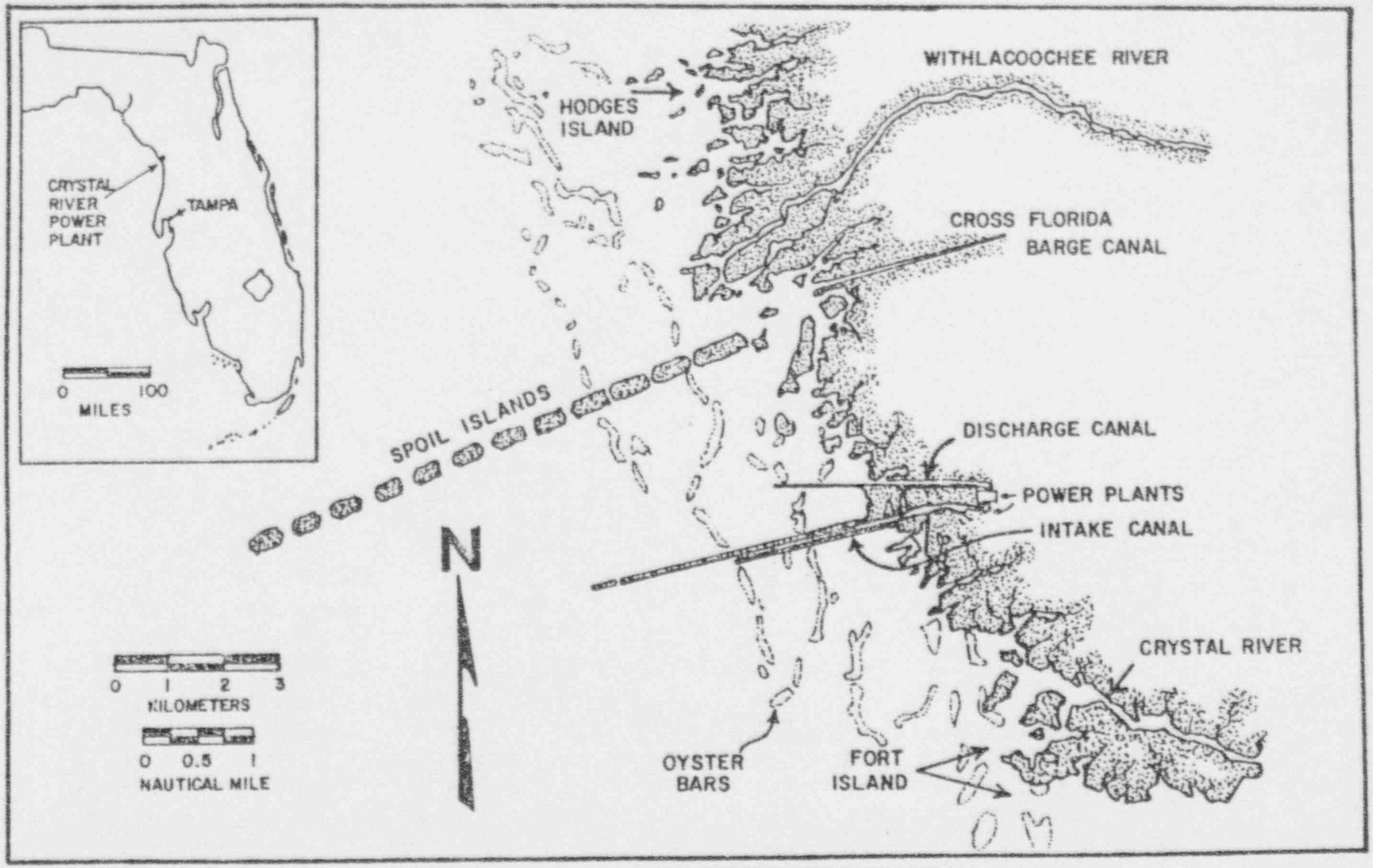

Fig. III-1. The Crystal River power plants in relation to the major features of the regional coastline (from McKellar, 1975).

Located among these oyster bars are the bays currently under study. Figure 2 shows the location of these sampling stations. Stations A, B, C, and D were the initial primary bay stations and (as directed by the NRC Environmental Technical Specifications) have been sampled from the start of the project. However, it was discovered after the project was underway that only stations B and D (McKallar's former outer discharge and control bays, respectively) and station A (Smith's former discharge bay) were directly comparable with areas previously studied. In addition, the designated canal stations of I-S and Dis-B (see Fig. 31) would not by themselves yield meaningful data regarding the canal ecosystems. As a result of these inadequacies in the initial phases of this study, several stations were added to complement those of the original sampling design. After comparability studies were run during the summer between Smith's former inner discharge control area (located at Fort Island) and the most inshore area to the south of the intake canal, we decided to add station E as a control for the bay in area A. Station OB was added in the summer as a comparable discharge bay for intake control area C. Stations I-M, I-O, and Dis-1, Dis-2 (see Fig. 31) in the intake and discharge canals, respectively, were added in order to analyze the canals via the upstream-downstream method of Odum (1956).

The marsh metabolism and harvest area are shown in Fig. 34. Since the barge used formerly by Don Young was no longer available, it was decided (after a personal site visit by Young) to develop a land based operation. The study area in the discharge marsh is identical to the area studied previously by Young. Since the intake marsh site of Young's on Negro Island was no longer accessible (as explained above),

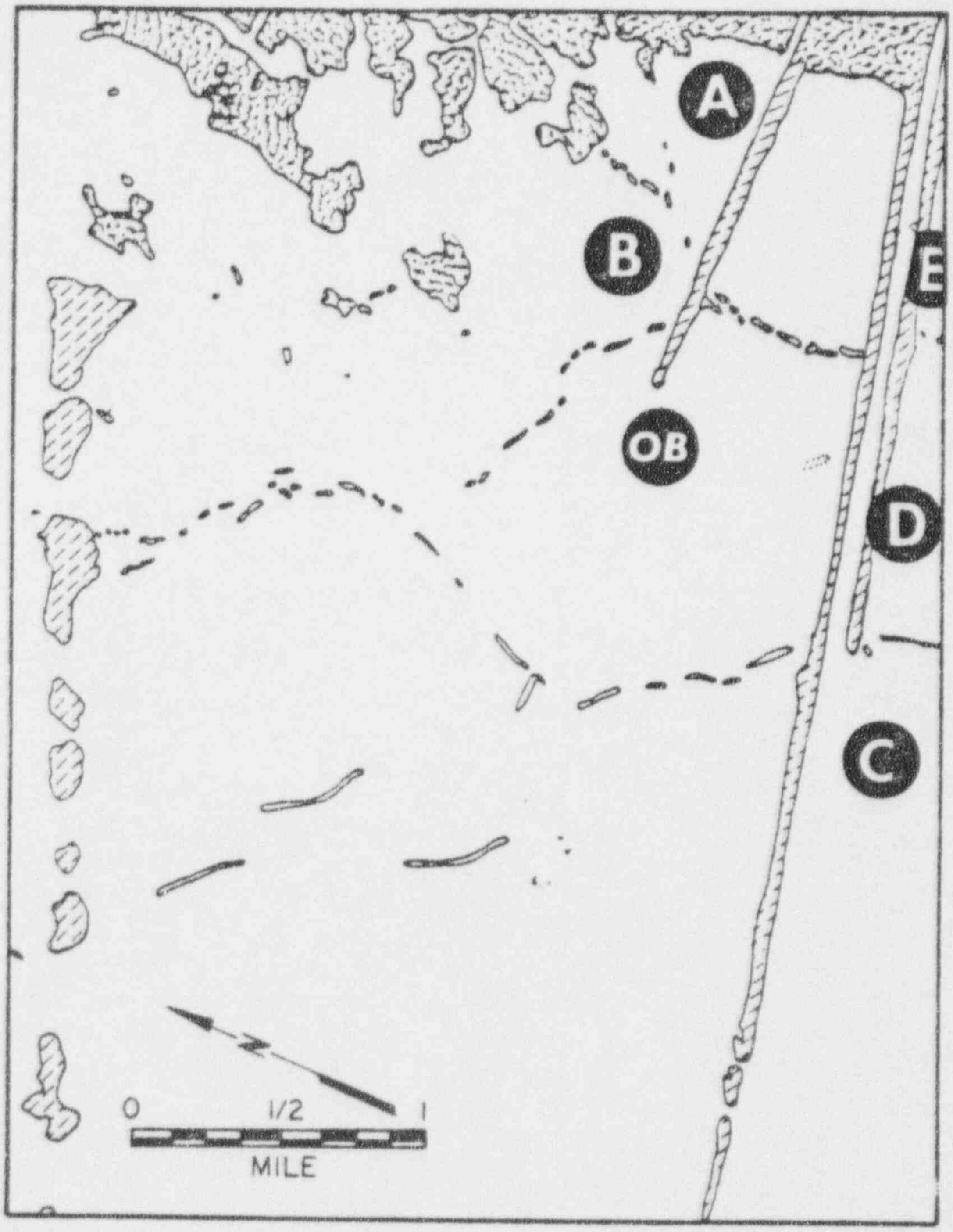

Fig. III-2. Sampling station locations in the Crystal River estuary.

close inspection of the area revealed a comparable site on the south side of the intake canal.

In all cases, efforts were made to duplicate sampling methods utilized in the previous studies to insure comparability. Sampling and calculation methods will be described in greater detail in the chapters on each bay in this report.

COMMUNITY METABOLISM OF THE INNER DISCHARGE AND THE CONTROL BAYS NEAR THE CRYSTAL RIVER POWER PLANT

by

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Introduction

This chapter contains measurements of estuarine metabolism in the inner discharge bay and an unaffected bay of similar depth. These measurements may be compared with those given by Smith (1976) for the period December, 1972, through May, 1974.

Study Site

Presented in Fig. 3 are the two bays studied on this project. The inner discharge bay (A) is that area most proximate to the end of the discharge canal. It is bordered in part by *Spartina* - *Juncus* salt marsh and separated from the outer discharge bay (B) by a line of oyster reefs The average 24 hour depth of the inner discharge bay (A) is about 0.8 meters. The control bay (E) is south of the plant site, bordered in part by a line of oyster reefs. The average 24 hour depth of the control bay is approximately 1.5 meters.

The control station used in this study was different from the control station used by Smith (1976). In Smith's study, the data from two separate sites, Fort Island and Hodges Island (Fig. 1), were grouped together for analysis as one control station. In the present study, the south intake area (Fig. 1), known as control bay E, was chosen as the control station to the inner discharge bay. Its location facilitated same day sampling as the inner discharge bay rather than separate day sampling as done by Smith (1976).

Control bay E probably approximates conditions as they would exist

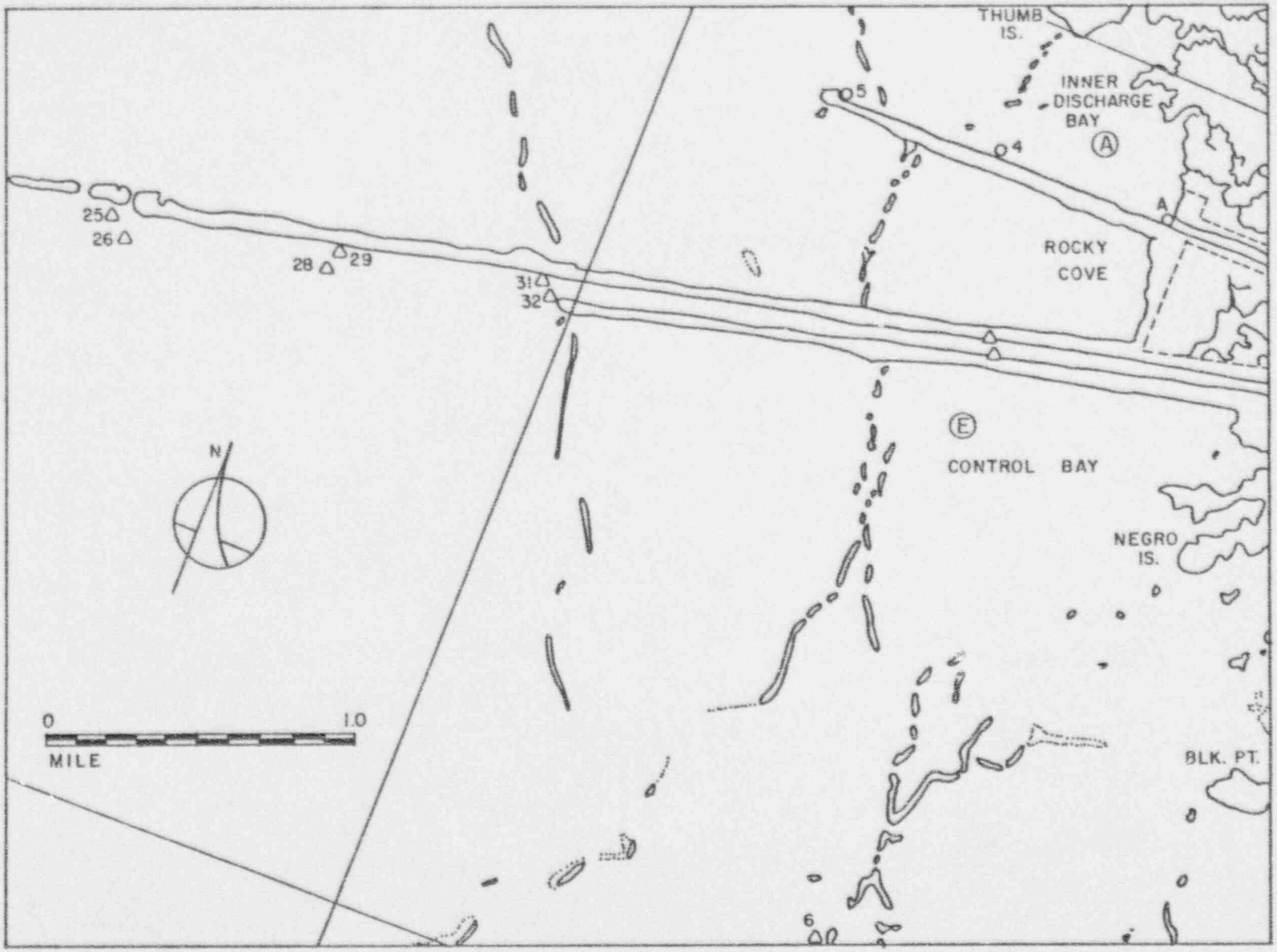


Fig. III-3. Location of the inner discharge bay and the control bay E at the Crystal River Power Plant.

in the inner discharge bay were the power plant and canal structures absent. Both the control bay E and the inner discharge bay A are physically similar, being bounded on the landward side by Spartina-Juncus marsh and by oyster reefs on the westward side. In the past, control bay E has been used as a control station for the inner discharge bay by other researchers monitoring fish, invertebrate and macrophyte stocks (Smith, 1976).

Materials and Methods

The measurements of community metabolism were collected using methods as nearly identical as possible to those used in previous studies at the Crystal River Power Plant (McKellar, 1975; Smith, 1976; Kemp, 1977). The methods for diurnal sampling were based upon techniques developed by Odum and Hoskins (1958), Odum and Wilson (1962) and Odum (1967). The dawn-dusk-dawn sampling was based upon methods used by McConnell (1962). Plankton metabolism, a component of the total community metabolism was determined by use of the light and dark bottle incubation technique (American Public Health Association, 1975).

Diurnal sampling was done twice per quarter and involved a sampling period of twenty-four hours. Each bay was sampled once every four hours. Three sampling stations were randomly selected in each bay per sampling period. Two water samples per station were collected for dissolved oxygen analysis.

The dawn-dusk-dawn sampling was done approximately every two weeks. This method was an abbreviation of the diurnal method and involved sampling at the minimum (dawn) and maximum (dusk) times of oxygen production. Each bay was sampled at one station where two water samples were collected for analysis.

Dissolved Oxygen Analysis

Dissolved oxygen was measured by the sodium azide modification of the Winkler method, following procedures in Standard Methods for the Examination of Water and Wastewater (American Public Health Association, 1975). The Winkler method was adapted for use with 125 ml flat topped reagent bottles instead of the standard 300 ml BOD bottles. McKellar (1975) and Smith (1976) present discussions on the advantages, disadvantages, and errors inherent to the usage of the 125 ml bottles.

The water samples were collected by allowing surface water to flow into a bucket. Water was siphoned from the bottom of the bucket into the collection bottle. The bottle was allowed to flush at least twice, with water filling from the bottom. The siphon was then slowly removed and the cap replaced on the bottle to dispel excess water. Reagents were then added to fix the oxygen as follows: 1) 0.5 ml of $MnSO_4$ below the surface 2) 0.5 ml of alkali-iodide-azide below the surface. The bottle was carefully stoppered and inverted 15+ times to insure proper mixing. The precipitate was allowed to settle and then the bottle shaken again.

For each dissolved oxygen measurement taken (two/station), only one collection bottle was filled from a bucket of sea water. The time passage involved in filling a bottle allowed for two potentially different water masses to be sampled at a station.

Upon return to the laboratory and settling of the precipitate, 0.5 ml of concentrated H_2SO_4 was added to each bottle which was shaken until the precipitate completely dissolved. Titration followed within a period of time not exceeding twelve hours. Smith (1976) presents results of an experiment testing the effects of acidification and time delay of samples prior to titration on the final dissolved oxygen (D.O.) measurement. The differences found were considered too small to have a significant effect on the overall data. For this reason titration of the samples is sometimes delayed, but never more than twelve hours.

For titration, a 101 ml portion of each sample was withdrawn and titrated with 0.012 N thiosulfate solution. Paragon starch was used as an indicator. The use of 0.012 N thiosulfate allowed direct reading of the titrant as dissolved oxygen: 1 ml thiosulfate - 1 mg/liter D.O.

The above procedure was used for oxygen determinations of both the twenty four hour diurnal series and abbreviated dawn-dusk-dawn methods for metabolism of the total water column. The measurement of the plankton component of the community metabolism was done by use of the light-dark bottle method. For this procedure, 300 ml BOD bottles were used. The dark bottles were taped to exclude light and the tops capped with black plastic. The light bottles were used unmodified.

One set, consisting of two light bottles and two dark bottles, was anchored in each of the two bays at dawn. The bottles were suspended at a depth of approximately 0.5 meters from chains attached to a four foot length of PVC pipe, floated at each end by a plastic milk carton. The bottles were allowed to incubate for 24 hours.

In addition to the light and dark bottles, two 125 ml bottles of water were collected to determine the initial amount of dissolved oxygen present. In all cases, light, dark or initial, each bottle was filled with water from a single surface collection.

Plankton respiration is calculated from the loss of oxygen in the dark bottle. Net productivity is calculated by determining the oxygen increase in the light bottle.

With the use of the 300 ml BOD bottles in this method, fixation and acidification was carried out using 2.0 ml volumes of the appropriate reagents. Titration was performed using 101 ml sample volumes since 0.012 N thiosulfate was used as the titrant.

Other Measurements

A number of measurements, in addition to dissolved oxygen, were recorded at each station sampled. Most of these additional measurements were involved in the calculations for community metabolism.

Water Depth

Reference stakes were set in each of the bays. Depth transects, representing at least fifty measurements were conducted to determine the average water depth in relation to a set point on the reference stake.

Light Penetration

On many dates the water was too shallow to use the Secchi disk and data are biased upward by their omissions. Secchi disk readings were taken at all stations under all sampling regimens. Originally the disk readings were calibrated to measurements made with a Montedoro-Whitney photometer in each bay.

Extinction coefficients from the Secchi disk readings were calculated with the following equation:

$$K = 1.7/d$$

where d was the depth at which the Secchi disk was no longer visible (Atkins and Poole, 1930).

Insolation

Insolation data were collected with the use of a Weathermeasure pyroheliometer. This component of the data collection was initiated in July, 1977 to supplement those environmental parameters required by the contract.

Wind Speed

Wind readings were measured at each bay using a Dwyer Wind Meter.

Current Velocity

Current velocity was determined in each bay by release of a glass flotation device on a 4.43 meter cord. The time for full extension of the cord was recorded.

Salinity

Salinity was measured with a Beckman Induction Salinometer. The readings were taken at a depth of approximately 0.5 meters below the surface. The salinometer was periodically recalibrated. Salinometer drift between calibrations was minimal.

Temperature

The Beckman salinometer has a temperature function in the probe. Temperature readings were made at the same depth as the salinity measurements. The probe was periodically checked against a 0-100°C thermometer.

Community Metabolism Calculations

There are two concepts of net production in diurnal curves. One includes net negative daytime production and one does not. Methods used in this study accounted for the correction of negative net productivity in the calculation of total net productivity. This correction was not used by Smith (1976) in the calculation of his metabolic data. To equate the comparison of the preoperational study to the operational study, the diurnal measurements made by Smith were recalculated to include negative net productivity. In the subsection, "Comparison with Preoperational Studies", all of Smith's diurnal measurements are reported as the recalculated values. These corrections in values have also been incorporated in any graphs presented from Smith's report. It was not necessary to correct Smith's dawn-dusk-dawn measurements as they were calculated according to the equations given by McKellar (1975) which were also used in the dawn-dusk-dawn calculations of this study.

The model in Fig. 4 from Smith (1976) illustrates the dynamics of oxygen concentration in the water. The concentration present at any given time will be a function of the rates of photosynthesis and respiration, advection with various water masses and diffusive exchange with the atmosphere.

The rate of diffusion was a particularly difficult parameter to evaluate. Diffusion is influenced by tidal stage, bottom topography, wind and currents among other things. Smith (1976), using the nitrogen filled dome method of Hall (1970, based on original work by Copeland and Duffer, 1964) measured an average diffusion coefficient of 0.35 g O_2/m^2/hr/100 percent deficit for the inner discharge bay. This same diffusion coefficient was used for the inner discharge bay in the present study. Additional measurements in this study resulted in an average diffusion coefficient of 0.48 g O_2/m^2/hr/100 percent deficit for the control bay, (E).

Figs 5a and 5b are typical diurnal metabolism graphs for the inner discharge bay and its control bay (E). The graphs follow a standard format to facilitate comparison between stations.

To calculate the metabolism, first the gm O_2/m^3 was plotted in (a). Six measurements were taken per sampling period and the averages of these measurements were plotted and connected. Using NOAA, Dept. of Commerce, 1977 tide tables and the reference stake readings, the depth was plotted in (b). By multiplying the gm O_2/m^3 by the depth, m, the oxygen concentration on an area basis can be calculated and plotted in (f) as

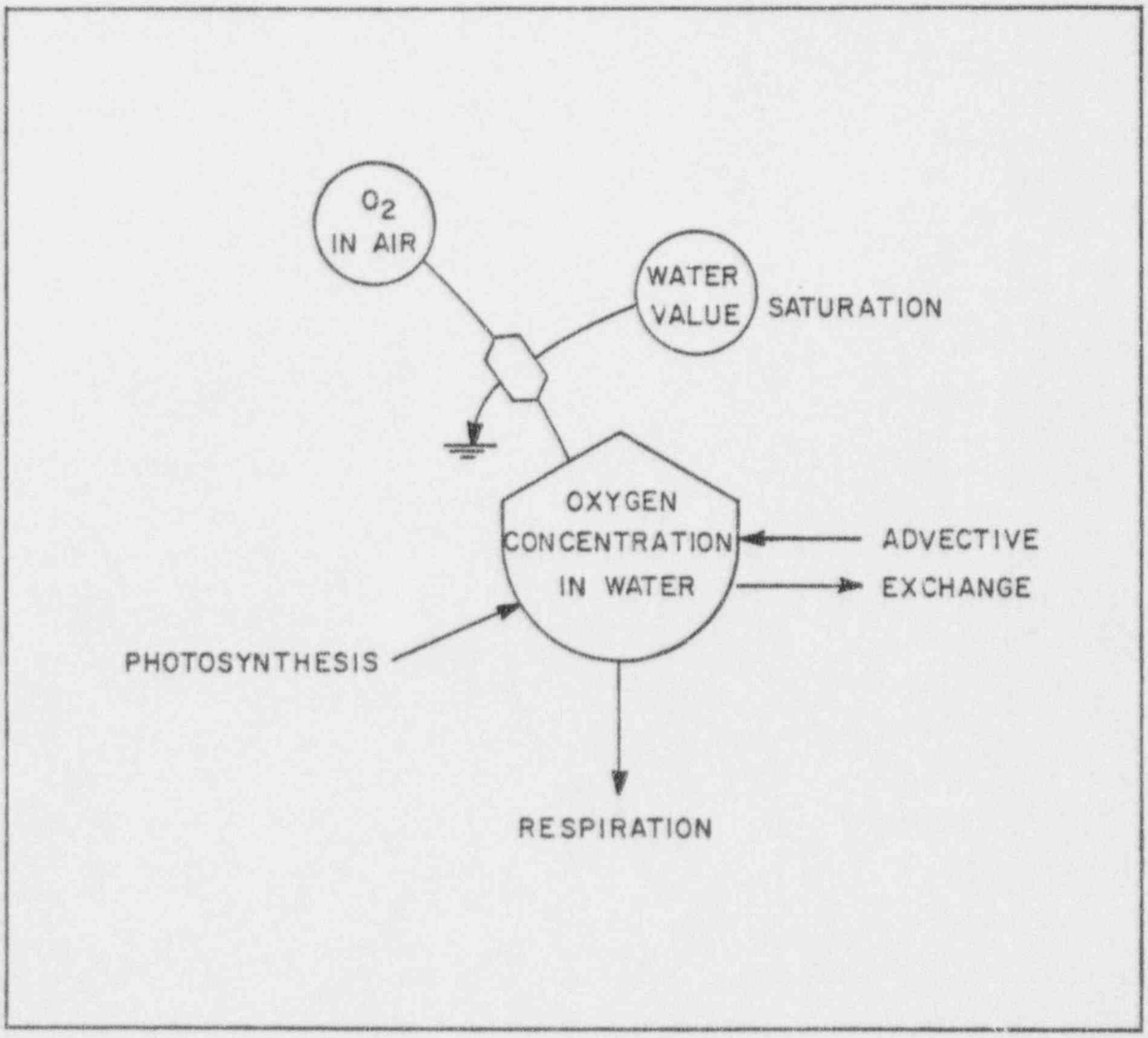


Fig. III-4. Model of factors affecting oxygen dynamics in water (Smith, 1976).

Fig. III-5a and 5b. Example of graphical format for calculation of community metabolism from diurnal measurements in the inner discharge bay, Oct. 1, 1977 and the control bay E, Oct. 2, 1977. Open circles represent average measurements.

(a) oxygen concentration gm O_2/m^3

(b) depth meters

(c) temperature °C

(d) salinity ppt

(e) percent saturation of oxygen

(f) rate of change of oxygen gm O_2/m^2/hr. Solid lines connecting solid dots (•——•) represent the rate of change uncorrected for diffusion. Solid lines connected with open circles (o——o) represent the rate of change corrected for diffusion.

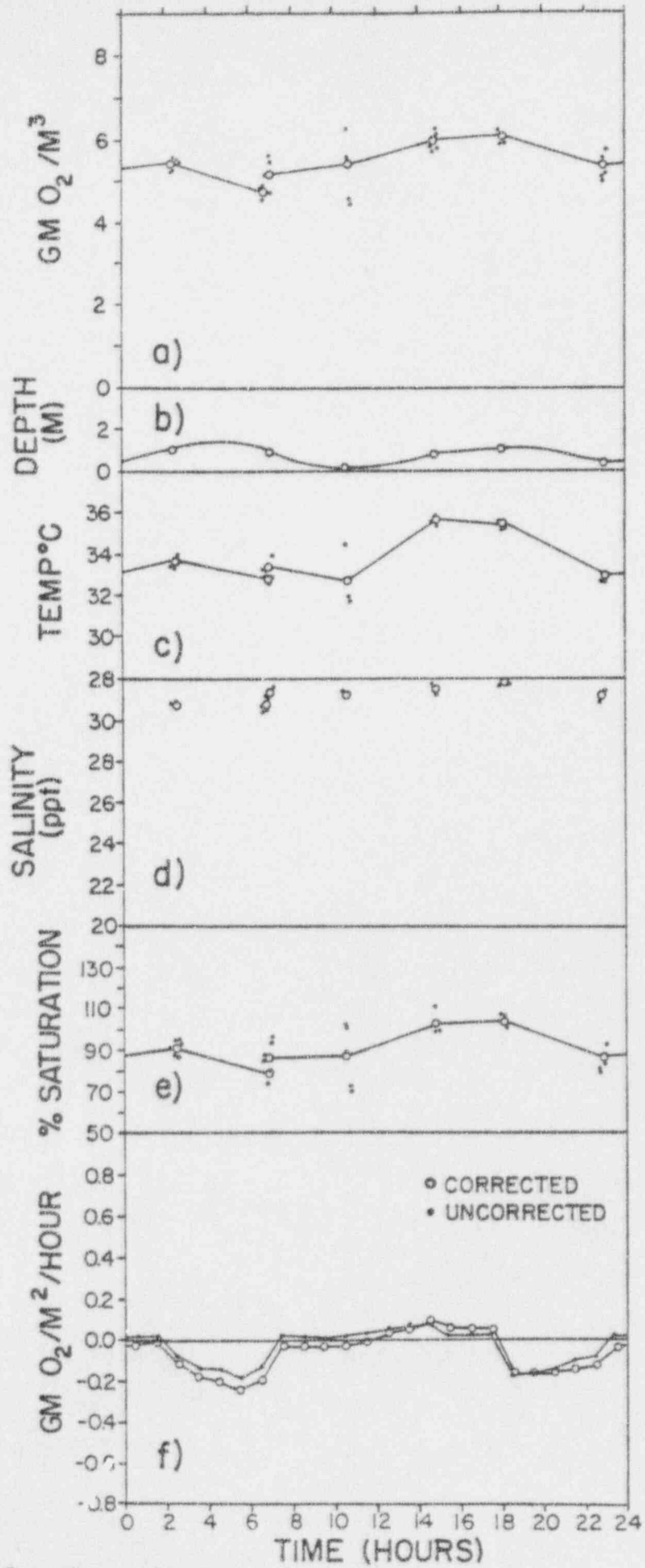


Fig. III-5a. Inner discharge bay.

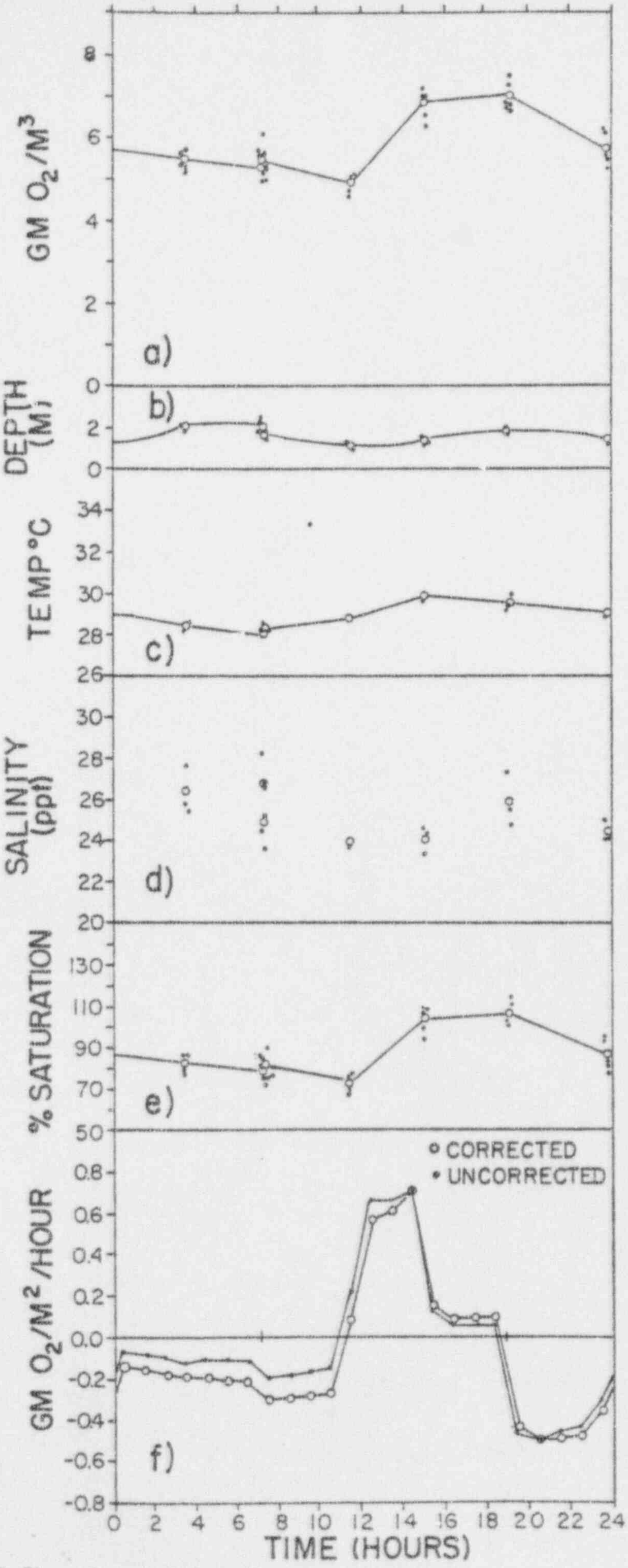


Fig. III-5b. Control bay E.

$O_2/m^2/hr$. This plot of oxygen concentration was uncorrected for diffusion processes.

The average temperatures were plotted in (c) as well as the salinities in (d). The salinity values were not connected by lines due to the complexity of daily salinity patterns. The salinity and temperature values were used in conjunction with the oxygen solubility in seawater nomogram of Green and Carritt (1967) to determine the 100 percent saturation value of oxygen for a given temperature and salinity. For temperatures greater than 35°C, the tables of Truesdale, et al (1955) were used.

The measured oxygen concentration values in (a) were converted to percent saturation values and plotted in (e). To correct the rate curve (f) for diffusion, the plotted values in (e) were subtracted from 100 percent and multiplied by the appropriate diffusion coefficient. This new figure was then added to the uncorrected rate of change value in (f) if the saturation value for that time was greater than 100 percent. It was subtracted if the saturation was less than 100 percent. The resulting curve, connected with solid lines and open circles (o--o) was the diffusion corrected rate of oxygen change per hour.

From the corrected rate of change curve, the net productivity and respiration were calculated. The time period from sunrise to sunset represents net productivity. The area under/above the curve was measured using a digital planimeter. The negative values below zero on the rate of change curve represent negative net productivity and are added to the positive values to arrive at the final net productivity:

Example:

$$2.3\ gm/m^2/day + (-1.0\ gm/m^2/day) = 1.3\ gm/m^2/day$$

$$+P_N \quad + \quad (-P_N) \quad = P_N \text{ final}$$

Respiration was that process occurring between sunset and sunrise and was measured in the same fashion as the net productivity. Although respiration was a negative value, its absolute value was recorded on subsequent tables in this report. The absolute respiration value added to the net productivity yielded the 24 hour gross productivity.

The dawn-dusk-dawn measurements were an abbreviated form of the diurnal measurements. McKellar (1975) and Smith (1976) found the dawn-dusk-dawn method to underestimate gross production from less than 10 percent to as much as 33 percent of a full diurnal curve analysis. This study's dawn-dusk-dawn results were not adjusted to compensate for this underestimation and thus must be taken as conservative estimates.

The method of graphical analysis for the dawn-dusk-dawn method was the same as that used for the diurnal analysis. Two typical dawn-dusk-dawn graphs are shown in Fig. 6a and 6b.

The graphical analysis method was used on the first and second quarter data analysis. As the graphical method proved to be very time consuming, the analysis of the third quarter's data was performed using the following equations which yielded results comparable to the graphical method (McKellar, 1975):

$$D_{day} = (K)(\overline{S}_{day})(t_{day})$$

where K = diffusion constant in gm/m^2/hr/100 percent saturation deficit

$\overline{S}_{day}$ = average percent saturation deficit during the day

$$(\overline{S} = (S_{dawn} + S_{dusk})/2)$$

t_{day} = time in hours between sunrise and sunset

$$P_{net\ day} = (O_{2\ dawn} - O_{2\ dusk})(\overline{Z}_{day}) - D_{day}$$

where O_2 = oxygen concentrations at dawn and dusk

$\overline{Z}$ = average daytime depth of water column

Fig. III 6a and 6b. Example of graphical format for calculation of community metabolism from dawn-dusk-dawn measurements in the inner discharge bay, Sept. 8-9, 1977, and the control bay E, Sept. 8-9, 1977. Open circles represent average measurements.

(a) oxygen concentration gm O_2/m^3

(b) depth meters

(c) temperature °C

(d) salinity ppt

(e) percent saturation of oxygen

(f) rate of change of oxygen gm $O_2/m^2/hr$. Solid lines connecting solid dots (•———•) represent the rate of change uncorrected for diffusion. Solid lines connected with open circles (o———o) represent the rate of change corrected for diffusion.

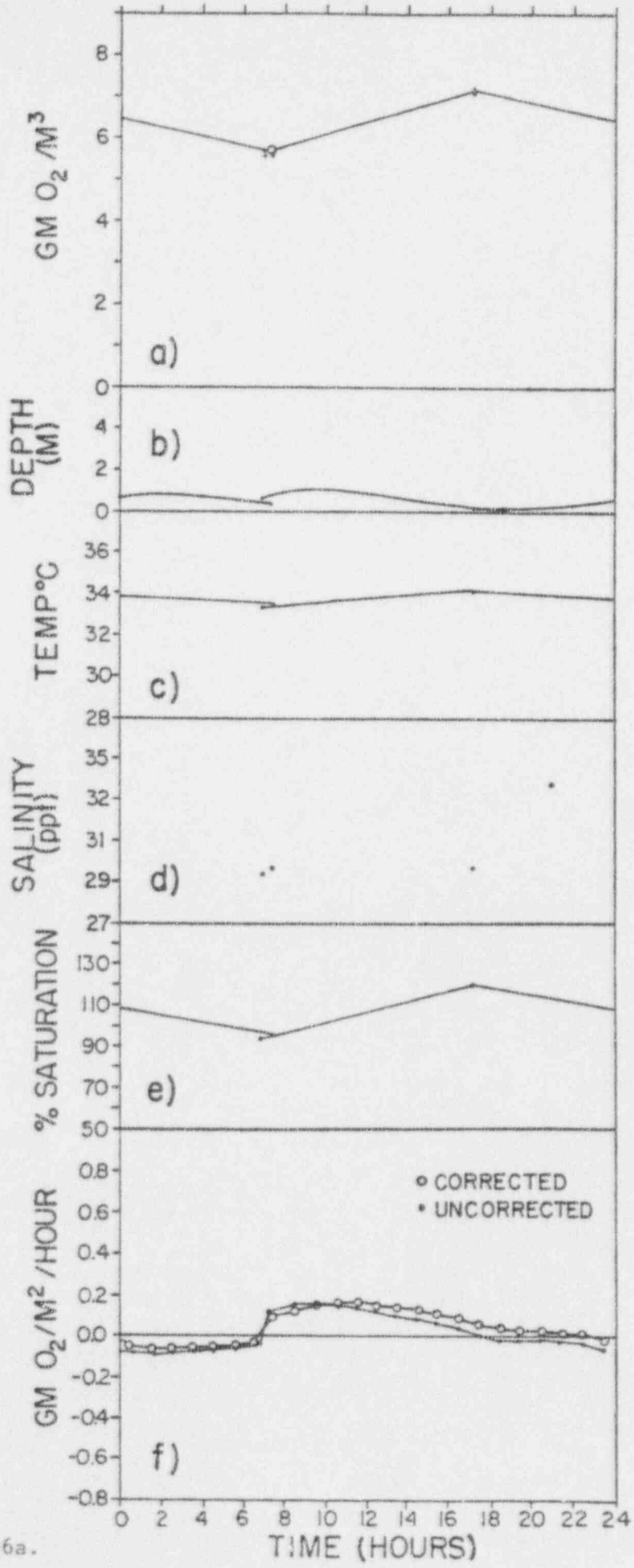

GM O$_2$ /M^3
8
6
4
2
0
a)
DEPTH (M)
4
2
0
b)
TEMP°C
36
34
32
30
28
c)
SALINITY (ppt)
35
32
31
29
27
d)
% SATURATION
130
110
90
70
50
e)
GM O$_2$/M^2 /HOUR
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
f)
○ CORRECTED
• UNCORRECTED
0
2
4
6
8
10
12
14
16
18
20
22
24
TIME (HOURS)

Fig. III-6a.

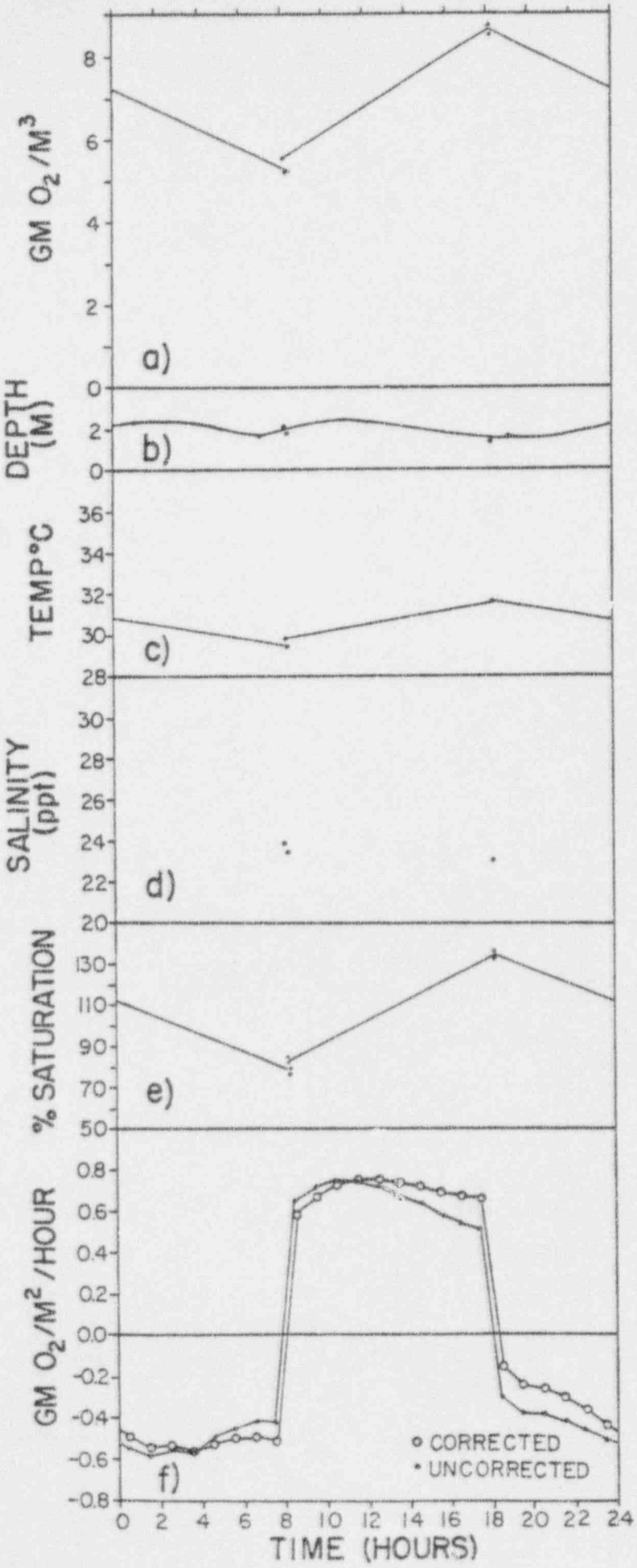

GM O_2/M^3
8
6
4
2
0
a)
DEPTH (M)
2
0
b)
TEMP°C
36
34
32
30
28
c)
SALINITY (ppt)
30
28
26
24
22
20
d)
% SATURATION
130
110
90
70
50
e)
GM O_2/M^2 /HOUR
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
f)
○ CORRECTED
• UNCORRECTED
0
2
4
6
8
10
12
14
16
18
20
22
24
TIME (HOURS)

Fig. III-6b.

D_{day} = daytime diffusion rate

Nighttime respiration was calculated in an identical manner using net nighttime oxygen diffusion and the time interval between sunset and sunrise.

Results

The sampling records of community metabolism and their associated environmental parameters for the inner discharge bay and the control bay at the Florida Power Corporation Crystal River plant are presented in Tables 1 and 2. Those data collected during diurnal sampling periods are designated with an asterisk. Unmarked values are from dawn-dusk-dawn sampling.

Statistical analysis using the t-test on all parameters is presented in Table 3. The analysis was set up to test for significant differences ($\alpha = 0.05$) by seasons between the inner discharge bay and the control bay.

Significant differences exist between the discharge and control bays in summer and fall with regards to gross productivity (P_G), net productivity (P_N), respiration (R), temperature and extinction coefficients. Salinity differences between the bays are significant at the 95% confidence level in the summer and the 90% confidence level in the fall. The plankton productivities, P_G and P_N, are significantly different during the summer season but not during the fall season. Plankton respiration exhibits no difference between bays in either season.

Temperature, Salinity, and Light Extinction

The salinities between the two bays are significantly different in summer and fall at the 95% and 90% levels of confidence, respectively. The average salinity in the control bay ranged from 19.8 to 29.5 ppt

Table III-1. Record of metabolism and environmental parameters for the control bay E. Dates marked with an asterisk were complete diurnal measurements. Unmarked dates were dawn-dusk-dawn measurements.

Control Bay E

Station	Season	PG gm O_2/ m^2/day	PN gm O_2/ m^2/day	R gm O_2/ m^2/day	Plankton PG gm O_2/ m^2/day	Plankton PN gm O_2/ m^2/day	Plankton R gm O_2/ m^2/day	Insolation	Temp °C	Salinity ppt	Extinction coef.	Date mo·d·yr
E	2	8.00	3.68	4.32				5570	30.3	24.4	1.1	7-13-77*
E	2	4.90	1.89	3.01				4780	29.1	25.9	1.2	8-9-77
E	2	7.52	3.55	3.97	4.15	3.69	0.46	3870	28.0	22.1	1.1	8-22-77
E	2	15.92	9.39	6.53	1.74	1.27	0.47	5230	28.6	19.8	1.1	8-23-77
E	2	13.12	7.12	6.00	2.58	1.58	1.00	6579	30.8	23.5	1.1	9-8-77
E	2	10.94	5.05	5.89	1.63	0.94	0.69	6462	30.1	25.9	1.0	9-19-77
E	2	8.66	4.16	4.50	1.84	1.42	0.42	4896	30.4	25.4	1.0	9-20-77
$\overline{X}$		9.87	4.98	4.88	2.39	1.78	0.61	5341	29.6	23.9	1.1	
S.E.		1.41	0.95	0.48	0.47	0.49	0.11	362.88	0.40	0.85	0.03	
E	3	7.49	4.64	2.85	0.97	0.78	0.19	5466	28.8	25.0	1.1	10-1-77*
E	3	4.74	1.23	3.51	1.38	0.63	0.75	5238	28.9	25.2	1.1	10-2-77*
E	3	6.12	2.88	3.24	0.76	0.52	0.24	6462	18.4	28.3	1.0	10-17-77
E	3	5.85	2.66	3.20	0.53	0.29	0.24	6227	18.3	28.4	0.9	10-18-77
E	3	4.72	1.44	3.28	0.88	0.51	0.37	2961	20.5	29.5	0.9	11-1-77
E	3	3.60	1.74	1.86	0.14	0.14	0.00	4441	14.7	29.3	0.9	11-14-77
E	3	2.83	2.08	0.75	0.29	0.26	0.03	4347	15.7	29.4	0.9	11-15-77
E	3	3.81	1.71	2.10	0.21	0.20	0.01	2619	17.8	23.8	0.9	11-29-77
E	3	4.76	1.46	3.30	0.44	0.26	0.18	3416	19.5	23.0	0.9	11-30-77
$\overline{X}$		4.88	2.20	2.68	0.62	0.40	0.22	4575	20.3	26.9	0.9	
S.E.		0.48	0.36	0.31	0.14	0.07	0.08	462.00	1.72	0.87	0.03	

* = Diurnal;

P_G = gross productivity

P_N = net productivity

R = respiration

Season 1 = April 1, 1977 to June 30, 1977
Season 2 = July 1, 1977 to September 30, 1977
Season 3 = October 1, 1977 to November 30, 1977

Table III-2. Record of metabolism and environmental parameters for the inner discharge bay. Dates marked with an asterisk were complete diurnal measurements. Unmarked dates were dawn-dusk-dawn measurements.

Discharge: Inner Bay

Station	Season	PG gm O_2/ m^2/day	PN gm O_2/ m^2/day	R gm O_2/ m^2/day	Plankton PG gm O_2/ m^2/day	Plankton PN gm O_2/ m^2/day	Plankton R gm O_2/ m^2/day	Insolation	Temp °C	Salinity ppt	Extinction coef.	Date mo·d·yr
A	1	0.40	0.14	0.26	0.24	0.21	0.03	---	26.3	24.6	1.9	4-7-77*
A	1	2.99	2.39	0.60	0.39	-0.39	0.78	---	35.3	28.4	1.8	6-30-77
X̄		1.70	1.26	0.43	0.31	-0.09	0.40	---	30.8	26.5	1.9	
S.E.		1.30	1.13	0.17	0.08	-0.06	0.38	---	4.50	1.90	0.05	
A	2	0.18	-0.10	0.28	0.29	-0.65	0.94	4200	35.1	28.0	2.0	7-1-77
A	2	1.80	1.80	0.00	-0.39	-0.92	0.53	7400	37.3	29.3	1.3	7-11-77*
A	2	0.43	0.18	0.25	0.04	-0.45	0.49	5570	37.1	29.8	1.1	7-13-77*
A	2	-0.13	-0.45	0.32	0.14	-0.04	0.18	4780	34.9	30.1	2.3	8-9-77
A	2	-0.28	-0.45	0.17	2.03	0.25	1.78	6030	34.3	30.9	2.3	8-11-77
A	2	1.45	0.44	0.84	1.44	1.16	0.28	3870	30.1	28.1	1.7	8-22-77
A	2	2.45	1.75	0.70	1.84	1.73	0.11	5230	30.7	26.3	1.4	8-23-77
A	2	1.70	1.35	0.35	0.73	0.53	0.20	6579	33.8	29.6	1.9	9-8-77
A	2	0.15	0.15	0.00	1.55	1.15	0.40	6462	35.8	32.5	1.95	9-19-77
A	2	0.49	0.39	0.10	0.97	0.72	0.25	4896	35.9	32.5	1.75	9-20-77
X̄		0.82	0.50	0.30	0.86	0.34	0.52	5501	34.5	29.7	1.8	
S.E.		0.30	0.27	0.09	0.26	0.27	0.16	354.16	0.77	0.62	0.13	
A	3	1.92	0.13	1.79	0.66	0.37	0.29	5466	33.8	31.2	1.5	10-1-77*
A	3	0.83	0.16	0.67	0.97	0.78	0.19	5238	33.4	31.1	2.1	10-2-77*
A	3	0.27	0.27	0.00	0.56	0.42	0.14	6462	26.7	28.5	1.3	10-17-77
A	3	0.48	0.48	0.00	0.66	0.40	0.26	6227	26.1	28.0	1.1	10-18-77
A	3	0.16	0.06	0.10	0.68	0.56	0.12	2961	27.3	29.7	1.4	11-1-77
A	3	0.27	0.27	0.00	0.49	0.27	0.22	4441	19.5	29.3	1.4	11-14-77
A	3	0.39	0.39	0.00	0.61	0.31	0.30	4347	23.3	30.0	1.4	11-15-77
A	3	0.39	0.37	0.02	0.06	-0.01	0.07	2619	23.8	25.6	1.2	11-29-77
A	3	0.37	0.29	0.08	1.00	1.00	0.00	3416	25.4	25.9	1.1	11-30-77
X̄		0.56	0.27	0.30	0.63	0.45	0.18	4575	26.6	28.8	1.4	
S.E.		0.18	0.04	0.20	0.09	0.10	0.03	462.0	1.53	0.68	0.1	

* = dirunal; P_G = gross productivity; P_N = net productivity; R = respiration
Season 1 = spring; season 2 = summer; season 3 = fall

Table III-3. Results of statistical t-tests between the inner discharge bay and the control bay by seasons.

Parameters	Season 2 7-1-77 to 9-30-77 Inner discharge bay	 Control bay	Season 3 10-1-77 to 11-30-77 Inner discharge bay	 Control bay
Gross Productivity P_G gm/m^2/day				
Mean	0.82*	9.86*	0.56*	4.88*
Std. error	0.30	1.41	0.18	0.48
N	10	7	9	9
Net Productivity P_N gm/m^2/day				
Mean	0.51*	4.98*	0.27*	2.20*
Std. error	0.27	0.95	0.04	0.35
N	10	7	9	9
Respiration R gm/m^2/day				
Mean	0.30*	4.89*	0.29*	2.68*
Std. error	0.09	0.48	0.20	0.31
N	10	7	9	9
Plankton P_G gm/m^2/day				
Mean	0.86*	2.37*	0.59	0.77
Std. error	0.26	0.45	0.09	0.33
N	10	5	8	9
Plankton P_N gm/m^2/day				
Mean	0.35*	1.78*	0.45	0.49
Std. error	0.27	0.49	0.09	0.16
N	10	5	9	9
Plankton R gm/m^2/day				
Mean	0.52	0.61	0.20	0.28
Std. error	0.16	0.10	0.03	0.09
N	10	5	8	9
Extinction Coefficient				
Mean	1.76*	1.09*	1.39*	0.95*
Std. error	0.13	0.03	0.10	0.03
N	10	7	9	9
Temperature °C				
Mean	34.5*	29.6*	26.6*	20.3*
Std. error	0.77	0.40	1.53	1.72
N	10	7	9	9
Salinity ppt				
Mean	29.7*	23.8*	28.8△	26.9△
Std. error	0.62	0.85	0.68	0.87
N	10	7	9	9

* denotes significance at 95% level.
△ denotes significance at 90% level.

and from 24.5 to 32.5 ppt in the discharge bay.

Salinity patterns are complex, being influenced by seasonal current changes and daily tidal and weather patterns. The mouth of the Crystal River, approximately 5 km south of the power plant site, is an important influence of fresh water, accounting for the lower salinities in the control bay.

During the summer of 1977 a significant rise in salinity in the discharge bay over Smith's previously measured values was noted (Fig. 7). This rise may be attributed to several possible causes, among which are increased volumes of offshore water being pumped through the three units. This results in an increased proportion of higher salinity offshore water mixing with ambient salinity inshore water in the discharge bay, thus raising the average salinity. Additionally, water pumped through the plant experiences a rise in salinity due to evaporation of part of the water.

Significant differences in temperature between the two bays exist in both summer and fall. The difference in temperature (ΔT) between the two bays, based on seasonal averages, is 4.9°C for summer and 6.3°C for fall. The ΔT of the combined seasonal averages is 5.6°C. The discharge bay temperature ranged from 16.2 - 38.9°C and the control bay temperatures ranged from 13.6 - 31.7°C (Fig. 8). Lowered temperatures occurred in the discharge bay on August 22-23, 1977, due to the nuclear unit shutting down. The unit continued to pump water of ambient intake temperature.

The coal unit was nonoperational from October 17, 1977 through December 31, 1977. This reduced the temperature of the discharge water.

The extinction coefficients (meter^{-1}) are significantly different

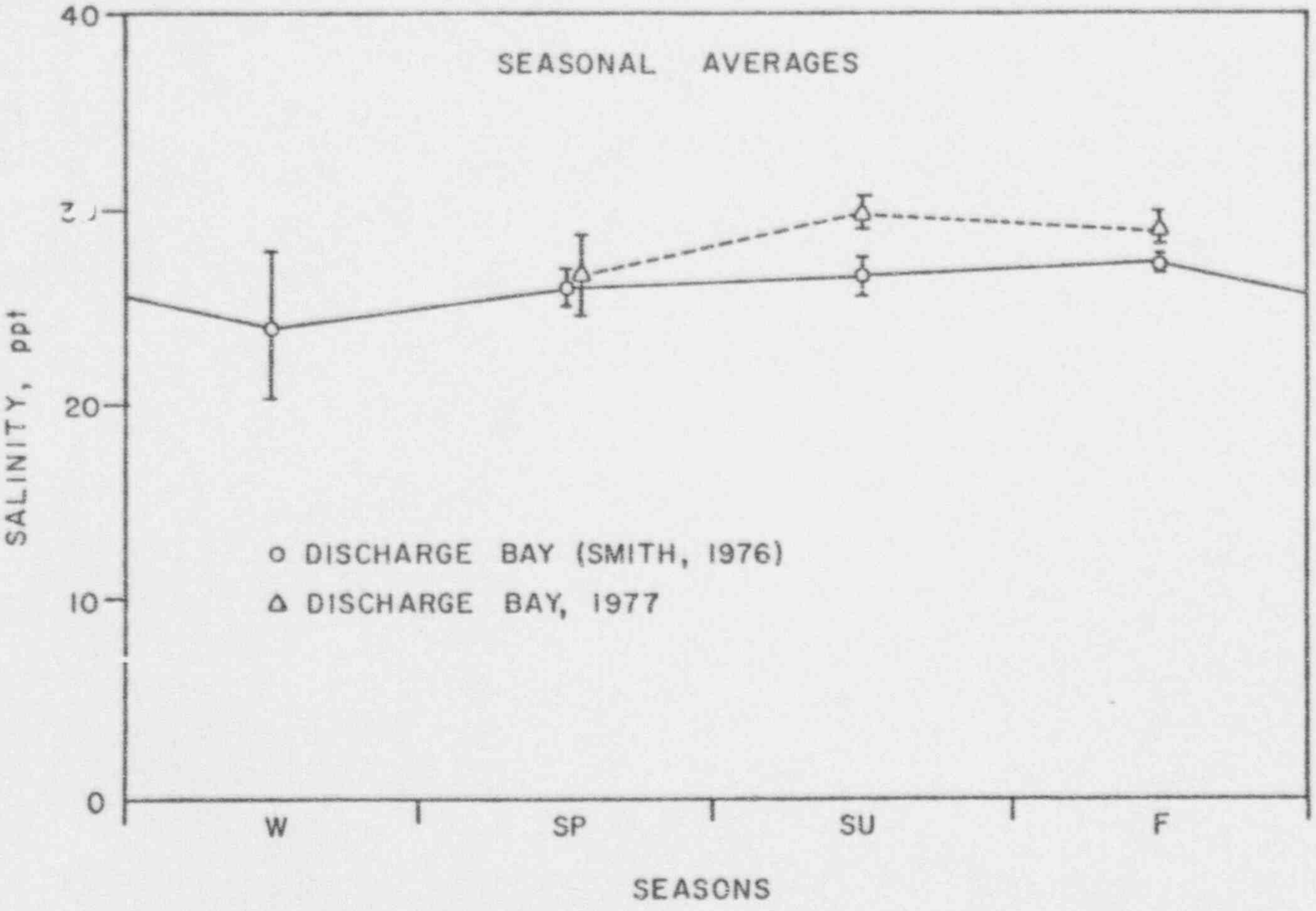


Fig. III-7. Comparison of salinity in the inner discharge bay between preoperational (1972-1974) and operational (1977) studies. Bars about points represent plus and minus one unit of standard error.

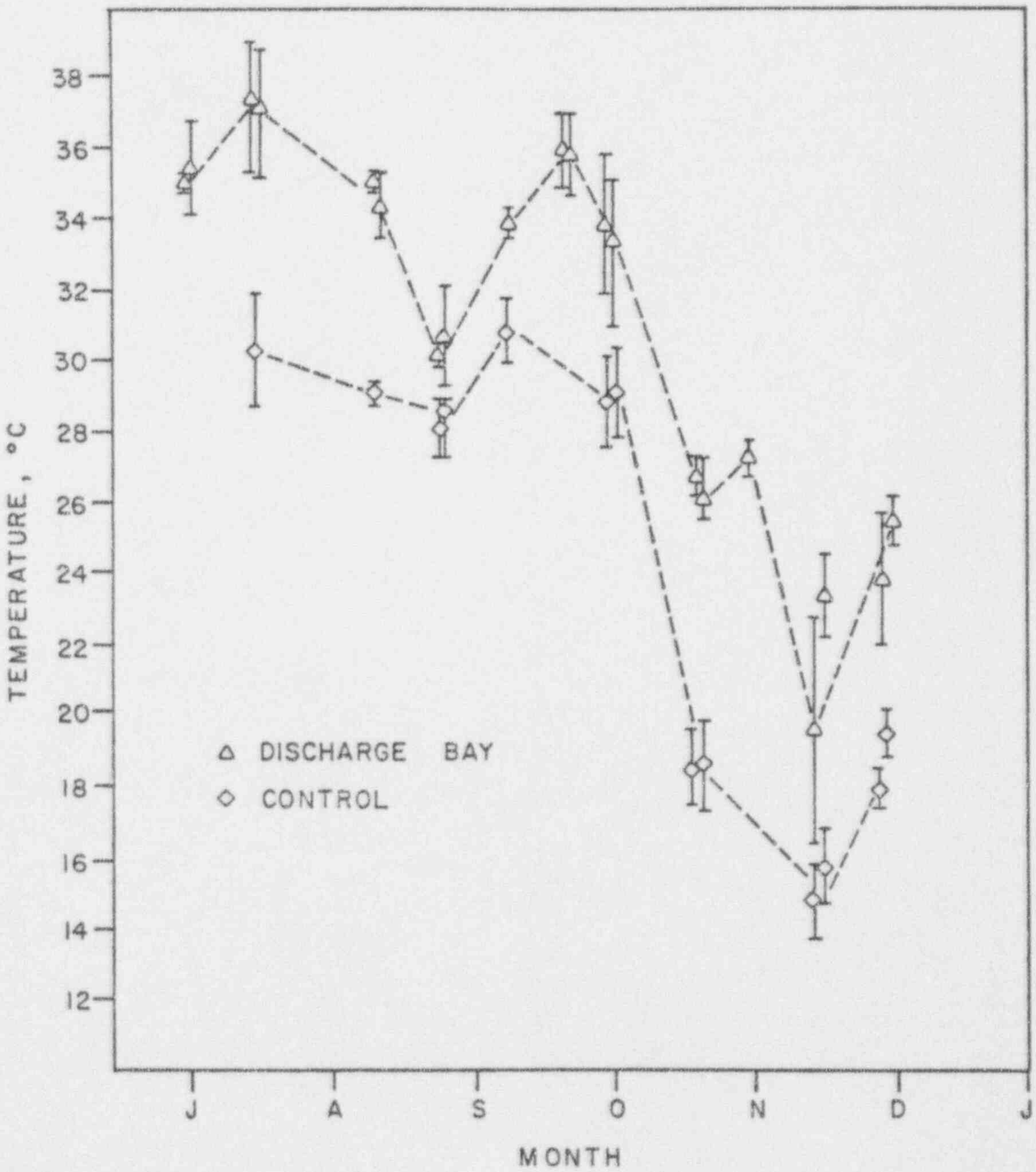


Fig. III-8. Average temperatures with ranges for inner discharge bay and control bay in 1977.

throughout the year. They range from 1.1 to 2.3 in the discharge bay and from 0.9 to 1.2 in the control bay.

Turbidity was measured as the extinction coefficient for light penetration as determined with a Secchi disk. A limited number of light penetration measurements were made by Smith (1976) during the preoperational study. Although Smith's data was not reported in detail to allow for statistical analysis, the average extinction coefficients with their ranges, from both studies, are presented in Table 4. It is evident that in both studies the discharge bay is more turbid than the control bay. A greater range of extinction coefficients was observed in the discharge bay in the 1977 study indicating some surges of high turbidity water.

Community Metabolism

To test the similarity in community metabolism in the Fort Island site and control bay E, diurnal measurements were taken during July, 1977. Table 5 reveals approximately similar productivities for the past and present control sites under similar conditions of insolation.

The seasonal trends of the average daytime net photosynthesis and the night respiration for the total community metabolism are illustrated in Fig. 9. A relatively stable rate of respiration is maintained throughout the three seasons in the discharge bay. The net productivity in the discharge bay appears to have a greater rate of net production in the spring, but that figure is based on data from only two sampling periods and has a large standard error.

The control bay, while sampled through only two seasons to date, displays the normal pattern of greater P_N and R values in the summer than in the fall. No overlap between the control and discharge bay was

Table III-4. Average extinction coefficients for light penetration of water in the discharge and control bays. Units = meters^{-1}.

1972-1974*	Discharge bay	1977 study
1.5 Range 1.2 - 1.7 N = 8		1.6 1.1 - 2.3 N = 21
1972-1974*	Control	1977 study
0.9 Range 0.9 N = 2		1.0 0.9 - 1.2 N = 16

*(Smith, 1976)

Table III-5. Comparison of diurnal productivities of Smith's control station at Fort Island and the new control bay E used in this study (1977).

Location	Date mo·d·yr	kcal/m^2/day Insolation	gm/m^2/day P_N	gm/m^2/day R	gm/m^2/day P_G
Fort Island	7-15-77	5711	3.4	4.5	7.9
Control bay E	7-13-77	5570	3.7	4.3	8.0

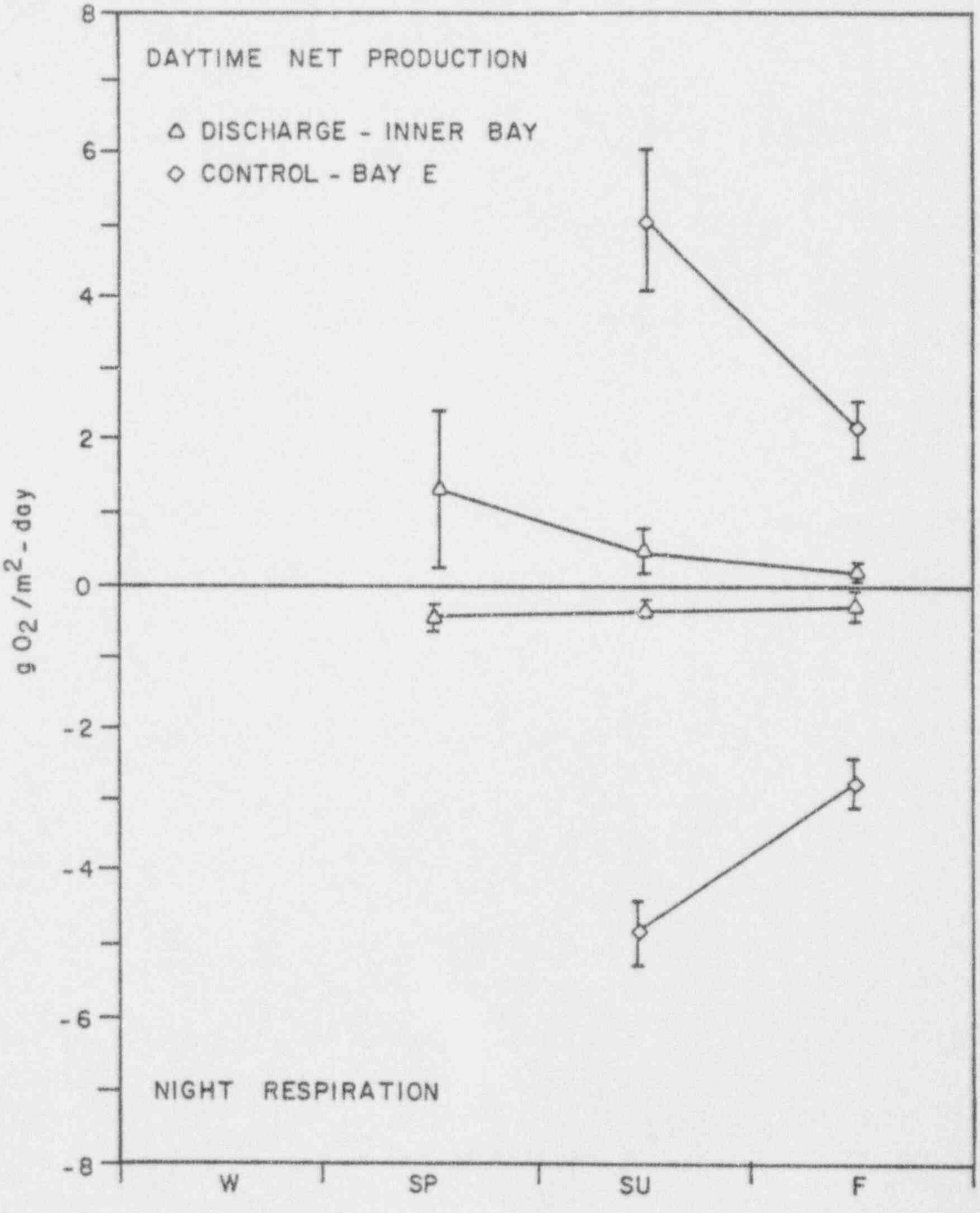


Fig. III-9. Seasonal averages of daytime net photosynthesis and night respiration in the inner discharge bay and control bay E for 1977. Bars about the points represent standard error.

observed for P_G values (Fig. 10). The discharge bay is functioning at a distinctly lower level of productivity than the control bay. In addition, while the control bay follows a seasonal trend of increased productivity in summer with a fall decline, the discharge bay exhibits relatively large, nonseasonal fluctuations.

Table 6 gives the ecological efficiencies for gross production and the productivity to respiration ratios ($P_G/2R_{night}$) for the control and discharge bay. Table 7 is the statistical analysis of the data in Table 6.

Ecological efficiency measures the efficiency of the primary producers of the ecosystem. It is defined as follows:

$$\text{Ecological efficiency} = \frac{\text{energy fixed/time}}{\text{energy available}}$$

$$= \frac{P_G \text{ kcal/m}^2\text{/day}}{\text{insolation kcal/m}^2\text{/day}}$$

Gross productivities normally range between 0.2 - 1.0% efficient.

The inner discharge bay has an unusually low combined seasonal average of 0.06% efficiency. The combined seasonal average of the control bay is within normal range at 0.55% efficiency.

The productivity to respiration ratios were not calculated in the more common form of P_{net}/R. The frequent occurrance of negative P_N values in the discharge bay necessitated the use of the form $P_G/2R$. Both ratios are based on the assumption that respiration should approximate 50% of P_G or 100% of P_N for self-maintenance in a stabilized ecosystem utilizing all energy flows. Thus, a P/R ratio of one is indicative of a stabilized system.

Statistically there is no significant difference in the P/R ratios between the two bays. This result can be misleading as the P_G and R

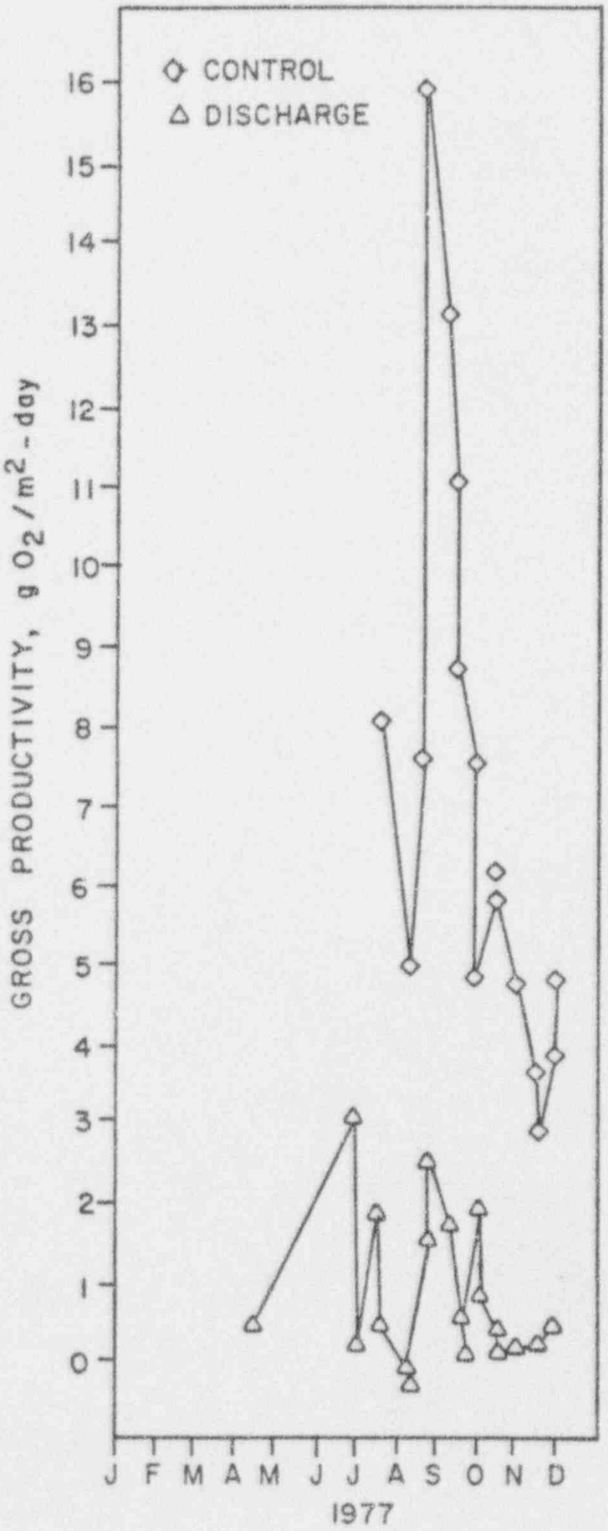


Fig. III-10. Gross productivity of the inner discharge bay and control bay E in 1977.

Table III-6. Record of ecological efficiencies and $P_G/2R$ ratios for the inner discharge bay and control bay E, 1977.

Season	Date (mo·d·yr)	Insolation kcal/m²/day	Inner Discharge Bay		Control Bay E	
			% Ecological efficiency	$P_G/2R$	% Ecological efficiency	$P_G/2R$
1	4-7-77			0.77		
	6-30-77			2.49		
	7-1-77	4200	0.02	0.32		
	7-11-77	7400	0.10	0.00		
	7-13-77	5570	0.03	0.86	0.57	0.92
2	8-9-77	4780			0.41	0.81
	8-22-77	3870	0.15	0.86	0.52	0.95
	8-23-77	5230	0.19	1.75	1.22	1.22
	9-8-77	6579	0.10	2.43	0.80	1.09
	9-19-77	6462	0.02	0.00	0.65	0.93
	9-20-77	4896	0.04	2.45	0.71	0.96
	10-1-77	5466	0.14	0.54	0.55	1.30
	10-2-77	5238	0.06	0.62	0.36	0.67
	10-17-77	6462	0.02	0.00	0.38	0.94
	10-18-77	6227	0.03	0.00	0.38	0.91
3	11-1-77	2961	0.02	0.80	0.64	0.72
	11-14-77	4441	0.02	0.00	0.32	0.92
	11-15-77	4347	0.04	0.00	0.26	1.90
	11-29-77	2619	0.06	9.75	0.58	0.91
	11-30-77	3416	0.04	2.31	0.56	0.72
Season 2 & 3 average		5220	0.06	1.33	0.55	1.00
Standard error		334.4	0.01	0.57	0.06	0.07

Season 1 = spring

Season 2 = summer

Season 3 = Fall

Table III-7. Statistical evaluation of ecological efficiencies and P_G/2R ratios of the inner discharge bay and control bay, 1977.

Season	1		2		3	
Station	Inner discharge bay	Control bay	Inner discharge bay	Control bay	Inner discharge bay	Control bay
Ecological efficiencies						
Mean			0.08	0.70	0.05	0.45
Std. dev.			0.06	0.26	0.04	0.13
Std. error			0.02	0.10	0.01	0.04
Minimum			0.02	0.41	0.02	0.26
Maximum			0.19	1.22	0.14	0.64
Sig. Dif. α =0.05			yes	yes	yes	yes
N			8	7	9	9
P_G/2R						
Mean	1.63		1.08	0.98	1.56	1.00
Std. dev.	1.22		1.01	0.13	3.16	0.38
Std. error	0.86		0.36	0.05	1.05	0.13
Minimum	0.77		0.00	0.81	0.00	0.67
Maximum	2.49		2.45	1.22	9.75	1.90
Sig. Dif. α = 0.05			no	no	no	no
N	2		8	7	9	9

Season 1 = spring

Season 2 = summer

Season 3 = fall

values in the discharge bay fluctuated widely, as evidenced by the large standard deviation (Table III-7) while those values in the control bay remained relatively constant. The P/R ratios in the discharge bay ranged from 0.00 to 9.75 and from 0.67 to 1.90 in the control bay.

The gross productivity of the plankton component of each bay was shown to be significantly different only in the summer (Table 3). Examination of the percent of total community gross productivity due to the plankton P_G reveals widely differing community structure between the two bays (Table 8). The total community P_G of the discharge bay is accounted for entirely by the plankton gross productivity. While the average plankton P_G value is slightly higher than the total community P_G, the values fall within one unit of standard error of each other (Table 3). Visual observation of the discharge bay at low tide in the summer revealed only a few sparse beds of stunted Halodule.

The plankton gross productivity in the control bay comprised only 16 - 24% of the total community gross productivity. The benthic primary producers were responsible for an average of 80% of the total community P_G. Visual observation and collection at low tide in the summer showed abundant growth of Sargassum and Ruppia in addition to Padina, Caulerpa, Gracilaria, and Codium.

Comparison with Preoperational Studies

The preoperational study on the inner discharge bay and its control was conducted from December, 1972 through May, 1974 by Smith (1976). The productivity measurements from Smith's study reflect the energy flows and structure of the discharge bay at a time when it had been receiving thermal effluent for six years from two electrical generating stations.

Table III-8. Percent of total metabolism gross productivity (P_G) accounted for by plankton gross productivity (P_G) in the inner discharge bay and control bay (1977).

	Inner Discharge Bay			Control Bay		
	Season 2	Season 3	Average	Season 2	Season 3	Average
Total community P_G g/m^2/d	0.82	0.56	0.69	9.87	4.88	7.38
Plankton P_G	0.86	0.63	0.75	2.37	0.77	1.57
Percent of total metabolism due to plankton	100%	100%	100%	24.0%	16.0%	20%
Percent of total metabolism due to benthos	0%	0%	0%	76%	84%	80%

Season 2 = summer

Season 3 = fall

The initiation of operation of a third generating unit in January, 1977, increased the volume and intensity of the thermal effluent. The present study monitored the impact of the higher water temperatures upon the metabolism of the inner discharge bay.

Tables 9 and 10 present the metabolism data and the environmental parameter data from the preoperational study (adapted from Smith, 1976).

To test for significant differences between the control station and the inner discharge bay during the preoperational study, a two tailed t-test was run (Table 11). Significant differences in the community productivities were present in all seasons but winter.

In those seasons where there was a significant difference between the control and discharge bay community productivities, the productivities, P_G, P_N and R, in the discharge bay were approximately 50% of those of the control station. During those same seasons, the average difference between ambient and discharge bay temperatures (ΔT) was 3.0°C.

In the comparisons of the results of the two studies (Tables 12 and 13), only the data from the summer and fall seasons were analyzed. In the current operational study, the winter sampling period is still in progress, thus eliminating that season for comparison. The spring data were also omitted for comparison due to a small number of samples for the 1977 data.

Significant differences in gross productivity, net productivity, respiration, salinity and temperature exist between the preoperational and operational studies in the discharge bay during summer and fall. A

Table III-9. Record of community metabolism and environmental parameters for the inner discharge bay during the preoperational study. Adapted from Smith (1976). Asterisks indicate diurnal measurements. Unmarked dates are dawn-dusk-dawn measurements.

Station	Season	PG gm O_2/ m^2·day	PN gm O_2/ m^2·day	R gm O_2/ m^2·day	Plankton P6 gm O_2/ m^2·day	Plankton PN gm O_2/ m^2·day	Plankton R gm O_2/ m^2·day	Insolation kcal/ m^2·day	Temperature °C	Salinity ppt	Date mo·day·yr
A	1	9.1	4.8	4.3					28.3	22.5	5-10-73
A	1	6.2	2.9	3.3					28.4	21.2	5-11-73
A	1	3.7	2.6	1.1				6500	32.0	28.0	5-24-74
A	1	2.4	1.7	0.7				6409	33.0	27.7	5-25-74
A	1	4.1	2.3	1.8	1.6	1.2	0.4	5834	30.7	27.7	5-26-74
A	1	3.0	1.5	1.5					31.5	22.3	6-14-72*
A	1	3.8	1.7	2.1					30.3	24.5	6-29-72*
A	1	5.7	3.5	2.2					33.0	28.0	6-17-73
A	1	4.1	1.6	2.5					33.0	28.0	6-17-73*
A	1	3.0	2.1	0.9					33.5	27.0	6-18-73
A	1	1.3	0.0	1.3					33.3	26.5	6-19-73
A	1	4.3	2.4	1.9	4.7	2.5	2.2		33.0	27.5	6-20-73
A	1	3.8	1.7	2.1					32.5	27.0	6-21-73*
A	1	2.2	1.0	1.2					32.0	26.0	6-22-73
$\overline{X}$		4.0	2.1	1.9	3.2	1.9	1.3	6248	31.8	25.9	
SE		0.52	0.31	0.26	1.55	0.65	0.90	208.5	0.46	0.62	
A	2	10.7	5.9	4.8					31.3	22.5	7-7-72*
A	2	6.1	3.5	2.6	1.0	0.7	0.3	6115	34.0	27.5	7-26-73
A	2	5.7	2.2	3.5					34.0	25.0	8-2-72*
A	2	2.2	0.9	1.3	0.6	0.5	0.1	2889	34.0	260.0	8-2-73
A	2	5.4	1.9	3.5					30.5	27.5	8-22-73
A	2	2.5	1.2	1.3	1.3	0.9	0.4		31.5	27.2	8-23-73
A	2	2.9	1.4	1.5					31.2	27.5	8-24-73
A	2	2.4	2.3	0.1					33.0	28.5	8-25-73
A	2	2.4	0.6	1.8					31.5	27.2	8-26-73
A	2	3.7	1.1	2.6					32.0	27.5	8-27-73
$\overline{X}$		4.4	2.1	2.3	1.0	0.7	0.3	4502	32.3	26.6	
SE		0.85	0.50	0.44	0.20	0.12	0.09	1613	0.42	0.55	

Table III-9 (cont.)

Station	Season	PG gm O_2/ m^2·day	PN gm O_2/ m^2·day	R gm O_2/ m^2·day	Plankton PG gm O_2/ m^2·day	Plankton PN gm O_2/ m^2·day	Plankton R gm O_2/ m^2·day	Insolation kcal/ m^2·day	Temperature °C	Salinity ppt	Date mo·day·yr
A	3	2.7	1.1	1.6	0.7	0.5	0.2		22.0	27.0	10-29-73
A	3	3.6	1.2	2.4	0.7	0.5	0.2		21.5	27.5	10-30-73*
A	3				0.9	0.7	0.2	3850	21.0	26.5	10-31-73
A	3	3.5	1.3	2.2	1.0	0.6	0.4	4490	25.0	27.5	11-1-73
$\overline{X}$		3.3	1.2	2.1	0.8	0.6	0.2		22.4	27.1	
SE		0.28	0.06	0.24	0.08	0.05	0.05		0.90	0.24	
A	4	5.6	2.0	3.6					25.8	27.8	12-14-72*
A	4	1.8	1.5	0.3					20.0	27.5	1-22-73*
A	4	2.3	0.7	1.7					16.0	16.2	2-1-73*
$\overline{X}$		3.2	1.4	1.8					20.6	23.8	
SE		1.19	0.38	0.96					2.84	3.81	

Key

Season 1 = April 1 - June 30 = spring
2 = July 1 - September = summer
3 = October 1 - November 30 = fall
4 = December 1 - March 21 = winter
PG = Gross Productivity
PN = Net Productivity
R = Respiration
* = Diurnal

Key to Table 10.

Season 1 = April 1 - June 30 = spring
2 = July 1 - September 30 = summer
3 = October 1 - November 30 = fall
4 = December 1 - March 31 = winter

P_G = gross productivity

P_N = net productivity

R = respiration

* = diurnal

Table III-10. Record of the community metabolism and environmental parameters for the control station during the preoperational study. Adapted from Smith (1976). Asterisks indicate diurnal measurements. Unmarked dates are dawn-dusk-dawn measurements.

Station Fort Island (similar to present station E)	Season	PG gm O_2/ m^2·day	PN gm O_2/ m^2·day	R gm O_2/ m^2·day	Plankton PG gm O_2/ m^2·day	Plankton PN gm O_2/ m^2·day	Plankton R gm O_2/ m^2·day	Insolation kcal/ m^2·day	Temperature °C	Salinity ppt	Date mo·d·yr
Control*	1	9.9	5.4	4.5	3.5	2.7	0.8	6409	28.5	17.0	5-25-74
Control	1	9.0	4.7	4.3	3.4	2.5	0.9	5834	28.5	16.0	5-26-74
"	1	5.0	1.9	3.1	2.0	-3.2	5.2	3037	29.0	11.0	6-25-73
"	1	10.5	5.1	5.4	1.8	1.1	0.7	6543	28.5	12.5	6-26-73
"	1	6.4	3.5	2.9				6343	29.0	14.3	6-26-73*
"	1	11.0	5.2	5.8				6144	28.5	11.0	6-27-73
"	1	10.6	5.6	5.0	1.2	0.9	0.3	6648	28.5	12.5	6-28-73
$\overline{X}$		8.9	4.5	4.4	2.4	0.8	1.6	5851	28.6	13.5	
SE		0.88	0.50	0.42	0.45	1.06	0.91	480	0.09	0.89	
E	2	6.2	1.8	4.4					29.5	13.5	8-2-72*
E	2	3.7	1.1	2.6					30.0	23.5	8-10-72
E	2	8.0	4.7	3.3					30.5	12.5	8-16-72*
E	2	10.2	4.0	6.2					28.8	13.5	8-24-73*
E	2	8.5	1.6	6.9					29.5	16.0	8-26-73
E	2	11.1	3.8	7.3					29.0	14.0	8-27-73
$\overline{X}$		8.0	2.8	5.2					29.6	15.5	
SE		1.10	0.61	0.80					0.26	1.66	
E	3	5.5	2.1	3.4	0.5	0.2	0.3	3100	18.5	22.0	11-12-73
E	3	8.4	4.0	4.4	0.5	0.3	0.2	4140	16.8	21.0	11-13-73
E	3	8.5	4.3	4.2	0.4	0.2	0.2	4280	20.0	19.5	11-14-73
E	3	8.5	3.4	5.1	0.4	0.3	0.1		21.2	17.5	11-15-73
$\overline{X}$		7.7	3.4	4.3	0.4	0.2	0.2	3840	19.1	20.0	
SE		0.74	0.49	0.35	0.03	0.03	0.04	372	0.95	0.98	
E	4	4.7	2.1	2.6					13.8	13.8	2-13-73*
E	4	2.0	0.5	1.5					12.8	23.3	2-22-73
$\overline{X}$		3.4	1.3	2.1					13.3	18.6	
SE		1.35	0.80	0.55					0.50	4.75	

* Control station combines data from both Fort Island and Hodges Island.

Table III-11. Statistical results of two-tailed t-test between the inner discharge bay and the control bay (preoperational study) by seasons. Adapted from Smith, 1976. Seasonal means were calculated from data collected in 1972, 1973 and 1974.

Parameters		Spring April 1 - June 30		Summer July 1 - Sept 30	
		Inner discharge bay	Control bay	Inner discharge bay	Control bay
Gross productivity P_G gm/m^2/day	Mean	4.05*	8.91*	4.40*	7.95*
	std. error	0.52	0.88	0.85	1.10
	N	14	7	10	6
Net productivity P_N gm/m^2/day	Mean	2.13*	4 49*	2.10	2.83
	std. error	0.30	0.50	0.50	0.61
	N	14	7	10	6
Respiration R gm/m^2/day	Mean	1.92*	4.42*	2.30*	5.11*
	std. error	0.26	0.42	0.44	0.80
	N	14	7	10	6
Plankton P_G gm/m^2/day	Mean	3.15	2.38	0.97	no data
	std. error	1.55	0.46	0.20	
	N	2	5	3	
Plankton P_N gm/m^2/day	Mean	1.85	0.80	0.70	no data
	std. error	0.65	1.06	0.11	
	N	2	5	3	
Plankton R gm/m^2/day	Mean	1.30	1.58	0.27	no data
	std. error	0.90	0.91	0.09	
	N	2	5		
Temperature °C	Mean	31.8*	28.6*	32.3*	29.5*
	std. error	0.46	0.09	0.42	0.26
	N	14	7		
Salinity ppt	Mean	23.9*	13.5*	26.6	15.5
	std. error	0.62	0.89	0.55	1.66
	N	14	7	10	6

---

* denotes significant differences between the means at the 95% confidence level.

Table III-11. (cont.)

Parameters		Fall Oct. 1 - Nov. 30		Winter Dec. 1 - Mar. 31	
		Inner discharge bay	Control bay	Inner discharge bay	Control bay
Gross	Mean	3.27*	7.72*	3.25	3.35
productivity	std. error	0.30	0.74	1.17	1.35
P_G	N	3	4	3	2
gm/m^2/day					
Net	Mean	1.20*	3.45*	1.40	1.30
productivity	std. error	0.06	0.49	0.40	0.80
P_N	N	3	4	3	2
gm/m^2/day					
Respiration	Mean	2.07*	4.28*	1.85	2.05
R	std. error	0.24	0.35	0.93	0.55
gm/m^2/day	N	3	4	3	2
Plankton	Mean	0.83*	0.45*	no	no
P_G	std. error	0.08	0.03	data	data
gm/m^2/day	N	4	4		
Plankton	Mean	0.57*	0.25*	no	no
P_N	std. error	0.05	0.03	data	data
gm/m^2/day	N	4	4		
Plankton	Mean	0.25	0.20	no	no
R	std. error	0.05	0.04	data	data
gm/m^2/day	N	4	4		
Temperature	Mean	22.4*	19.1*	20.6	13.3
°C	std. error	0.90	0.95	2.84	0.50
	N	4	4	3	2
Salinity	Mean	27.1*	20.0*	23.8	18.6
ppt	std. error	0.24	0.98	3.82	4.75
	N	4	4	3	2

* denotes significant differences between means at the 95% confidence level.

Table III-12. Statistical results of two-tailed t-test of the inner discharge bay between the pre-operational study (Smith, 1976) and the current operational study (1977) by the summer and fall seasons.

Parameters		(summer) Season 2 Inner discharge bay		(fall) Season 3 Inner discharge bay	
		Pre-operational study (Smith, 1976)	Operational study 1977	Pre-operational study (Smith, 1976)	Operational study 1977
Gross productivity P_G gm/m^2/day	Mean	4.40*	0.81*	3.27*	0.56*
	std. error	0.85	0.30	0.28	0.18
	N	10	10	3	9
Net productivity P_N gm/m^2/day	Mean	2.10*	0.51*	1.20*	0.27*
	std. error	0.50	0.27	0.06	0.04
	N	10	10	3	9
Respiration R gm/m^2/day	Mean	2.30*	0.29*	2.07*	0.30*
	std. error	0.44	0.09	0.24	0.20
	N	10	10	3	9
Plankton P_G gm/m^2/day	Mean	0.97	0.86	0.83	0.59
	std. error	0.20	0.26	0.08	0.09
	N	3	10	4	8
Plankton P_N gm/m^2/day	Mean	0.70	0.35	0.58	0.45
	std. error	0.12	0.27	0.05	0.10
	N	3	10	4	8
Plankton R gm/m^2/day	Mean	0.27	0.52	0.25	0.20
	std. error	0.09	0.16	0.05	0.03
	N	3	10	4	8
Temperature °C	Mean	32.3*	34.5*	22.4*	26.6*
	std. error	0.42	0.77	0.90	1.53
	N	10	10	4	9
Salinity ppt	Mean	26.6*	29.7*	27.1	28.8
	std. error	0.55	0.61	0.24	0.68
	N	10	10	4	9

* denotes significant differences between means at the 95% confidence level.

Table III-13 Statistical results of the two-tailed t-test of the control bay between the pre-operational study (Smith, 1976) and the current operational study (1977) by the summer and fall seasons.

		(summer) Season 2 Control bay		(fall) Season 3 Control bay	
Parameters		Pre operational study (Smith, 1976)	Operational study (1977)	Pre operational study (Smith, 1976)	Operational study (1977)
Gross productivity P_G $gm/m^2/day$	Mean	7.95	9.86	7.73*	4.88*
	std. error	1.10	1.41	0.74	0.48
	N	6	7	4	9
Net productivity P_N $gm/m^2/day$	Mean	2.83	4.97	3.45	2.20
	std. error	0.62	0.95	0.49	0.37
	N	6	7	4	9
Respiration R $gm/m^2/day$	Mean	5.12	4.89	4.28*	2.68*
	std. error	0.80	0.48	0.35	0.31
	N	6	7	4	9
Plankton P_G $gm/m^2/day$	Mean	no data	2.37	0.45	0.77
	std. error		0.45	0.03	0.23
	N		5	4	9
Plankton P_N $gm/m^2/day$	Mean	no data	1.78	0.25	0.50
	std. error		0.49	0.03	0.16
	N		5	4	9
Plankton R $gm/m^2/day$	Mean	no data	0.60	0.20	0.28
	std. error		0.11	0.04	0.09
	N		5	4	9
Temperature °C	Mean	29.5	29.6	19.1	20.3
	std. error	0.26	0.40	0.95	1.72
	N	6	7	4	9
Salinity ppt	Mean	15.5*	23.9*	20.0*	26.9*
	std. error	1.67	0.85	0.98	0.87
	N	6	7	4	9

* denotes significance at the 95% confidence level

comparison of the gross productivities of the discharge bay in the two studies shows that an average decrease in P_G of 80% has occurred.

The statistical results of Tables 11, 12 and 13 are illustrated in Figs. 11 - 14. The bars about the points represent one unit of standard error.

The seasonal averages of gross productivity in the preoperational study (Fig. 11) show the lowered P_G's for the control site. With the addition of the current operational study's data (Fig. 11), a further depression in discharge bay gross productivities is exhibited. This is a decrease of approximately 80% of the preoperational discharge bay gross productivity. At present, the discharge bay gross productivities average about 10% of the gross productivities of control bay E.

Reducing the gross productivity into its component parts in Fig. 12, it is observed that the P_N and R values in the discharge bay maintain themselves at a rather constant level throughout the year. In the current study (Fig. 12), the discharge bay values for P_N and R are again maintained at near constant levels, although at considerably lower values.

Temperatures in the preoperational stud of the discharge bay and control site exhibited identical trends (Fi . 13) with the discharge bay temperature averaging 3°C greater than the control site. With the operation of the third generating unit and resultant increase in thermal load, water temperatures in the discharge bay increased an average of 3°C over the previous discharge bay temperatures (Fig. 14).

The ecological efficiencies calculated from Smith's (1976) data (Table 14) fall within the normal range of 0.2 - 1.0% for gross productivity. The preoperational control station had an efficiency of 0.66% and the operational control station study 0.55%. The inner discharge

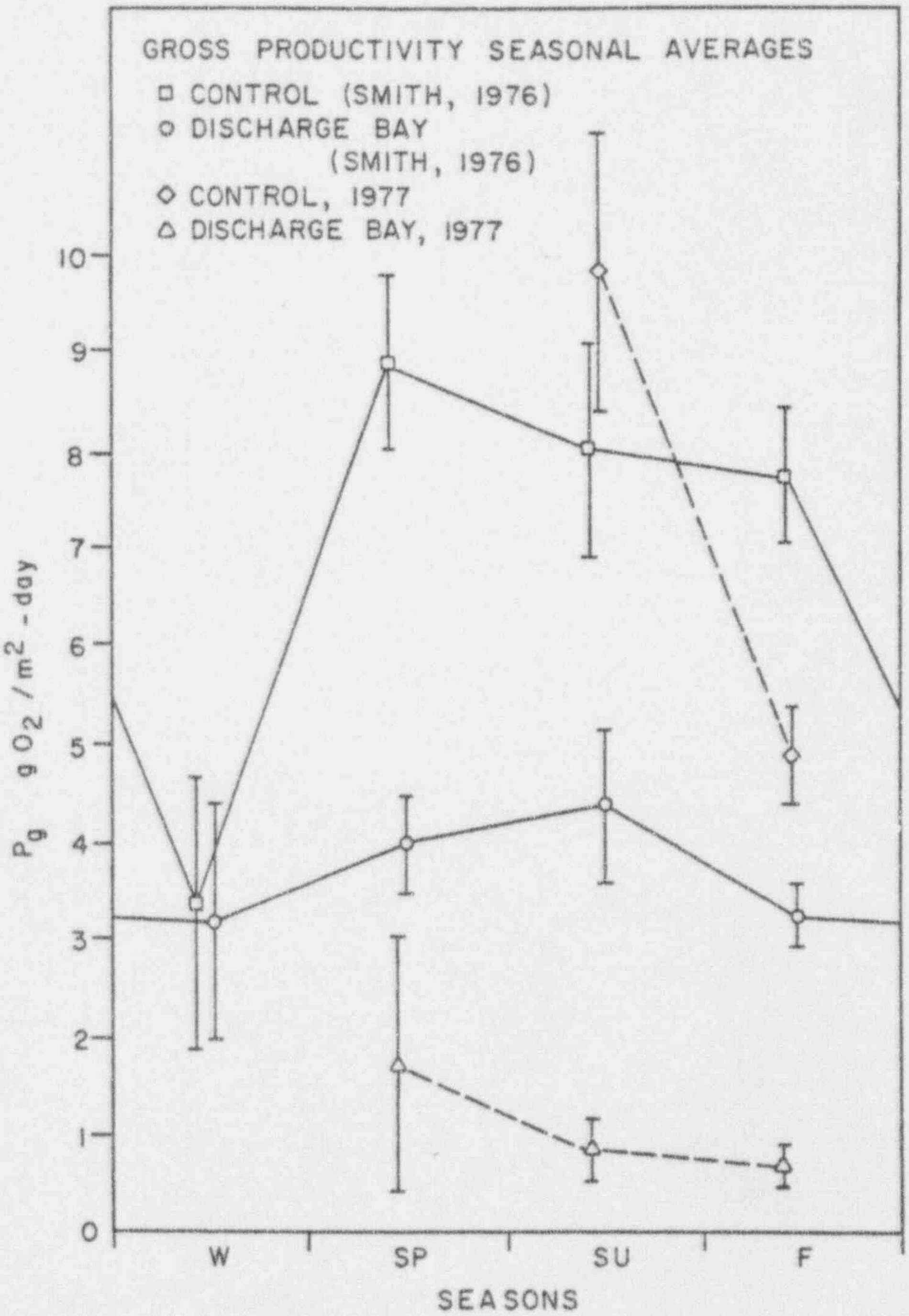


Fig. III-11. Comparison of seasonal averages of gross productivity in the control and inner discharge bay between the preoperational and operational study. Bars about the points represent plus and minus one unit of standard error.

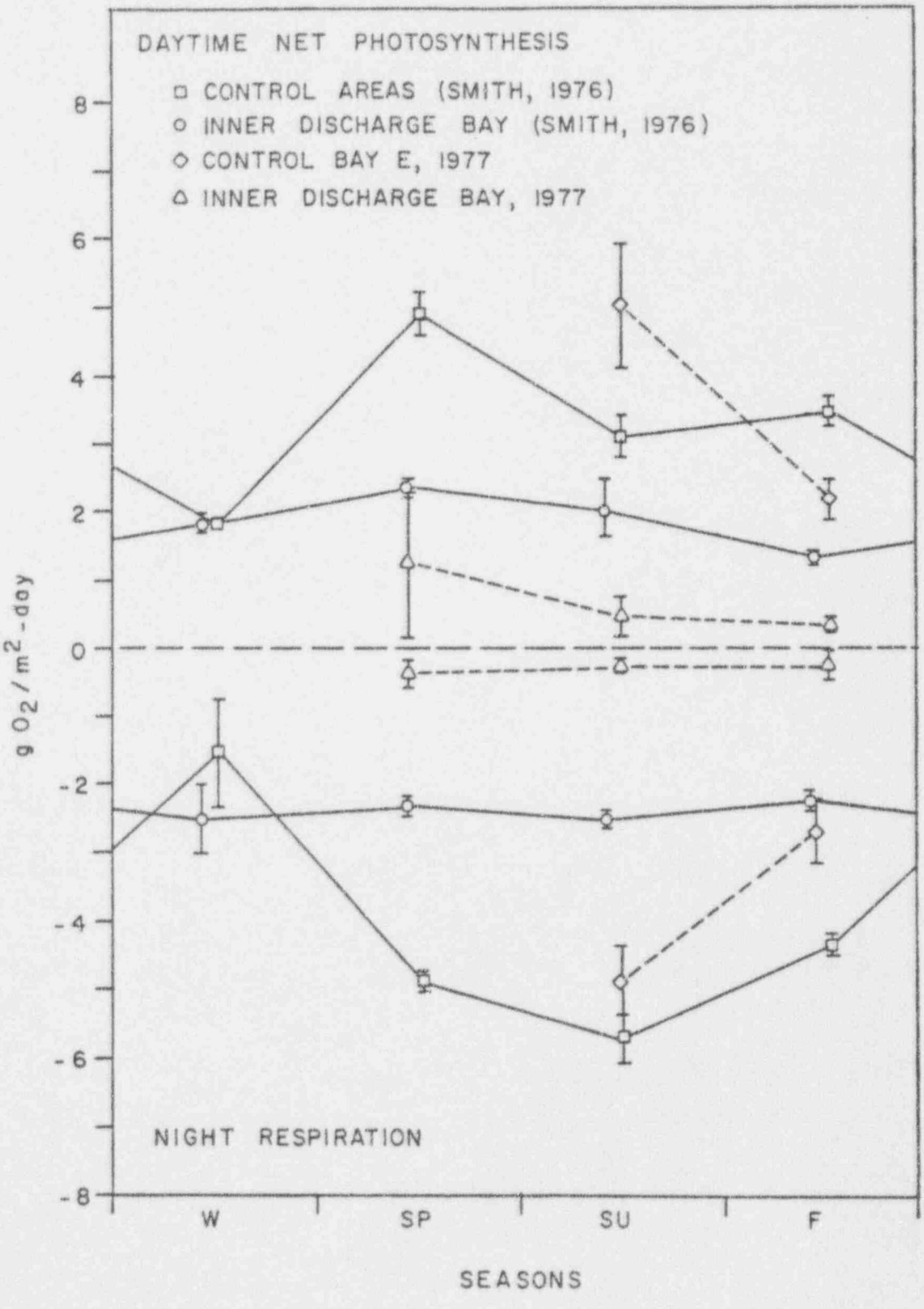


Fig. III-12. Seasonal averages of daytime net photosynthesis and night respiration in the inner discharge bay and control bay for 1972-74 (Smith, 1976) and 1977. Bars about points represent plus and minus one standard error.

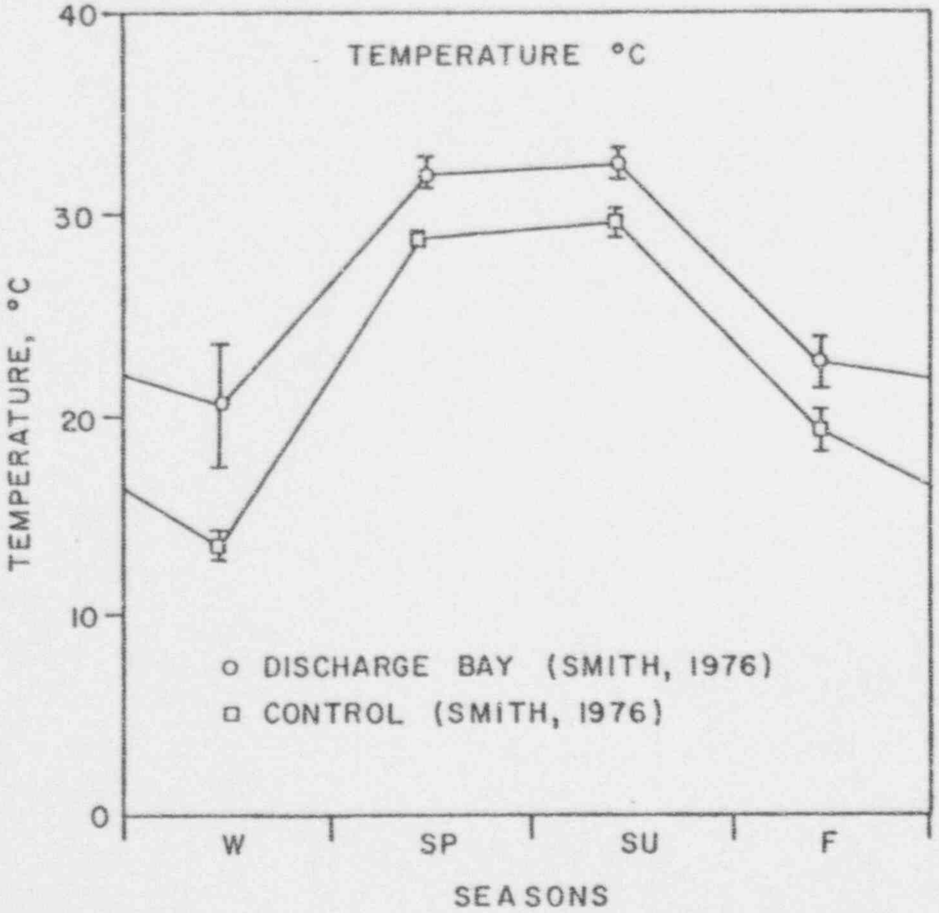


Fig. III-13. Seasonal averages of water temperature in the inner discharge bay and control areas during the preoperational study. Bars about points represent plus and minus one standard error.

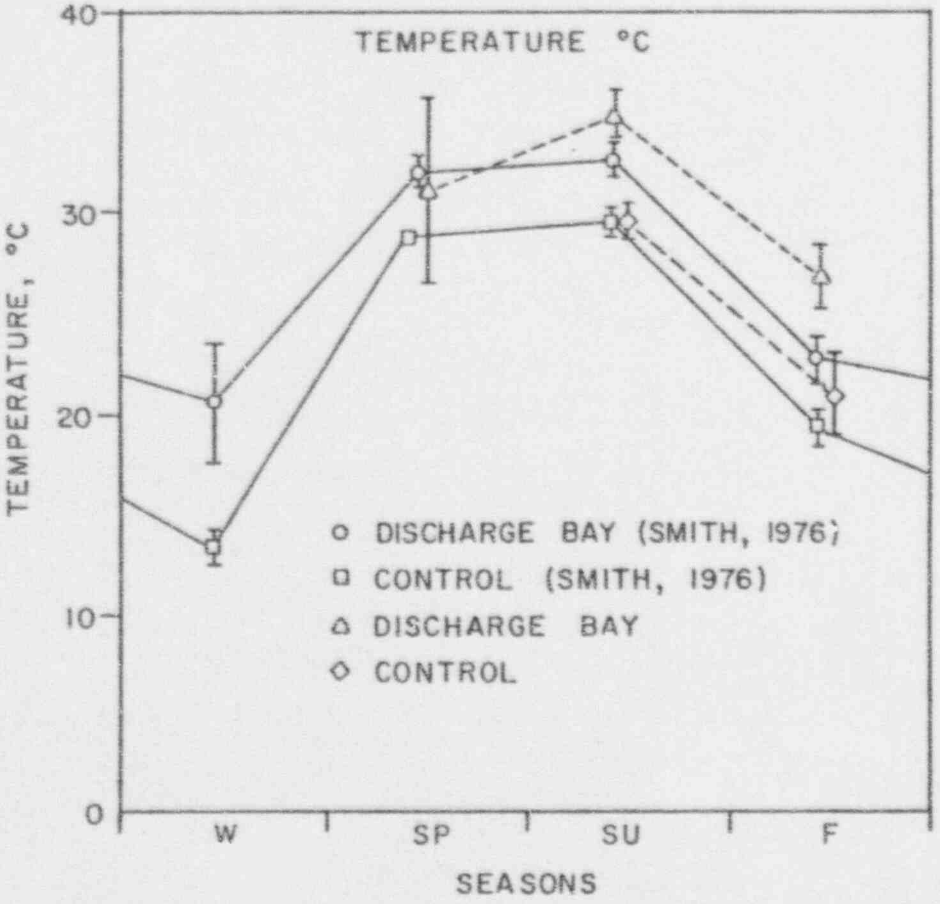


Fig. III-14. Comparison of seasonal averages of water temperature in the inner discharge bay and control stations between the preoperational and operational studies. Bars about the points represent plus and minus one unit of standard error.

bay with a preoperational gross productivity approximately half that of its control station (Table 14) had an efficiency of 0.32%.

In a comparison of the preoperational and operational stations of the inner discharge bay, it is evident that a large decrease in the ecological efficiency of the metabolism has occurred. The 1977 operational study values for ecological efficiency in the discharge bay declined approximately 80% from those values reported in the preoperational study for the same bay.

Data from the preoperational study (Table 15) shows that the plankton productivity accounted for about 40% of the total community productivity. Thus, it was inferred that benthic metabolism was predominant. In the current study (Table 8) plankton productivity now seems to account for approximately the entire gross productivity of the inner discharge bay.

Discussion

The data collected in this study suggests that most of the total community metabolism of the inner discharge bay was attributed to the plankton metabolism. As there was no statistically significant difference in the amount of plankton productivity in the inner discharge bay between the preoperational and operational studies, it appears that the major change has been a decrease in benthic productivity. During the preoperational study benthic metabolism averaged about 60% of the total community metabolism in the inner discharge bay (Smith, 1976). In the present study the levels of benthic production showed a large decline in net productivity and respiration. This effect suggests the possibility of photorespiration and/or a change in the benthic community structure from that of the preoperational study. The survey of community structure by Connell, Metcalf and Eddy (1978) shows that only four genera of macroalgae were found in the inner discharge bay while 15 genera were present in its control bay. The mean biomass (gm dry wt/m^2) of macroalgae in the inner discharge bay was less than 3% of that found in the control bay for the three quarters reported. Sea grass in the inner discharge bay was dominated by one species _Halodule_ _wrightii_. This seagrass was absent for most of the year in those stations closest to the canal. Quarterly transects also indicated a decrease in percent cover in September.

The low values for the plankton metabolism of the inner discharge bay were comparable to those found in the control bay, which is a benthic dominated system (Table 15). Similar low levels of plankton productivity were reported for several shallow bays 6.9 - 1.5 m deep) in Texas (Odum and Hoskins, 1958), but again these were benthic dominated systems. Thus, the inner discharge has plankton productivities similar to those of benthic dominated systems, with the important exception that the amount of plankton metabolism is not significantly different from the total metabolism.

Summary

1. Metabolism in the inner discharge bay in 1977 was approximately 10% of the control bay.
2. Discharge bay metabolism in 1977 was 20% of the discharge bay metabolism in 1972-74.
3. Plankton productivity measured in bottles was not significantly different from the levels observed in the preoperational study.
4. Ratio of production to respiration fluctuated widely.

Table III-14. Record of ecological efficiencies for the inner discharge bay and control bays: preoperational study (adapted from Smith, 1976).

	Date mo·d·yr	Insolation kcal/m^2/day	% Ecological efficiency*
Inner discharge bay			
Season 1	5-26-74	5834	.28
Season 2	7-26-73	6115	.40
Season 2	8-2-73	2889	.30
Season 3	11-1-73	4490	.31
$\overline{X}$			.32
s.e.			.03
Control bays			
Season 1	5-25-74	6409	.62
Season 1	5-26-74	5834	.62
Season 1	6-25-73	3037	.66
Season 1	6-26-73	6443	.65
Season 1	6-26-73	6443	.40
Season 1	6-27-73	6144	.72
Season 1	6-28-73	6648	.64
Season 3	11-12-73	3100	.71
Season 3	11-13-73	4140	.81
Season 3	11-14-73	4280	.79
$\overline{X}$			.66
s.e.			.04

* Ratio of (g oxygen production x 4 kcal/g) to kcal of total insolation including visible and infrared.

Season 1 = spring

Season 2 = summer

Season 3 = fall

Season 4 = winter

$\overline{X}$ = mean

Table III-15. Component percentages of total metabolism gross productivity (P_G) of the inner discharge bay and control bays in preoperational study (adapted from Smith, 1976).

	Average total community P_G g/m^2/day	Average Plankton P_G	Average % of metabolism due to plankton	Average % of metabolism due to benthos	N
Inner discharge bay					
Season 1	4.0	3.2	80%	20%	2
Season 2	4.4	1.0	23%	77%	3
Season 3	3.3	0.8	24%	76%	3
Season 4		no data			
$\overline{X}$			42%	58%	
Control bay					
Season 1	8.9	4.4	49%	51%	5
Season 2		no data			
Season 3	7.7	0.4	52%	48%	4
Season 4		no data			
$\overline{X}$			50%	50%	

Season 1 = spring

Season 2 = summer

Season 3 = fall

Season 4 = winter

$\overline{X}$ = mean

COMMUNITY METABOLISM OF THE OUTER DISCHARGE AND CONTROL BAYS

by

Jeff Lucas

Introduction

This chapter contains results of metabolism measurements in the outer discharge bay (B) and unaffected bay (D) of similar depth used for comparison (See Fig. 2 of introduction to this report). In 1972-73, McKellar (1975) conducted a total community metabolism study to measure the effects of units 1 and 2 on the outer bay ecosystem receiving discharged water. His results suggest a slight depression in gross productivity in the outer discharge bay compared to a similar control bay. The discharge bay was found to be plankton dominated while the control bay was a benthic dominated system.

Methods and Materials

Total community metabolism was determined from diurnal oxygen changes in the bays using two methods modified from Odum and Hoskins (1958). The first method involved the analysis of full diurnal oxygen curves from measurements made every 4 hours in a 24 hour period. The second method was an abbreviation of the first where oxygen changes were estimated from samples taken at times of minimal (dawn) and maximal (dusk) oxygen concentration.

Oxygen was measured using a sodium azide modification of the Winkler method (see McKellar, 1975). In addition, Secchi disk, wind, current velocity, salinity, temperature, and depth were measured at each station. Diffusion coefficients were taken from McKellar (1975). Plankton metabolism was determined by oxygen changes in light and dark bottles.

Diurnal net productivity and respiration values were calculated from an oxygen rate of change curve (Fig. 15). The change in oxygen concentration per hour is multiplied by the depth and plotted on the rate of change curve. Temperature and salinity data are used to determine the percent oxygen saturation using a nomogram from Green and Carritt (1965). This percent saturation was then multiplied by the diffusion coefficient and added (if percent saturation >100) or subtracted (if percent saturation < 100) to correct values.

Respiration was calculated by integrating the area between sunset and sunrise under zero gm $O_2/m^2/hr$ on the rate of change curve. Net productivity was calculated by integrating the area above zero between dusk and dawn and subtracting the integrated area below the zero line between dusk and dawn.

A detailed review of methods and materials has been listed by Benkert (previous chapter of this report).

Results

Temperature, Salinity and Light Penetration

Data on temperature, salinity, and light penetration are given in Table 16 and Fig. 16.

Water temperatures ranged from 18.5 to 36.1°C in the discharge bay and 15.0 to 31.6°C in the intake bay (Fig. 16a). Peak temperatures occurred from June to September. The average ΔT was 4.5°C between the two bays with a range from 1.3 to 6.2°C. One fossil fuel unit was shut off and the nuclear unit pumped ambient temperature water on August 22 and 23, thus reducing ΔT on these two days to 1.8°C and 1.2°C, respectively.

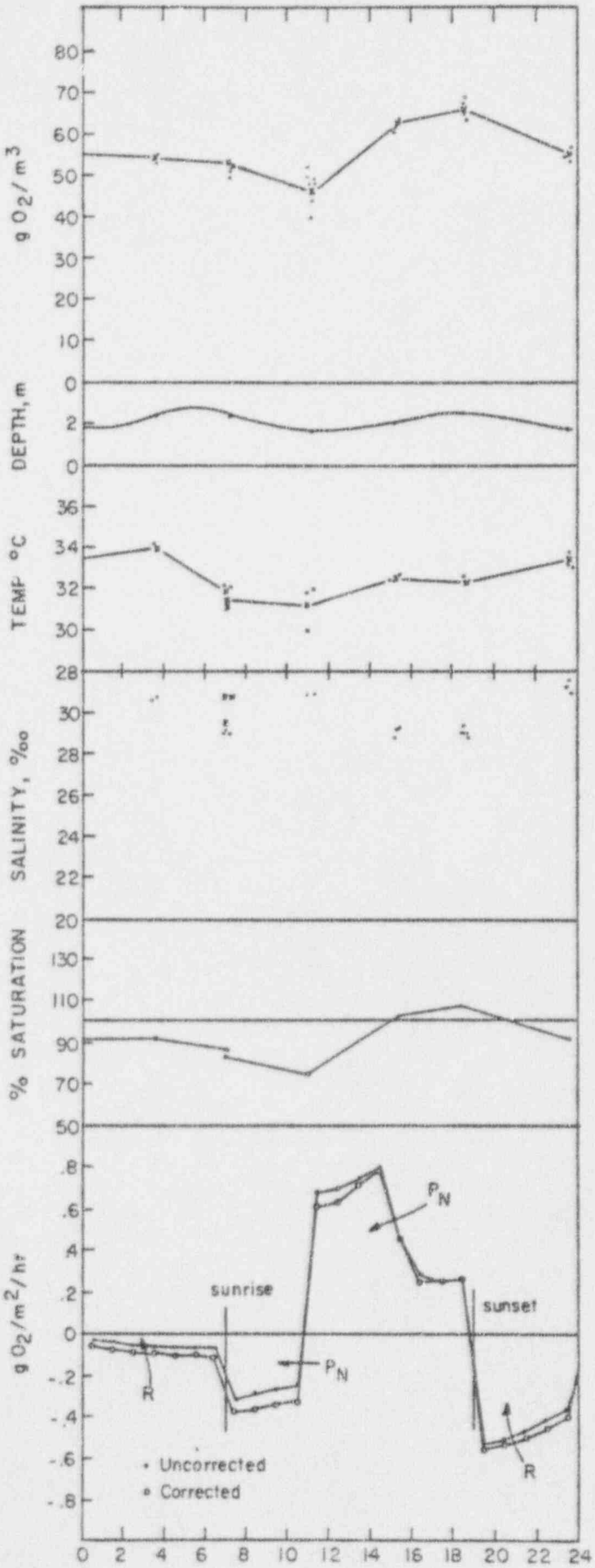


Fig. III-15. Diurnal graph of outer discharge bay - Oct. 2, 1977.

Fig. III-16. Water temperature, salinity and light extinction for the outer control (Station D) and discharge (Station B) bays, 1977. (a) Water temperatures shown represent average diel temperatures measured. Lines are drawn through monthly averages; (b) salinity values represent average diel salinities; (c) light extinction coefficients calculated from Secchi disc depths; (d) where (K = 1.7/d) and from subphotometer data.

$$K = \frac{\ln(I_1/I_2)}{z_z - z_1}$$

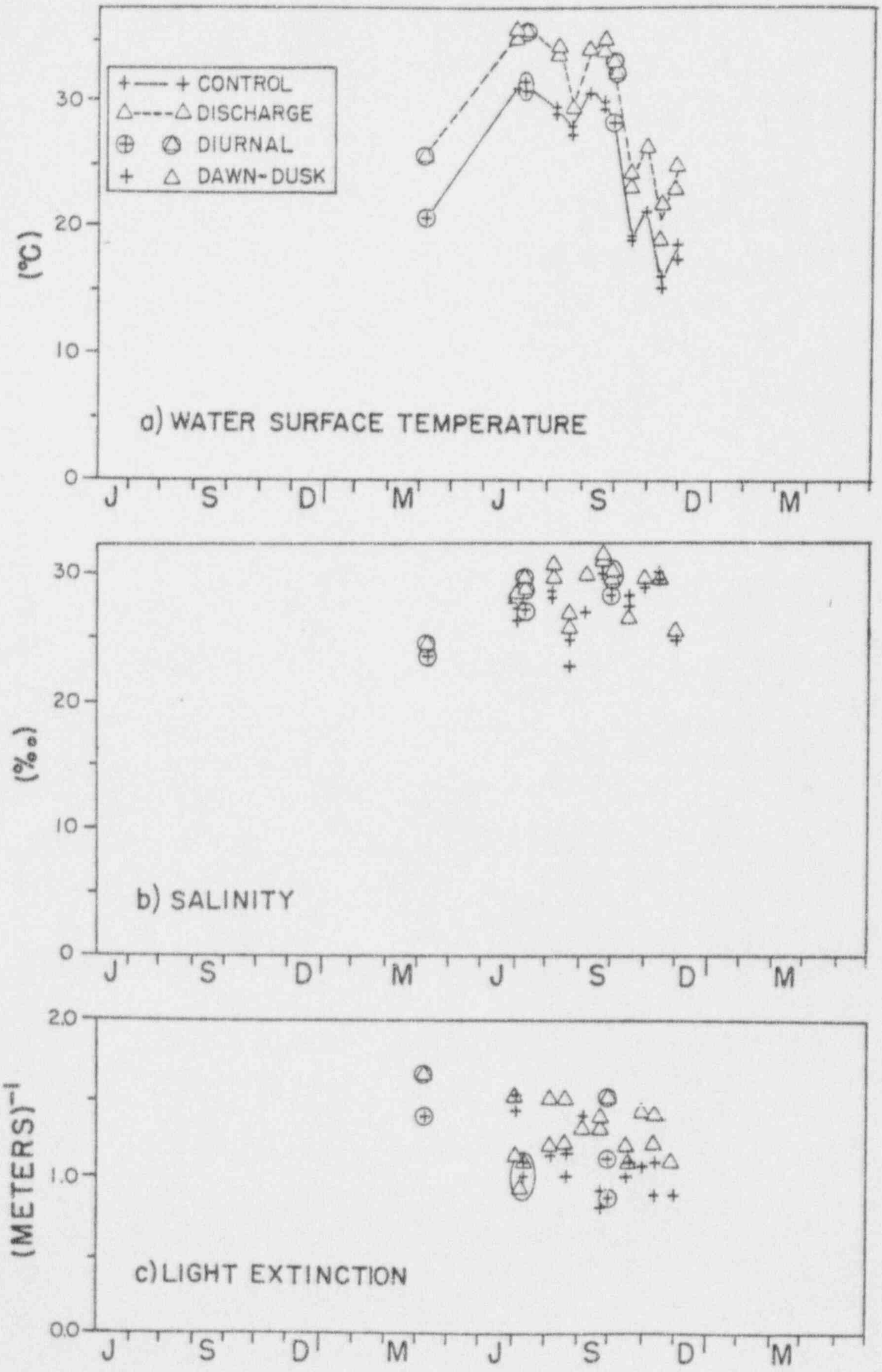

+—— + CONTROL
△----△ DISCHARGE
⊕ ◯ DIURNAL
+ △ DAWN-DUSK
(°C)
0
10
20
30
a) WATER SURFACE TEMPERATURE
J S D M J S D M
(‰)
0
10
20
30
b) SALINITY
J S D M J S D M
(METERS)$^{-1}$
0.0
1.0
2.0
c) LIGHT EXTINCTION
J S D M J S D M

Table III-16. Average salinities, temperatures and light extinctions. Number of observations is listed in parenthesis; standard error is listed with average. (1977)

	Spring	Summer	Fall	Winter
Temperature (°C)				
Discharge	25.7(1)	35.73(4)±0.18*	31.24(11)± 1.29*	22.88(5)±1.33*
Control	20.40(1)	31.10(4)±0.21*	27.23(11)±1.29*	17.48(5)±1.05*
Salinity (o/oo)				
Discharge	24.3(1)	28.95(4)±0.24*	29.15(11)±0.61	27.94(5)±2.41
Control	23.70(1)	26.90(4)±0.18*	27.64(11)±0.70	27.60(5)±1.19
Extinction(meter^{-1})				
Discharge	1.62(1)	1.17(4)±0.12	1.32(11)±0.5**	1.24(5)±0.07*
Control	1.37(1)	1.24(4)±0.12	1.15(11)±0.08**	0.98(5)±0.05*

* Means for discharge and control significant at the 95% confidence level (2 sample t-test).

** Means for discharge and control significant at the 90% confidence level (2 sample t-test).

Unit 2 was shut down from October 17 to the end of this study, but this had no effect on reduction of ΔT with the average ΔT of 5.2°C (higher than the yearly average).

Salinities ranged from 22.5 to 30.9 o/oo in the control bay and 24.3 to 31.5 o/oo in the discharge bay. The salinities for the discharge bay averaged 1.3 o/oo higher than those of the control bay and in only 2 of 12 samples was the salinity of the control bay higher than that of the discharge bay. The difference was statistically significant in the summer samples (Table 16).

Light extinction coefficients ranged from 0.9 to 1.6 for the discharge bays and 0.9 to 1.7 for the intake bays. Extinction coefficients were significantly higher (therefore turbidity was higher) in the discharge bay in the fall and winter months. The ΔT increased 1.5°C from a ΔT of 3°C in the 1972-74 study to a ΔT of 4.5°C in this study. In comparing stations between years, only the summer discharge samples for 1977 were significantly different from the 1972-74 discharge samples (35.7°C and 30.3°C, respectively - two sample t-test, $p < 0.05$). Mean temperatures in summer and winter were also significantly higher in the control 1977 samples than in the 1972-74 control samples (31.1°C and 27.7°C, respectively - two sample t-test, $p < 0.05$) but all other differences were not significant.

Salinities recorded in the preoperational study ranged from 20 to 30 o/oo, with similar salinities exhibited by both bays (McKellar, 1975, Fig. 17b). In contrast, 83% of the paired samples taken in this study showed an increase in salinity in the discharge bay. Salinities averaged 1.3% higher in the discharge bay. This difference probably reflects the increased pumping of higher salinity offshore waters into the discharge bays. In

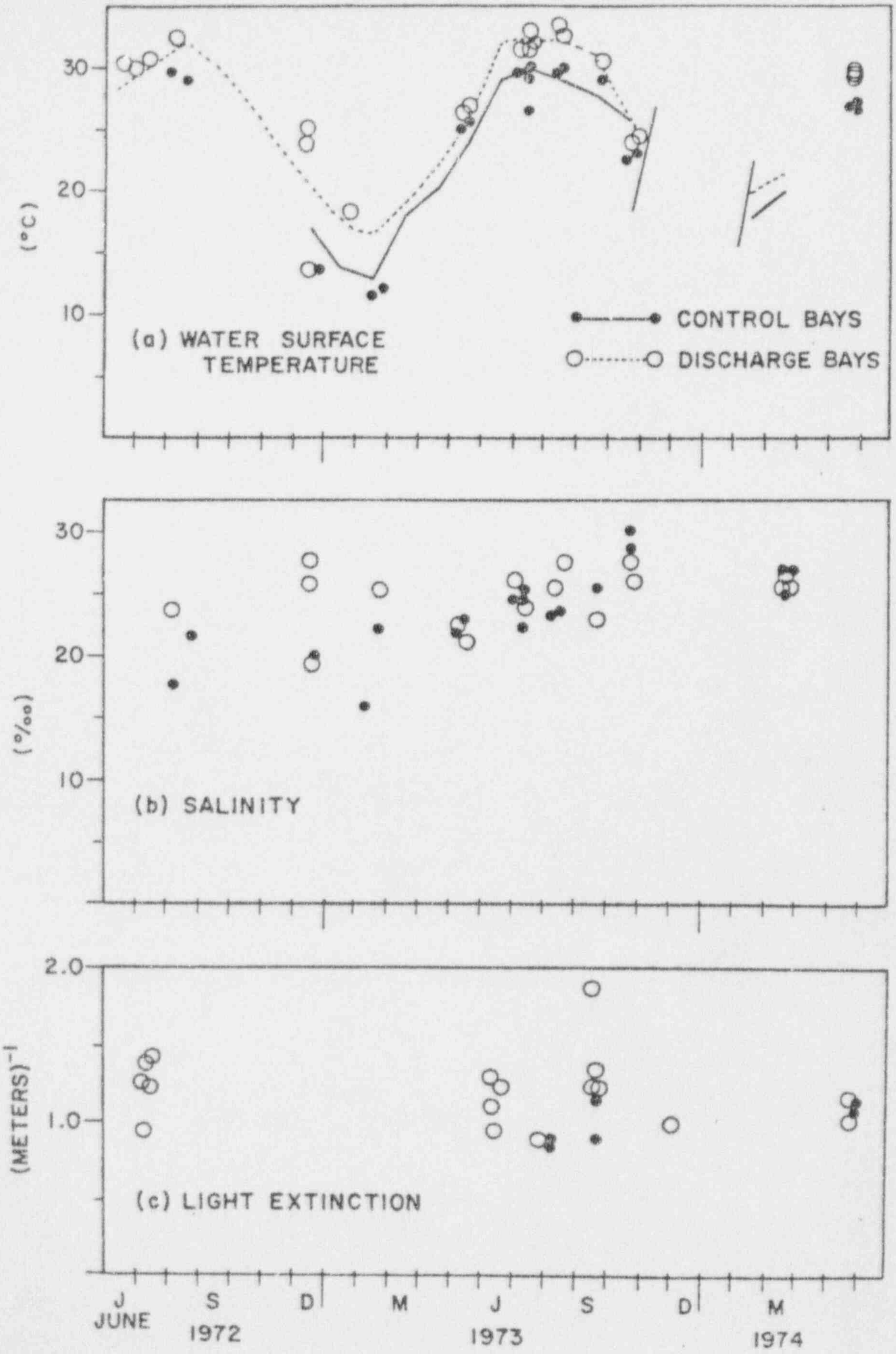


Fig. III-17. Water temperature, salinity and light extinction for outer control and discharge bays. Figures from McKellar (1975) on 1972-74 data. Presentation as in Fig. 6.

the discharge bays, salinities were significantly greater in 1977 than in 1972-74 during summer (29.0 and 23.7 o/oo, respectively) and fall (29.2 and 25.7 o/oo, respectively - two sample t-test, $p = 0.05$). Salinities in the control bays were also higher in 1977 than 1972-74 in the summer (26.9 and 24.8 o/oo, respectively) and fall (27.6 and 24.7 o/oo, respectively)($p = 0.10$).

Higher light extinction values (and therefore higher turbidity) in the discharge bay were significant during fall and winter (two sample t-test).

Total Metabolism

Data on total metabolism of the whole water column are given in Figs. 18 and 19 and Table 17. Gross productivity values ranged from 0.73 to 10.39 gm O_2/m^2/day in the discharge bay and 1.39 to 9.32 gm O_2/m^2/day in the control bay. Productivities for the intake bay peaked in the summer with the lowest values measured in spring and winter (Fig. 18). The discharge bay exhibited a more sustained peak in late summer and fall but productivity did not reach the maximum of that in the control bay. Seasonal differences were not significant (Table 17).

Both net daytime productivity and night respiration followed trends similar to those of gross productivity. Respiration was lower in the discharge bay in the summer, but similar in all the other months (Fig. 19). Net daytime productivity was significantly higher in the winter samples for the discharge bay, but all other differences were not significant (Table 17). Ranges for net productivity were -0.30 to 6.44 and -0.42 to 5.58 gm O_2/m^2/day (12 hr) for the discharge and control bays, respectively.

The ratio of gross productivity to total respiration indicates the

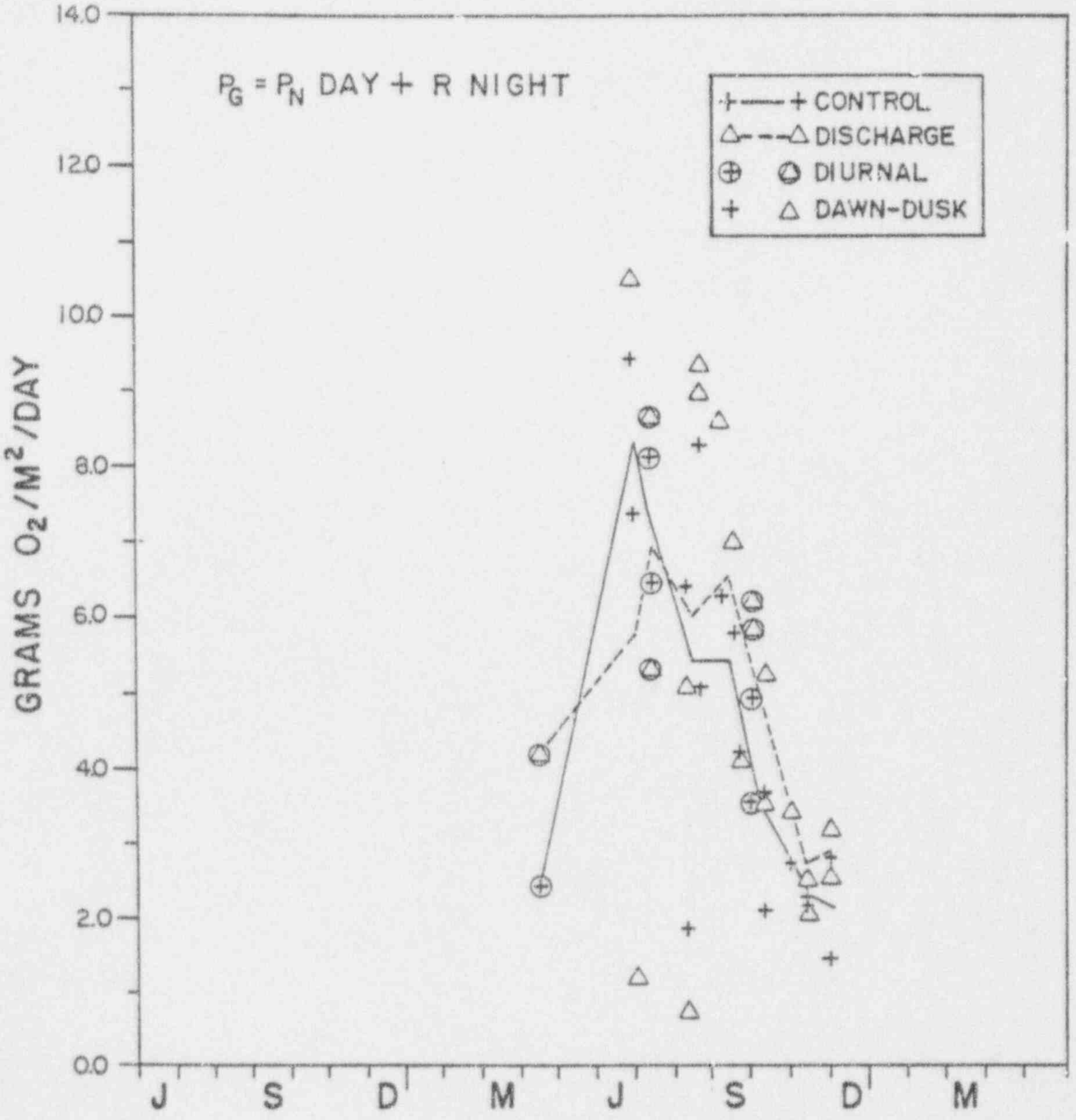


Fig. III-18. Gross productivities of the outer discharge and control bays, 1977. Lines are drawn through monthly averages for both stations.

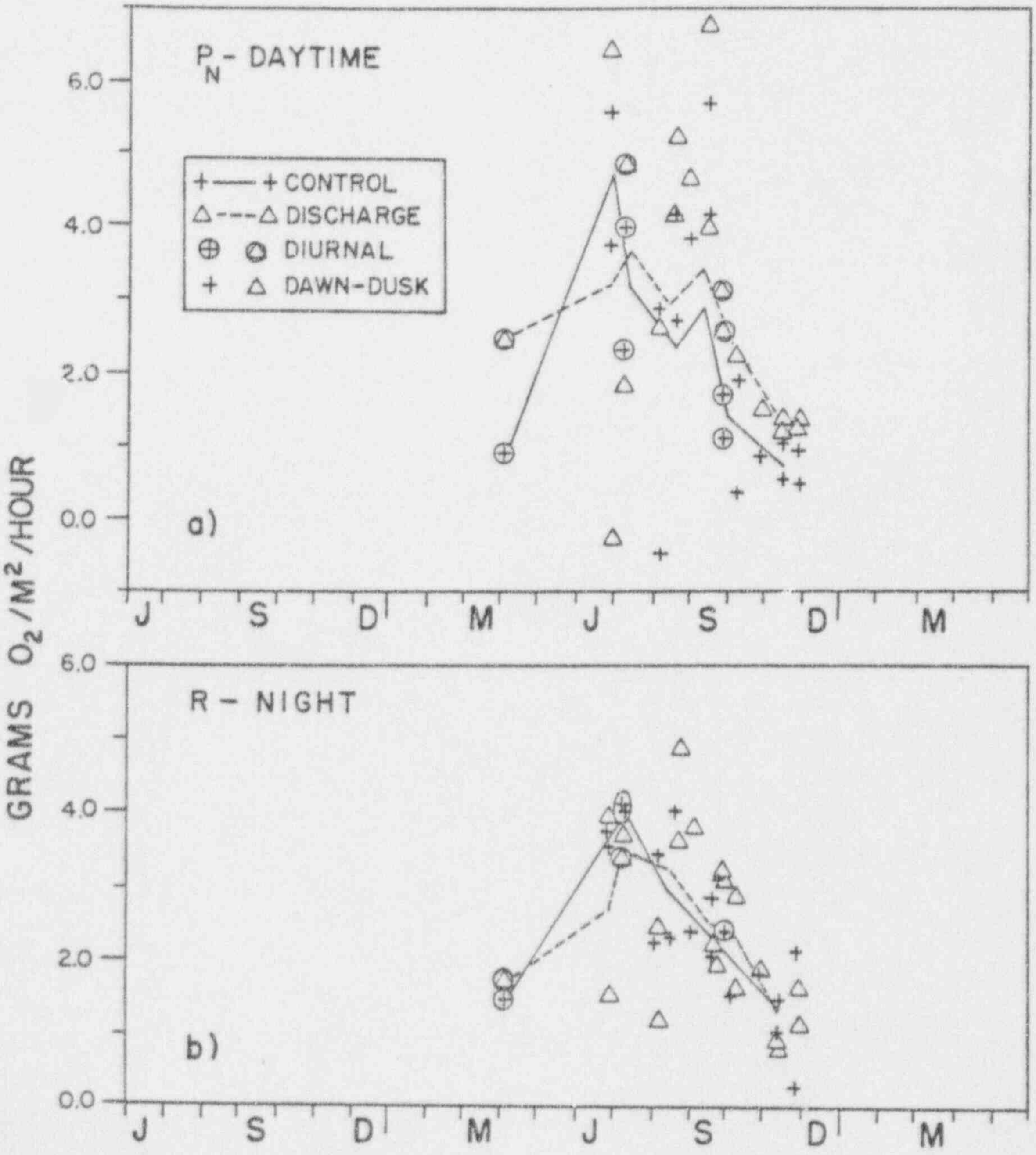


Fig. III-19. Net daytime productivity and night respiration for the outer control and discharge station in 1977. Lines are drawn through monthly averages for both stations.

Table III-17. Season averages for gross productivity ($P_G = P_N + R_{night}$), net productivity (P_N) and night respiration (R) for the outer control and discharge bays. Number of observations is listed in parenthesis; standard error is listed after value. (1977)

Season	P_G (gm $O_2/m^2 \cdot$day)	P_N (gm $O_2/m^2 \cdot$day)	R (gm $O_2/m^2 \cdot$day)
Spring			
Control	2.36(1)	0.96(1)	1.40(1)
Discharge	4.14(1)	2.45(1)	1.69(1)
Summer			
Control	7.73(4)±0.63	3.89(4)±0.67	3.85(4)±0.13
Discharge	6.34(4)±2.02	3.21(4)±1.51	3.14(4)±0.56
Fall			
Control	4.66(11)±0.57	2.08(11)±0.42	2.57(11)±0.22
Discharge	5.78(11)±0.76	2.97(11)±0.50	2.82(11)±0.32
Winter			
Control	2.18(5)±0.23	0.78(5)±0.11*	1.40(5)±0.30
Discharge	2.63(5)±0.23	1.33(5)±0.06*	1.30(5)±0.19
$\bar{X}$ Control	4.54(21)±0.99	2.06(21)±0.34	2.48(21)±0.23
Discharge	5.05(21)±0.61	2.60(21)±0.40	2.47(21)±0.25

* Means for control and discharge are statistically significant at the 95% confidence level (two sample t-test).

Table III-18. Season P/R averages for the outer discharge and control stations. Standard error is listed after values. Number of observations is listed in parenthesis. (1977)

Season	P/R
Spring	
Control	0.84(1)
Discharge	1.22(1)
Summer	
Control	1.01±0.10(4)
Discharge	0.91±0.21(4)
Fall	
Control	0.90±0.07(11)
Discharge	1.00±0.09(11)
Winter	
Control	1.05±0.07(5)
Discharge	0.93±0.19(5)

degree of autotrophy or heterotrophy of a system. No values were significantly different from unity, indicating a balance of organic production and consumption in the bays. Comparison of seasonal P/R ratios show no significant differences between bays (Table 18).

Ecological efficiencies were calculated for each sample for which indication data was available (Table 19). Average ecological efficiencies were nearly identical between the control and discharge bay (0.35% and 0.34%, respectively). Neither total nor season averages were found to be statistically different (two sample t-test, $p = 0.05$).

Plankton Metabolism

Data on metabolism in water measured in dark and light bottles are given in Figs. 20 and 21 and Table 20. Gross plankton productivity ranged from 0.96 to 6.69 gm O_2/m^2/day and 0.51 to 5.04 gm O_2/m^2/day in the discharge and control bays respectively. Net plankton productivity ranged from -1.38 to 6.06 gm O_2/m^2/day in the discharge bay and 0.52 to 3.58 gm O_2/m^2/day in the control bay. Respiration ranged from 0.05 to 2.91 gm O_2/m^2/day in the discharge bay and 0.12 to 2.32 gm O_2/m^2/day in the control bay.

For the control bay, gross plankton productivity peaked in mid summer with an average productivity of 4.05 gm O_2/m^2/day and continued to decline through the last winter samples when the average productivity was 0.72 gm O_2/m^2/day (Table 20 and Fig. 20). Gross plankton productivity in the discharge decreased from spring (2.89 gm O_2/m^2/day) to summer (1.90 gm O_2/m^2/day) and remained low until the August samples (Table 20). Seasonal differences in the discharge bay were not statistically significant except gross plankton productivities were significantly higher in the intake bays in the summer samples.

Table III-19. Ecological efficiencies and solar insolation values for outer control and discharge bays. (1977)

Date	Insolation kcal/m^2·day	Efficiencies (%)	
		Control	Discharge
7-1	4200	0.69	0.11
7-11	7400	0.43	0.46
7-13	5570	0.46	0.37
8-9	4780	0.16	0.06
8-10	6030	0.42	0.33
8-22	3870	0.52	0.15
8-23	5230	0.62	0.68
9-8	6579	0.38	0.52
9-19	6462	0.25	0.25
9-20	4896	0.46	0.57
10-1	5466	0.36	0.45
10-2	5238	0.27	0.44
10-17	6462	0.12	0.32
10-18	6227	0.23	0.22
11-1	2961	0.35	0.44
11-14	4441	0.19	0.18
11-15	4347	0.20	0.22
11-29	2619	0.21	0.47
11-30	3416	0.32	0.29
		$\overline{X}$ =0.35±0.04(S.E)	0.34±0.04

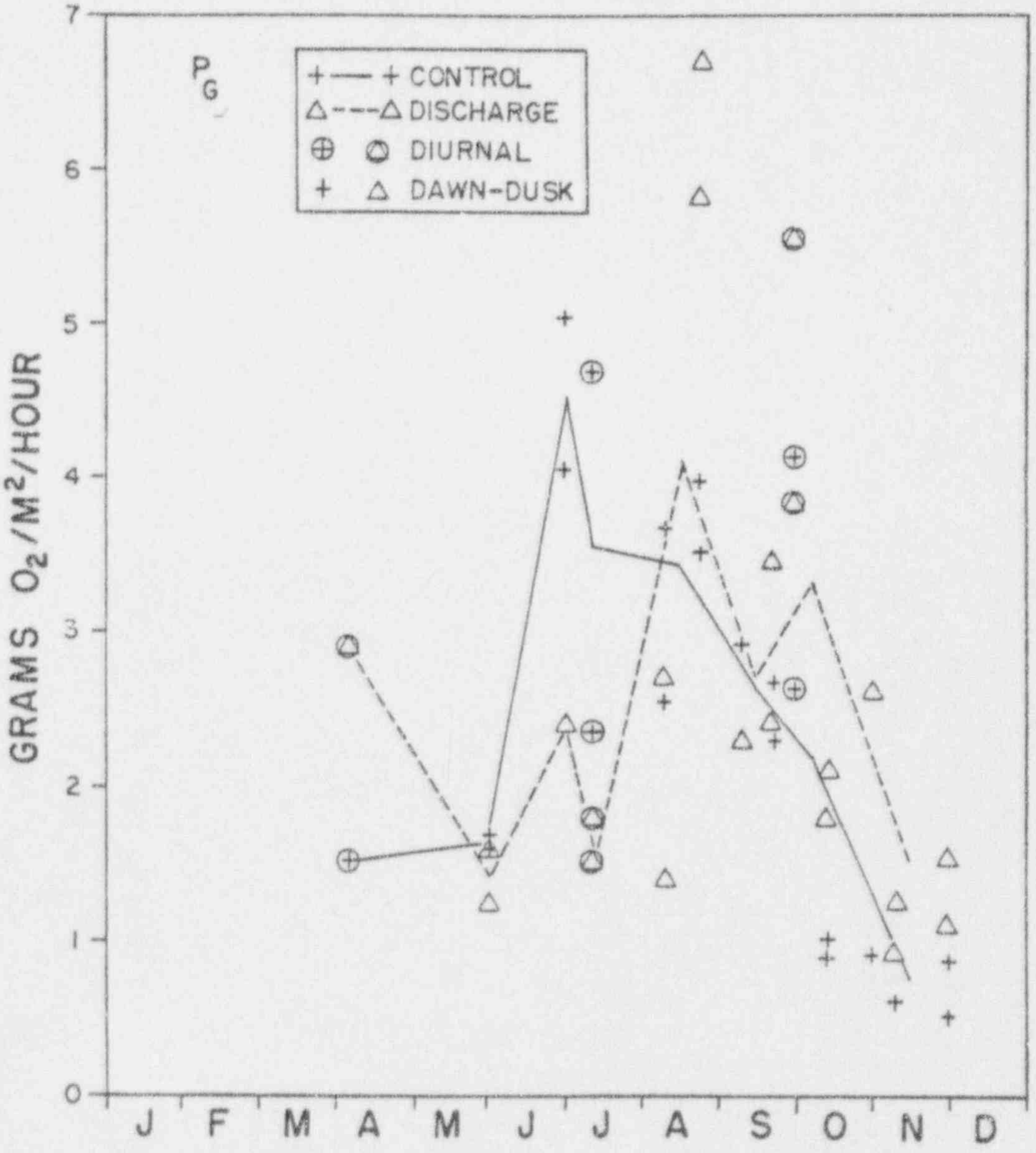


Fig. III-20. Gross plankton productivities for the outer discharge and control bays in 1977. Lines connect monthly means.

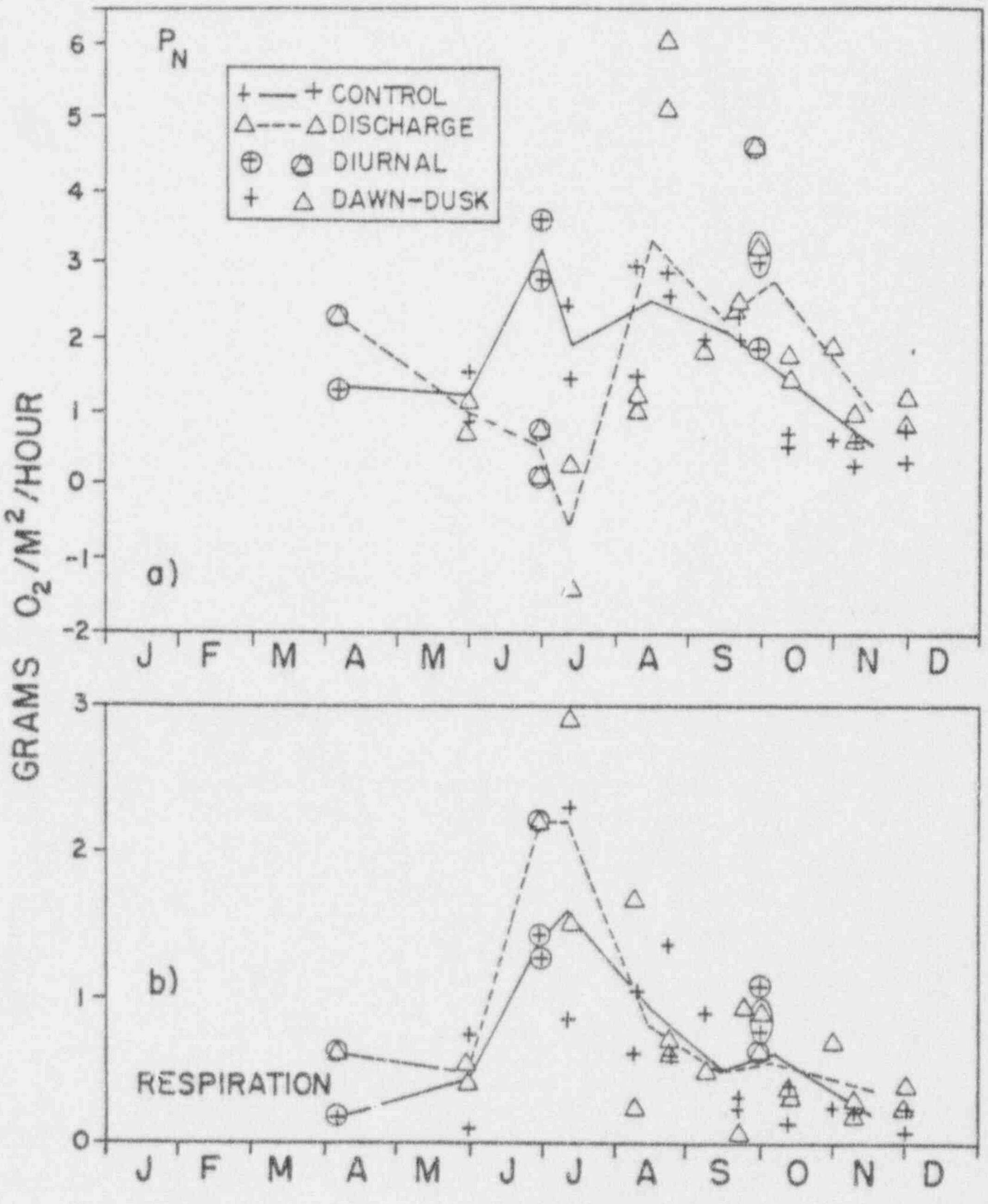


Fig. III-21. Net plankton productivity and plankton respiration for outer control and discharge bays in 1977. Lines connect monthly means.

Table III-20. Season averages for gross plankton productivity ($P_G = P_N + R$) net productivity (P_N) and respiration (R) for the outer control and discharge bays. Number of observations is listed in parenthesis; standard error is listed after value. (1977)

Season	P_G Plankton ($gm\ O_2/m^2 \cdot day$)	P_N Plankton ($gm\ O_2/m^2 \cdot day$)	R Plankton ($gm\ O_2/m^2 \cdot day$)
Spring			
Control	1.51(1)	1.34(1)	0.17(1)
Discharge	2.89(1)	2.27(1)	0.63(1)
Summer			
Control	4.05(4)±0.60*	2.55(4)±0.43*	1.49(4)±0.30
Discharge	1.90(3)±0.26*	-0.03(4)±0.46*	2.20(3)±0.41
Fall			
Control	2.76(11)±0.32	2.06(11)±0.25	0.70(11)±0.12
Discharge	3.46(11)±0.54	2.82(11)±0.52	0.64(11)±0.13
Winter			
Control	0.72(4)±0.10	0.53(5)±0.10	0.22(5)±0.04
Discharge	1.48(5)±0.29	1.11(5)±0.21	0.38(5)±0.08

* Means for control and discharge are statistically significant at 95% confidence (two sample t-test).

Net plankton productivity values in the intake bay were significantly greater than those of the discharge bay only in summer (Table 20). Overall trends were similar to those exhibited by gross productivities.

Plankton respiration for both bays peaked in the summer (1.49 and 2.20 gm O_2/m^2/day for intake and discharge, respectively) and declined to winter values of 0.22 and 0.38 gm O_2/m^2/day (intake and discharge, respectively). Plankton respiration was higher in the discharge bay in spring and summer and approximately equal to the intake plankton respirations in fall and winter. None of the differences were statistically significant (Table 20).

Both outer bays appear to be plankton dominated since gross plankton productivity in bottles was greater than 50% of the gross productivity of the free water measurements on a yearly average. Both stations were plankton dominated for all seasons with two exceptions. In the summer, plankton productivity was 30% of the total community gross productivity for the discharge bay, and in the winter, plankton productivity was 33% of the total community gross productivity for the intake bay.

Discussion

McKellar (1975) showed that the ecosystem in the outer discharge bay exhibited a similar metabolism in comparison with a similar control bay. Gross productivities were only slightly lower than productivity values of the control bay and P/R ratios were approximately 1.0 for the year. In adapting to the higher turnover rate, the outer discharge community exhibited smaller biomass storages with increased turnover rates. The major producer component in the discharge bay was smaller phytoplankton, whereas the more shallow inner bay had a larger benthic metabolism.

This study (1977-78) indicates decreased plankton gross productivity for the discharge bay in summer months, half that of the control bay in the averaged summer values (Table 5). Respiration rates of the plankton were higher.

During the fall and winter sampling periods, respiration declined and productivities increased above the control values. The P/R ratios of one suggest a balance of produced and consumed organic matter by the system in the year overall.

Since the averaged gross productivities for the discharge bay were higher than those of the intake bay, the discharge outer bay ecosystem may have utilized the additional energies supplied by the actions of the power plants.

In 1977-78 the plankton productivity averaged over 50% of the gross productivity of the diurnal curve, which was similar to the conditions of 1973-74. Higher plankton metabolism may be due to increased available nutrients from the marshes, brought in by increased flow rates. A repeated post dawn depression in water oxygen levels suggests the existence of photorespiration diurnal decrease of mixing, or some other phenomenon, in these bays (Odum, Nixon and DiSalvo, 1971).

Summary

1. Temperature and salinity increased significantly in the outer discharge bay with respect to the control bay and the outer discharge bays in 1972-73.
2. Gross productivities in the outer discharge bay were higher on the average than control values but lower than preoperational values.
3. The peak of summer productivity was delayed in the outer discharge bay corresponding to a significant decrease in plankton productivities.

4. For the spring, fall, and winter seasons, the outer discharge bay appeared to increase productivity.

COMMUNITY METABOLISM OF BAYS OB AND C

by

John W. Caldwell

Introduction

This chapter contains the results of a study of the bays furthest offshore from the power plants (OB and C). Monitoring of area C (Fig. 22) provided information about the source of cooling water for the plants as well as serving as a "control" area for its counterpart on the discharge side. Monitoring of area OB indicated changes, if any, in flows, temperatures, and size of the thermal plume occurring further out in the bay system.

Materials and Methods

A detailed discussion of the methods used in this study is given in the first chapter of this report (Benkert).

Diurnal measurements at four hour intervals were taken in area C (Fig. 22) beginning in April, 1977. These measurements were collected once each quarter (April-spring, July-summer, October-fall) on successive days. Diurnal sampling in area OB (Fig. 22) was begun in July, also on successive days and again in the fall (October).

Dawn-dusk-dawn collections were made approximately every two weeks in area C beginning in May, 1977 and in area OB in June, 1977.

Three stations were established in each bay. Salinity, temperature, dissolved oxygen, current speed and direction, wind velocity, Secchi depth, and water depth were recorded at each station. Triplicate O_2 samples were collected at each station during the dawn-dusk-dawn program; duplicate samples were collected during the diurnal runs.

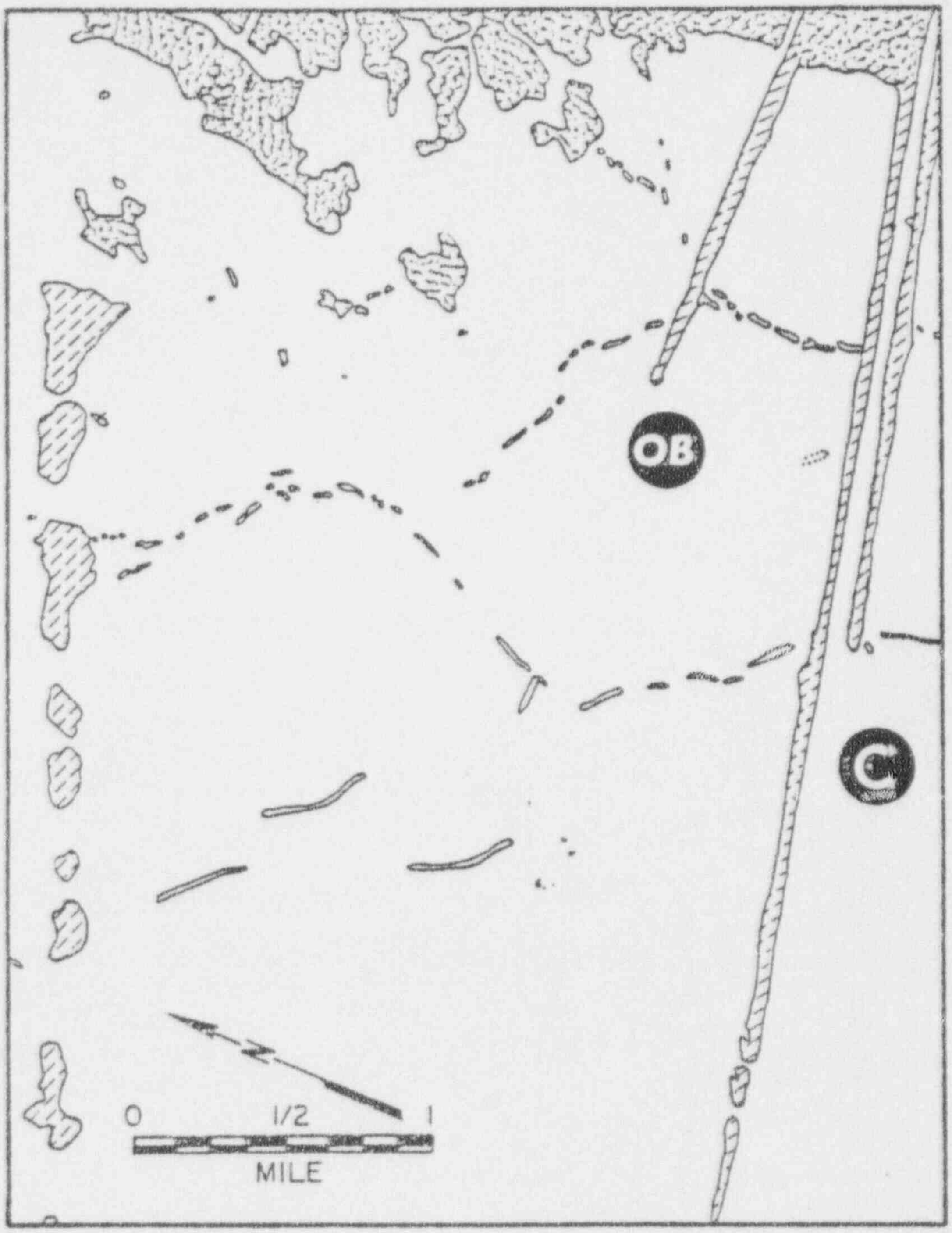


Fig. III-22. Map of Crystal River estuary showing locations of outer bay sampling areas.

Productivities calculated from diurnal samples were plotted graphically as shown in the example in Fig. 23. Dawn-dusk-dawn measurements were calculated according to the equation of McKellar, 1975.

Results

Temperature and Salinity

Data on temperature and salinity are given in Table 21 and Table 22.

Surface water temperatures ranged from 15.58 to 31.82°C in the control bay (C) and 19.98 to 35.00°C in the discharge bay (OB). Water temperatures in the discharge bay were higher (significant at $p = 0.1$, two sample t-test) than the corresponding ambient (control) bay over the year. This ΔT (average 3.4 °C) is a result primarily of the thermal loading of the estuary by the operation of the fossil fuel and nuclear power plants.

The highest average temperatures for both bays were recorded during the summer (Fig. 24), with temperatures gradually decreasing through fall and winter. The ΔT ranged from a high of 4.49°C in the winter to a low of 2.59°C in the summer. Winter and summer discharge bay temperatures were significantly different from their control counterparts while fall discharge values, though higher than in the control, were not significant (Table 22). Fluctuation in ΔT resulted primarily from the periodic shutting down and reduction in operation of one or more of the power plants.

Salinity values for the season are plotted in Fig. 24b. Highest salinity measurements were recorded in the fall. No significant differences were detected between the control and discharge bays (Table 22).

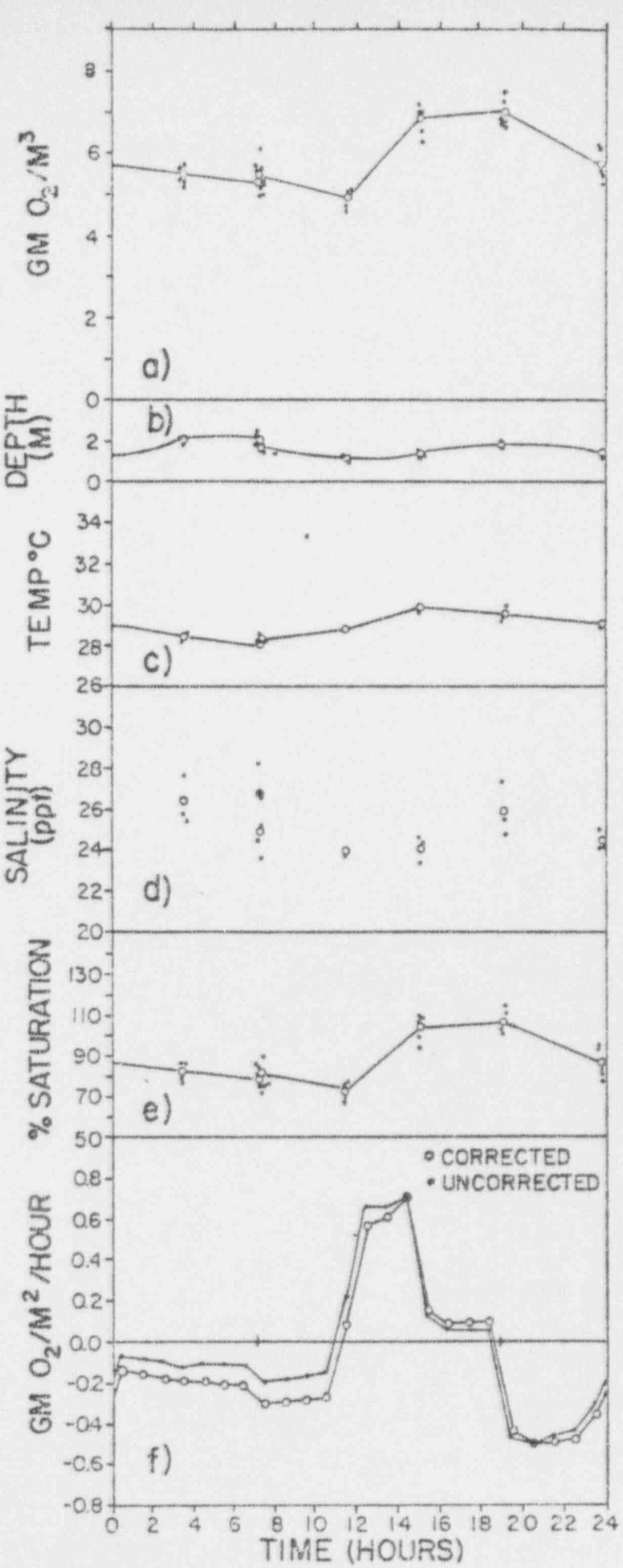


Fig. III-23. Example of diurnal curve calculation.

Table III-21. Mean annual temperature (^{o}C) and salinity (o/oo) values for control area (C) and discharge bay (DB). Number of observations, standard error (S.E.), and minimum and maximum values are indicated for each average. (1977)

	No. of observations	Mean	S.E.	Minimum	Maximum
Temperature (°C)					
Control	21	25.34**	±1.25	15.58	31.82
Discharge	18	28.77**	±1.32	19.98	35.00
Salinity (o/oo)					
Control	21	28.10	±0.47	24.11	31.08
Discharge	18	28.37	±0.47	25.16	31.48

* Means for control and discharge are significant at the 95% confidence level (two sample t-test).

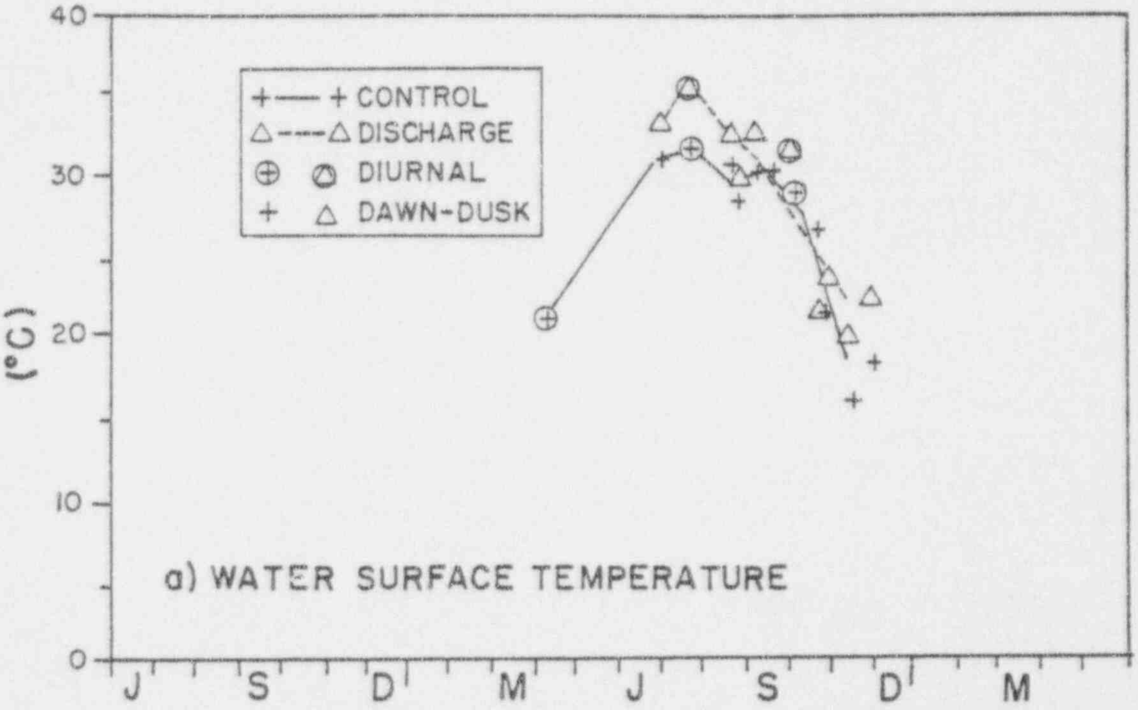
** Means for control and discharge are significant at the 90% confidence level (two sample t-test).

Table III-22. Mean seasonal temperatures (°C) and salinities (o/oo) for the control area (C) and discharge bay (OB). The number of observations is shown in parentheses. The standard error (S.E.) is indicated with each average. (1977)

	Spring	Summer	Fall	Winter
Temperature (°C)				
Control	20.69(1)	29.77±0.48(8)*	26.39±1.89(7)	17.72±1.03(5)*
Discharge	no data	32.36±0.93(6)*	30.37±2.06(7)	22.21±0.93(5)*
Salinity (o/oo)				
Control	24.11(1)	27.71±0.70(8)	29.29±0.60(7)	27.85±1.07(5)
Discharge	no data	27.99±0.54(6)	29.37±0.82(7)	27.46±0.95(5)

* Means for control and discharge are significant at the 95% confidence level (two sample t-test).

** Means for control and discharge are significant at the 90% confidence level (two sample t-test).



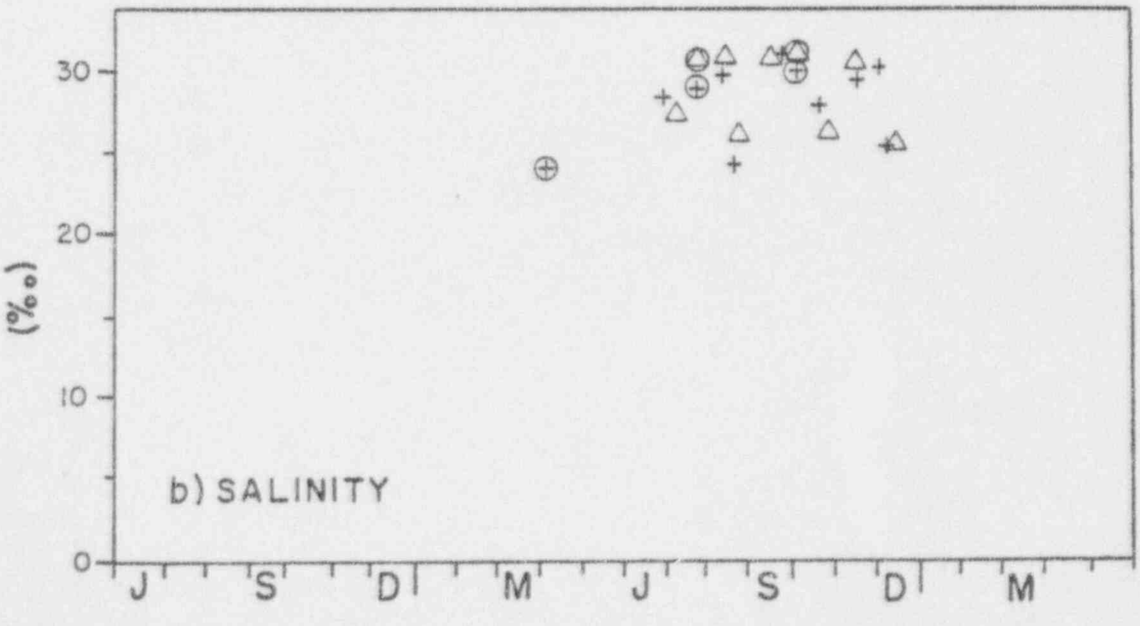


Fig. III-24a. Surface water temperatures for control (C) and discharge (OB) bays. Lines connect monthly means. (1977)
Fig. III-24b. Surface salinity values for control (C) and discharge (B) bays. (1977)

Total Metabolism

Data for productivities are shown in Figs. 25 and 26 and Tables 23 and 24.

Annual mean gross primary productivity (P_G) estimates ranged from 0.99 to 11.86 gm O_2/m^2/day in the control area and 0.15 to 9.26 gm O_2/m^2/day in the discharge bay (Table 23).

Mean annual net productivity (P_N) values were slightly higher in the control area, measurements ranged from 0.66 to 6.02 gm O_2/m^2/day in the control and -2.21 to 4.54 gm O_2/m^2/day in the discharge bay.

Annual night respiration (R) averages were also slightly higher in the control bay. Estimates of R in the two bays included 0.30 to 6.02 gm O_2/m^2/day in the control and 0.80 to 4.85 gm O_2/m^2/day in the discharge.

Gross productivity estimates (P_G) were highest in the control area during the summer (7.98 gm O_2/m^2/day, Fig. 25), tapering off through the fall and reaching their lowest levels in the winter (2.97 gm O_2/m^2/day). Similar estimates for the discharge bay peaked in the fall (9.86 gm O_2/m^2/day) with lower values occurring in both the summer and winter (Fig. 25). Comparison between the two bays showed significantly higher P_G values in the control bay during the summer (Table 24).

Net productivity values (P_N) showed a trend similar to gross productivity (Fig. 26). Values in the control bay during the summer were significantly higher than the discharge bay (Table 24); the control reaching its lowest levels in the winter (1.26 gm O_2/m^2/day). The discharge bay reached its highest net productivity levels in the fall (3.25 gm O_2/m^2/day) followed by winter and summer, respectively. The trend was reversed in fall and winter with discharge values significantly

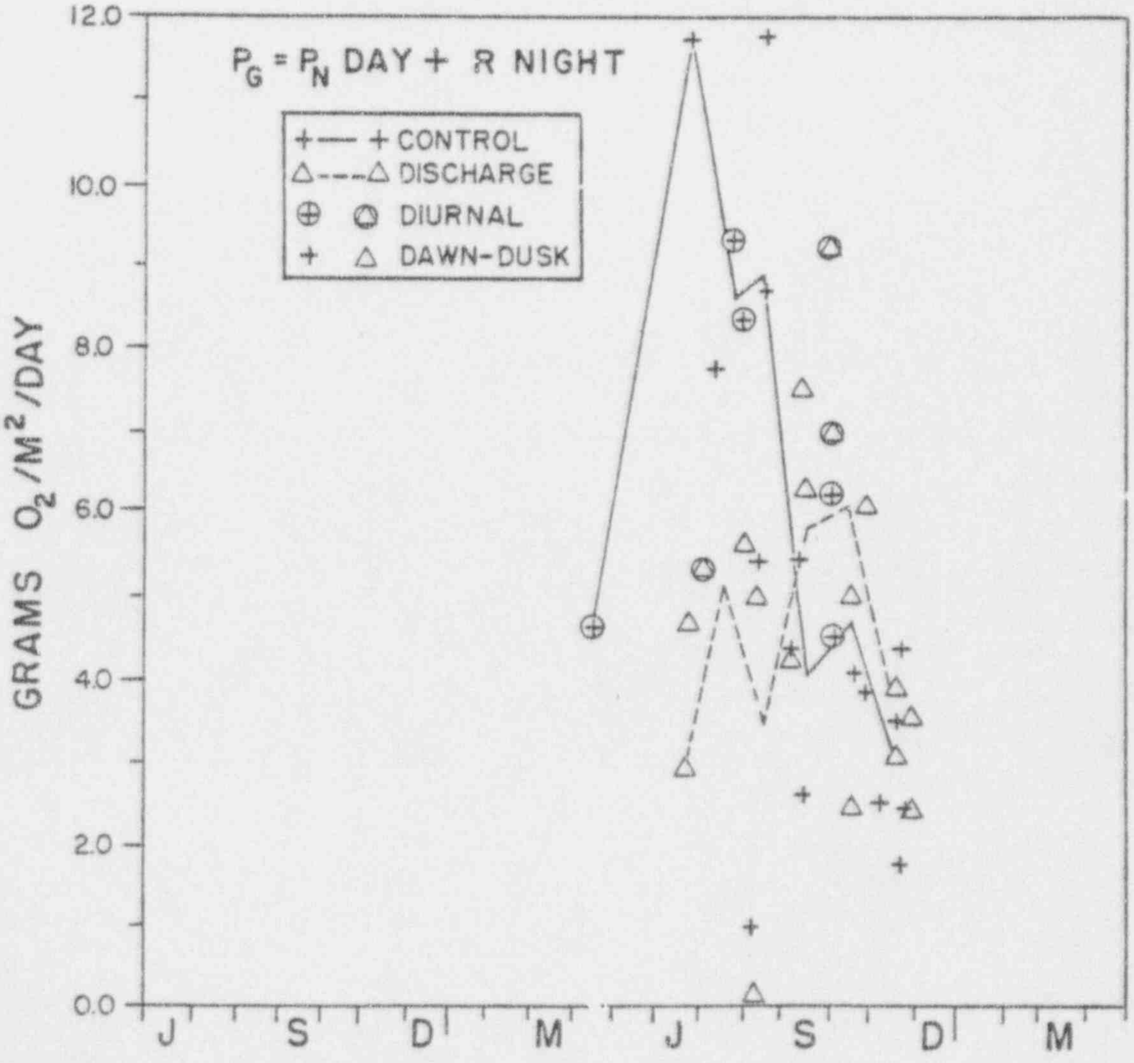


Fig. III-25. Gross productivity (P_G) estimates for the control (C) and discharge (OB) bays. (1977)

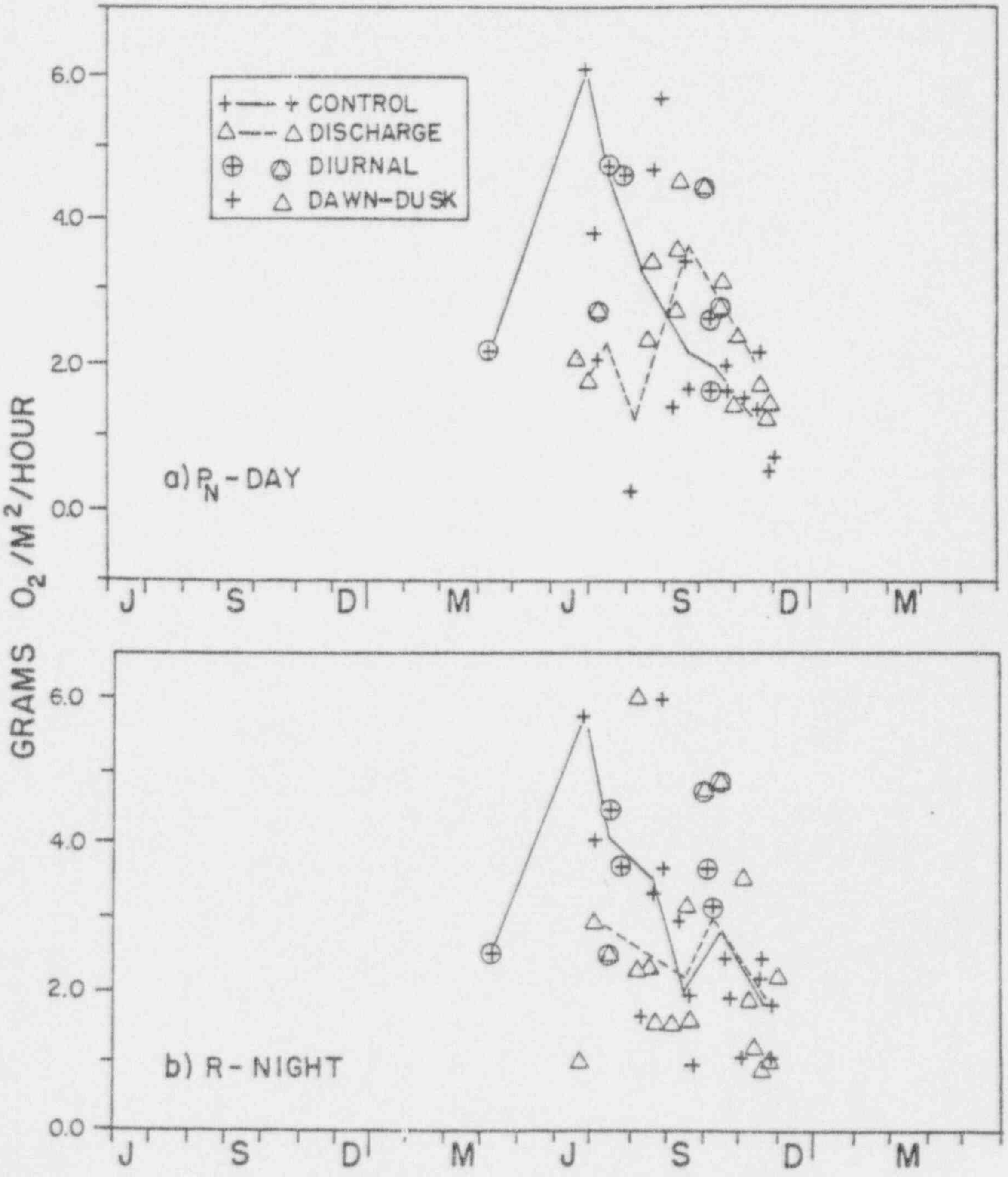


Fig. III-26a. Net productivity (P_N) estimates for the control (C) and discharge (OB) bays. Lines connect monthly means. (1977)
Fig. III-26b. Night respiration (R) estimates for the control (C) and discharge (OB) bays. Lines connect monthly means. (1977)

Table III-23. Mean annual estimates of gross primary productivity (P_G), net productivity (P_N) and night respiration (R) for the control (C) and discharge bays (OB). The number of observations are shown in parentheses; standard error (S.E. and maximum and minimum values are indicated for each average. Data are expressed in gm $O_2/m^2 \cdot$day. (1977)

	No. of observations	Mean	S.E.	Minimum	Maximum
Gross productivity (P_G)					
Control	21	5.44	±0.67	0.99	11.86
Discharge	18	4.70	±0.50	0.15	9.26
Net productivity (P_N)					
Control	21	2.64	±0.37	0.66	6.02
Discharge	18	2.40	±0.34	-2.21	4.54
Night respiration (R)					
Control	21	2.80	±0.33	0.30	6.02
Discharge	18	2.30	±0.29	0.80	4.85

* Means for control and discharge are significant at the 95% confidence level (two sample t-test).

** Means for control and discharge are significant at the 90% confidence level (two sample t-test).

Table III-24. Mean seasonal estimates for gross primary productivity (P_G), net productivity (P_N), and night respiration (R) for the control (C) and discharge bays (OB). Number of observations are shown in parenthesis; the standard error (S.E.) is indicated with each average. The data are expressed in gm $O_2/m^2 \cdot$day. (1977)

	Spring	Summer	Fall	Winter
Gross primary productivity (P_G)				
Control	4.68	7.98±1.25(8)*	4.41±0.44(7)	2.97±0.45(5)
Discharge	no data	3.98±0.83(6)*	5.86±0.86(7)	3.93±0.63(5)
Net productivity (P_N)				
Control	2.21(1)	4.08±0.65(8)*	2.04±0.28(7)*	1.26±0.27(5)**
Discharge	no data	1.71±0.81(6)*	3.25±0.39(7)*	2.02±0.27(5)**
Night respiration (R)				
Control	2.47(1)	3.90±0.63(8)*	2.37±0.35(7)	1.71±0.25(5)
Discharge	No data	2.27±0.37(6)*	2.61±0.60(7)	1.90±0.48(5)

* Means for control and discharge are significant at the 95% confidence level (two sample t-test).

** Means for control and discharge are significant at the 90% confidence level (two sample t-test).

higher than the control area (Table 24).

Gross primary productivity, net productivity, and night respiration were all lower in the discharge bay in the summer (significant, $p = 0.05$; paired t-test), but were higher in the same bay during fall and winter.

Night respiration (R) followed a trend similar to gross and net productivity (Fig. 26). The control was significantly higher (Table 24) than the discharge bay during the summer.

Plankton Metabolism

Gross plankton productivity ranged from 0.73 to 9.88 gm O_2/m^2/day in the control area and 0.80 to 7.26 gm O_2/m^2/day in the discharge area. Over the year, gross plankton productivity was significantly higher in the control bay (Table 25).

Mean annual net plankton productivity was slightly higher in the control area as compared to the discharge bay (3.06 gm O_2/m^2/day and 2.18 gm O_2/m^2/day, respectively), the values ranging from 0.43 to 8.75 gm O_2/m^2/day in the control and -0.14 to 6.23 gm O_2/m^2/day in the discharge area (Table 25).

Plankton respiration values were recorded from 0.20 to 4.29 gm O_2/m^2/day in the control and 0.07 to 1.24 gm O_2/m^2/day in the discharge bay. The annual plankton respiration average was significantly higher in the control bay (Table 25).

Gross plankton productivity peaked in both the control and discharge bays (6.54 gm O_2/m^2/day and 4.03 gm O_2/m^2/day, respectively) during the summer (Fig. 27), with the control bay showing the higher productivity. This difference was not significant, although it should be noted that the summer discharge mean represents only two samples (Table 26). The control was also slightly higher in the fall with the trend reversing itself in the winter (discharge higher than control).

Table III-25. Mean annual gross plankton productivity, plankton net productivity, and plankton respiration for the control area (C) and discharge bay (OB). The number of observations, standard error (S.E.), and minimum and maximum values are indicated for each average. Units are gm $O_2/m^2\cdot$day. (1977)

	No. of observations	Mean	S E.	Minimum	Maximum
Gross plankton productivity					
Control	21	4.39**	±0.59	0.73	9.88
Discharge	14	2.87**	±0.47	0.80	7.26
Net plankton productivity					
Control	21	3.06	±0.45	0.43	8.75
Discharge	14	2.18	±0.43	-0.14	6.23
Plankton respiration					
Control	21	1.35*	±0.23	0.20	4.29
Discharge	14	0.69*	±0.10	0.07	1.24

* Means for control and discharge are significant at the 95% confidence level (two sample t-test).

** Means for control and discharge are significant at the 90% confidence level (two sample t-test).

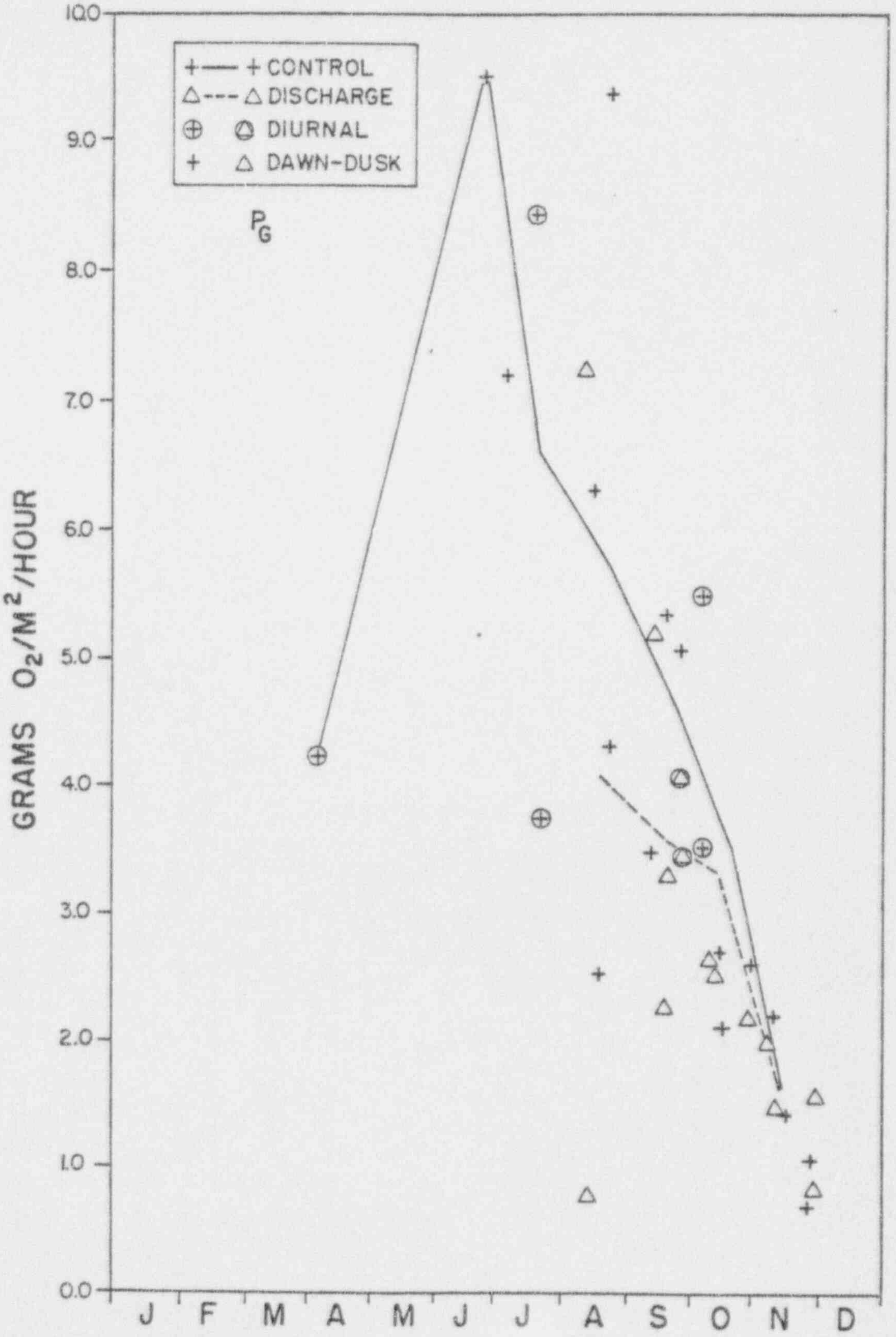


Fig. III-27. Gross plankton productivity estimates for the control (C) and discharge (OB) bays. (1977)

Table III-26. Mean seasonal gross plankton productivity, net plankton productivity, and plankton respiration for the control area (C) and discharge bay (OB). The number of observations are shown in parentheses; standard error (S.E.) is indicated for each average. Units are gm $O_2/m^2\cdot$day. (1977)

	Spring	Summer	Fall	Winter
Gross plankton productivity				
Control	4.22(1)	6.54±1.00(8)	3.96±0.49(7)	1.60±0.34(5)
Discharge	no data	4.03±3.23(2)	3.40±0.37(7)	1.67±0.22(5)
Net plankton productivity				
Control	2.97(1)	4.21±0.94(8)	3.07±0.41(7)	1.22±0.28(5)
Discharge	no data	3.05±3.19(2)	2.58±0.39(7)	1.28±0.19(5)
Plankton respiration				
Control	1.25(1)	2.34±0.34(8)*	0.92±0.17(7)	0.38±0.11(5)
Discharge	no data	0.99±0.05(2)*	0.82±0.12(7)	0.38±0.15(5)

* Means for control and discharge are significant at the 95% confidence level (two sample t-test).

** Means for control and discharge are significant at the 90% confidence level (two sample t-test).

Net plankton productivity showed a trend similar to gross productivity (Fig. 28a); both bays peaking in the summer, decreasing to a low in the winter. Plankton respiration was similar (Fig. 28b). The control bay was significantly higher than the discharge bay in the summer (Table 26) and both bays showed equal respiration values in the winter.

Gross plankton productivity, net plankton productivity, and plankton respiration were generally less in the discharge bay over the year. Only in the winter were discharge values higher in gross and net plankton productivity. As with total metabolism, greatest differences occurred during the summer months with plankton respiration significantly less ($p = 0.05$, two sample t-test).

Ecological efficiencies were calculated for both bays as a measure of efficiency of solar insolation utilization (Table 27). Ecological efficiency was less in the discharge bay in the summer, greater in the same bay during the fall and winter, and equal in both bays over the year.

Both control and discharge bays were plankton dominated throughout the year (more than 50% of gross productivity) except in winter in the discharge area when the plankton contribution was estimated as 43%.

Discussion

Temperature and Salinity

Water temperatures in the discharge bay were higher than the corresponding ambient (control) bay over the year. This ΔT (average 3.43°C) is a result primarily of the thermal loading of the estuary by the operation of the fossil fuel and nuclear power plants. Peak temperatures were recorded during the summer, however, with the smallest ΔT being recorded. The lowest temperatures were found in the winter with this season showing the highest Δ T.

Salinities, although slightly higher in the discharge area, were not significantly different. The expected (McKellar, 1975) drawing in and consequent release into the discharge area of higher salinity offshore water due to the increased pumping of the nuclear plant apparently did not manifest itself in this discharge bay. It is possible that, due to the distance of this discharge bay from the power plant discharge, by the time water reaches the bay it is "diluted" somewhat by the advective exchange of water between the bay itself and the open gulf. This exchange of water is probably more prevalent in this area because its western boundary is not clearly defined by the oyster bars present in the other discharge bays.

Total Metabolism

Gross primary productivity, net productivity, and night respiration were all depressed in the summer in the discharge bay, but were higher in the same bay during fall and winter. This depression suggests an initial disordering of the system as a result of the high temperatures encountered in the discharge bay during the summer, with an enhancement (maximum 35°C) of the system during the cooler months which enabled the bay to sustain higher productivities and respiration for a longer period of time than its control counterpart. The 35°C temperature maximum achieved during the summer probably represents a level of temperature stress the present ecosystem is less tolerant of, resulting in a depression of prodictivity. In the cooler months the system is able to utilize the additional energy (heat) available to stimulate productivity. All of this suggests the present system has a temperature maximum above which the system is depressed and below which the system is stimulated.

Plankton Metabolism

Gross plankton productivity, net plankton productivity and plankton respiration were generally depressed in the discharge bay over the year. Only in the winter were discharge values higher in gross and net plankton productivity. As in the total metabolism estimates, greatest differences in plankton metabolism values occurred during the summer months with plankton respiration showing the most significant depression. Again, this is probably a result of the high temperatures encountered during the summer, although stimulation of the system during the cooler months was not as evident until the winter. Even during this season, discharge values were only slightly higher and not significant.

Ecological Efficiency

This parameter followed the same trend as the productivity estimates, showing a depression in the discharge bay in the summer and a stimulatory effect in the same bay during the fall and winter. Again, this emphasizes the transition effect of the high summer temperatures on the discharge system and the enhancement of the system during the cooler months.

Summary

1. Temperatures measured at area OB in the discharge bay were 3.4°C warmer over the year when compared to the control bay.
2. Salinity was not significantly different between the two bays.
3. Gross primary productivity, net productivity, and night respiration were less in the discharge bay during the summer.

4. Gross primary productivity, net productivity, and night respiration were higher in the discharge bay than in the control bay during the fall and winter.

5. Gross plankton productivity, net plankton productivity and plankton respiration were lower in the discharge bay than in the control area in the summer.

6. Metabolism measurements were similar to the other outer discharge bay and higher than the inner bay system.

7. Mean annual ecological efficiency estimates for the control and discharge bays were equal.

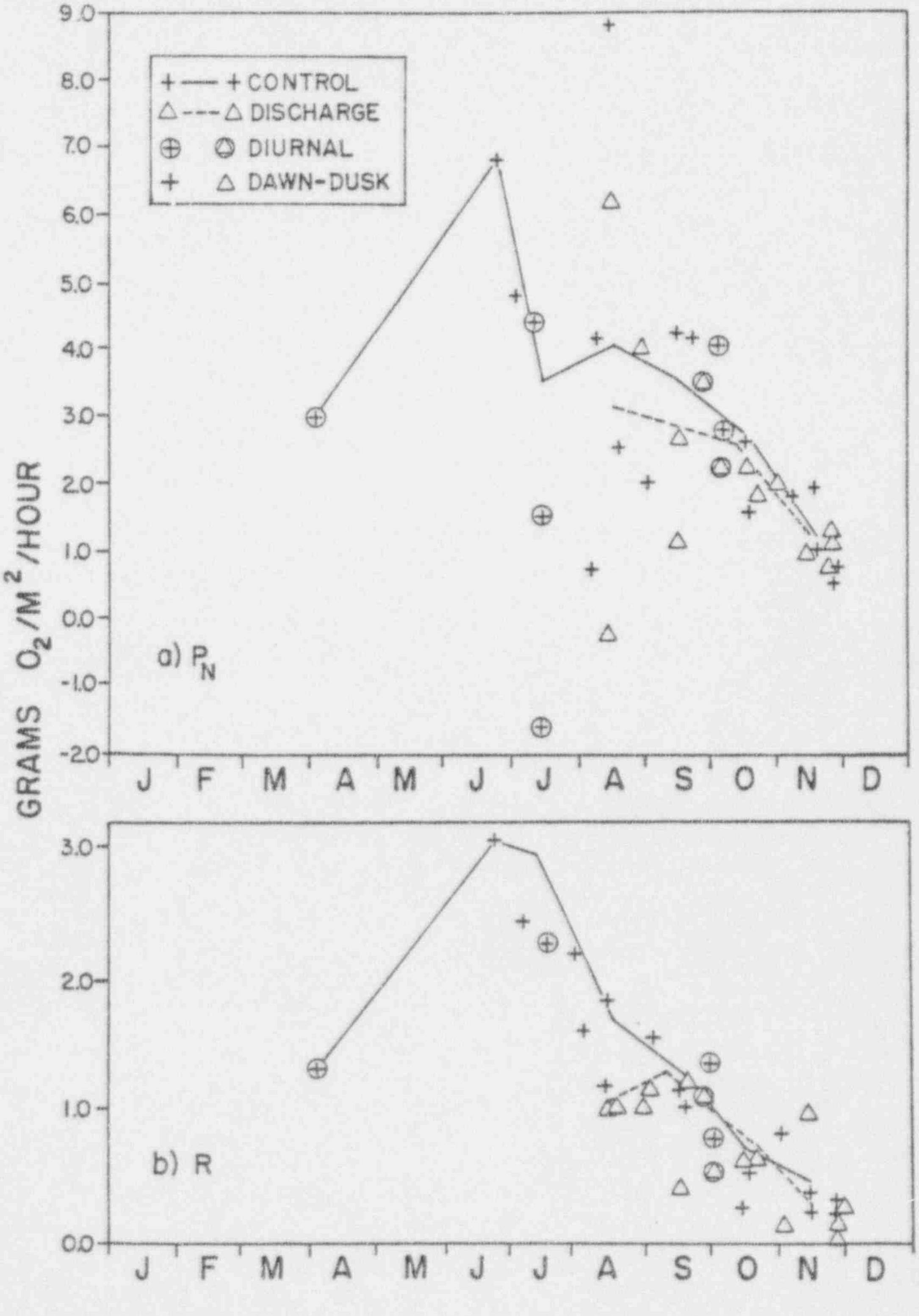


Fig. III-28a. Net plankton productivity estimates for the control (C) and discharge (OB) bays. Lines connect monthly means. (1977)
Fig. III-28b. Plankton respiration estimates for the control (C) and discharge (OB) bays. Lines connect monthly means. (1977)

Table III-27. Ecological efficiencies and solar insolation values for control (C) and discharge OB) bays. (1977)

Ecological Efficiencies

Date	Insolation ($kcal/m^2 \cdot day$)	Efficiencies (%) (C) Control	Efficiencies (%) (OB) Discharge
7/1	4200	0.75	0.46
7/11	7400	0.50	---
7/13	5570	0.60	0.38
8/9	4780	0.08	0.01
8/10	6030	0.35	---
8/22	3870	0.87	0.59
8/23	5230	0.91	0.37
9/8	6579	0.26	0.26
9/19	6462	0.33	0.47
9/20	4896	0.21	0.43
10/1	5466	0.46	0.68
10/2	5238	0.35	0.54
10/17	6462	0.25	0.31
10/18	6227	0.25	0.16
11/1	2961	0.36	0.84
11/14	4441	0.31	0.28
11/15	4347	0.41	0.38
11/29	2619	0.27	0.38
11/30	3416	0.30	0.45
		$\overline{X}$ = 0.41±0.05 (S.E.)	$\overline{X}$ = 0.41±0.05 (S.E.)

COMMUNITY METABOLISM OF THE CANAL ECOSYSTEMS

by

Robert Knight

Introduction

This chapter includes data on metabolism in canals. Kemp (1977) studied metabolism and other properties of the intake and discharge canal ecosystems. At that time unit 3 was not yet in operation and therefore flows were lower and temperatures in the discharge canal were lower. Kemp found that net photosynthesis, estimated gross photosynthesis, and nighttime respiration were higher in the discharge canals except during the summer and early fall when the pattern was reversed with lower values for the three parameters in the discharge canal. The discharge canal had higher current velocity (20 cm/sec as opposed to 9 cm/sec in the intake canal), higher nutrient levels, and a higher metabolism in winter. Metabolism was less in the discharge canal when water temperatures reached 37.7°C.

In the present study, data from the discharge canal are compared to the intake canal and data for both canals are compared to the previous study. With the addition of the third unit, water flow has increased from 2410 m^3/min to 4776 m^3/min, resulting in calculated current velocities of 11 m/min in the intake canal and 23 m/min in the discharge canal. Maximum temperatures observed in the discharge canal have exceeded 39°C.

Methods

Three upstream-downstream diurnal oxygen studies have been made for each canal in 1977. Three stations were measured in each canal so that a total of twelve metabolism values are available for comparison to previous studies.

Duplicate oxygen samples were taken from surface water at each station at four hour intervals. Stations were labeled as I-O, I-M, and I-S for the intake canal and D-B, D-1, and D-2 for the discharge canal (Fig. 29). Average flow times between stations were calculated from pumping rates and channel cross-sectional area (Fig. 29). Temperature, depth, salinity, current speed, and Secchi depth were recorded when each sample was collected.

Data were graphed for each station, and depth, dissolved oxygen (DO), and percent saturation were estimated for each hour. Average depth, percent saturation, and DO change per hour for a given water mass were obtained using the flow times given in Fig. 29 without correction for tidal flow. Because of higher current velocities during this study the correction for tidal flow was not important ($<$10% of total flow). A corrected rate-of-oxygen-change graph was constructed using diffusion coefficients of: intake canal - 0.6 g $O_2/m^2/hr$ at 100% saturation deficit; intake basin - 0.4; and discharge canal - 2.0. These values were derived from a graph presented by McKellar (1975) using the current velocities given above.

There are two concepts for net daytime photosynthesis; one includes negative daytime net photosynthesis. Both methods of calculating community metabolism from diurnal oxygen curves were applied to the canal data (see Fig. 30). The first of these methods is similar to the one employed by Kemp (1977) for these same systems and was made so that the before and after data could be compared.

The first method counts any daytime positive area above the zero rate-of-change line as P_{net} and <u>any</u> area under the line as R_{night}. This

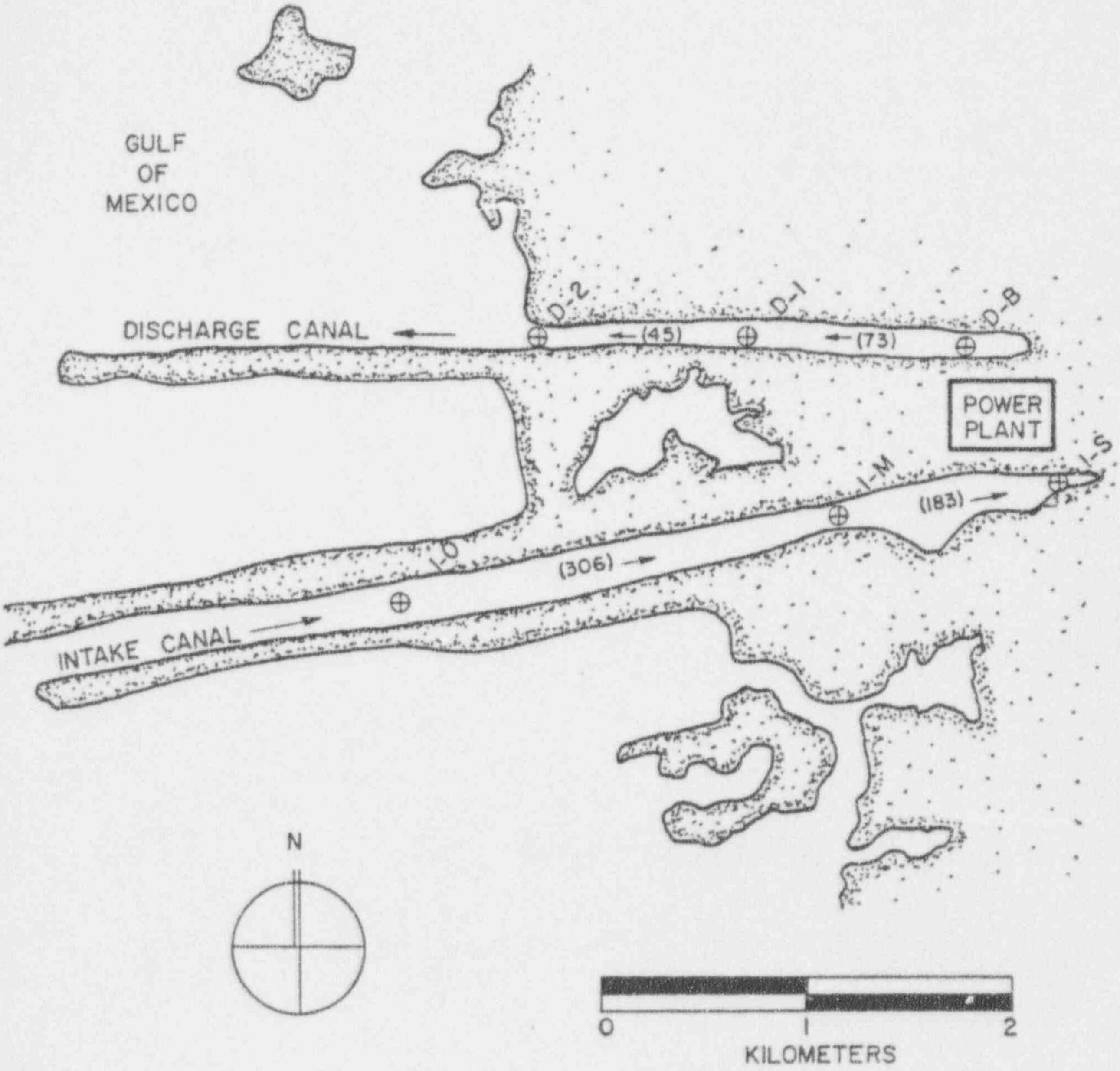


Fig. III-29. Map showing intake and discharge canal sampling stations. Numbers in parentheses are average flow times between stations in minutes.

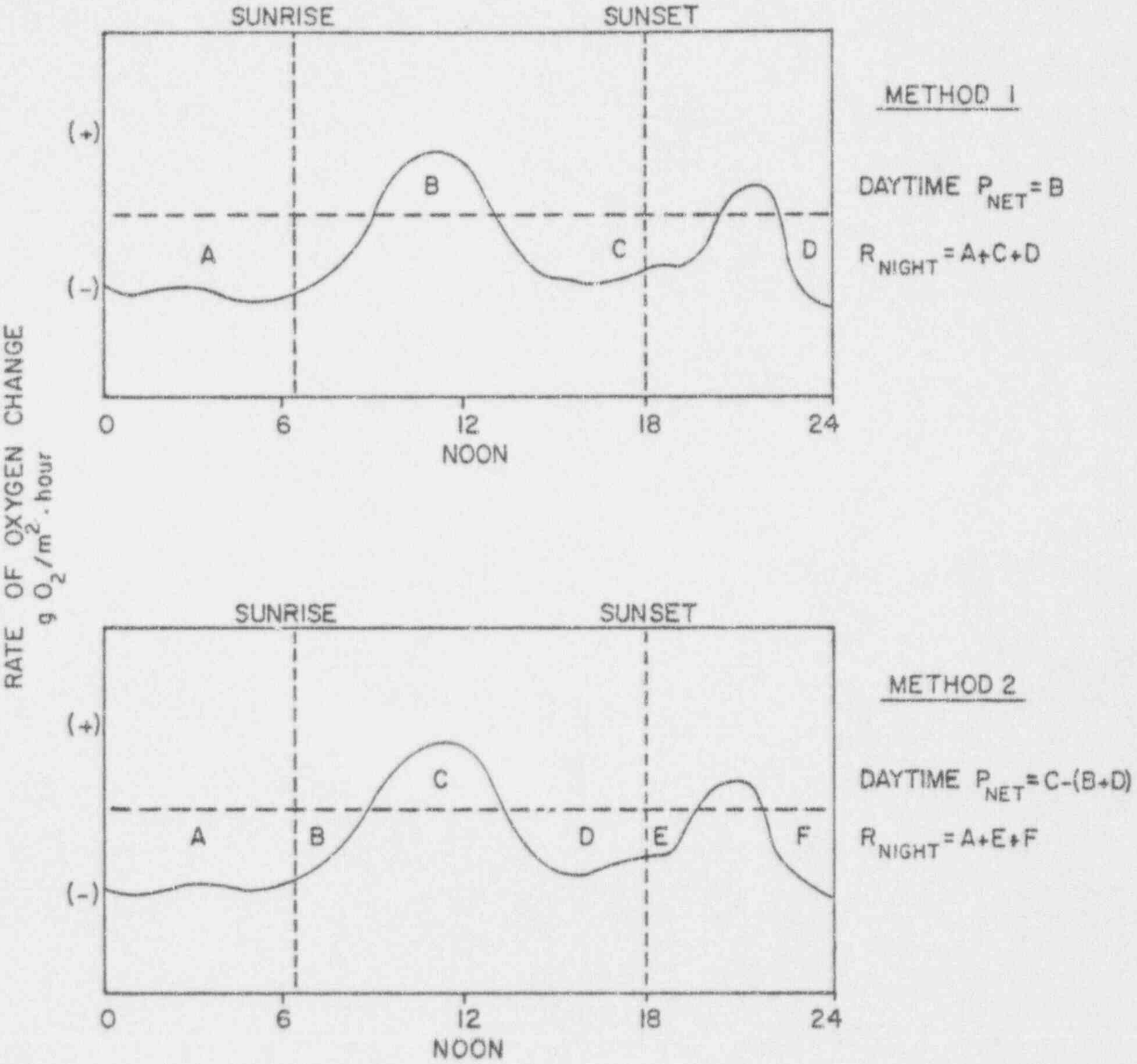


Fig. III-30. Illustration of two methods for calculating metabolism from diurnal oxygen curves for canal data. Letters on the figures represent the area bounded by the solid and dotted lines.

method is satisfactory for "normal" curves where the oxygen rate-of-change is always positive during the day and negative at night. Our data gave examples of several situations with daytime negative rate-of-changes and nighttime positive values.

Negative daytime values can indicate a negative P_{net} where R is exceeding P_{gross} and the system is living off of storages or imports of organic matter. Positive nighttime values may indicate localized turbulence or mixing of dissimilar water masses and were discounted by both methods.

Results

Diurnal curves summarizing data from the power plant canals and oxygen saturation values from the point of intake, discharge, and outer bay are located in Appendix III-4.

Table 28 is a presentation of metabolism values calculated from the graph according to the first method given in Fig. 30. None of the data are significantly different between the intake and discharge canals at 95% level of confidence.

Table 29 presents the calculations made on the same data using the second method presented in Fig. 30. Using this calculation method we see that P_{net} was nearly zero or negative in many cases. Nighttime respiration was found to be lower using this method. Due to the variability of the data, no significant differences were observed between intake and discharge so that we can make only tentative conclusions. P_{net} appeared to be lower in the discharge canal than in the intake and R_{night} was about the same for the two canals.

Fig. 31 shows old and new data on daytime net photosynthesis and

Table III-28. Results of diurnal metabolism studies in canals at the Crystal River plant with third unit in operation. Calculations were made according to the method used by Kemp (1977).

Date 1977	Site	Sunlight kcal/m^2·day	Max. temp. °C	Metabolism g O_2/m^2·day			P/R
				P_N	R_N	P_G	
July 13	Intake canal						
to	Io→Im	5570	32.1	3.56	8.15	11.71	.72
July 14	Im→Is		31.7	3.28	7.36	10.64	.72
	Mean			3.42	7.76	11.18	.72
	(2 S.E.)			(0.28)	(0.79)	(1.07)	.76
	Discharge canal						
	DB→D1	5570	39.2	3.02	5.81	8.83	.76
	D1→D2		38.8	1.09	13.89	14.98	.54
	Mean			2.06	9.85	11.90	.60
	(2 S.E.)			(1.93)	(8.08)	(6.15)	
Oct. 1	Intake canal						
to	Io→Im	5466	30.0	2.92	5.69	8.61	.76
Oct. 3	Im→Is		30.3	1.72	7.43	9.14	.62
	Io→Im	5238	30.0	1.91	4.39	6.30	.72
	Im→Is		29.9	1.49	6.09	7.58	.62
	Mean			2.01	5.90	7.91	.67
	(2 S.E.)			(.63)	(1.25)	(1.25)	
	Discharge canal						
	D13→D1	5466	36.5	.62	13.13	13.75	.52
	D1→D2		35.6	7.29	5.33	12.62	1.18
	DB→D1	5238	36.4	.26	9.59	9.85	.51
	D1→D2		35.7	.08	5.22	5.30	.51
	Mean			2.06	8.32	10.38	.62
	(2 S.E.)			(3.49)	(3.80)	(3.76)	

Arrows indicate zone between which oxygen curves were subtracted to obtain changes in flowing water.

(Parentheses indicate 2 standard errors of the mean.)

Table III-29. Results of diurnal metabolism studies in canals at Crystal River plant with third unit in operation (1977). Alternate method of calculation was used.

Date 1977	Site	Sunlight kcal/m^2. day	Max. temp. °C	Metabolism g O_2/m^2	
				P_{net}	R_{night}
July 13 to July 14	Intake canal				
	Io → Im	5570	32.1	2.43	7.14
	Im → Is		31.7	-3.52	7.36
	Mean			-0.54	7.25
	(2 S.E)			(5.95)	(0.22)
	Discharge canal				
	DB → D1	5570	39.2	-1.54	1.28
	D1 → D2		38.8	-2.92	10.04
	Mean			-2.23	5.66
	(2 S.E.)			(1.38)	(8.76)
Oct. 1 to Oct. 3	Intake canal				
	Io → Im	5466	30.0	1.51	4.48
	Im → Is		30.3	-0.46	5.43
	Io → Im	5238	30.0	0.82	3.69
	Im → Is		29.9	-0.03	4.48
	Mean			0.38	4.52
	(2 S.E.)			(0.94)	(0.71)
	Discharge canal				
	DB → D1	5466	36.5	-3.92	8.58
	D1 → D2		35.6	6.60	4.83
	DB → D1	5238	36.4	-3.97	5.45
	D1 → D2		35.7	-3.92	1.25
	Mean			-1.30	5.03
	(2 S.E.)			(5.27)	(3.01)

Arrows indicate zone between which oxygen curves were subtracted to obtain changes in flowing water.

(Parentheses indicate 2 standard errors of the mean.)

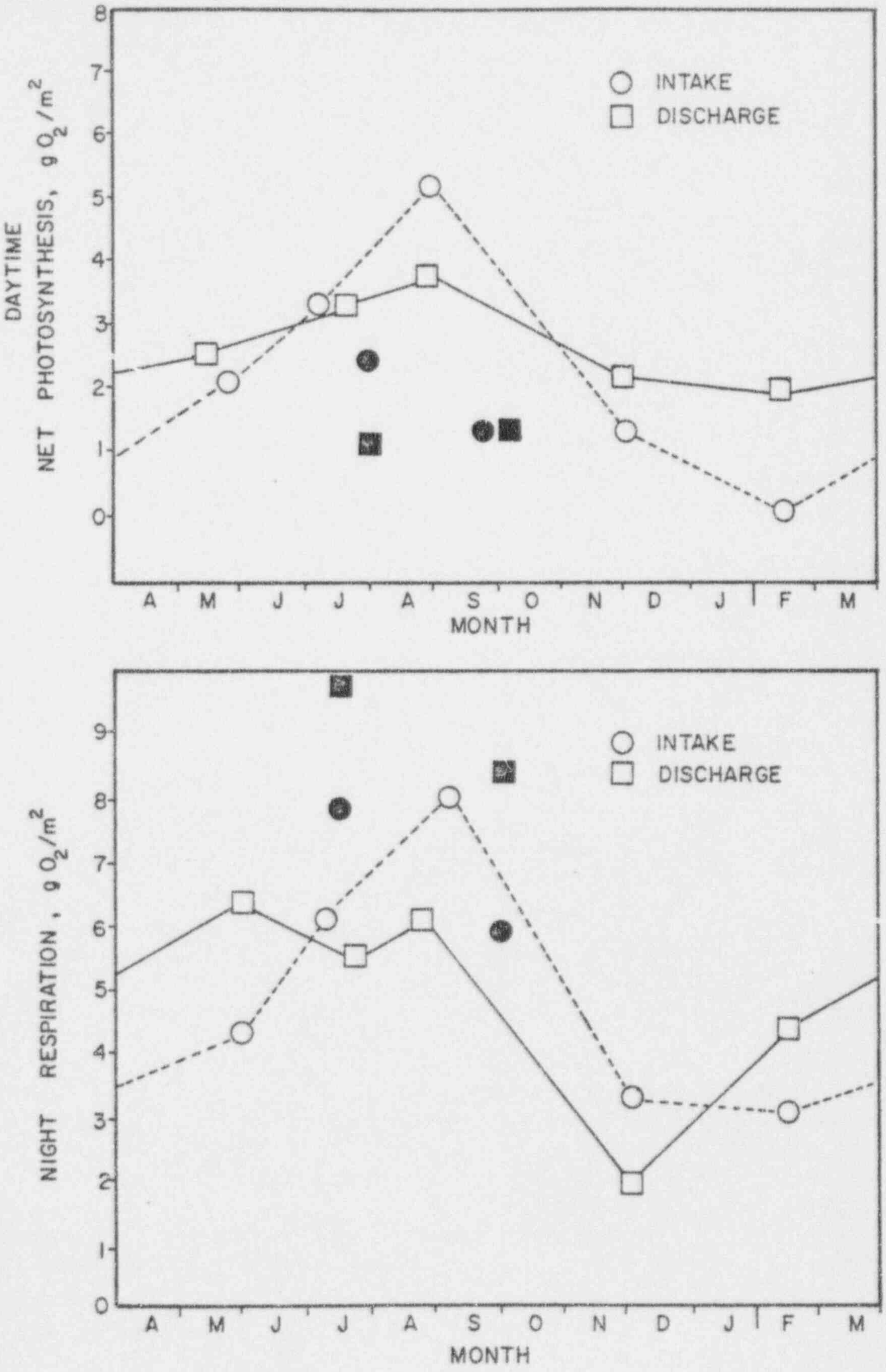


Fig. III-31. Graphs of daytime net photosynthesis and night respiration for the intake and discharge cooling canals. The solid points represent data from the present study and the other points are from Kemp (1977).

night respiration. So far respiration is higher and net photosynthesis lower. P/R values are compared in Fig. 32. Since the addition of the third generating unit respiration is greater than photosynthesis and P/R ratios are lower than before.

Increased flow had little effect on respiration in the intake canal and gross photosynthesis may have been slightly increased in the discharge canal (Fig. 33).

Summary

1. The increased flow rate had no consistent effect on community metabolism in the intake canal.
2. Community respiration and gross production may have been greater and net production less in the discharge canal in the present study as compared to the intake canal and conditions in 1972-74.
3. Zero change or a net decrease in organic matter was measured for both canals in this study.

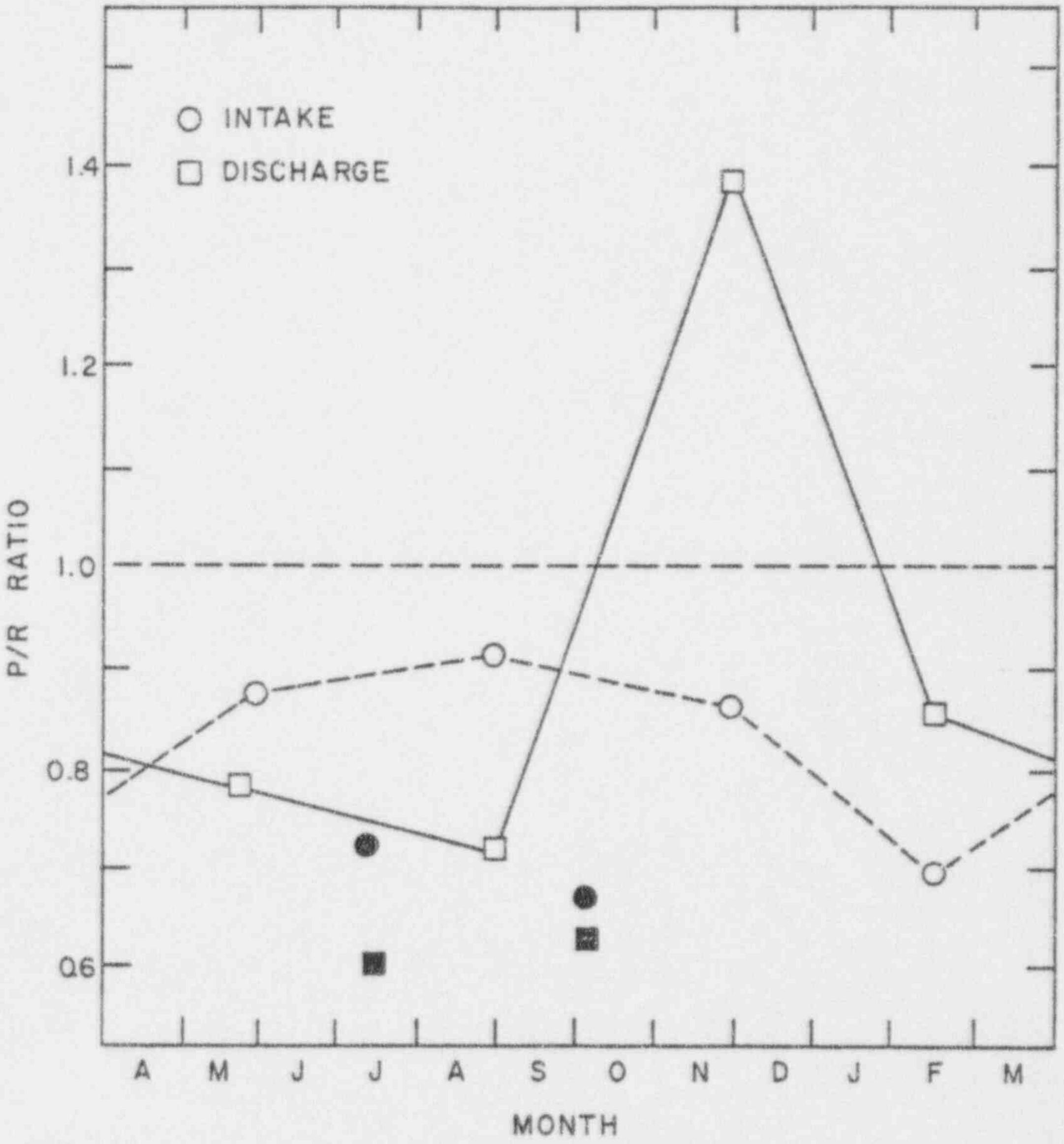


Fig. III-32. Ratios of production to respiration for the canal communities at the Crystal River plant before (open points) and after (solid points) the addition of a third generating unit.

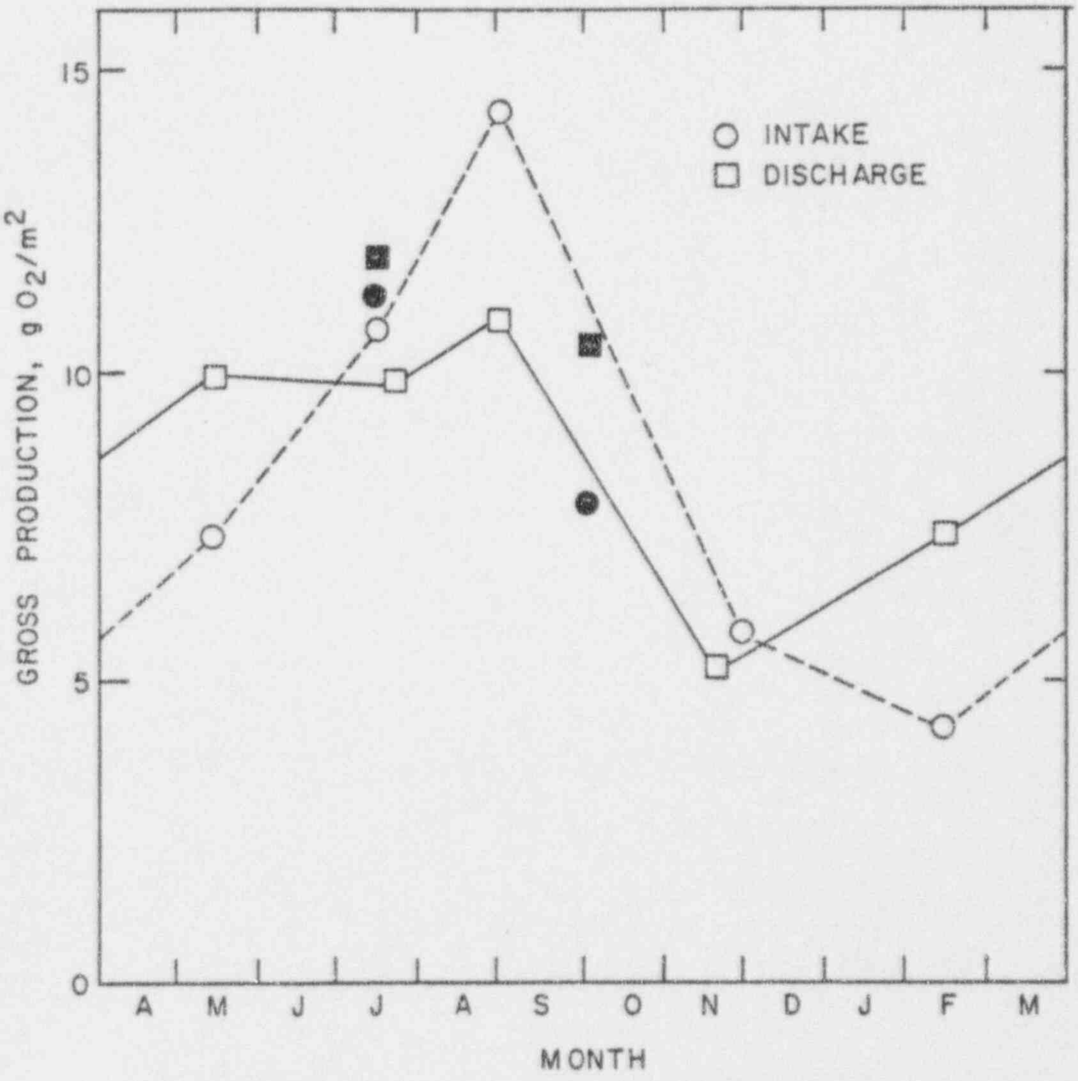


Fig. III-33. Gross primary production for the intake and discharge canals compared before (open points) and after (solid points) the addition of a third unit.

MARSH METABOLISM MEASUREMENTS

by

Douglas A. Hornbeck

Introduction

The purpose of this study was to assess how the operation of Unit #3 of the Crystal River power plant affected the marshes in the proximity of the discharge canal. Areas which were affected by thermal effluent and control marshes which were not affected were studied. Measurements of marsh structure and function were made and compared with data collected prior to operation of Unit #3 (preoperational data) and reported by Young (1975).

The present study duplicated methods used previously, inasmuch as practical, to provide a basis for comparing conditions prior to and subsequent to initial operation of the nuclear unit.[1] Quarterly measurements of structure included harvest of the dominant grasses for height and weight parameters; counts of the periwinkle snail, *Littorina*; and counts of crab holes. Measurements of function included net photosynthesis and respiration made by analysis of CO_2 fluxes of the marsh community. Physical parameters monitored were solar radiation input, air temperature, water temperature, and tide level.

The Sites

The sites chosen for the present study were in two areas, one of which received tidal inundation by water of elevated temperature due to its proximity to the discharge canal (see Fig. III-34). The control area received no thermal additions from the effluent due to a long jetty constructed to avoid recycling previously heated water through the power plant. These areas paralleled those of the previous study as closely as possible.

[1] Data for two quarters obtained in 1975 before Unit 3 went in operation were never worked up. These data will be analyzed in order to make comparisons.

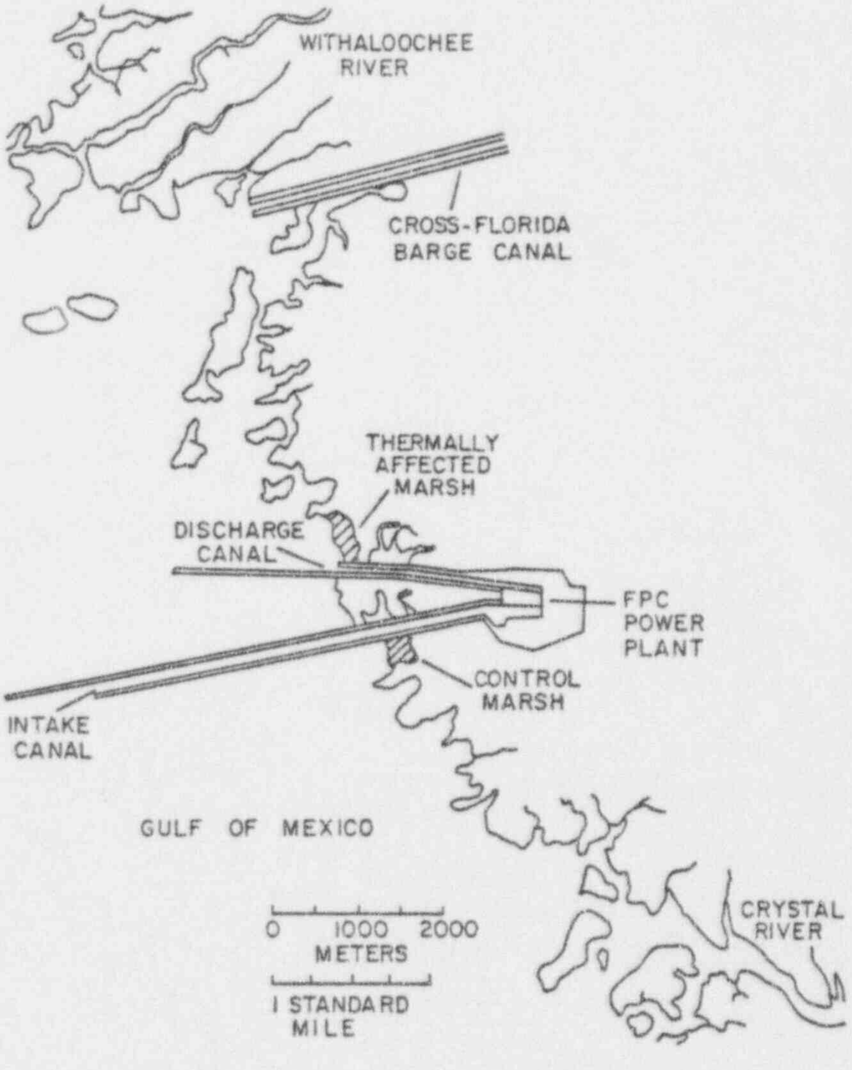


Fig. III-34. Map indicating locations of thermally affected and control marsh study sites.

Both control and thermally impacted marshes received semi-diurnal tidal inundation. The floristic composition of these marshes were similar, with two species dominating. Most of the marsh surface of areas surrounding the Crystal River site was covered with patches of Juncus roemarianus, which grows to a height of 2 meters. These areas were of higher elevation, receiving less frequent and less severe tidal inundation. Spartina alterniflora was typically found along the fringes of the Juncus marshes where it is more exposed to tidal action. Water which flooded the thermally impacted marshes was 2.6 - 7.2°C higher than that which flooded the control marsh.

Materials and Methods

To quantify standing crops of Juncus roemarianus and Spartina alterniflora, quarterly harvests of vegetation were collected in the thermally affected and control areas. Five replicate samples for Juncus and nine replicate samples for Spartina were collected each quarter. Each sample represented 0.25 m^2 of marsh surface. The number of dead, flowering, and live stems in various length classes were recorded for each quadrat. Wet and dry weights for live and dead material were also determined. As each quadrat was harvested, the number of Littorina encountered was recorded. Also, the number of holes in the marsh substrate was counted as an index of crab activity.

Measurements of Functions (Metabolism)

Measurements of plant community metabolism were made by enclosing an area of marsh plants and substrate with covered chambers which were flushed with ambient air. Gaseous exchange of CO_2 and water between the air and biota was quantified by measuring concentration differences across the individual chambers. Figure III-35 shows the major components of the sampling system.

Chambers and Field Apparatus

The environmental chambers consisted of a rigid cylindrical metal frame covered with clear plastic. The area of marsh covered by each chamber was 0.25 m^2. The chamber height varied from 1.0 to 2.0 meters depending on the height of the plants being measured. Six mil polyethylene was used to cover the chambers. Two ports were constructed in the top of each chamber to accept 10 cm ducting for air delivery. Since these ports were at the top to prevent tidal inundation, the input opening was directed downward to facilitate adequate mixing. A mud seal at the bottom and a positive pressure within the chambers eliminated the problem of leaks.

Since a constant flow of air was maintained through the chambers, they constituted an open system. Large, constant delivery centrifugal blowers drew ambient air from an elevation of at least 3 meters and forced the air to the chambers through 10 cm flexible plastic ducting and PVC pipe. From the chamber, air was vented to the outside through a short section of the PVC pipe. Flow rate and chamber turnover time were conducted from measurements of air speed in a straight section of PVC pipe with a hot wire anemometer.

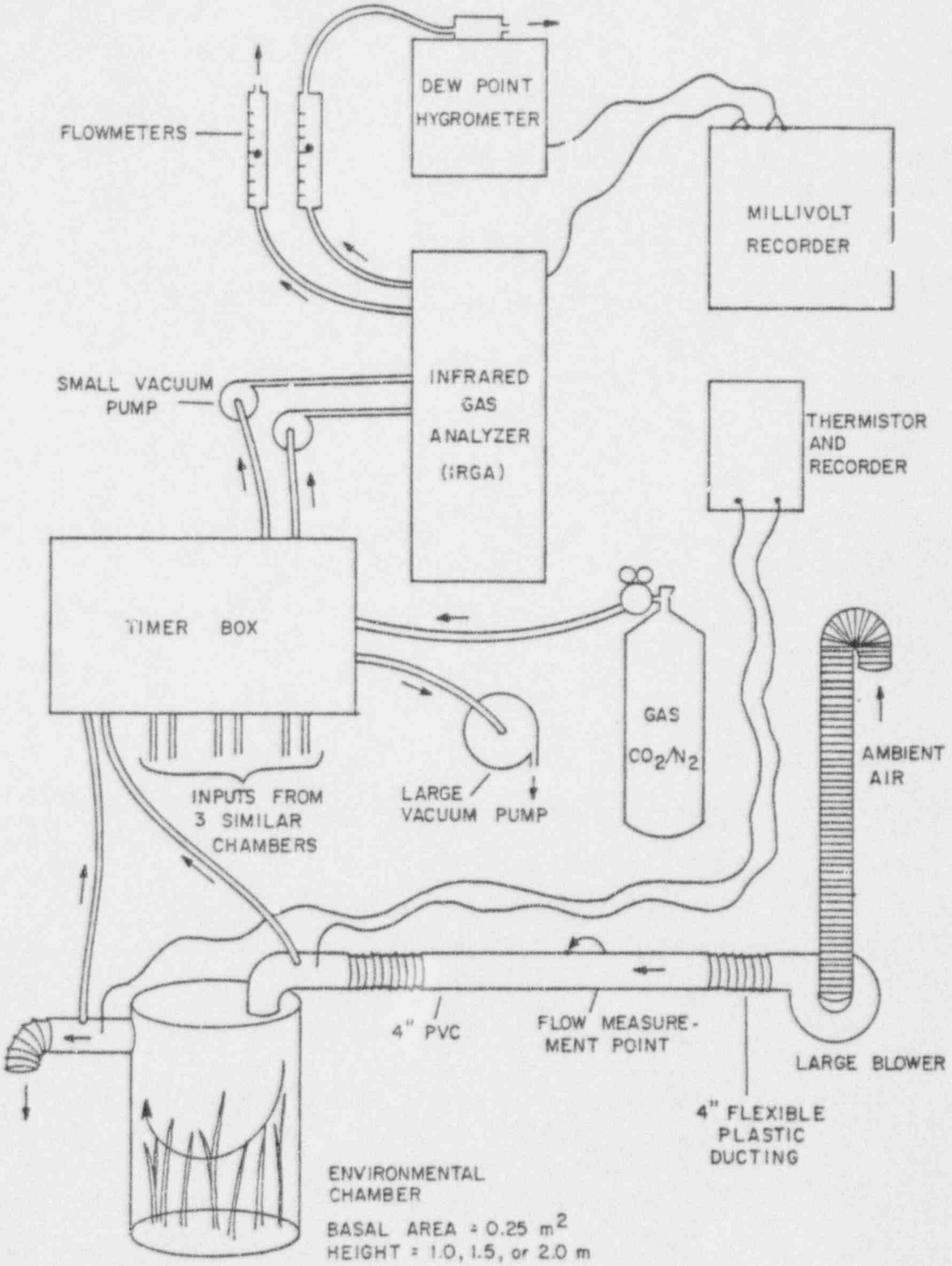


Fig. III-35. General schematic of metabolism apparatus. Arrows indicate direction of air flow.

The appropriate level of air delivery rate for approximating natural conditions is a balance between factors for which flow should be increased, including lowering the temperature in the chambers and maximizing production; and factors for which flow should be reduced including obtaining large enough CO_2 changes for instrument sensitivity. To find the proper flow rate to optimize productivity, experiments were conducted at peak sun hours when solar intensity changes least rapidly. Flow was varied from high-low-high by venting excess air through a variable opening in the ducting while monitoring rates of CO_2 uptake. Figure III-36 shows the resultant hyperbolic curve of photosynthesis versus turnovers for a particular chamber. Delivery rates were chosen at a point where the asymptote was closely approached.

Sample Air Flows

A timer box was constructed to facilitate sampling of the four chambers. A timer drum with single pole-double throw switches controlled electric solenoid valves which selected air streams to be sent to the analyzer according to a predetermined sequence. The four chambers were sampled once each hour. A large vacuum pump kept the eight sections of 30 meter length (7.9 mm ID, 11.1 mm OD) tygon tubing from the chambers to the timer box continually flushed with fresh samples. Two small vacuum pumps were used to draw samples from the air stream. Changes in the sample air during the travel period to the analyzer were minimized by the short residence time, low vacuum (25-50 mm Hg) and precautions against leaks in the system.

Additional Measurements

Other data collected included air and water temperature and solar

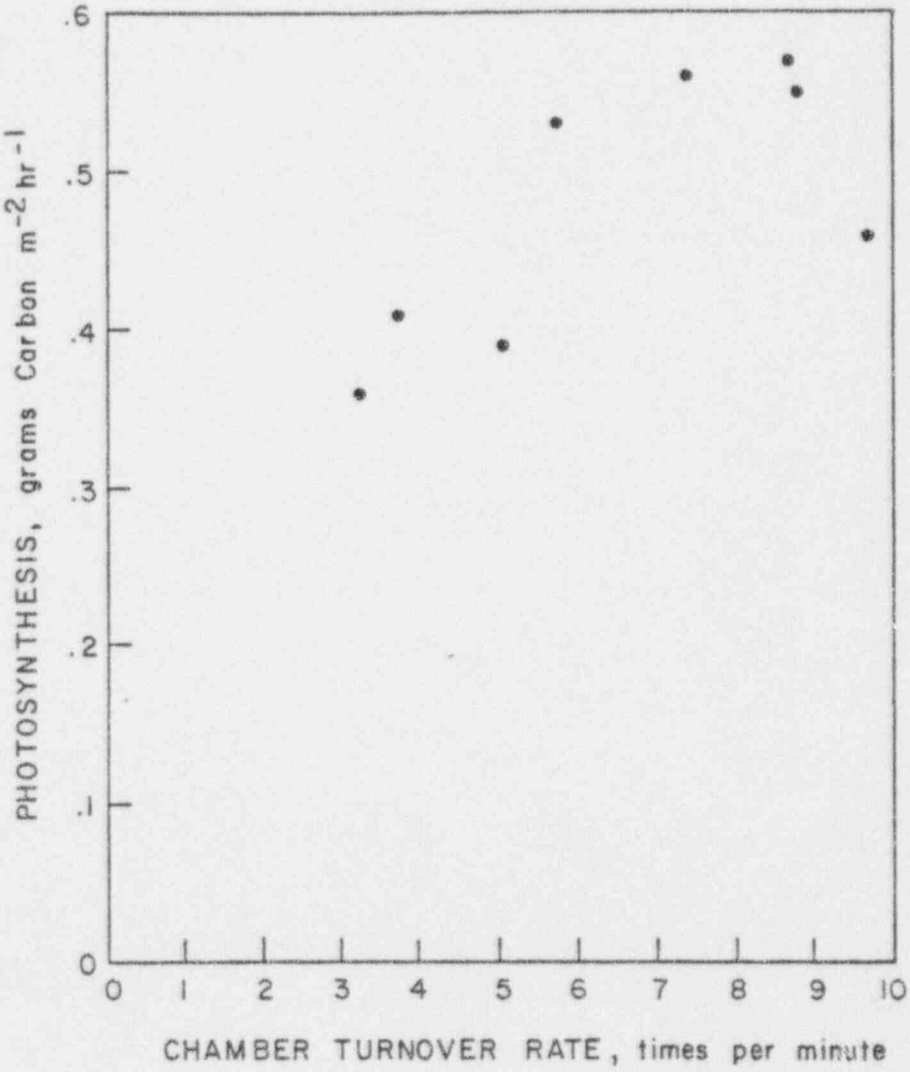


Fig. III-36. Sample plot of chamber turnover versus photosynthesis rates for determining optimum air flow rates.

radiation. Temperature probes were inserted in the input and outlet streams of one chamber to monitor temperature elevation across the chamber. A thermistor probe recorder maintained continuous traces of temperature measurements. Water temperature was checked at high tide with a probe placed low in the marsh. Solar radiation was determined with a Lintronic temperature compensated dome solarimeter.

Infra-red Gas Analyzer and Calibration

By design, the IRGA (Beckman model 215-B) allows the user versatility in application, sensitivity, and a range of gas concentrations to be analyzed. However, several calibration procedures are required because of this flexibility. Bottled standard gases of known concentrations of CO_2 in a balance of dry nitrogen were used. Because the detector within the IRGA compares differences in energy absorption between gases in two identical cells, one may compare a standard gas to an unknown or compare two unknowns directly. Instrument sensitivity is inversely proportional to range of gas concentrations capable of being detected. Gross sensitivity is selected by choosing Range 1 for widest range and Range 3 for most sensitivity. A gain control is used for finer adjustments. To clarify nomenclature, the following terms are defined: a reference gas is a standard gas used to compare with an unknown; ambient refers to the input side of a chamber; and exhaust refers to output from a chamber. The sample cell and reference cell refer to the two gas tubes inside the IRGA.

Two IRGA methods are acceptable for metabolism studies, each requiring different sampling sequences and timer boxes. Due to equipment availability, both methods were used in this study. One approach is the absolute method where a reference gas is compared to ambient and exhaust air separately. The fifteen minute timer sequence for this method was: 1) seven minutes on ambient-reference and 2) eight minutes on exhaust-reference. In the differential method, ambient and exhaust were compared directly; the timer sequence being: 1) three minutes on ambient-reference (range 1), 2) five minutes on ambient-ambient (range 3), and 3) seven minutes on exhaust-ambient (range 3).

Calibration

The absolute method, used for the spring, 1977 sampling required only one calibration curve. A reference gas was maintained at a low flow rate (15 ml/min) through one cell during both calibration and data collection. Standard gases were introduced sequentially through the other cell so that the IRGA could be adjusted to give suitable response for the CO_2 concentrations expected in the ambient air. A calibration curve of millivolts versus $[CO_2]$ in the sample cell is shown in Fig. III-37 where an exponential model has been fit to the data. Daily checks of the calibration were made by introducing standard gases in the sample cell and adjusting the output when necessary.

The differential IRGA technique was finally adopted in this study because a greater sensitivity could be achieved if ambient and exhaust air were compared simultaneously in the IRGA. The millivolt output for this arrangement represented a change in $[CO_2]$ across the chamber instead of the absolute concentration of each sample. Because of the non-linearity of the instrument response, it was expected that the sensitivity, or change in ppm/change in millivolts would change according to the value of ambient $[CO_2]$ as well as providing the level of ambient CO_2. To automatically select for a narrow or wide range of response, the range (sensitivity) on the IRGA was wired to the timer box, thus

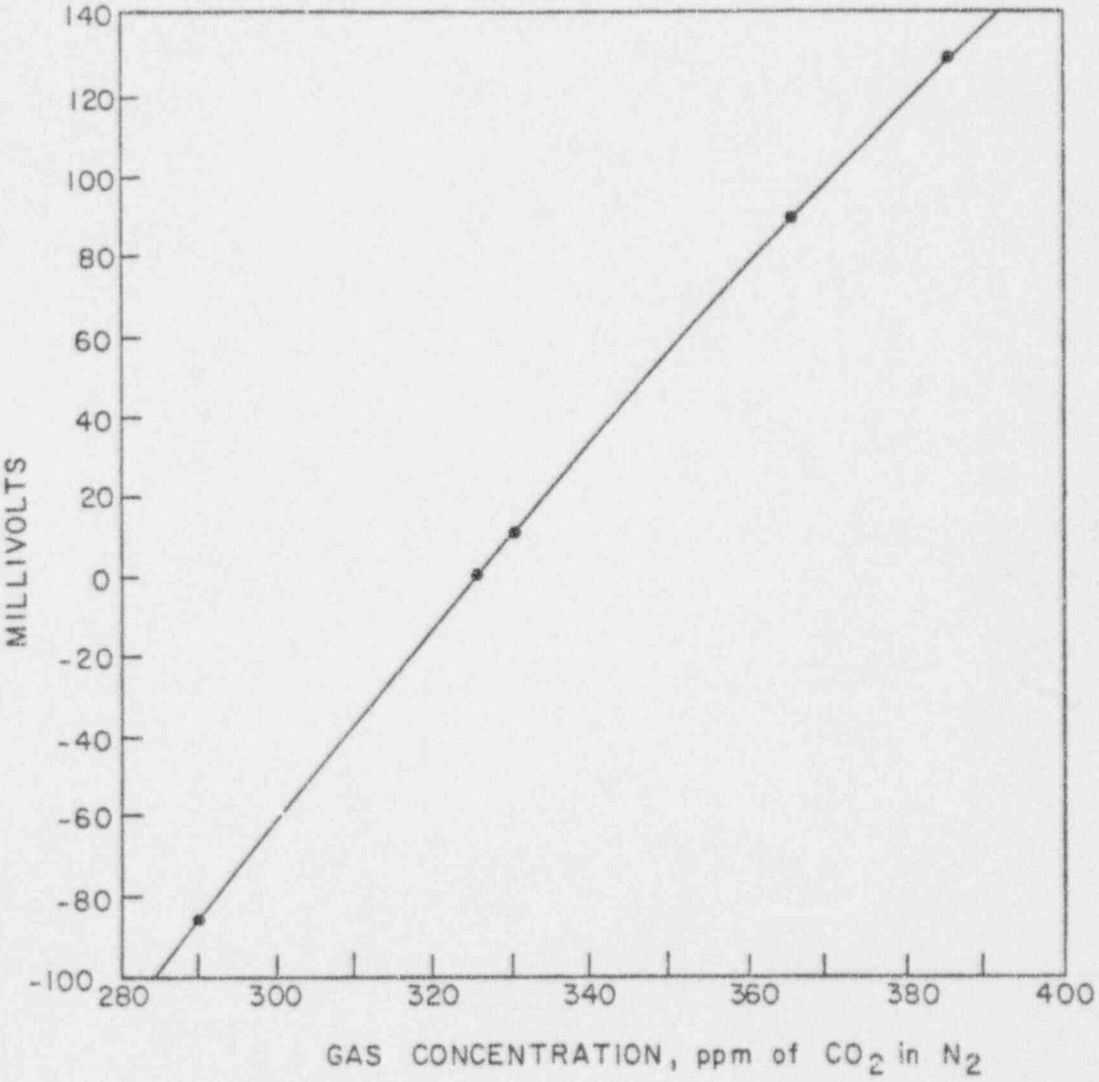


Fig. III-37. Sample Range 1 calibration curve for infrared gas analyzer Model 215-B. Reference gas was 325 ppm.

synchronizing the established switching program. Range 1, the least sensitive and widest range, was used only for ambient-reference comparisons, while the more sensitive range 3 was used for the ambient-ambient and ambient-exhaust readings. Machine drift was compensated for by routing the ambient air to both cells of the IRGA during each fifteen minute period and using the change in millivolts between ambient-ambient and ambient-exhaust to calculate the change in ppm of CO_2.

Differential range 1 calibration duplicated the absolute method. Range 3 calibration, however, may be done in different ways. One method is to set up a closed system of circulating standard gas in the sample side of the IRGA while the same standard gas passes through the other cell. The overall concentration of CO_2 in the sample is changed by a known amount by injecting CO_2 with a syringe. By noting the output response in change in millivolts, a sensitivity for that [CO_2] is obtained. By repeating with several standard gases, an overall sensitivity response curve is obtained.

A second method for Range 3 sensitivity determination was actually used. For a given reference gas, the concentration introduced to the sample cell versus millivolt output was approximately linear, as shown in Fig. III-37. The value of the slope in (change in millivolts)/(change in ppm) provided the machine sensitivity for the reference gas. A series of different reference gases was run giving similar linear results; a graph of sensitivity versus reference gas concentration was constructed. For the range of ambient [CO_2] experienced in the field, one sensitivity number could be used throughout the range. Although absolute [CO_2] was not needed for calculation of community metabolism, it was measured on Range 1 as a check on rapidly fluctuating or extreme conditions which would make Range 3 data suspect. As with the absolute method, the differential method required daily instrument calibration.

During the course of the study, several infrared analyzers were used as dictated by instrument availability and condition of repair. One of the instruments was factory adjusted to respond linearly over all CO_2 concentrations and sensitivities. In such a case, calibration was simplified since the sensitivity is constant at all ambient air concentrations and sensitivities.

Calculation of Photosynthesis and Respiration

The actual carbon fixation or release was calculated from the CO_2 and temperature data. The equation used, which corrects for stochiometry and the gas laws (after Brown and Rosenberg, 1968) was as follows:

$$\text{g C/hr} = \frac{F \times C \times \Delta[CO_2]}{T}$$

where:

F = flow rate (m^3/hr)

$\Delta[CO_2]$ = change in CO_2 concentration across the chamber (ppm)

T = air temperature (°K)

C = a constant defined as:

$$C = \frac{12\text{gC}\cdot\text{mole}^{-1} \times 10^3 \text{l}\cdot\text{m}^{-3} \times 273^{\circ}\text{K}}{22.41\ \text{mole}^{-1} \times 10^6 \text{ppm}}$$

$$= 0.14625\ \text{gCm}^{-3}\ {}^{\circ}\text{K ppm}^{-1}$$

It was assumed that atmospheric pressure remained constant. The rate of carbon fixation or release was plotted for each of the several chambers being measured, along with physical data for the corresponding time period. Usually the graphs for a twenty-four hour period include parts of two calendar days because normally chambers were set up during the daylight hours. Areas above the compensation (zero) line are designated net photosynthesis and those below the line as nighttime respiration. Although day length was known and could be corrected for for comparative purposes, diurnals were not adjusted. Physical data collected includes net solar insolation, which was plotted in kcals$\cdot$m$^{-2}\cdot$hr^{-1}; air temperature, and tide levels which were plotted in meters above or below mean low water.

Gross production, estimated as the sum of net daytime photosynthesis and night respiration, was used as an index of the total amount of solar energy flow through the marsh system as a result of carbon fixation. An efficiency index, which is a ratio between gross production and solar insolation, uses a conversion of grams carbon to kilocalories, and is defined below.

$$\text{Efficiency of gross production, \%}$$
$$= \frac{\text{gross production (g C m}^{-2}\text{ day) x (8 kcal g C}^{-1}\text{) x 100}}{\text{solar insolation (kcal m}^{-2}\text{ day}^{-1}\text{)}}$$

Results

Results consist of graphs of standing crop of live and dead biomass, graphs of stem density, graphs of stem height, records of photosynthesis and respiration from gas metabolism measurements made quarterly, and data on indicies of animal activity.

Biomass: Annual records of biomass of Spartina are given in Figs. III-38, III-39, and III-40, and for Juncus in Figs. III-41, III-42, and III-43. The above ground biomass of Spartina varied from a minimum in spring to a maximum in the end of the growing season in October. The dead biomass, however, was at a minimum in the fall, and increased to a maximum at the start of the new growing season. The sum of the two was fairly constant all year.

The above ground live biomass of Juncus was similar with a minimum in February and maximum in the fall. However, dead biomass reached a maximum in the summer and fall. The sum of live and dead biomass varied considerably seasonally from a minimum at the beginning of the growing season to a peak later in the year.

Plant density: Plant density results are presented for Spartina in Fig. III-44 and for Juncus in Fig. III-45. In the Spartina marshes, the density in the control area was seasonally fairly uniform, while in the thermally affected areas the plant density decreased from May to October. Juncus shoot density, that is, the number of Juncus shoots instead of the number of actual plants, displayed rather erratic seasonal patterns, but was approximately 700 live shoots m^2. Density of dead stalks of Spartina and Juncus is presented in Table III-30. Density of flowering stems of Spartina and Juncus is presented in Table III-31.

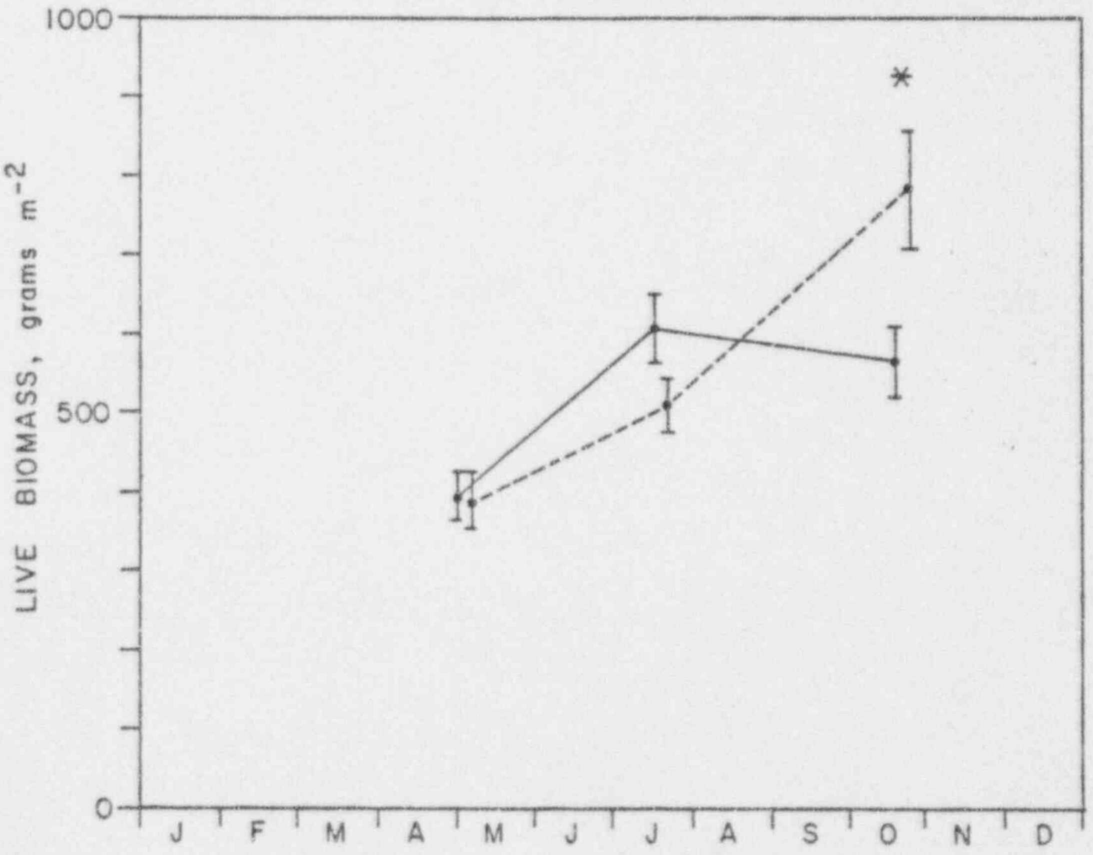


Fig. III-38. Mean seasonal values of Spartina above ground live biomass (dry weight at 70°C). Solid lines are thermally affected marshes. Broken lines are control marshes. Vertical lines are standard errors. (*) indicates significant differences between the means by t-test at the 95% confidence level (1977).

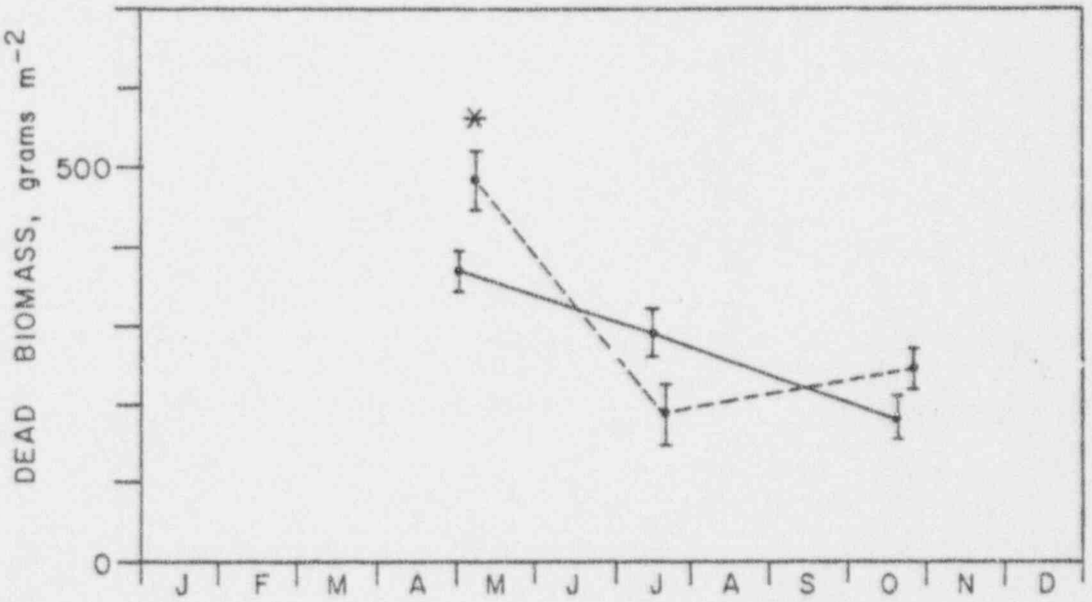


Fig. III-39. Mean seasonal values of Spartina above ground dead biomass (dry weight at 70°C). Solid lines are thermally affected marshes. Broken lines are control marshes. Vertical lines are standard errors. (*) indicates significant differences between the means by t-test at the 95% confidence level (1977).

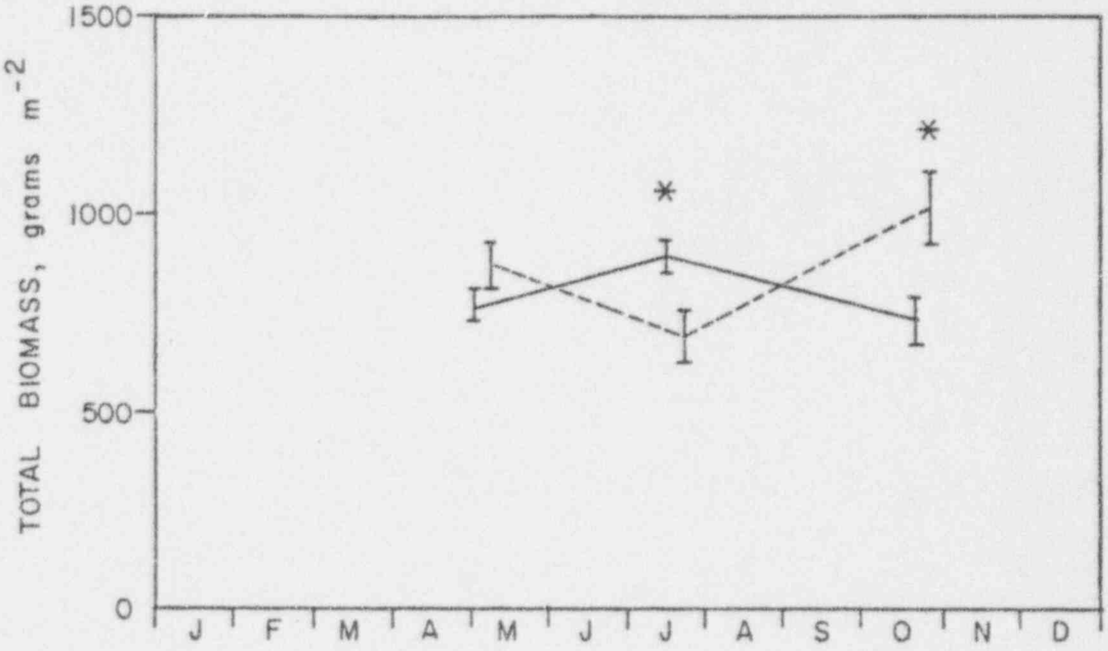


Fig. III-40. Mean seasonal values of Spartina above ground total biomass (dry weight). Solid lines are thermally affected marshes. Broken lines are control marshes. Vertical lines are standard errors. (*) indicates significant differences between the means by t-test at the 95% confidence level (1977).

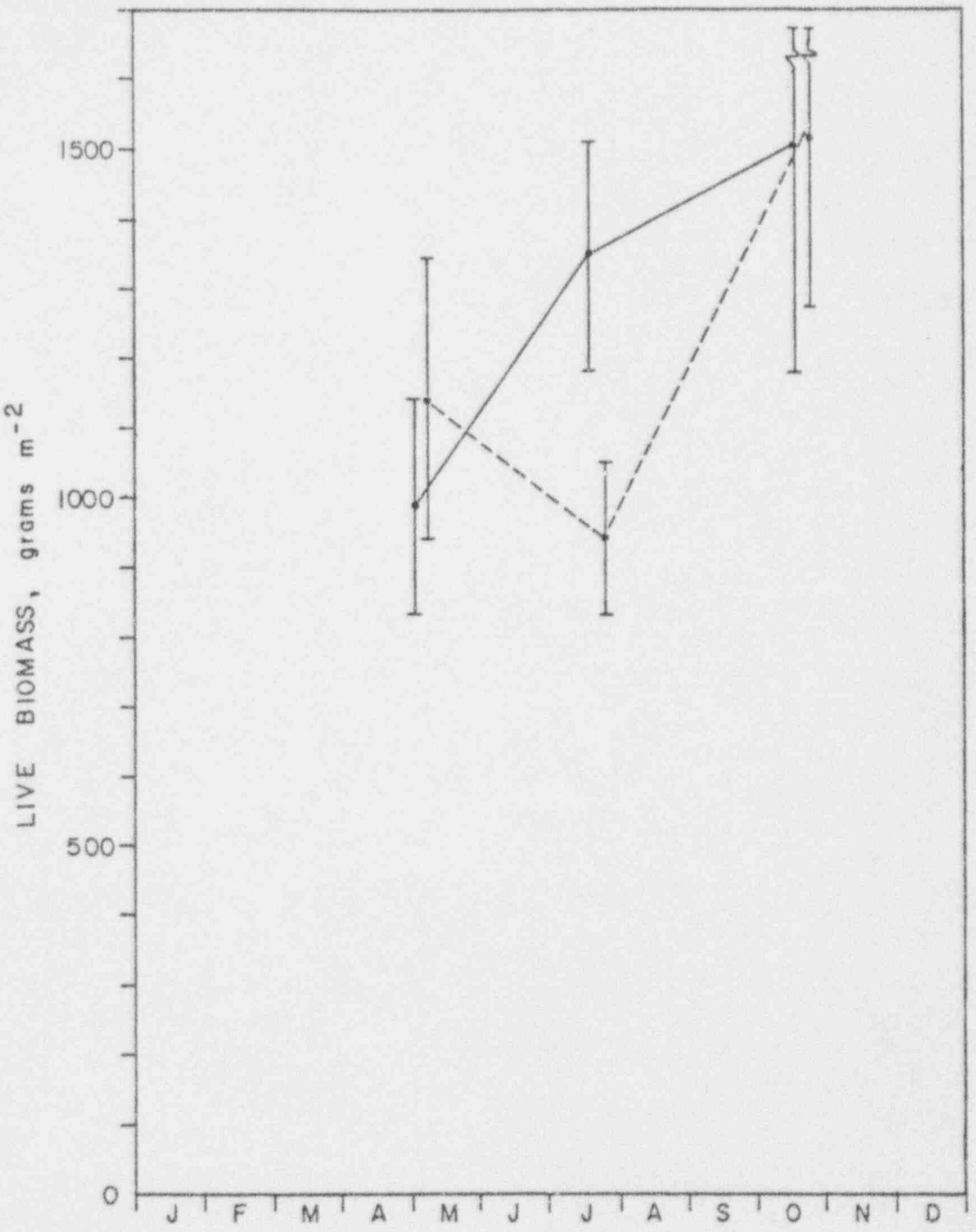


Fig. III-41. Mean seasonal values of Juncus above ground live biomass (dry weight at 70°C). Solid lines are thermally affected marshes. Broken lines are control marshes. Vertical lines are standard errors. (*) indicates significant differences between the means by t-test at the 95% confidence level (1977).

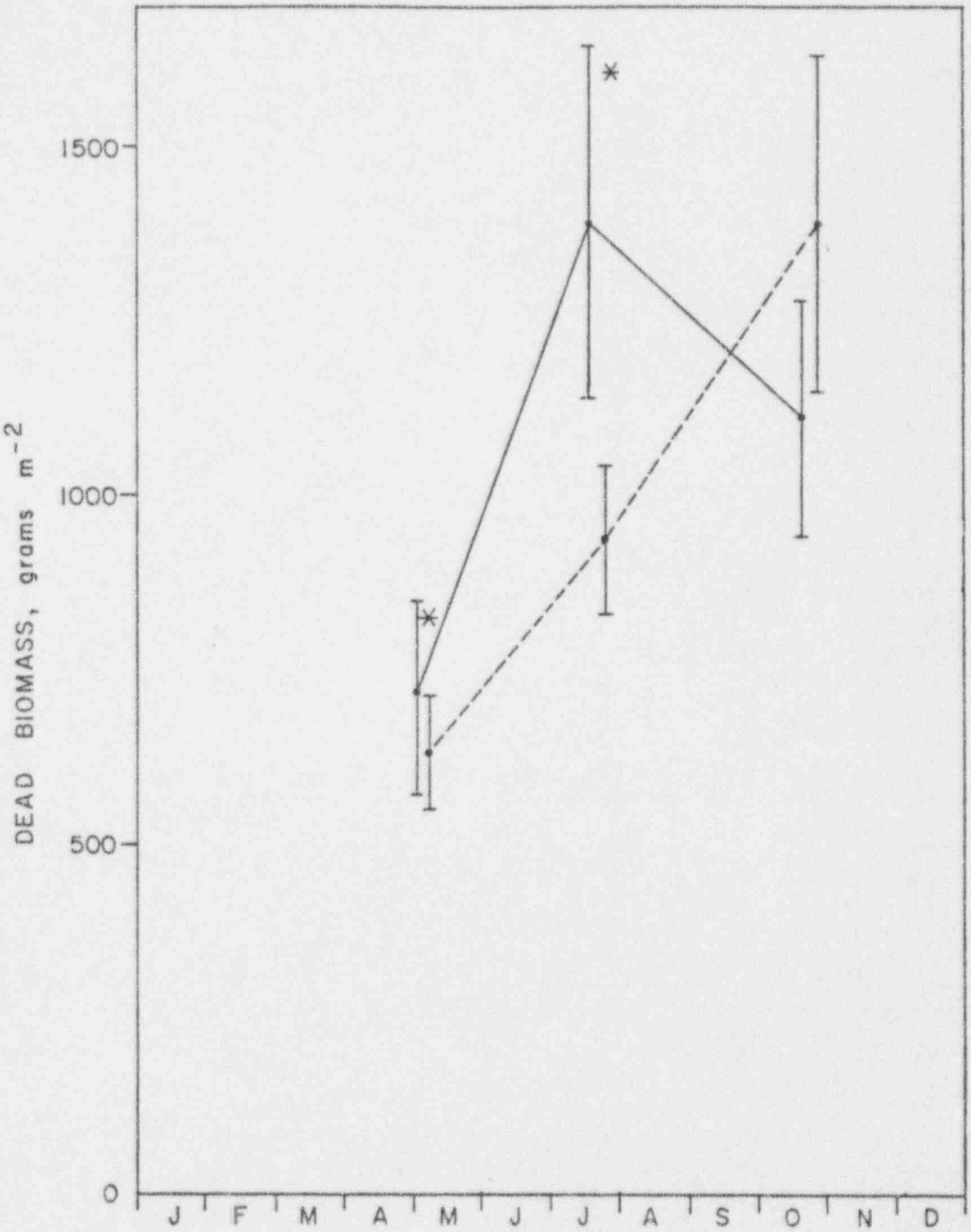


Fig III-42. Mean seasonal values of Juncus above ground dead biomass (dry weight at 70°C). Solid lines are thermally affected marshes. Broken lines are control marshes. Vertical lines are standard errors. (*) indicates significant differences between the means by t-test at the 95% confidence level (1977).

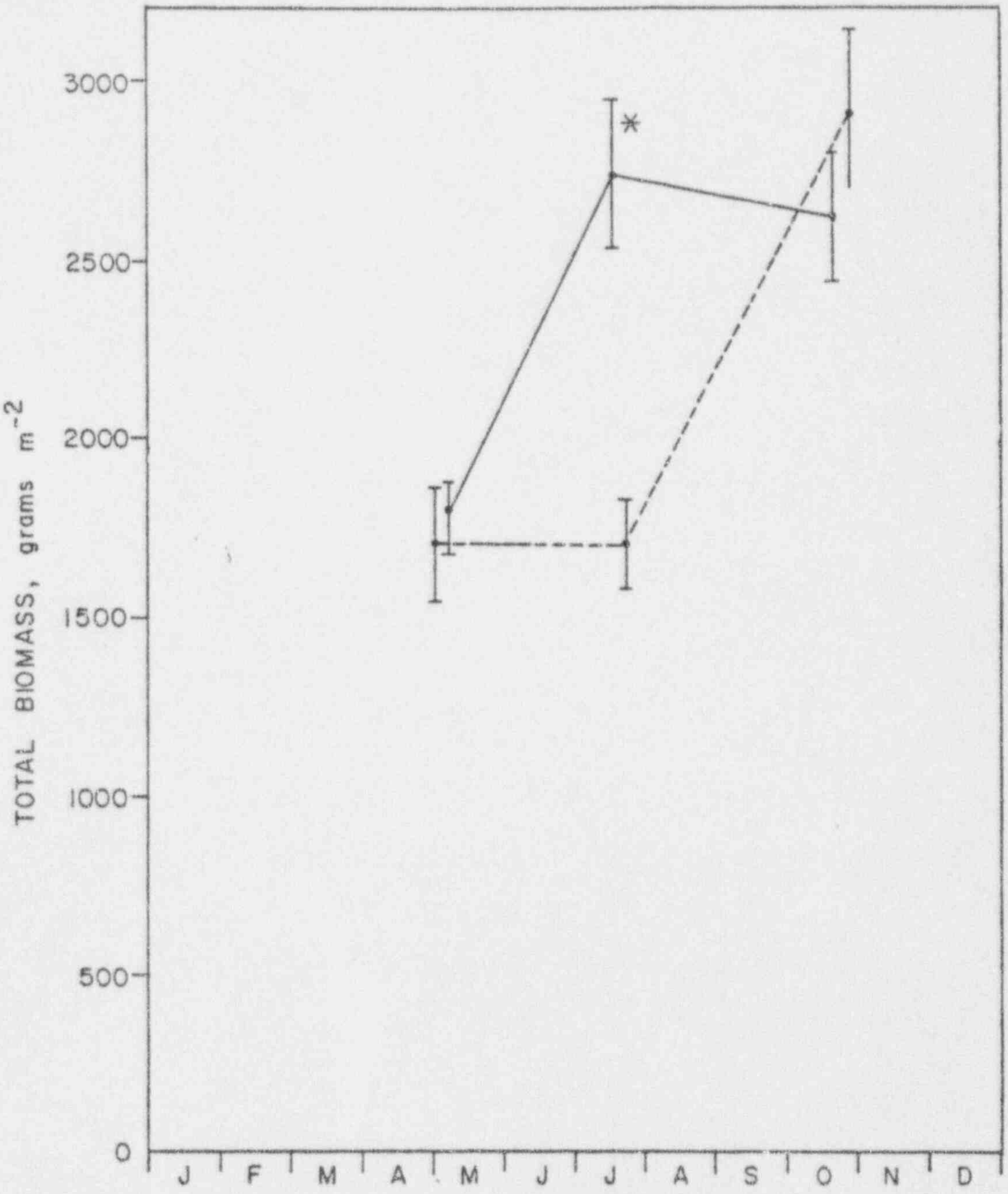


Fig. III-43. Mean seasonal values of Juncus above ground total biomass (dry weight at 70°C). Solid lines are themally affected marshes. Broken lines are control marshes. Vertical lines are standard errors. (*) indicates significant differences between the means by t-test at the 95% confidence level (1977).

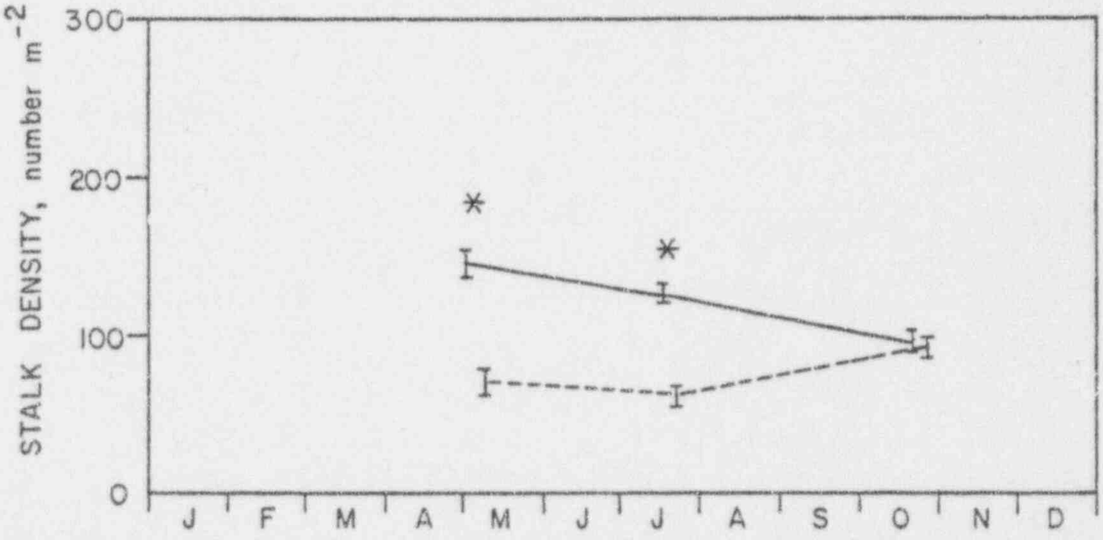
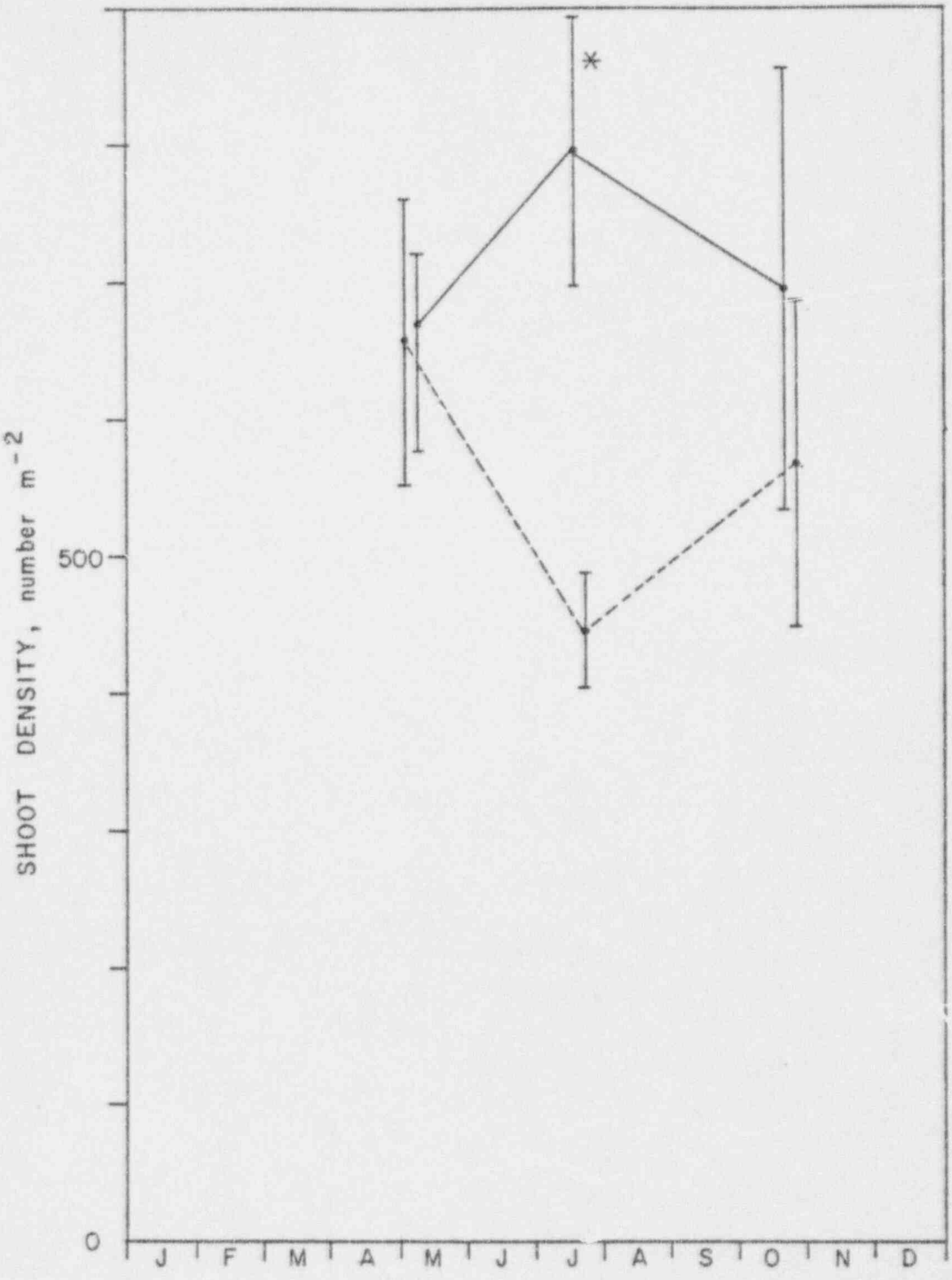


Fig.III-44. Mean seasonal stalk densities for *Spartina* marshes. Solid lines are thermally affected marshes. Broken lines are control marshes. Vertical lines are standard errors. (*) indicates significant differences between the means by t-test at the 95% confidence level (1977).



III-45. Mean seasonal shoot densities of Juncus marshes. Solid lines are thermally affected marshes. Broken lines are control marshes. Vertical lines are standard errors. (*) indicates significant differences between the means by t-test at the 95% confidence level (1977).

Table III-30. Annual record of density of above ground dead stalks of *Spartina* and *Juncus*. (*) indicates significant difference between the means by t-test at 95% confidence interval.

	Thermally affected			Control area		
	Mean	S.E.	N	Mean	S.E.	N
Spartina area						
May, 1977	165.8	9.5	9 *	101.3	12.3	9 *
July, 1977	74.7	11.9	9 *	27.1	6.0	9 *
Oct, 1977	9.6	2.0	5	14.0	7.6	6
Juncus area						
May, 1977	221.6	69.3	5	273.6	47.5	5
July, 1977	772.7	181.2	6 *	362.7	61.6	9 *
Oct, 1977	172.8	15.9	5 *	118.4	11.8	5 *

Table III-31. Annual record of density of flowering live stems of *Spartina* and *Juncus*. No significant difference was found between any of the corresponding means.

	Thermally affected			Control area		
	Mean	S.E.	N	Mean	S.E.	N
Spartina area						
May, 1977	0	0	11	0	0	9
July, 1977	0	0	9	0	0	11
Oct, 1977	7.1	2.1	9	11.1	2.9	9
Juncus area						
May, 1977	2.4	2.4	5	16.0	6.7	5
July, 1977	0	0	6	0	0	9
Oct, 1977	0	0	5	2.4	1.6	5

Plant height: Annual records of stalk height of Spartina is shown in Fig. III-46 and of Juncus in Fig. III-47. Generally, plants were shortest in May and tallest in the fall. For both Spartina and Juncus marshes, the thermally affected plants were significantly shorter than the control plants at the 95% confidence level.

Specific weight: Annual data of mean weight per stalk of Spartina are given in Fig. III-48, and mean weight per shoot of Juncus are given in Fig. III-49. For the Spartina plants, the specific weight varies widely over the growing season, with most rapid increase in the early summer. Juncus specific weight was least in the early part of the growing season and reached a maximum in the fall.

Community metabolism measurements: Values of net daytime photosynthesis nighttime respiration, and estimated gross production as measured by the gas analysis technique are given for Spartina and Juncus of thermally affected and control areas. Tables III-32, III-33, and III-34 are of spring, summer and fall of 1977, respectively. Annual records of net daytime photosynthesis as measured by the above-mentioned methods are plotted in Fig. III-50 for Spartina and Fig. III-51 for Juncus. Of the seasons reported, net daytime photosynthesis is greatest in the summer and least in the fall. Figs. III-52 and III-53 are night respiration of Spartina and Juncus, respectively. Night respiration of the Spartina marshes indicated no differences between the summer and fall, yet in the spring the rates were more variable and higher. Nighttime respiration of Juncus was greatest in the spring and least in the fall.

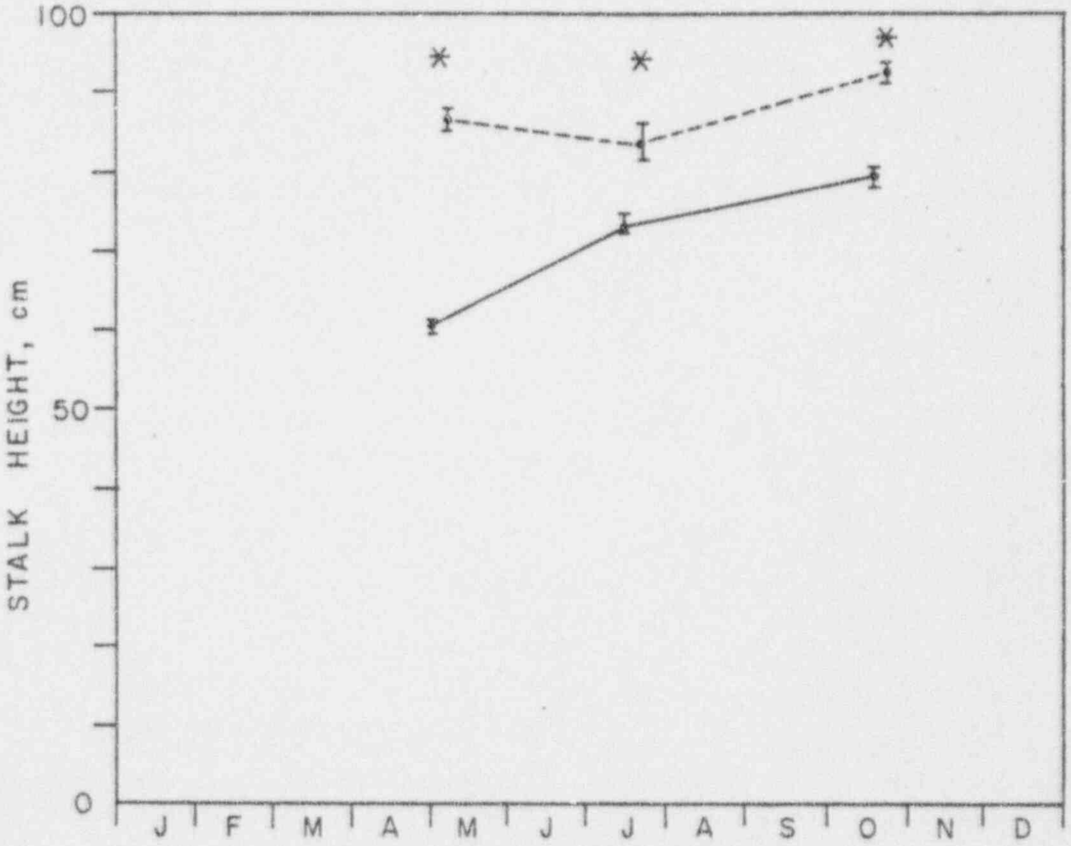


Fig. III-46. Mean seasonal values of Spartina stalk height. Solid lines are thermally affected marshes. Broken lines are control marshes. Vertical lines are standard errors. (*) indicates significant differences between the means by t-test at the 95% confidence level (1977).

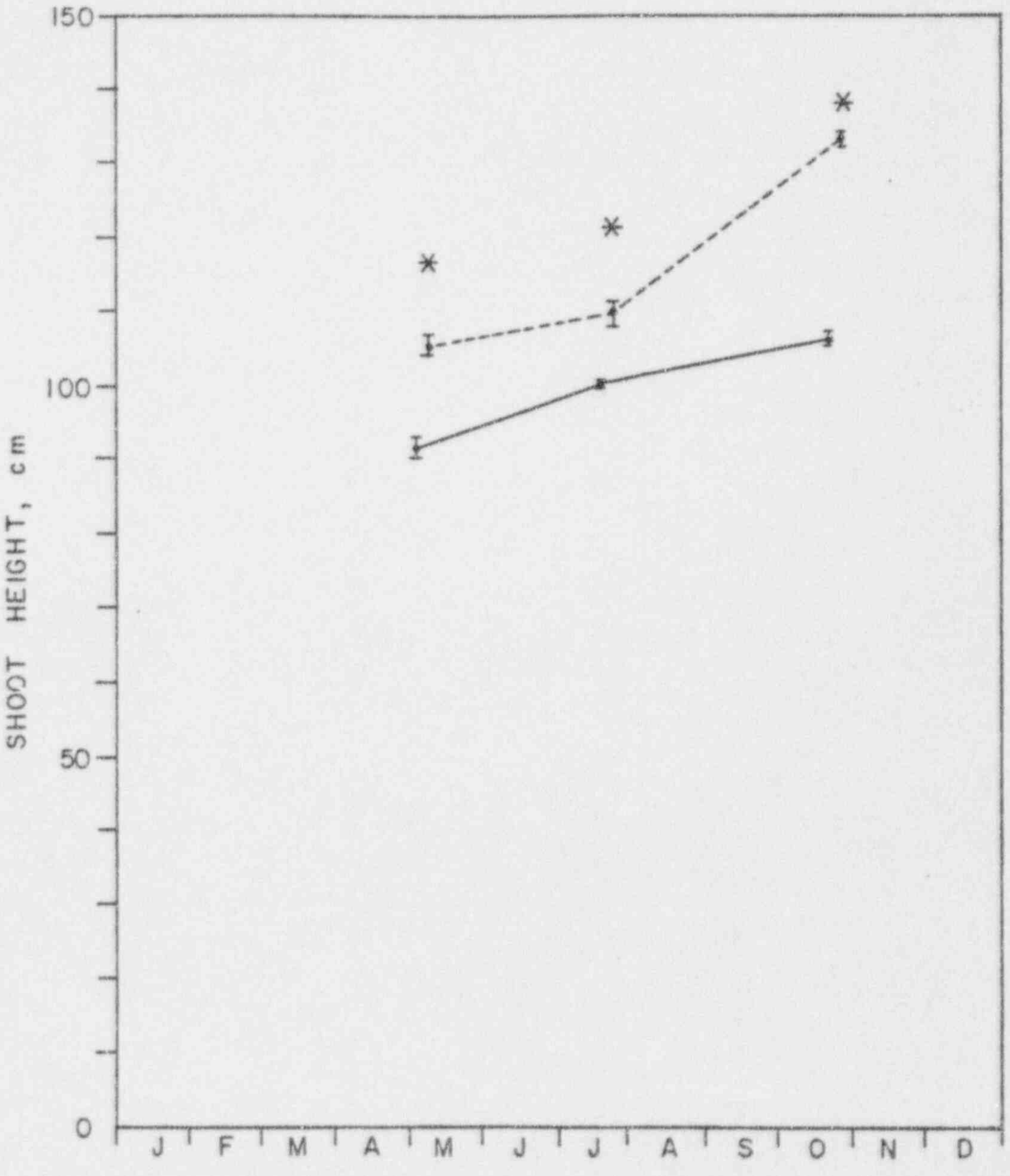


Fig. III-47. Mean seasonal values of Juncus shoot height. Solid lines are thermally affected marshes. Broken lines are control marshes. Vertical lines are standard errors. (*) indicates significant differences between the means by t-test at the 95% confidence level (1977).

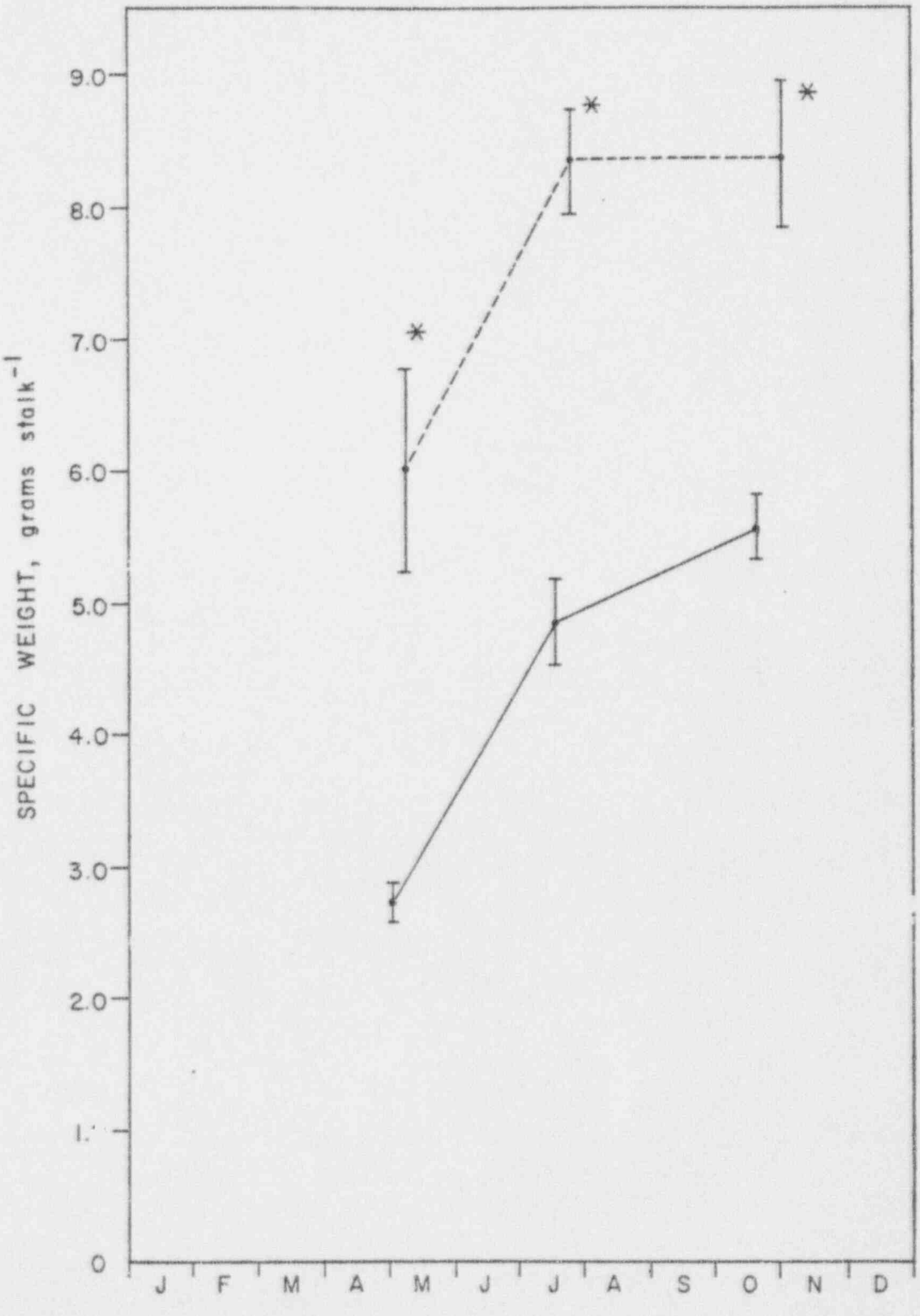


Fig. III-48. Mean values of specific weight (weight/stalk) of Spartina. Solid lines and broken lines are thermally affected and control marshes, respectively. Standard errors are the vertical lines. (*) indicates significant differences between the means by t-test at the 95% confidence level (1977).

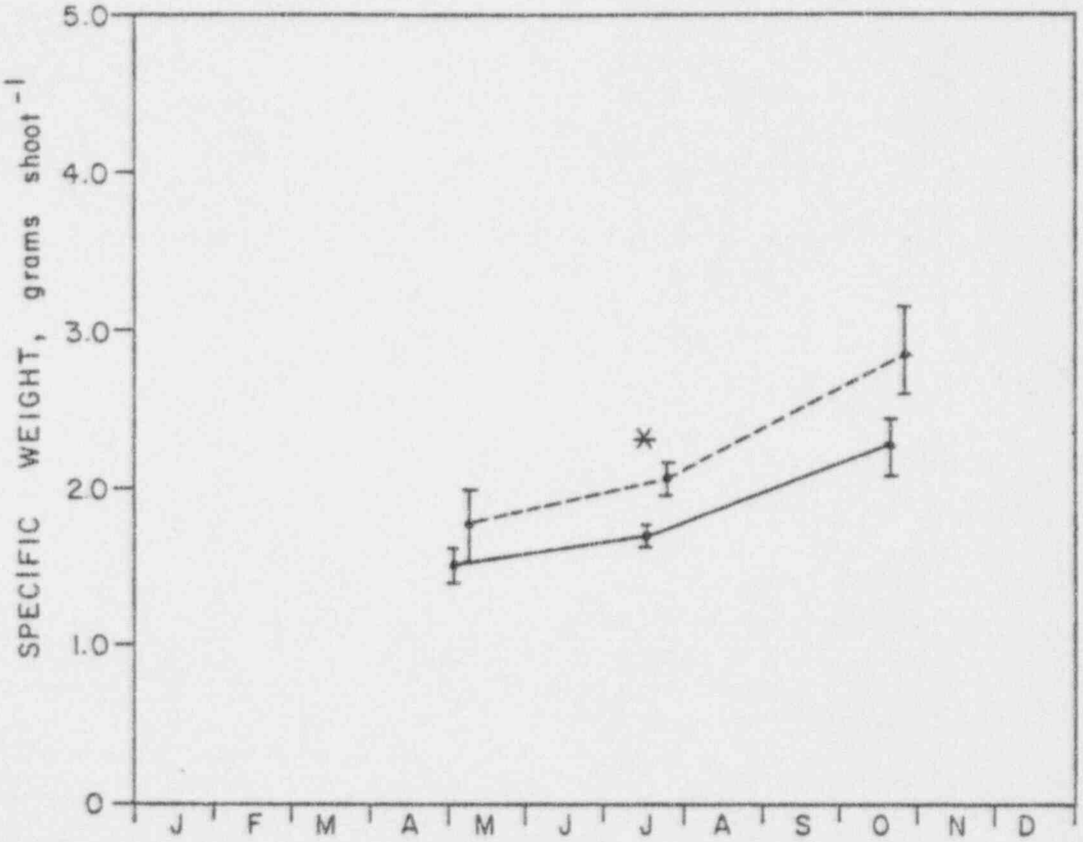


Fig. III-49. Mean values of specific weight (weight/shoot) of Juncus. Solid lines and broken lines are thermally affected and control marshes, respectively. Standard errors are the vertical lines. (*) indicates significant differences between the means by t-test at the 95% confidence level (1977).

Table III-32. Results of gas metabolism measurements of marshes at Crystal River in spring, 1977.

Component	Treatment	Date[1] 1977	Solar insolation kcal m^{-2} day^{-1}	Mean air temp. ^{o}C	Net daytime[2] photosynthesis g C m^{-2} day^{-1}	Nighttime respiration g C m^{-2} day^{-1}	Gross[3] production g C m^{-2} day^{-1}	Live[4] biomass g m^{-2}
Spartina	Thermally affected	May 1	4463	21.9	2.58	2.26	4.84	480
		May 1	4463	21.9	3.74	4.13	7.87	652
		May 2	4180	22.4	2.24	1.19	3.43	480
		May 2	4180	22.4	2.89	4.04	6.93	652
					2.86± .32	2.91± .72	5.77±1.0	
	Control	May 8	3535	23.8	2.14	1.35	3.49	280
		May 8	3535	23.8	1.75	1.38	3.13	380
		May 9	3251	25.8	1.93	1.52	3.45	280
					1.94± .11	1.42± .05	3.36± .20	
Juncus	Thermally affected	May 1	4463	21.9	4.26	6.45	10.71	1216
		May 1	4463	21.9	1.35	5.55	6.90	1244
		May 2	4180	22.4	3.65	1.80	5.45	1216
					3.09± .89	4.60±1.4	7.69±1.5	
	Control	May 9	3251	25.8	4.64	2.95	7.59	1656
		May 9	3251	25.8	5.12	2.82	7.94	1024
					4.88± .24	2.88± .07	7.77± .25	

1. Date of beginning of 24 hour sampling period.

2. Figures below the line are the mean and standard error of the mean for the cell.

3. Estimated by adding nighttime respiration to net daytime photosynthesis.

4. Above-ground live biomass of species indicated dried to a constant weight at 70°C.

Table III-33. Results of gas metabolism measurements of marshes at Crystal River in summer, 1977.

Component	Treatment	Date[1] 1977	Solar insolation kcal m^{-2} day^{-1}	Mean air temp. ^{o}C	Net daytime[2] photosynthesis g C m^{-2} day^{-1}	Nighttime respiration g C m^{-2} day^{-1}	Gross[3] production g C m^{-2} day^{-1}	Live[4] biomass g m^{-2}
Spartina	Thermally affected	July 24	3896	29.0	3.71	1.31	5.02	680
		July 24	3896	29.0	4.36	1.36	5.72	360
		July 25	4463	30.2	3.56	1.14	4.70	608
		July 25	4463	30.2	2.32	1.15	3.47	556
		July 26	5624	31.4	2.63	1.06	3.69	556
					3.32± .37	1.20± .06	4.52± .42	
	Control	July 16	2038	26.1	1.03	1.49	2.52	380
		July 16	2038	26.1	3.97	1.88	5.85	724
					2.50±1.5	1.69± .20	4.19±1.7	
Juncus	Thermally affected	July 24	3896	29.0	4.21	1.83	6.04	1400
		July 24	3896	29.0	5.07	1.94	7.01	1420
		July 25	4463	30.2	5.04	2.02	7.06	952
		July 25	4463	30.2	4.52	3.08	7.60	1452
		July 26	5624	31.4	4.05	1.59	5.64	952
		July 26	5624	31.4	5.39	2.07	7.46	1452
					4.71± .22	2.09± .21	6.80± .32	
	Control	July 20	4773	30.4	4.64	1.70	6.34	1456
		July 20	4773	30.4	6.28	1.78	8.06	760
		July 21	4412	31.9	4.26	1.68	5.94	1056
		July 21	4412	31.9	5.04	1.74	6.78	1136
					5.06± .44	1.73± .02	6.78± .46	

1. Date of beginning of 24 hour sampling period.

2. Figures below the line are the mean and standard error of the mean for the cell.

3. Estimated by adding nighttime respiration to net daytime photosynthesis.

4. Above-ground live biomass of species indicated dried to a constant weight at 70°C.

Table III-34. Results of gas metabolism measurements of marshes at Crystal River in fall, 1977.

Component	Treatment	Date[1] 1977	Solar insolation kcal m^{-2} day^{-1}	Mean air temp. ^oC	Net daytime[2] photosynthesis g C m^{-2} day^{-1}	Nighttime respiration g C m^{-2} day^{-1}	Gross[3] production g C m^{-2} day^{-1}	Live[4] biomass g m^{-2}
Spartina	Thermally affected	Oct 6	4154	22.9	0.81	0.94	1.75	516
		Oct 6	4154	22.9	2.04	0.91	2.95	536
		Oct 7	4128	24.9	0.12	1.52	1.64	380
		Oct. 7	4128	24.9	0.28	1.19	1.47	392
					0.81± .43	1.14± .14	1.95± .34	
	Control	Oct 10	4825	26.6	1.87	2.44	4.31	508
		Oct 10	4825	26.6	2.10	1.36	3.46	620
		Oct 11	2296	24.2	1.00	0.88	1.88	508
		Oct 11	2296	24.2	1.07	0.82	1.89	620
					1.51± .28	1.38± .38	2.89± .60	
Juncus	Thermally affected	Oct 6	4154	22.9	1.87	1.06	2.93	1176
		Oct 6	4154	22.9	2.40	0.99	3.39	2400
		Oct 7	4128	24.9	0.65	2.36	3.01	1468
		Oct 7	4128	24.9	1.15	1.50	2.65	1676
					1.52± .39	1.48± .32	3.00± .15	
	Control	Oct 10	4825	26.6	3.29	2.08	5.37	2200
		Oct 10	4825	26.6	3.34	1.14	4.48	1508
		Oct 11	2296	24.2	2.04	1.89	3.93	2200
		Oct 11	2296	24.2	2.05	0.77	2.82	1508
					2.68± .37	1.47± .31	4.15± .53	

---

1. Date of beginning of 24 hour sampling period.

2. Figures below the line are the mean and standard error of the mean for the cell.

3. Estimated by adding nighttime respiration to net daytime photosynthesis.

4. Above-ground live biomass of species indicated dried to a constant weight at 70°C.

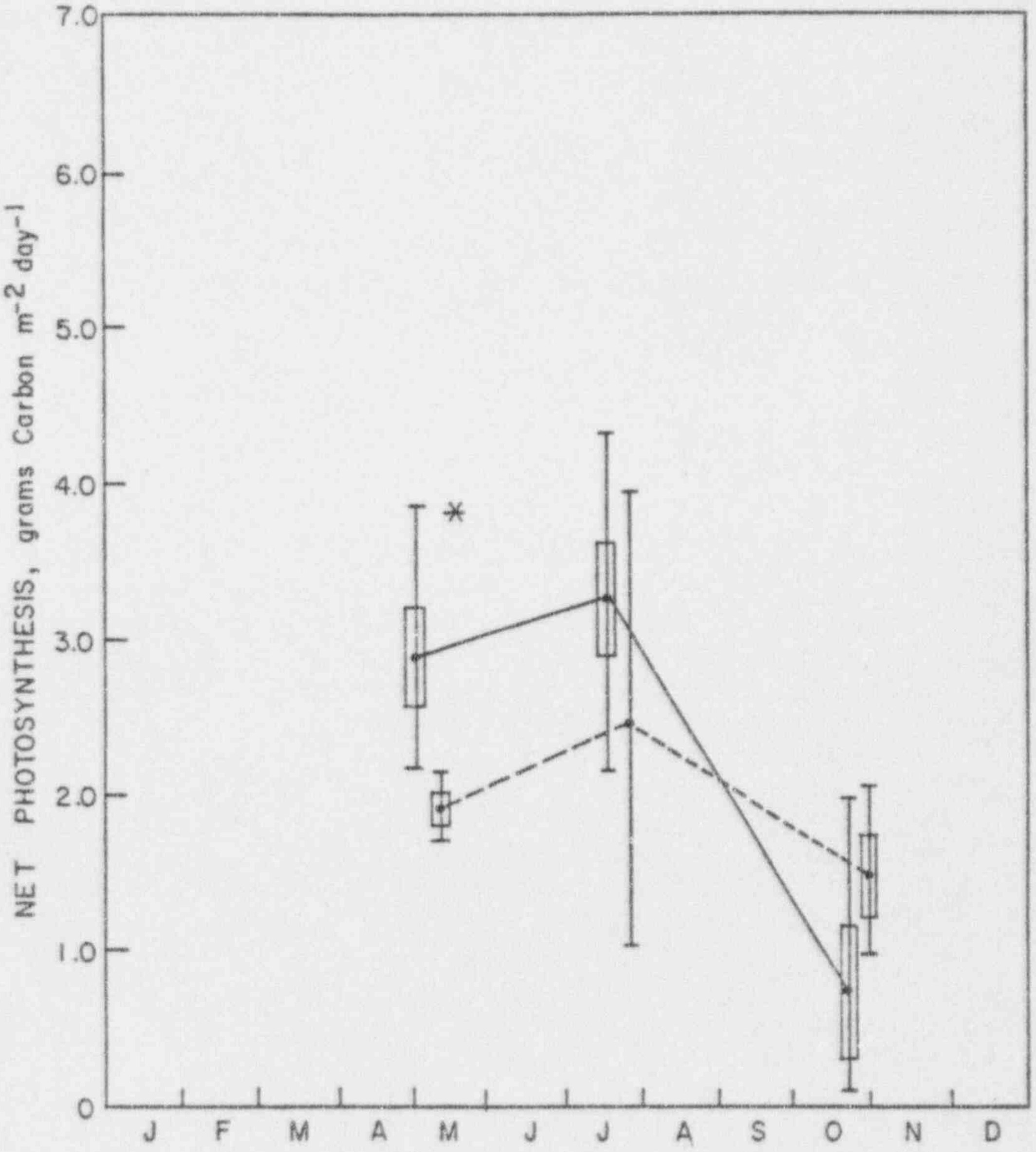


Fig. III-50. Mean seasonal values of net daytime photosynthesis for Spartina. Solid lines are thermally affected marsh. Broken lines are control areas. Vertical lines represent ranges; boxed portion indicates standard error.(*) represents significant differences between means at 90% confidence level. (1977)

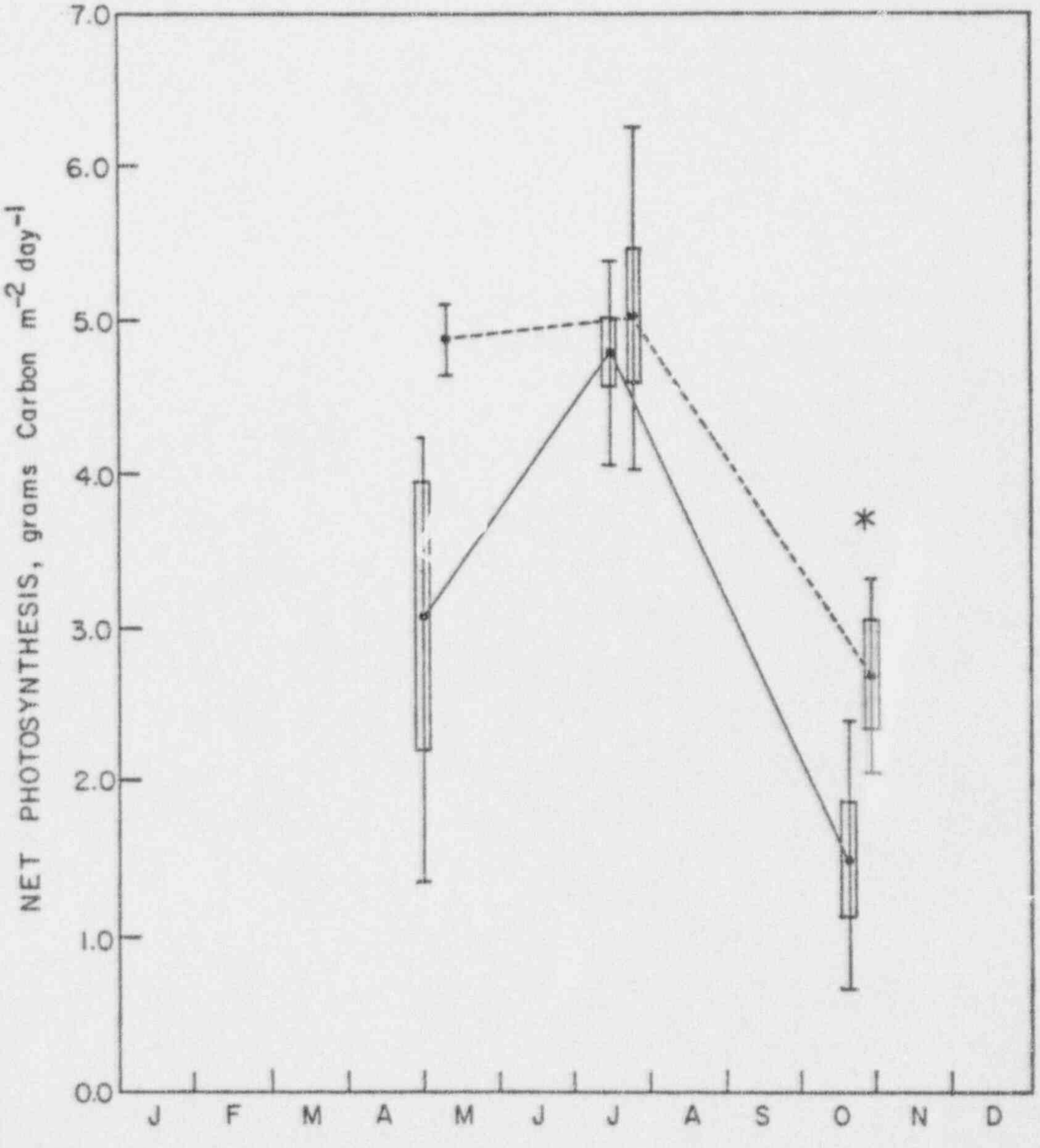


Fig. III-51. Mean seasonal values of net daytime photosynthesis for _Juncus_ as measured by gas metabolism methods. Solid lines are discharge marshes. Broken lines represent control area. Vertical lines represent ranges; boxed portion indicates standard error. (*) indicates significant differences between means at 90% confidence level. (1977).

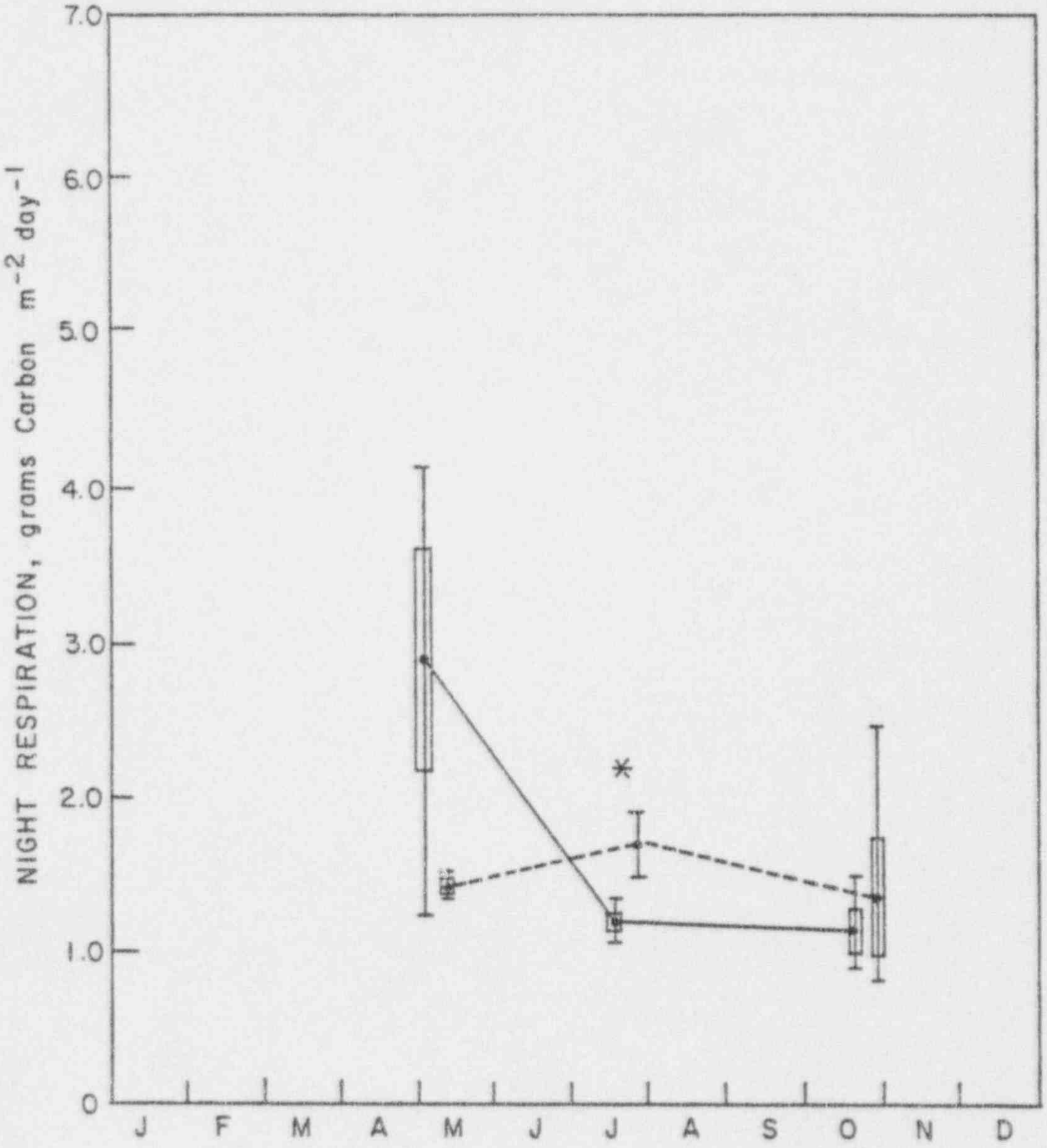


Fig. III-52. Mean seasonal values of night respiration for Spartina. Solid lines are discharge marshes. Broken lines are control areas. Vertical lines represent ranges; boxed portion indicates standard error. (1977).

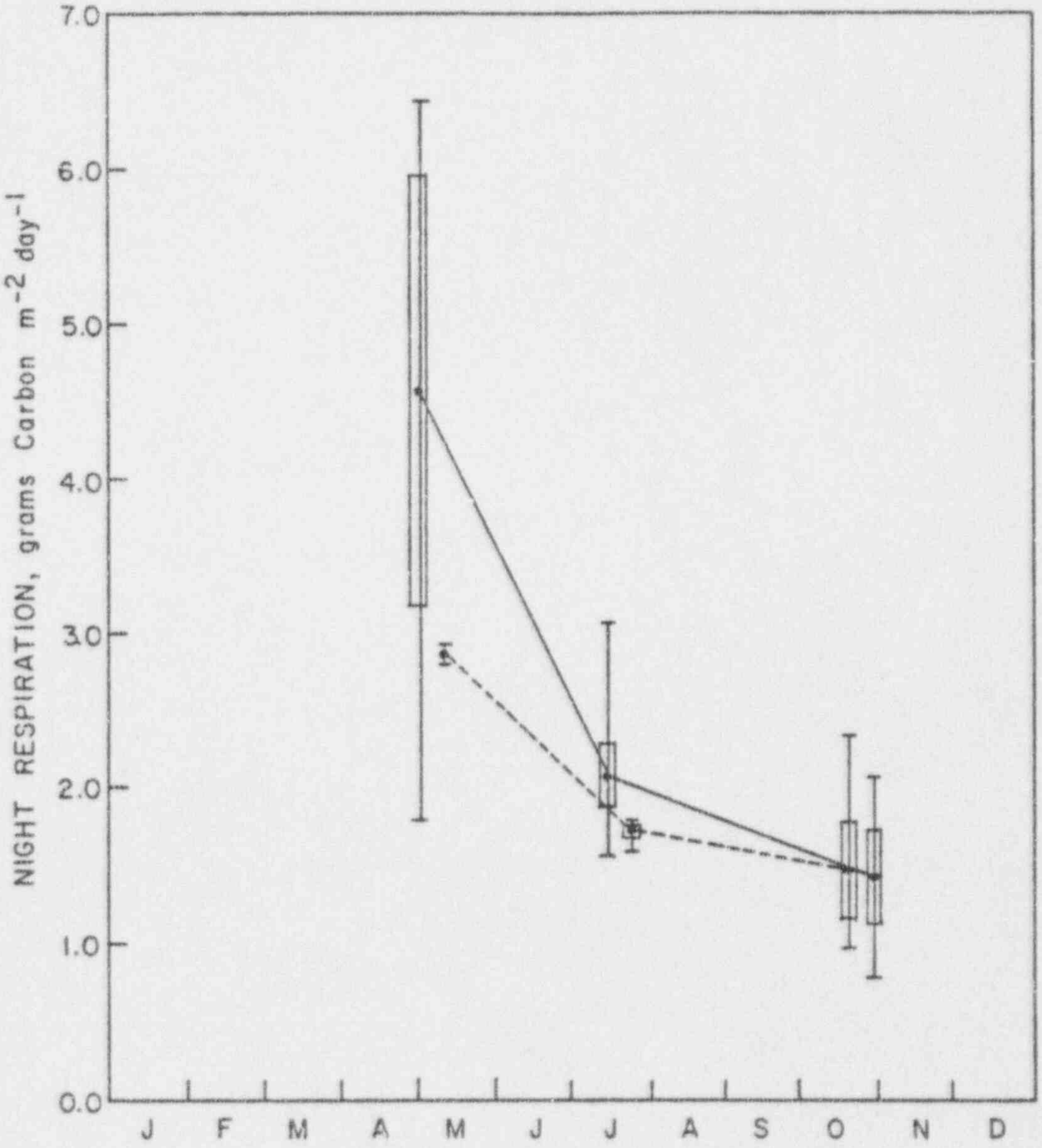


Fig. III-53. Mean seasonal values of night respiration for *Juncus*. Solid lines represent discharge areas. Broken lines are control marshes. Vertical lines represent ranges; boxed portion indicates standard error. (1977).

Figs. III-54 and III-55 show for Spartina and Juncus marshes, respectively, annual values of an efficiency index based on the ratio of gross production estimated from gas analysis measurements by adding net daytime photosynthesis and night respiration, to daily solar insolation. For thermally affected and control Spartina marshes, least efficiency was in the fall and greatest efficiency was in the spring and summer. For both Juncus sites, maximum efficiency was in the spring and minimum in the fall.

Animal activity indices:

Littorina density: Mean seasonal values of numbers of periwinkle snails m^{-2} are given for thermally affected and control Spartina and Juncus marshes in Table III-35. Maximum numbers of snails were found in the fall in the thermally affected marshes. Numbers in the control marshes were very low.

Crab hole density: Table III-36 presents crab hole density for Spartina and Juncus marshes in areas receiving thermally elevated effluent and control areas. In the Spartina marshes, maximum densities occurred in the July and October samples. The crab hole density was more uniform in the Juncus areas with maximum density in the same period: summer and fall.

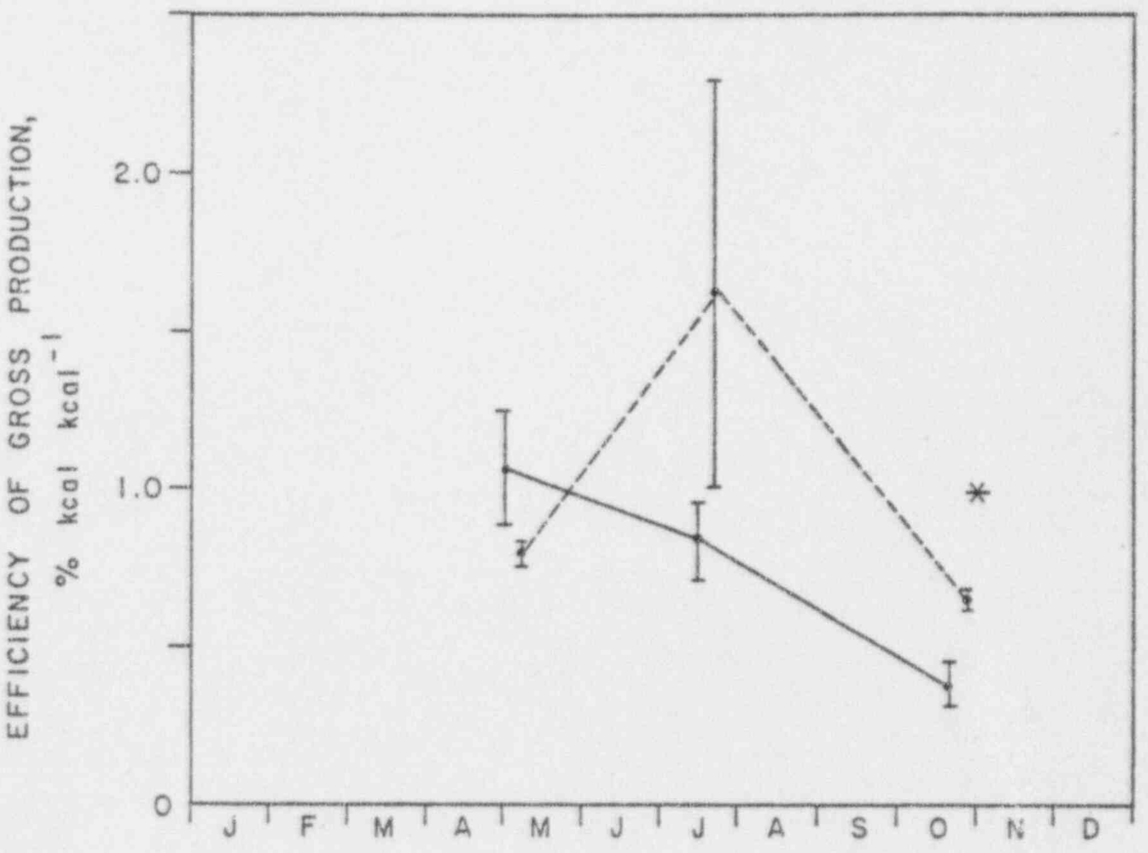


Fig. III-54. Mean seasonal values of an efficiency index of gross production for Spartina. Solid lines are thermally affected marsh. Broken lines are control areas. Vertical lines represent standard errors. (*) represents significant differences between the means at a 95% confidence level (1977).

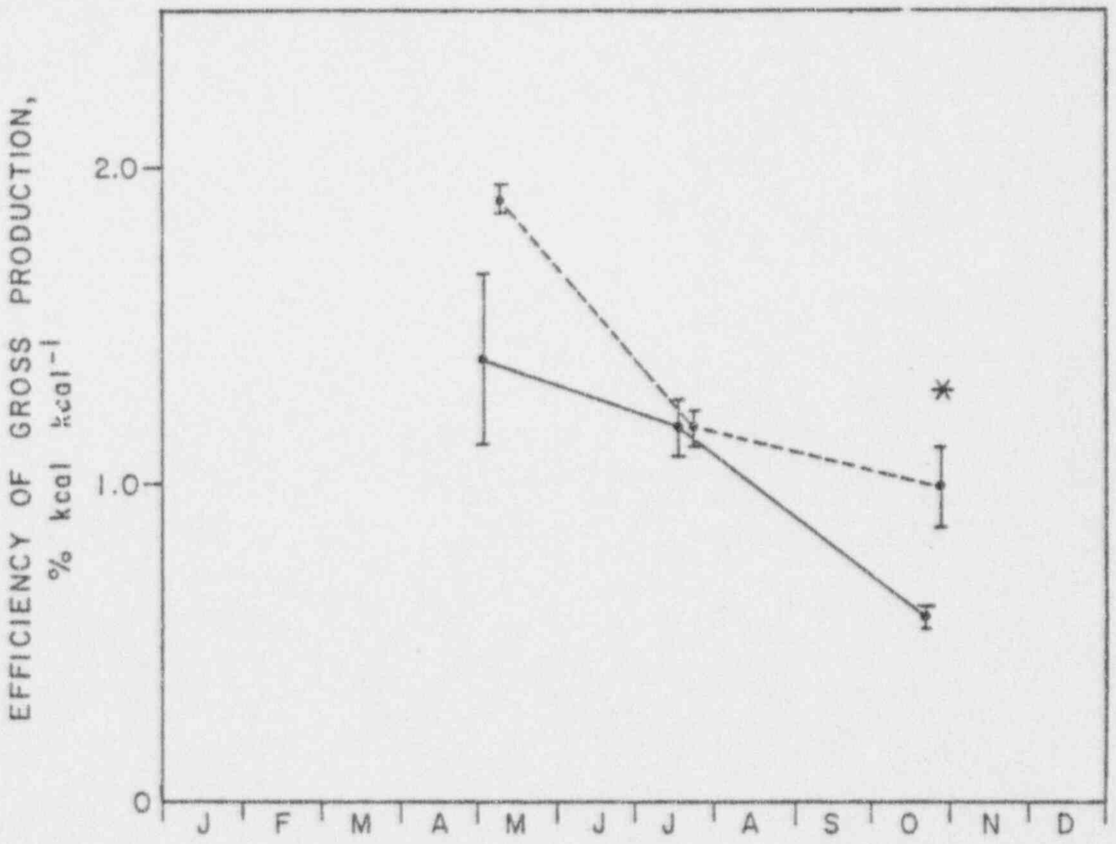


Fig. III-55. Mean seasonal values of an efficiency index of gross production for Juncus. Solid lines are discharge areas. Broken lines are control areas. Vertical lines represent standard errors. (*) indicates significant differences at 95% level (1977).

Table III-35. Annual record of *Littorina* (snail) density in *Spartina* and *Juncus* marshes. (*) indicates significant differences between the means by t-test at the 95% confidence level.

	Thermally Affected			Control		
	$\bar{X}$	SE	N	$\bar{X}$	SE	N
SPARTINA MARSH						
May 1977	1.8	±0.8	11	0	±0	9
July 1977	8.0	±4.2	9 *	0	±0	11 *
Oct 1977	10.7	±3.8	9 *	0.4	±0.4	9 *
JUNCUS MARSH						
May 1977	3.2	±0.80	5	0.8	±0.8	5
July 1977	2.0	±0.89	6 *	0	±0	9 *
Oct 1977	5.6	±3.0	5	0	±0	5

Table III-36. Annual record of crab hole density of *Spartina* and *Juncus* marshes (*) indicates significant dirferences between the means by t-test at the 95% confidence level.

	Thermally Affected			Control		
	$\overline{X}$	SE	N	$\overline{X}$	SE	N
SPARTINA						
May 1977	97.5	±16	11	84.4	±9.3	9
July 1977		no data[1]		237	±18	9
Oct 1977	134	±32	7	207	±22	9
JUNCUS						
May 1977	153	±42	5	102	±24	5
July 1977		no data[1]		189	±20	4
Oct 1977	197	±21	3	134	±21	5

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[1] Harvest of vegetation during high tides made counting of crab holes impossible.

Discussion

Seasonal Patterns

Prior to the beginning of the growing season, above ground live standing crop was at a minimum, as seen in Figs. III-38 and III-41. As solar insolation and air temperature became more favorable, the amount of carbon fixed during the daytime periods as measured by gas analysis increased, as does the gross community productions. (Tables III-32, III-33). Although not all of what is fixed by the plants accumulates as biomass, due to herbivory, death, export and other losses, Figs. III-46 and III-47 indicate that plant stature did increase over the growing season. Also, specific weight increased from winter to fall as shown in Figs. III-48 and III-49.

Comparisons of Thermally Affected and Control Marshes

As seen in Figs. III-38 and III-41, weight differences between thermally affected and control areas were generally not significant. However, plant densities were generally greatest in the thermally affected areas (Figs. III-44 and III-45), while stalk heights were greatest in the control marsh (Fig. III-46 and III-47). Thus, the weight of an individual plant or plant shoot was generally greater in the control areas, as shown rather dramatically in Fig. III-48 for *Spartina* and less so in Fig. III-49 for *Juncus*. Figures III-54 and III-55 seem to indicate that the communities in the control areas were more capable of capturing solar energy for use by marsh and estuarine fauna. Over the year the gross production of the thermal marsh was similar for *Spartina* and *Juncus*. All values of production are moderately high compared to those of many aquatic ecosystems.

Comparisons of Spartina and Juncus Marshes

Striking differences were displayed between Spartina and Juncus marshes, possibly due to greater tidal access to Spartina carrying off dead organic matter. Figures III-38 and III-41 indicate that live biomass of Juncus was approximately twice that of Spartina and accumulated through the year. Figures III-39 and III-42 show that the amount of Spartina dead material was less than Juncus and decreased through the year.

As Figs. III-52 and III-53 show, respiration measured by gas metabolism was similar for Spartina and Juncus on an area basis, however, since the live biomass of Juncus was so much greater, the specific respiration (per unit weight) was actually higher in the Spartina. Gross photosynthesis and efficiency were higher in Juncus. Net production was also greater for Juncus, much of which accumulated as biomass (Fig. III-41). Spartina had less net production and since its biomass was fairly constant (Fig. III-42) much organic matter may have been exported. As Young (1975) showed in the previous marsh studies of the same area, decomposition of Spartina occurs at a much greater rate than does Juncus material. Although the dead biomass of Juncus accumulated over the growing season measured, it should be noted that Juncus marshes can export large quantities of organic matter in pulses to the estuary during extreme storm tides.

Comparisons with Previous Study

Patterns of measurements of marsh structure and function in the present study are comparable in magnitude to the 1973 studies in similar sites (Young, 1974; Young, 1975). At the present time the only season for which values from gas metabolism measurements are directly comparable is July. Young (1975) found night respiration in thermal Spartina marshes to be 2.1 grams carbon $m^{-2} day^{-1}$ and gross production to be 7.9 grams carbon $m^{-2}day^{-1}$, both of which were less in the present study. For the Juncus areas, Young (1975) reports night respiration to be 2.3 grams carbon m^{-2} and gross metabolism of 6.14 grams carbon m^{-2}day, which are comparable to values of the present study.

COMPARISON OF SELECTED PREOPERATIONAL AND OPERATIONAL MEASUREMENTS (TWO STANDARD DEVIATION REQUIREMENT)

Introduction

This chapter contains a comparison between selected preoperational (1973) and operational (1977) measurements from the discharge area adjacent to the canal as required by the Environmental Technical Specifications (ETS). Specifically, this requirement involves the reporting of "any parameter measured that changes beyond 2 σ (two standard deviations) of the value measured in the preoperational monitoring program." For the two discharge bays, net productivity, respiration, and gross productivity were the parameters specified for comparison. For the marsh studies, net productivity, respiration, gross productivity, and live and dead biomass for both Juncus and Spartina components were utilized. Seasonal means with ± two standard deviations were calculated for each specified parameter in the preoperational program. Operational means falling outside these ranges are noted; two σ bars around operational means are provided for information purposes.

Results

Comparisons of preoperational (1973) and operational (1977) net productivity, night respiration, and gross productivity seasonal means for the inner discharge bay are shown in Figs. 56-58. Fall values for net productivity, night respiration, and gross productivity fell outside the preoperational 2 σ (two standard deviation) limit. All other values were within the prescribed ranges.

Figures 59-61 show comparisons between preoperational and operational seasonal averages for net productivity, night respiration, and gross productivity for the outer discharge bay. None of the operational values fell outside the preoperational 2 σ limit.

Estimates of preoperational and operational Spartina marsh metabolism are presented for net photosynthesis, night respiration, and

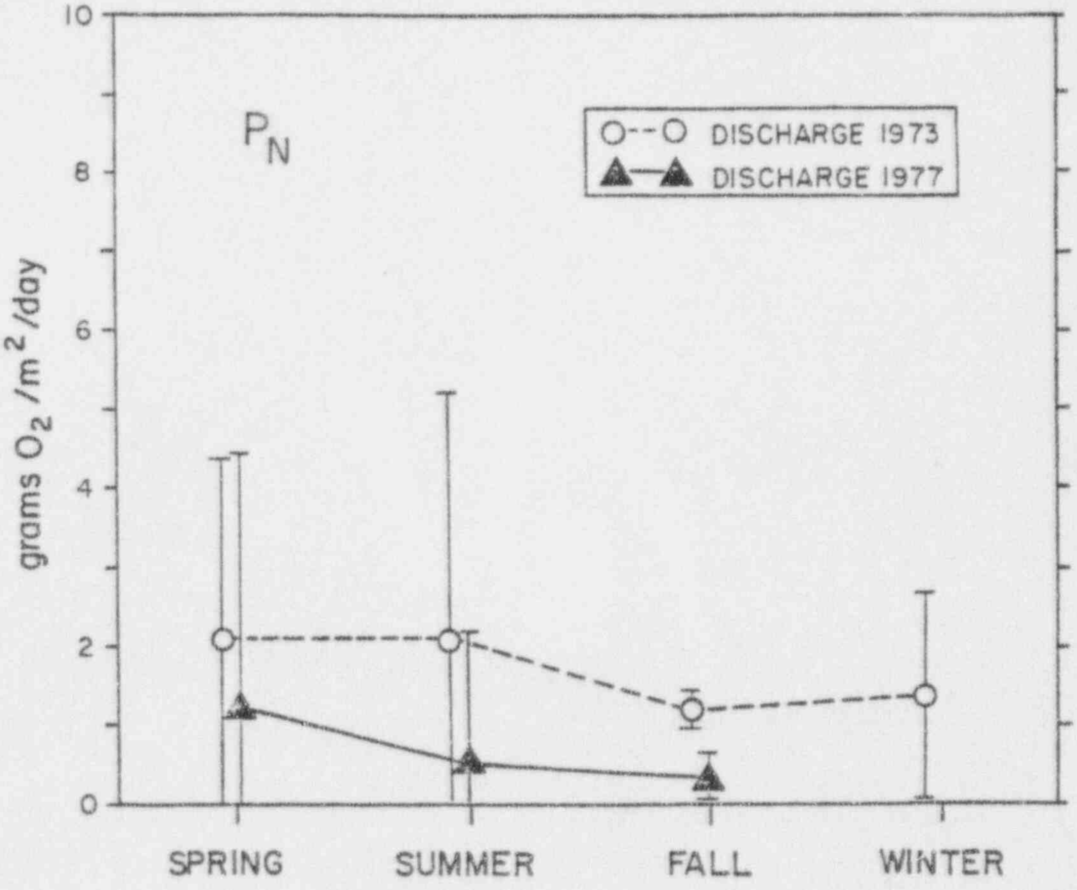

Fig. III-56. Comparison of preoperational (1973) and operational (1977) seasonal mean net productivity values for the inner discharge bay (A). Vertical lines represent ± two standard deviations of the mean.

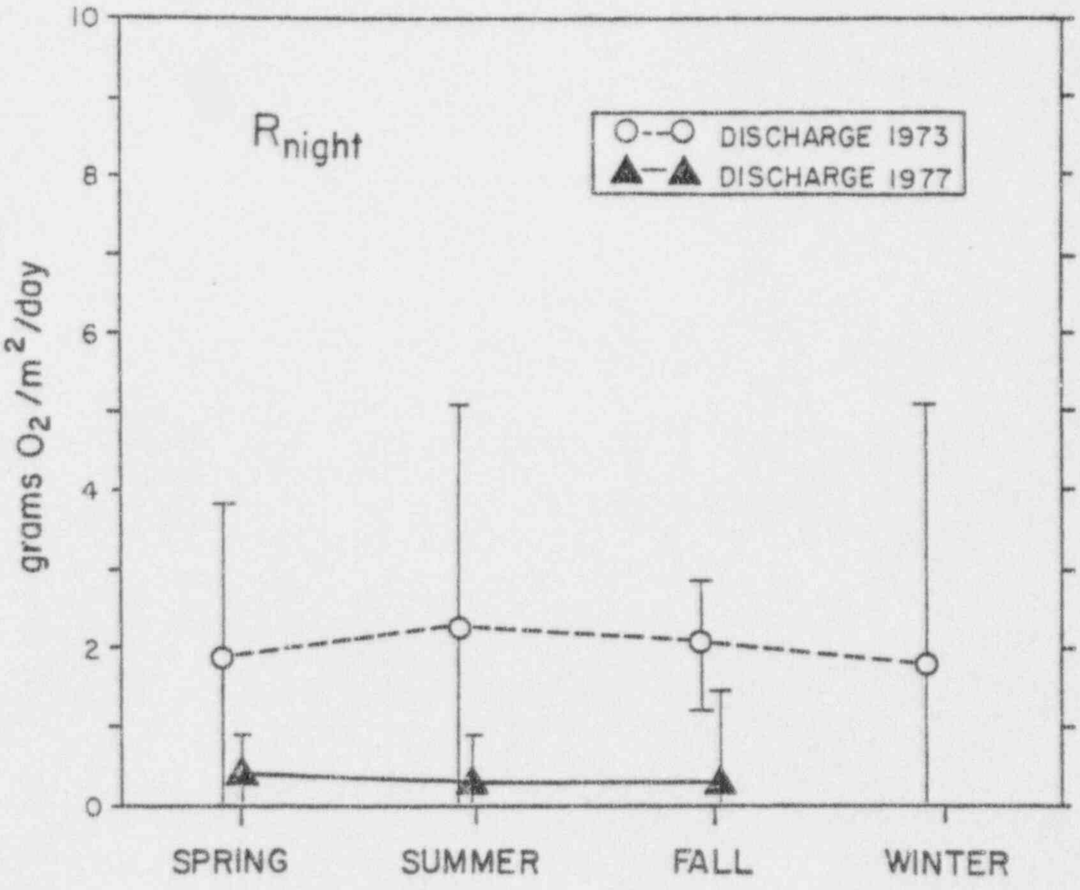

Fig. III-57. Comparison of preoperational (1973) and operational (1977) seasonal mean night respiration values for the inner discharge bay (A). Vertical lines represent ± two standard deviations of the mean.

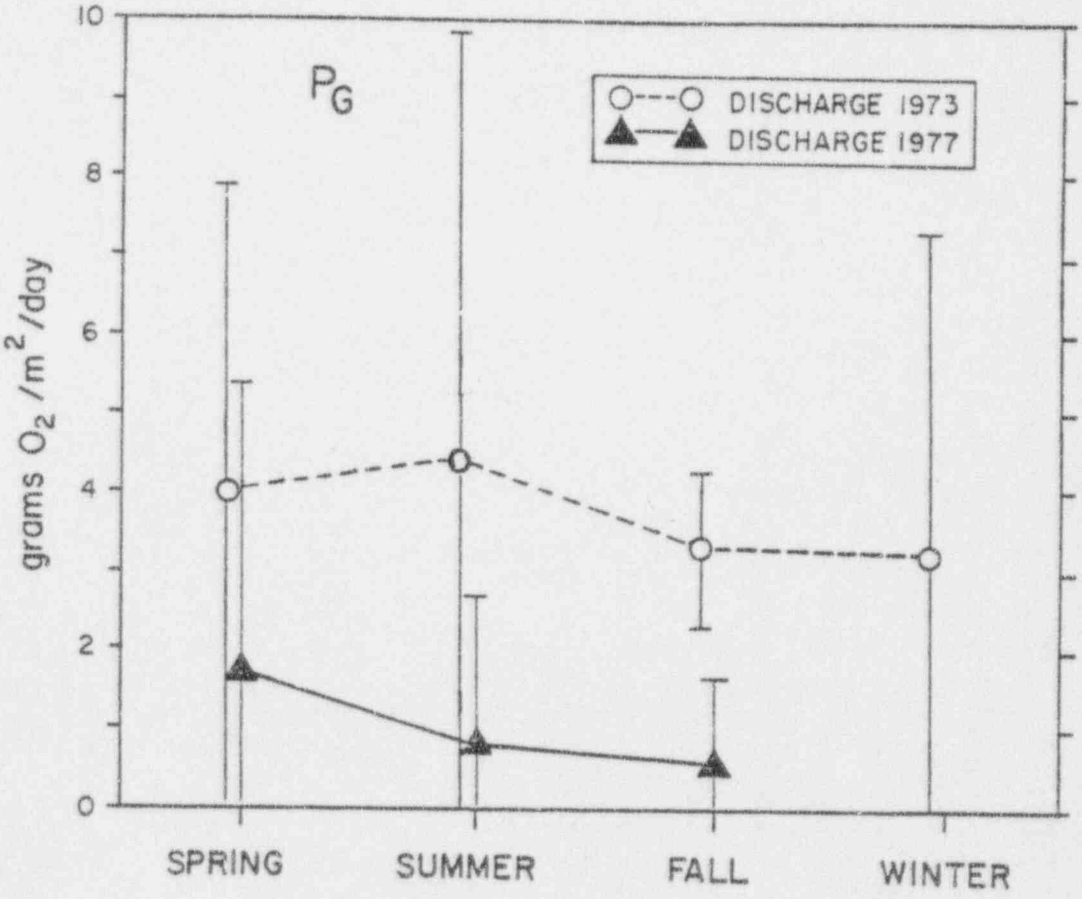

Fig. III-58. Comparison of preoperational (1973) and operational (1977) seasonal mean gross productivity estimates for the inner discharge bay (A). Vertical lines represent ± two standard deviations of the mean.

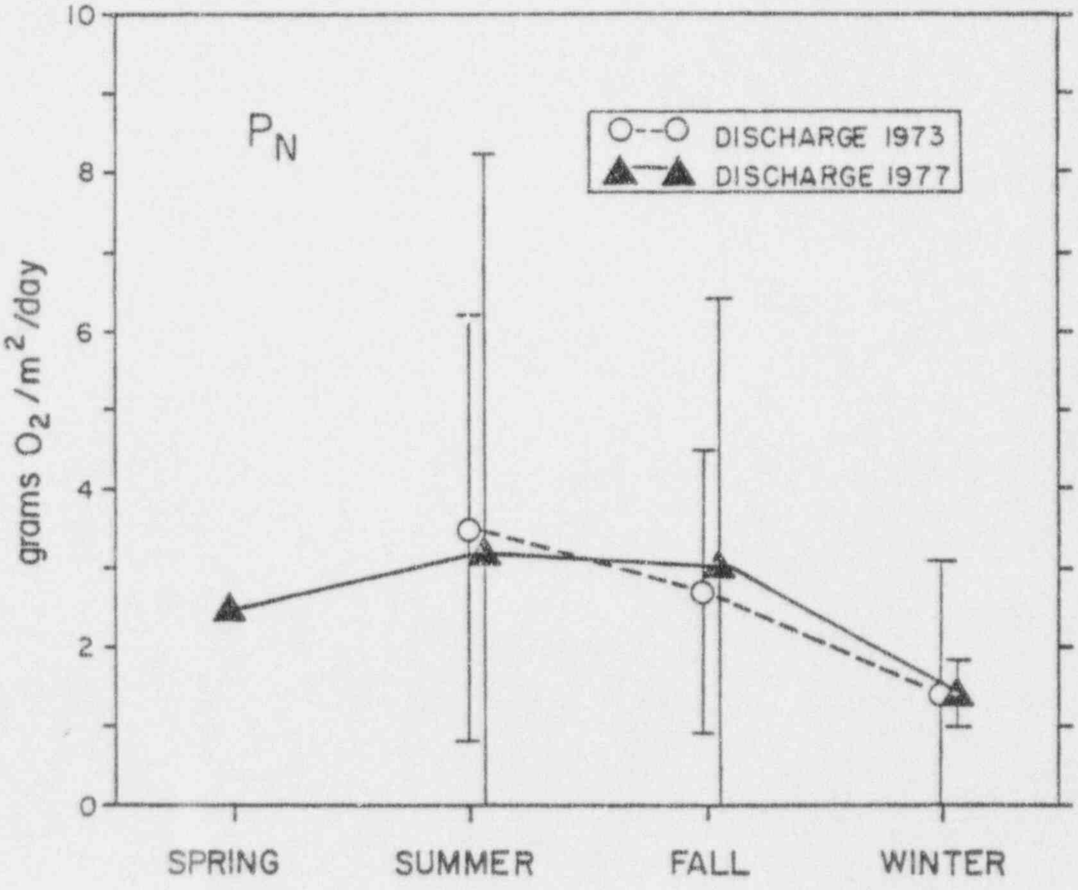

Fig. III-59. Comparison of preoperational (1973) and operational (1977) seasonal mean net productivity values for the outer discharge bay (B). Vertical lines represent ± two standard deviations of the mean.

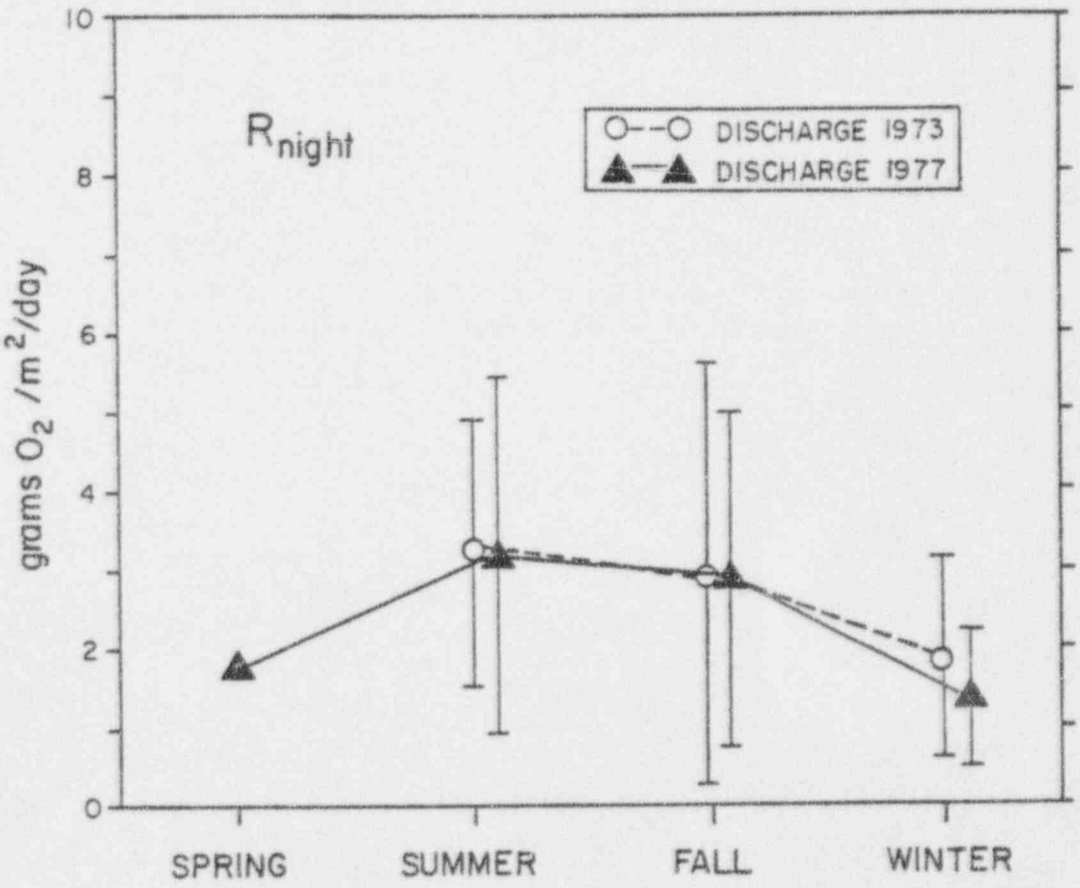

Fig. III-60. Comparison of preoperational (1973) and operational (1977) seasonal mean night respiration values for the outer discharge bay (B). Vertical lines represent ± two standard deviations of the mean.

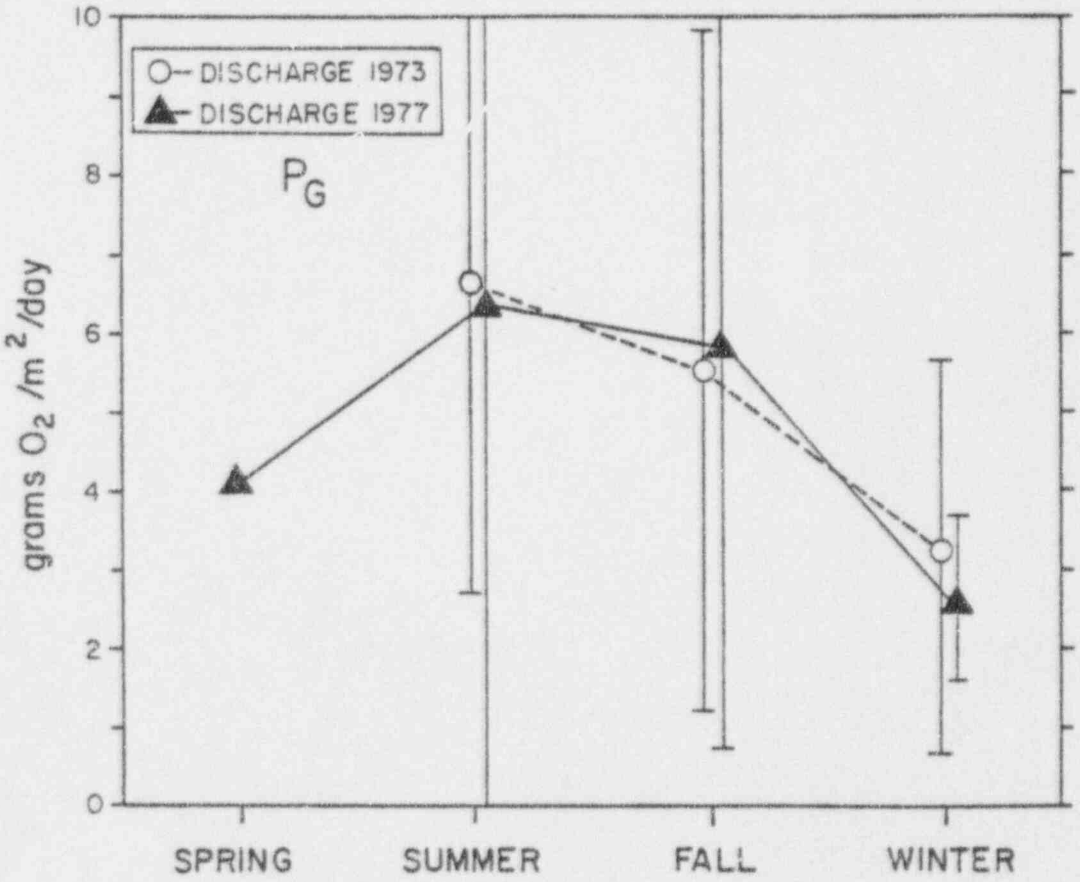

Fig. III-61. Comparison of preoperational (1973) and operationsl (1977) seasonal mean gross productivity estimates for the outer discharge bay (B). Vertical lines represent ± two standard deviations of the mean.

gross productivity in Figs. 62-64. The operational summer (July) value for night respiration fell outside the preoperational 2 σ limit. All other measurements were within the prescribed range.

Seasonal comparisons of net photosynthesis, night respiration, and gross productivity estimates for the Juncus marshes are shown in Figs. 65-67. All of these operational values were within the 2 σ limit.

Above ground biomass (live and dead) comparisons for 1973 and 1977 Spartina marshes are given in Fig. 68. Summer and fall operational dead biomass estimates fell outside (lower than) the preoperational 2 σ limit. Live biomass estimates were within the 2 σ range.

Figure 69 shows a comparison of the above ground biomass (live and dead) for the Juncus marshes. Live biomass estimates for the spring, summer, and fall were outside (higher than) the 2 σ limit. Dead biomass estimates were all within the preoperational inverval.

Summary

1) Fall operational (1977) estimates for net productivity, night respiration, and gross productivity in the inner discharge bay fell outside the preoperational (1973) 2 σ (two standard deviation) limit.

2) In the outer discharge bay, all mean seasonal estimates for net productivity, night respiration, and gross productivity were within the prescribed 2 σ limit.

3) The summer night respiration average for the Spartina marshes fell outside the preoperational 2 σ limit.

4) Metabolism estimates for the Juncus marshes fell within the prescribed 2 σ limit.

5) The Spartina dead biomass portion of the above ground biomass estimates fell outside the 2 σ limit during the summer and fall operational phases, although this portion was lower than recorded previously (1973).

6) The live biomass portion of the Juncus marshes fell beyond the 2 σ limit during the spring, summer, and fall, although these values were higher than recorded during the preoperational phase.

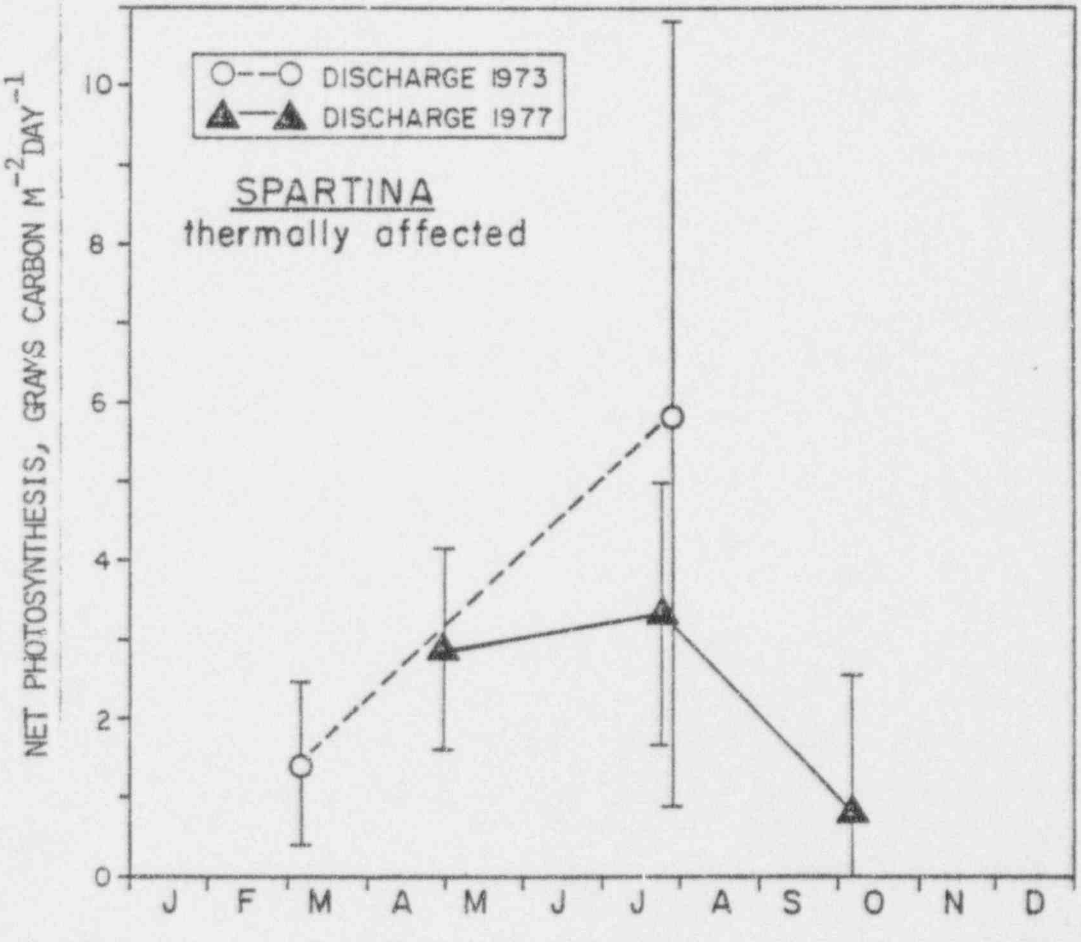

Fig. III-62. Comparison of preoperational (1973) and operational (1977) net photosynthesis for thermally affected *Spartina* marshes. The symbols are means with vertical lines representing ± two times the standard deviation.

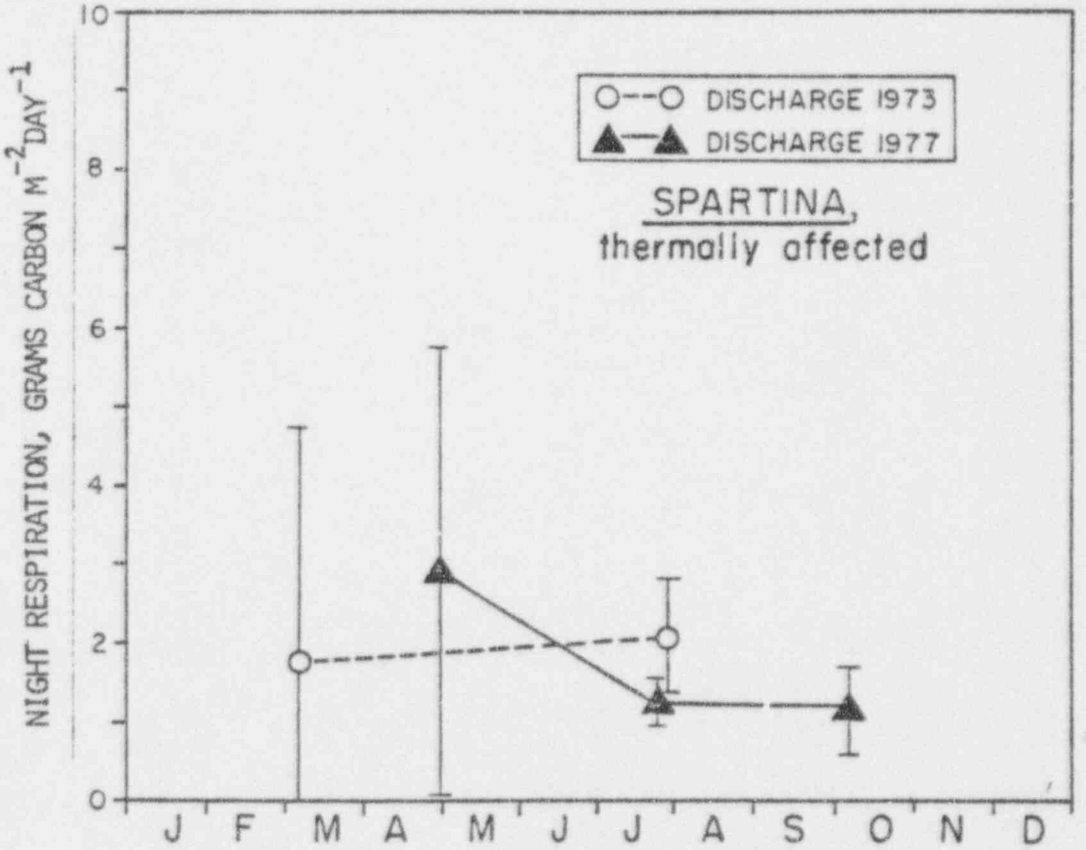

Fig. III-63. Comparison of preoperational (1973) and operational (1977) night respiration for thermally affected Spartina marshes. The symbols are means and the vertical lines are ± two times the standard deviation.

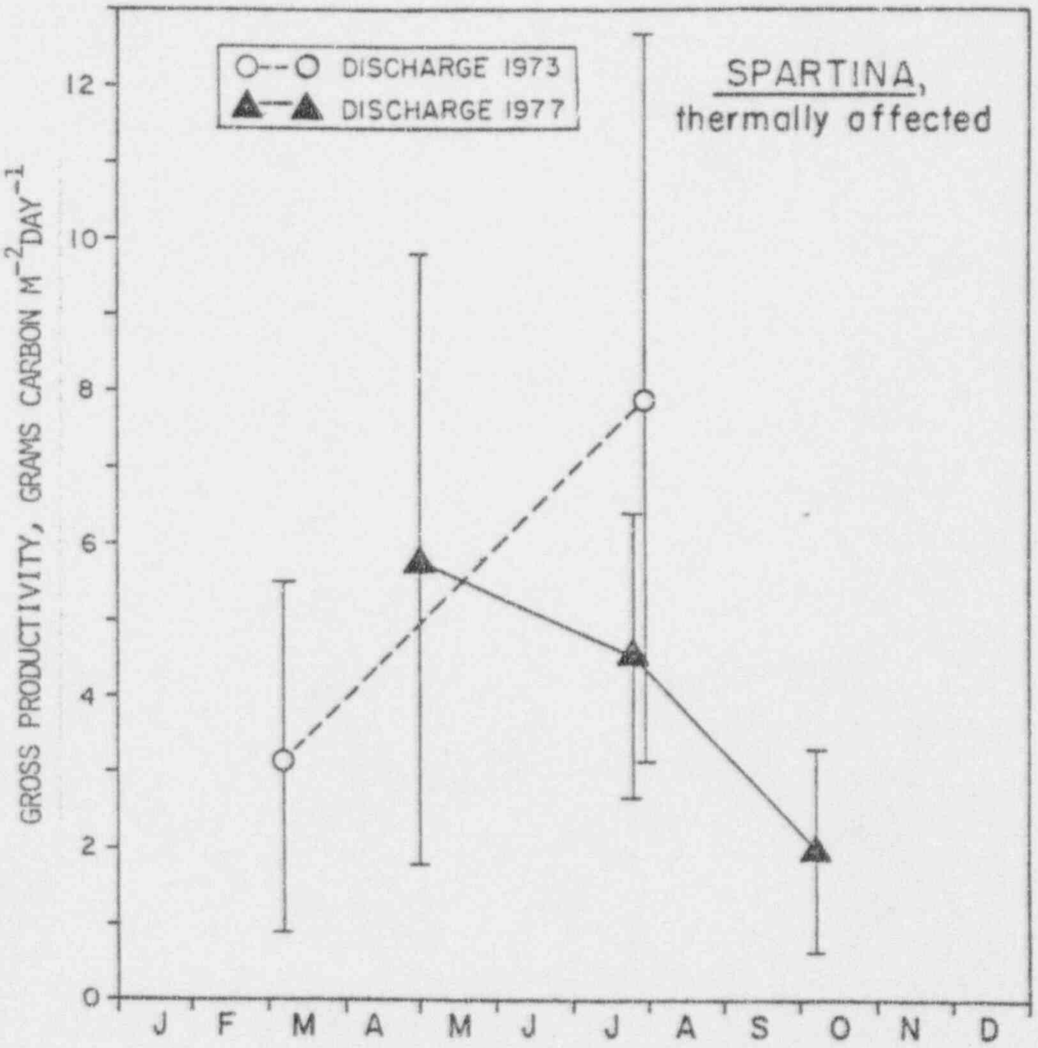

Fig. III-64. Comparison of preoperational (1973) and operational (1977) indices of gross productivity for thermally affected *Spartina* marshes. Symbols are means and vertical lines are ± two times the standard deviation.

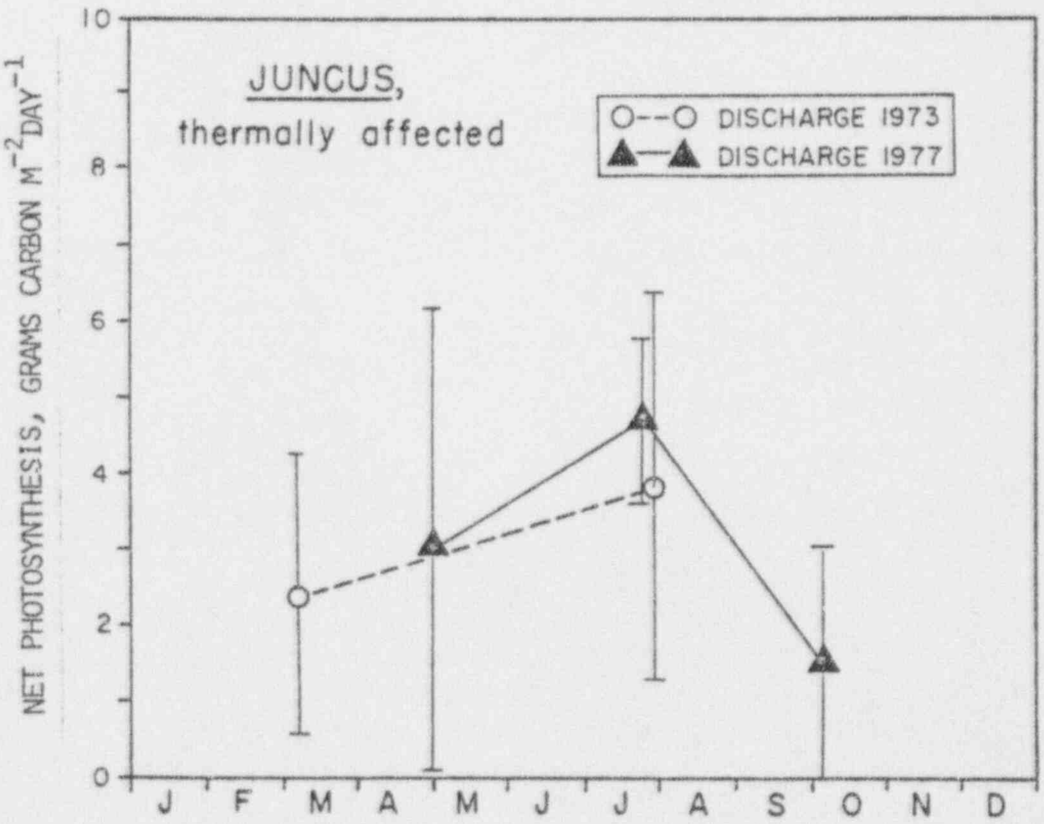

Fig. III-65. Comparison of preoperational (1973) and operational (1977) net photosynthesis for thermally affected *Juncus* marshes. Symbols are means and vertical lines are ± two times the standard deviation.

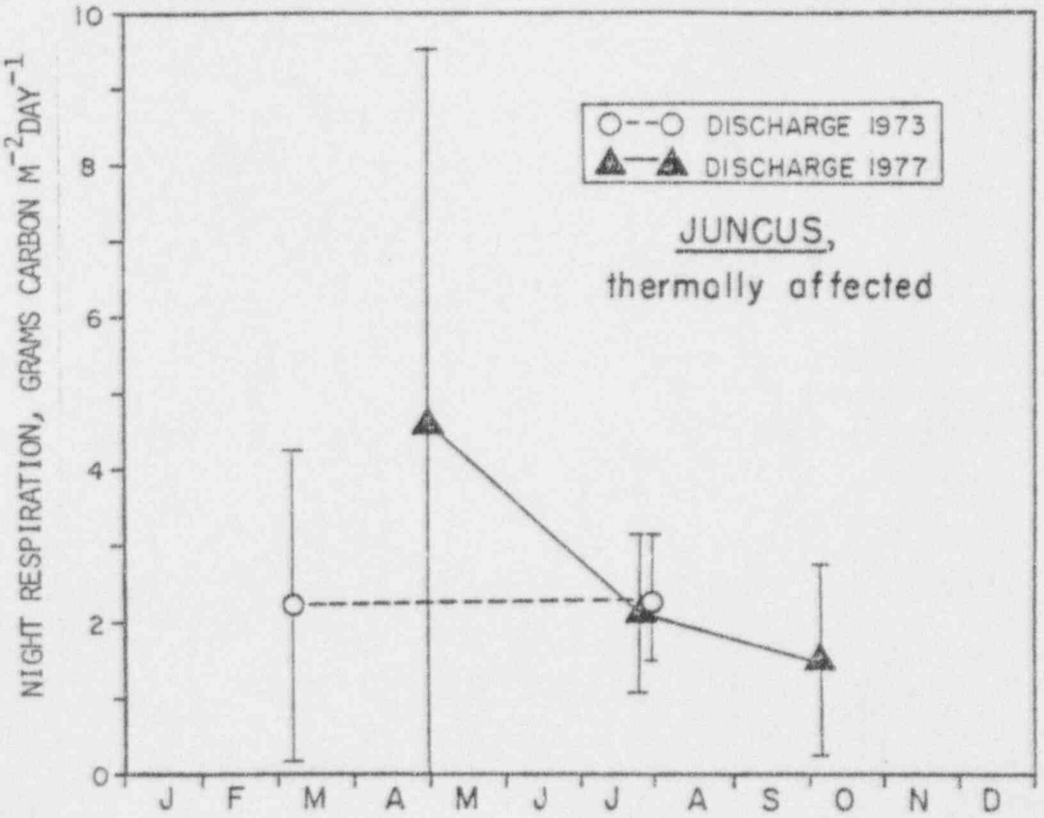

Fig. III-66. Comparison of preoperational (1973) and operational (1977) night respiration for thermally affected Juncus marshes. Symbols are means and vertical lines are ± two times the standard deviation.

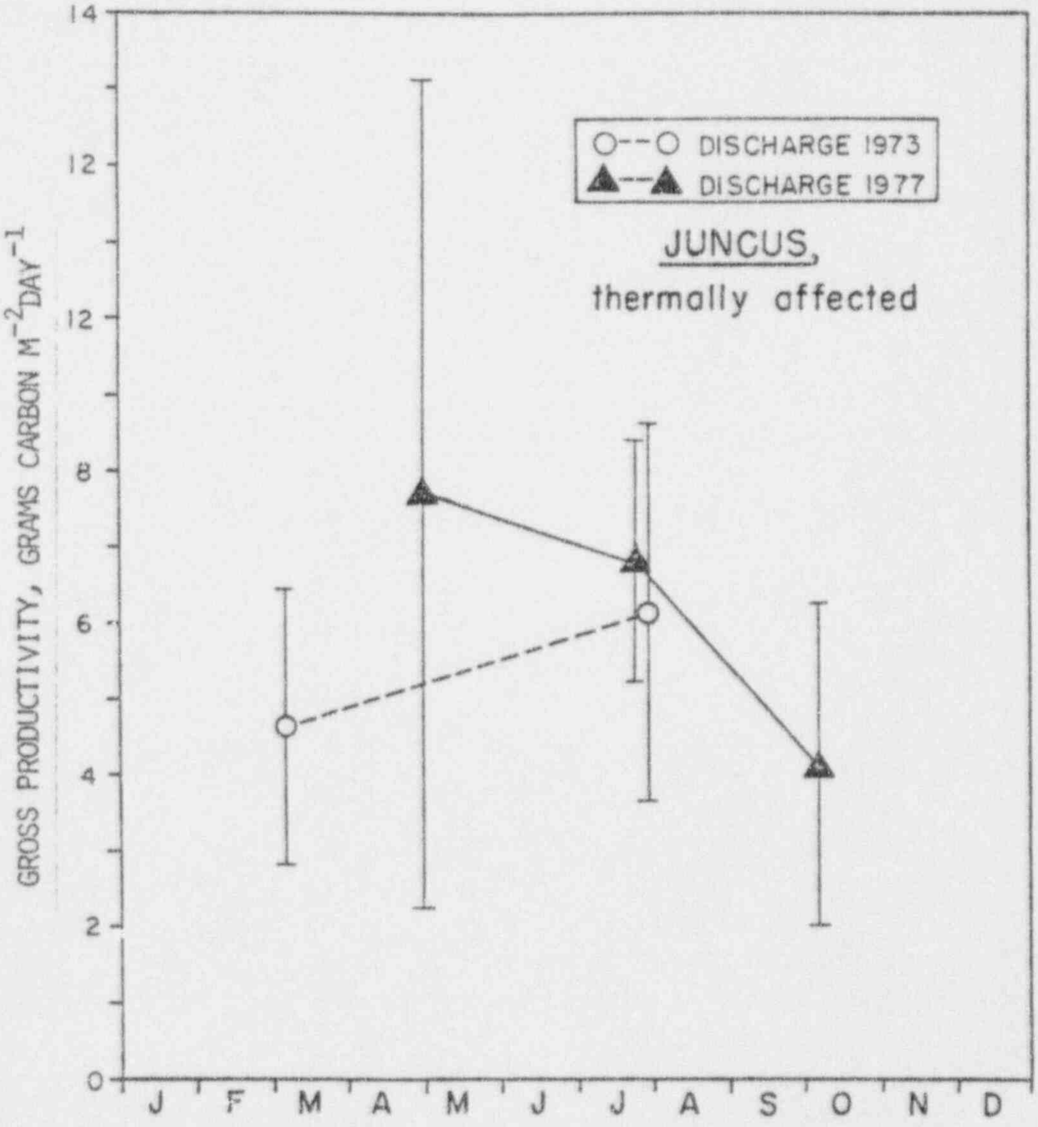

Fig. III-67. Comparison of preoperational (1973) and operational (1977) indices of gross productivity for thermally affected Juncus marshes. Symbols are means and vertical lines are ± two times the standard deviation.

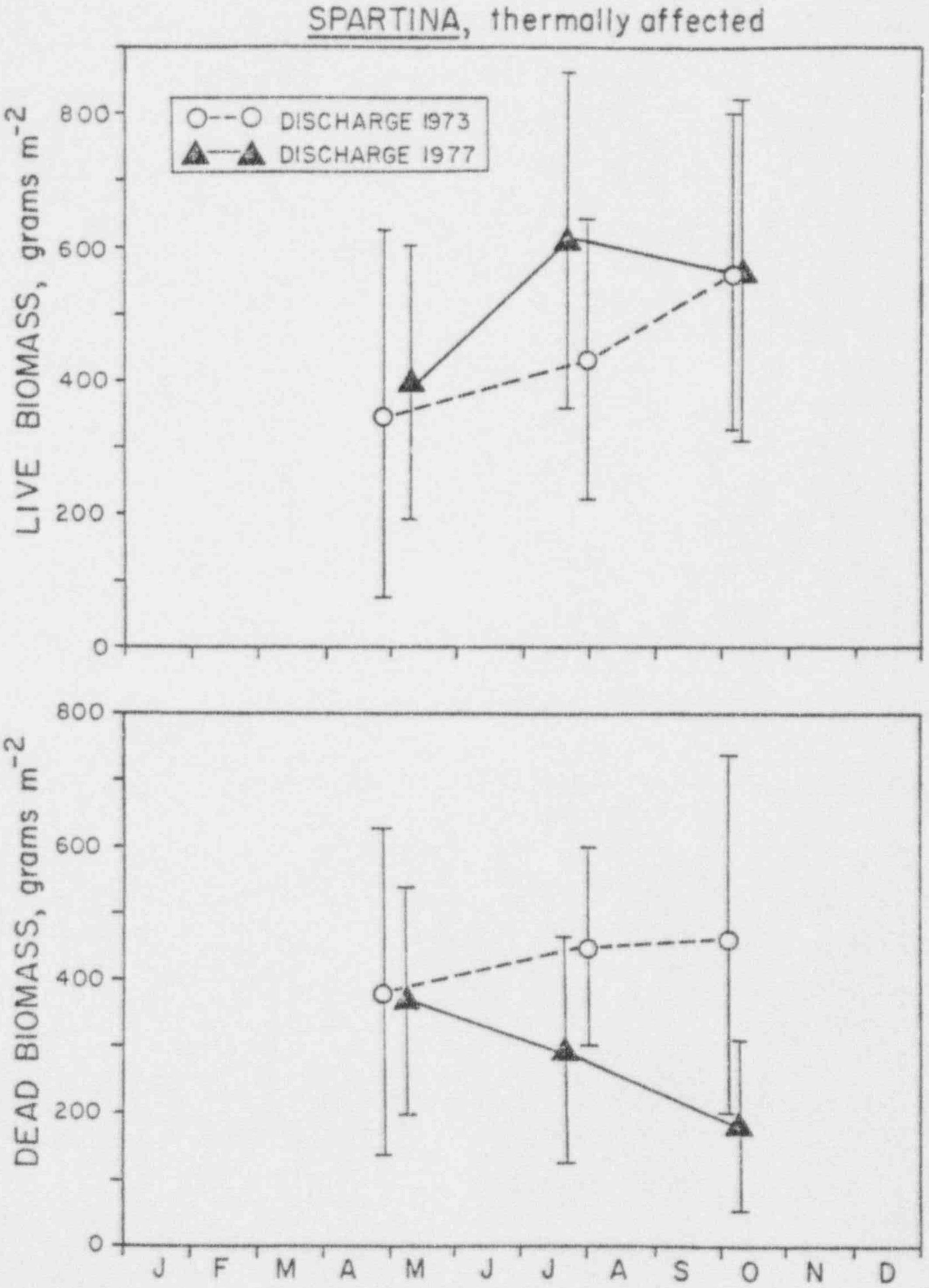

Fig. III-68. Comparison of preoperational (1973) and operational (1977) above ground live and dead biomass for thermally affected *Spartina* marshes. Symbols are means and vertical lines are ± two times the standard deviation.

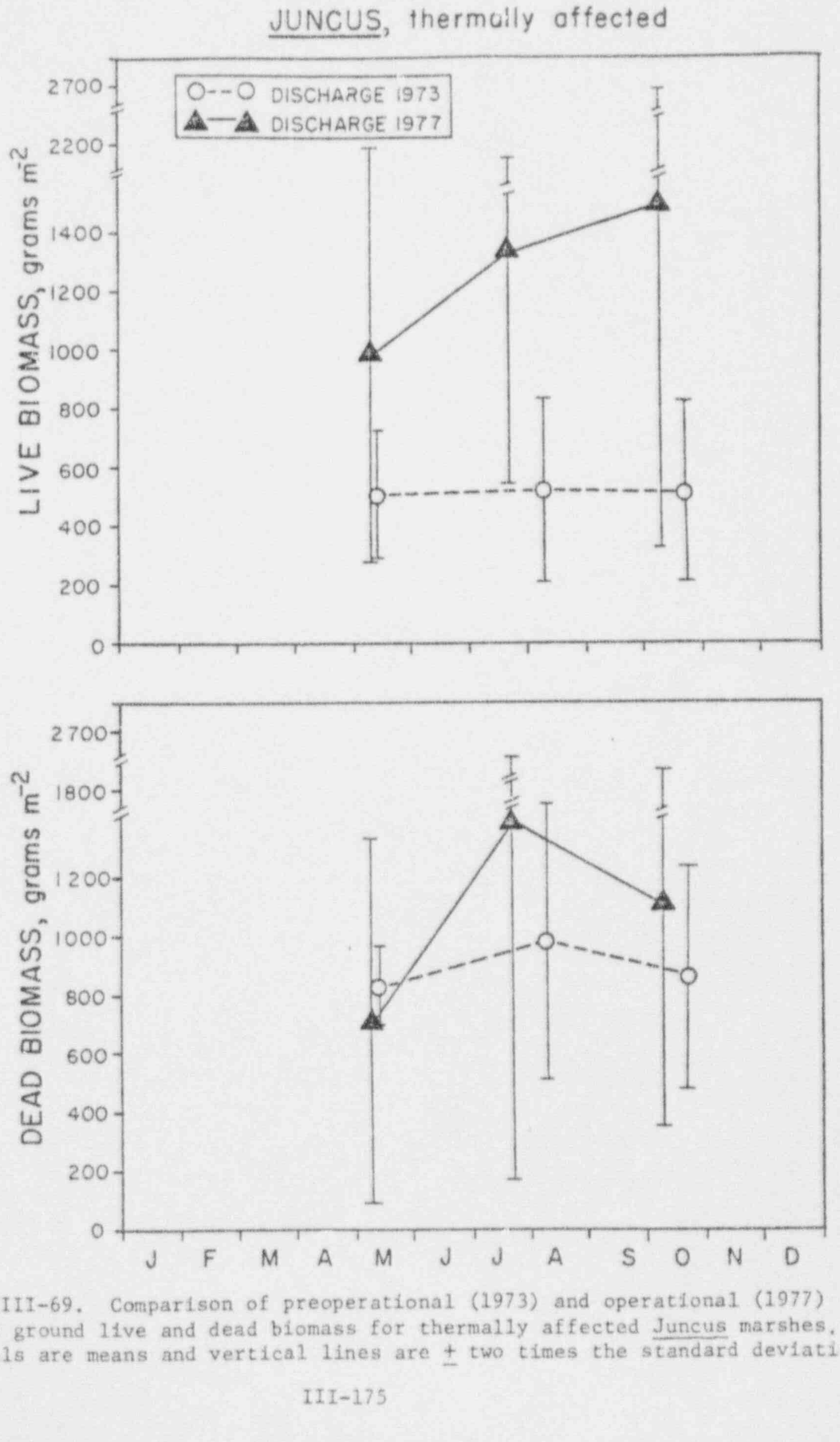

Fig. III-69. Comparison of preoperational (1973) and operational (1977) above ground live and dead biomass for thermally affected *Juncus* marshes. Symbols are means and vertical lines are ± two times the standard deviation.

PERSPECTIVES

H.T. Odum

As part of preoperational studies from 1972 to 1976, energy analyses were made of the alternatives of estuarine cooling at that time and cooling towers. Those studies were comprehensively summarized in a dissertation by Kemp (1977). The summary diagram in Fig. 70 compared energy flows of the alternatives, both measured in coal equivalents, of productive energy diverted from other useful work. (It is incorrect to compare dilute energies with concentrated types of energy without multiplying by the factor that measures the inherent energy used for converting one energy type into the other).

Figure 70 showed that much more high quality energy was used in cooling tower operations than was diverted from the estuarine production by the cooling flow at that time. Since 1/3 of the energy basis of the economy of the U.S. (expressed as coal equivalents) is from utilization of the environmental-based renewable resources entering the economy as free externalities, 1/3 of the energy embodied in the monies for cooling towers constitutes a load on the environmental resources elsewhere in the United States. As the diagram in Fig. 70 shows, this projected flow (110×10^9 Cal/yr) was greater than the sum of stresses by the cooling at that time (3.4×10^9 Cal/yr), which has 7 years of adaptation time.

Whereas further energy analysis of all changes is not part of this contract, and we have not seen the results of measurements by others, some perspective can be given on the change in metabolism observed so far with the new plant outflow. The inner discharge bay so far is showing 20% of the productivity before the new plant went on line. If this change

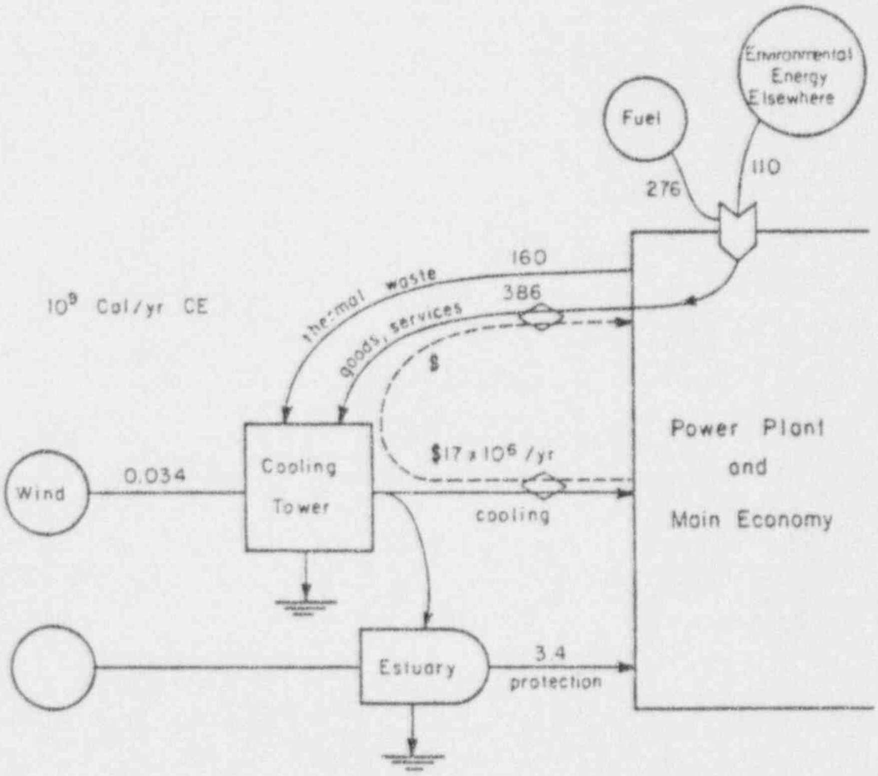

Fig. III-70. Summary of energy flows (CE = coal equivalents) with a cooling tower at Crystal River (Odum et al., 1976).

were added to the diagram in Fig. 70 the stress effect would become about 6×10^9 Cal/yr as compared to 3.4×10^9 Cal/yr, and thus still in a range much lower than the stress of the cooling tower alternative.

Adaptation of Ecosystems

When changes occur in the environmental conditions (the biotope or energy signature) of an ecological system its continual self organizing processes reorganize the community by substituting other species, varieties, and combinations as dominants. The immediate effect of a change is a depression of the effective productivity and metabolism as older components are stressed. Metabolism rises again as other components become more numerous that are adapted to utilize resources inherent in the new situation. This is particularly rapid in estuaries which have strong tidal exchanges that are continually supplying a wide array of genetic varieties available for the reorganization process. The reason that productivity and metabolism are pertinent measures of overall adaptation is that maximizing their total available energy is the design function for ecosystems. Maximum power (metabolism) requires development of the maximum possible structure of diversity, recycling, symbiosis mechanisms, larger members of the food chain, etc. Thus, total metabolism is a measure of the total order being maintained. What is most pertinent to decisions about alternative estuarine management is the level of adaptation that results after the transition.

The resilience of the adaptation should become apparent in coming months.

Prediction of Models

In studies done in the earlier period (1972-75) models were made of inner bay, outer bay, marshes, and oyster reefs which included the effect of temperature as a push and pull on total metabolism. These models were made on the principle that productivity and metabolism was that which was maximally possible for the conditions after necessary substitutions of flora, fauna, and microbes had occurred to provide the maximum performance possible. Therefore, it is probably too early to compare the levels of metabolism predicted by the models since they refer to the period after adaptation.

Discussion, Unanswered Questions

In this progress report at this stage, some questions can be raised that should be answered in the work yet to be done either by us or others. To understand similarities and differences between previous studies and measurements of metabolism and those made in studies during operation of Unit #3, comparison of production needs to be related to principal factors affecting photosynthesis: the light conditions, the effect of turbidities on light, the nutrient conditions, and the complex effect of temperature. The model in Fig. III-71 may be helpful in clarifying ideas discussed as follows:

Comparisons of efficiency of production as a function of incident light energy were made to eliminate the effect of different conditions of light input, cloudiness, etc. (see individual chapters). To determine possible changes in productivity due to inorganic turbidities requires comparison of turbidity data now with that before. Because the depths are of the order of 1 meter in the inner discharge bay, Secchi disk readings were not measureable on many days because one could see the bottom (Fig. III-72). Unfortunately, relatively few photometer extinction coefficient measurements were made in the preoperational period. Only a few light penetration measurements with photometer were made in this study because of instrument malfunctions. Thus, there is still an open question as to whether waters are more turbid on the average in 1977 compared to the preoperational study period.

There is an open question as to how low the inner bay metabolism

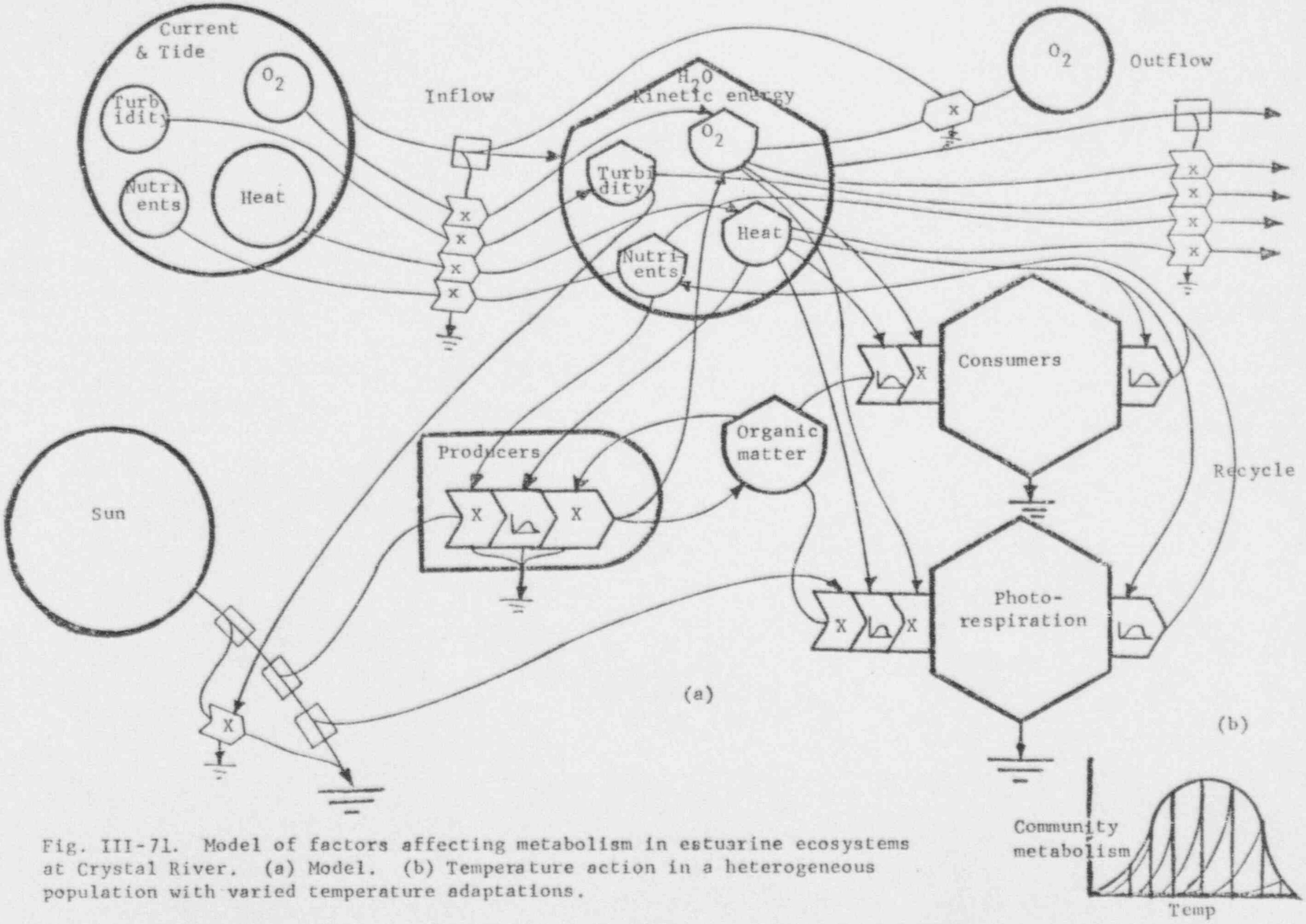

Fig. III-71. Model of factors affecting metabolism in estuarine ecosystems at Crystal River. (a) Model. (b) Temperature action in a heterogeneous population with varied temperature adaptations.

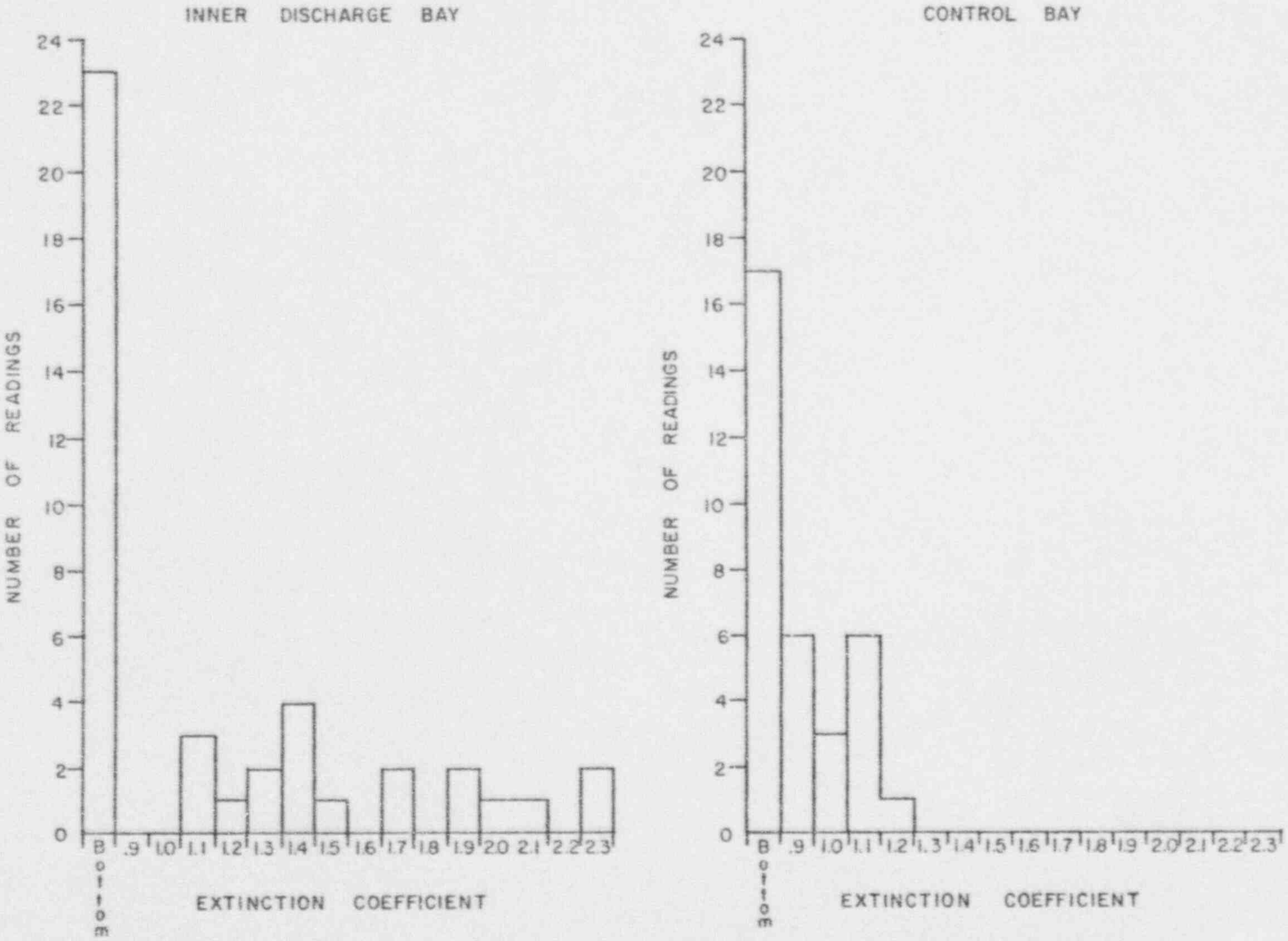

Fig. III-72. Extinction coefficients calculated from Secchi disk readings in the inner discharge and control bays (1977). Bar on left in each graph represents bottom readings.

actually is. The biological surveys show some bottom plants so that the metabolism is probably not zero. However, when the bottle (plankton estimate) metabolisms are subtracted from the diurnal curve metabolism the difference is so small as to be indistinguishable from zero, considering statistical error in methods and sampling.

There may be other alternatives to consider. If photorespiration or similar processes should be involved, then the action of the sun on production and respiration tends to cancel the effect on the diurnal oxygen changes observed (see model in Fig. III-71). The very small evidence of night respiration in the diurnal curves (Benkert section) may be interpreted as the consequence of very small living cells with short time constants that utilize their small diurnal storages in a couple of hours so that day respiration was possibly high, mostly counterbalancing production, but after dark may have dropped to nearly zero quickly. Whatever the interpretation, the metabolism in the inner bay was quite different from the earlier period, was more atypical, and different from that of the controls. By this interpretation, with less net production at any time, there was presumably less metabolism available to upper food chains. Whether this pattern would change with time remains to be seen.

To interpret these changes, we will incorporate the existing data in future reports.

In previous studies we used the push-pull concept to trace temperature effects of living processes causally to the quite different patterns of response of the whole ecosystem where feedbacks and recycles were involved. As shown in Fig. III-71(b), temperature increase accelerates reaction rates up to levels where living materials are not adapted and denaturation effects cause a sharp drop of function. Populations of organisms, each with different degrees of adaptation, may produce an overall effect that is more rounded. A simulation by Kemp and Ramsey (1976) used a rounded temperature maximum function to generate a fit to metabolism of the inner bay, which was better than a linear temperature effect.

As shown in Fig. III-71a, the action of temperature on the whole system by accelerating both production and respiration parts of the system serves to recycle faster. Biological components that recycle faster may tend to displace those with slower turnovers. Thus, sizes of organisms may be reduced. This was observed in the marsh studies (section by Hornbeck) with more smaller stems doing more metabolism each.

Similar substitution of smaller sizes (algae and bacteria) in the estuary may be accompanied by more photorespiration effects. Higher respiration and lower daytime net photosynthesis observed in the canals may also be explained with this model of temperature action.

Whether increased recycling has an overall positive or negative effect on gross photosynthesis (total biological work based on light) depends on whether the temperature effect is accompanied by more energy from the source (light, nutrients, and organic matter). Without added resources, temperature may pull down biological structure below that able to use available energy. With increased water flows some increase in resources may have been supplied, but apparently in the inner bay the net effect was a loss of gross production (uncertain because of photorespiration possibility).

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APPENDIX III-2

ENVIRONMENTAL PARAMETERS, RESPIRATION, AND PRODUCTIVITY FOR THE OUTER CONTROL AND DISCHARGE BAYS, 1977

Appendix III-2-1. Environmental parameters, respiration and productivities for the outer control and discharge bays, 1977. Bay B = discharge bay; Bay D = control bay.

Bay	Date	P_G	P_N	R	Plankton P_G	Plankton P_N	Plankton R	Insolation	Temp.	Salinity	Light extinction
B	April 7	4.14	2.45	1.69	2.89	2.27	0.63		25.7	24.3	1.62
D		2.36	0.96	1.40	1.51	1.34	0.17		20.4	23.7	1.4
B	June 30	10.39	6.44	3.95	2.39	0.21	2.2		35.6	28.5	1.1
D		9.32	5.58	3.74	5.04	3.58	1.46		31.3	25.4	1.4
B	July 1	1.20	-0.30	1.50		0.75		4200	35.3	28.7	1.5
D		7.26	3.73	3.53	4.07	2.75	1.32	4200	30.8	26.9	1.5
B	July 11	8.57	4.88	3.69	1.53	-1.38	2.91	7400	36.1	29.0	1.1
D		8.01	3.93	4.08	4.72	2.40	2.32	7400	31.6	27.2	0.97
B	July 13	5.20	1.83	3.43	1.78	0.29	1.49	5570	35.9	29.6	0.93
D		6.34	2.30	4.04	2.35	1.48	0.87	5570	30.7	27.1	1.1
B	Aug. 9	0.75	-0.48	1.23	2.68	1.01	1.67	4780	34.5	29.7	1.5
D		1.87	-0.47	2.29	3.65	3.02	0.63	4780	29.7	28.2	1.1
B	Aug. 11	5.04	2.65	2.39	1.39	1.14	0.25	6030	34.0	30.9	1.2
D		6.33	2.88	3.45	2.55	1.50	1.05	6030	29.2	28.4	1.1
B	Aug. 22	9.02	4.16	4.86	5.82	5.11	0.71	3870	29.7	26.9	1.4
D		4.98	2.65	2.33	3.98	2.60	1.38	3870	27.9	24.9	1.5
B	Aug. 23	8.83	5.23	3.60	6.69	6.06	0.63	5230	29.7	25.9	1.1
D		8.16	4.13	4.03	3.53	2.88	0.65	5230	28.4	22.5	1.7
B	Sept. 8	8.53	4.67	3.86	2.31	1.81	0.50	6579	34.6	29.7	1.3
D		6.23	3.83	2.40	2.91	2.00	0.91	6579	30.4	26.7	1.4
B	Sept. 19	3.98	1.98	2.00	3.44	2.51	0.93	6462	33.9	31.5	1.4
D		4.06	1.95	2.11	2.32	2.02	0.30	6462	29.5	30.9	0.9
B	Sept. 20	6.91	4.76	2.15	2.42	2.37	0.05	4896	34.9	31.3	1.3
D		5.66	2.79	2.87	2.67	2.35	0.32	4896	29.9	30.0	0.8
B	Oct. 1	6.19	3.12	3.07	5.55	4.62	0.93	5466	33.1	30.6	1.5
D		4.88	1.73	3.15	4.15	3.07	1.08	5466	28.5	28.3	0.9
B	Oct. 2	5.81	2.64	3.17	3.83	3.20	0.63	5238	32.4	30.0	1.5
D		3.49	1.12	2.37	2.66	1.86	0.80	5238	28.6	28.5	1.1
B	Oct. 17	5.11	2.19	2.92	1.80	1.43	0.37	6462	23.7	27.5	1.2
D		2.00	0.36	1.64	0.90	0.77	0.16	6462	18.8	28.0	1.0
B	Oct. 18	3.44	1.71	1.73	2.12	1.77	0.35	6227	23.1	26.7	1.1

Appendix III-2-2. (Continued)

Bay	Date	P_G	P_N	R	Plankton P_G	Plankton P_N	Plankton R	Insolation	Temp.	Salinity	Light extinction
D		3.58	1.91	1.67	1.02	0.62	0.40	6227	18.6	27.6	1.1
B	Nov. 1	3.24	1.44	1.80	2.58	1.88	0.70	2961	26.3	29.7	1.4
D		2.61	0.85	1.76	0.92	0.67	0.25	2961	20.8	29.3	1.1
B	Nov. 14	1.98	1.13	0.85	1.24	0.99	0.25	4441	18.6	29.4	1.2
D		2.09	0.51	1.58		0.65		4441	15.0	29.3	1.1
B	Nov. 15	2.41	1.45	0.96	0.96	0.65	0.31	4347	21.6	29.6	1.4
D		2.13	1.06	1.07	0.60	0.31	0.29	4347	15.6	30.0	0.9
B	Nov. 29	3.06	1.38	1.68	1.08	0.84	0.24	2619	23.1	29.5	1.1
D		1.39	0.96	0.43	0.86	0.74	0.12	2619	17.4	24.7	0.9
B	Nov. 30	2.44	1.25	1.19	1.56	1.18	0.38	3416	24.8	25.5	1.1
D		2.70	0.53	2.17	0.51	0.29	0.22	3416	18.6	24.7	0.9

APPENDIX III-3

METABOLISM DATA COLLECTED IN AREAS C AND OB, 1977

Appendix III-3-1. Metabolism data collected in Area C.

Date (mo/day) 1977	Area	Total metabolism (gm $O_2/m^2 \cdot day$) P_N	R	P_G	Plankton metabolism (gm $O_2/m^2 \cdot day$ P_N	R	P_G
4/7**	C	2.21	2.47	4.68	2.97	1.25	4.22
6/30*	C	6.02	5.82	11.84	6.83	3.05	9.88
7/1*	C	3.81	4.06	7.87	4.80	2.38	7.18
7/11**	C	4.8	4.4	9.2	4.356	4.29	8.646
7/13**	C	4.7	3.65	8.35	1.536	2.224	3.76
8/9*	C	.30	.69	.99	4.05	2.21	6.26
8/10*	C	2.03	3.30	5.33	.86	1.62	2.48
8/22*	C	4.77	3.63	8.40	8.75	1.11	9.85
8/23*	C	5.84	6.02	11.86	2.47	1.81	4.28
9/8*	C	1.40	2.92	4.32	1.97	1.49	3.46
9/19*	C	3.43	1.89	5.32	4.201	1.13	5.34
9/20*	C	1.67	.89	2.56	4.16	1.01	5.01
10/1**	C	2.61	3.66	6.27	4.09	1.35	5.44
10/2**	C	1.47	3.07	4.54	2.78	.74	3.52
10/17*	C	1.70	2.31	4.01	2.66	.22	2.88
10/18*	C	2.00	1.85	3.85	1.59	.51	2.1
11/1*	C	1.48	1.16	2.64	1.81	.79	2.60
11/14*	C	1.32	2.17	3.49	1.92	.20	2.12
11/15*	C	2.11	2.30	4.41	1.07	.35	1.42
11/29*	C	.66	1.08	1.74	.43	.30	.73
11/30*	C	.73	1.86	2.59	.86	.25	1.11

* Dawn-dusk measurement

** Diurnal measurement

Appendix III-3-2. Metabolism data collected in Area OB.

Date (mo/day) 1977	Area	Total metabolism (gm O_2/m^2 ·			Plankton metabolism (gm O_2/m^2·day)		
		P_N	R	P_G	P_N	R	P_G
6/30*	OB	2.08	.91	2.99			
7/1*	OB	1.88	2.97	4.85			
7/13**	OB	2.77	2.53	5.30			
8/9*	OB	-2.21	2.36	.15			
8/22*	OB	2.36	3.33	5.69	-.14	.94	.80
8/23*	OB	3.40	1.50	4.9	6.23	1.03	7.26
9/8*	OB	2.82	1.50	4.32	4.17	1.02	5.19
9/19*	OB	4.54	3.13	7.67	1.14	1.24	2.38
9/20*	OB	3.68	1.58	5.26	2.84	.47	3.31
10/1**	OB	4.41	4.85	9.26	2.34	1.16	3.5
10/2**	OB	2.50	4.54	7.04	3.51	.55	4.06
10/17*	OB	3.14	1.88	5.02	2.12	.63	2.75
10/18*	OB	1.66	.80	2.46	1.93	.65	2.58
11/1*	OB	2.54	3.65	6.19	2.00	.23	2.23
11/14*	OB	1.91	1.17	3.08	1.08	.97	2.05
11/15*	OB	2.73	1.35	4.08	1.29	.31	1.60
11/29*	OB	1.37	1.09	2.46	.89	.07	.96
11/30*	OB	1.57	2.25	3.82	1.16	.33	1.49

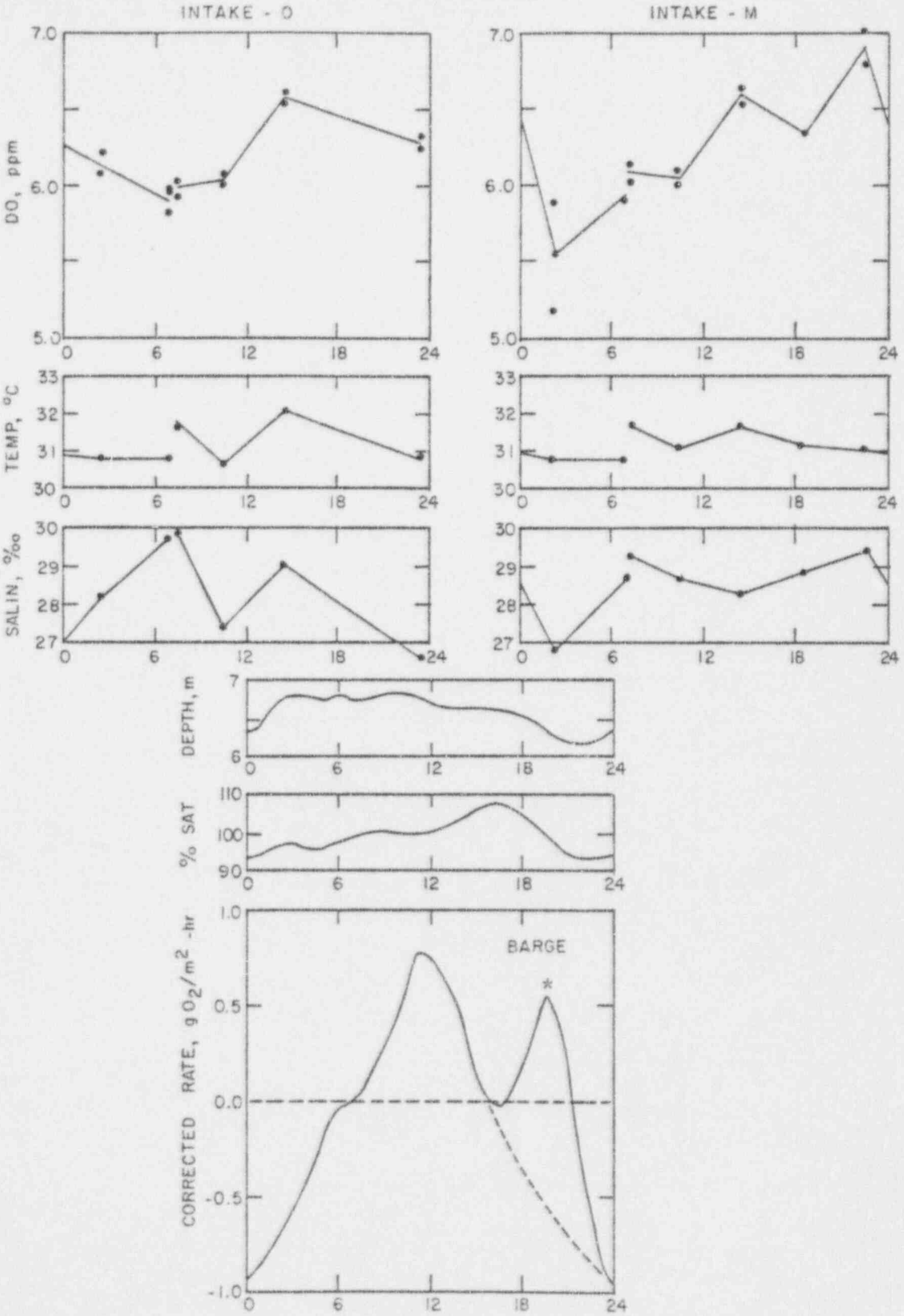
* Dawn-dusk measurement

** Diurnal measurement

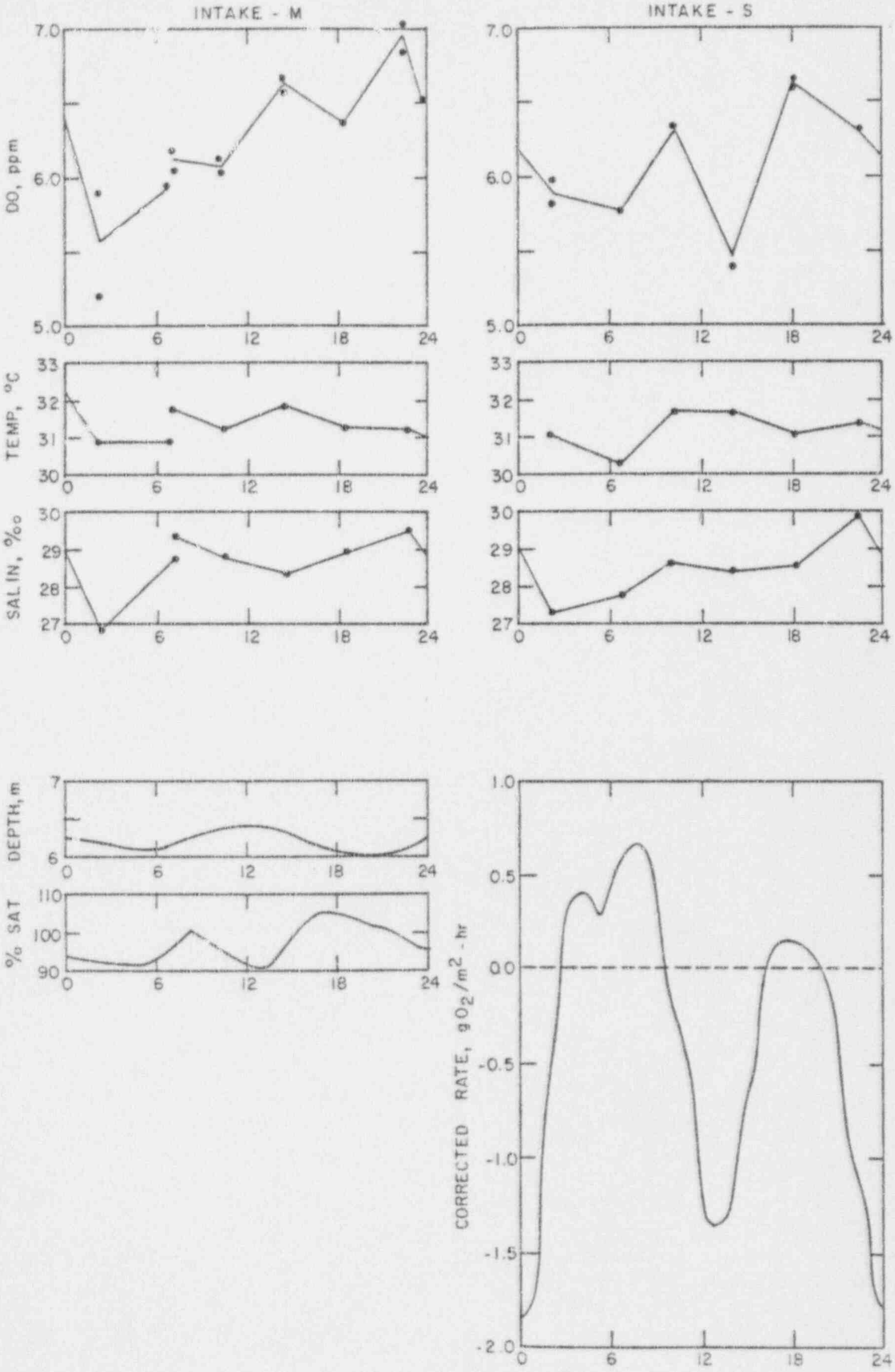
APPENDIX III-4

SUMMARY OF DIURNAL CANAL DATA

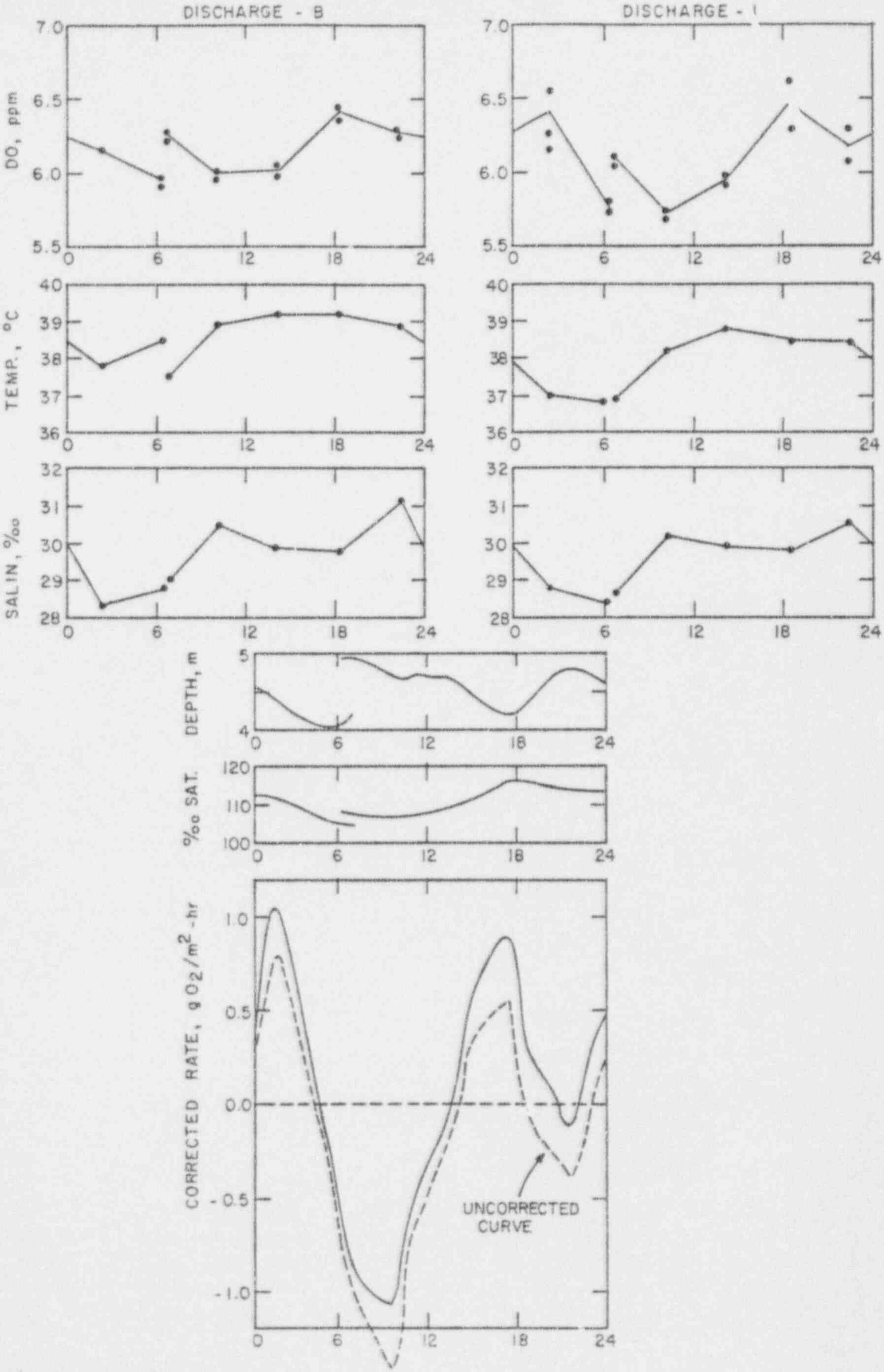
PERCENT SATURATION OF WATER WITH O_2 AT POINT OF DISCHARGE, INTAKE, AND OUTER BAY



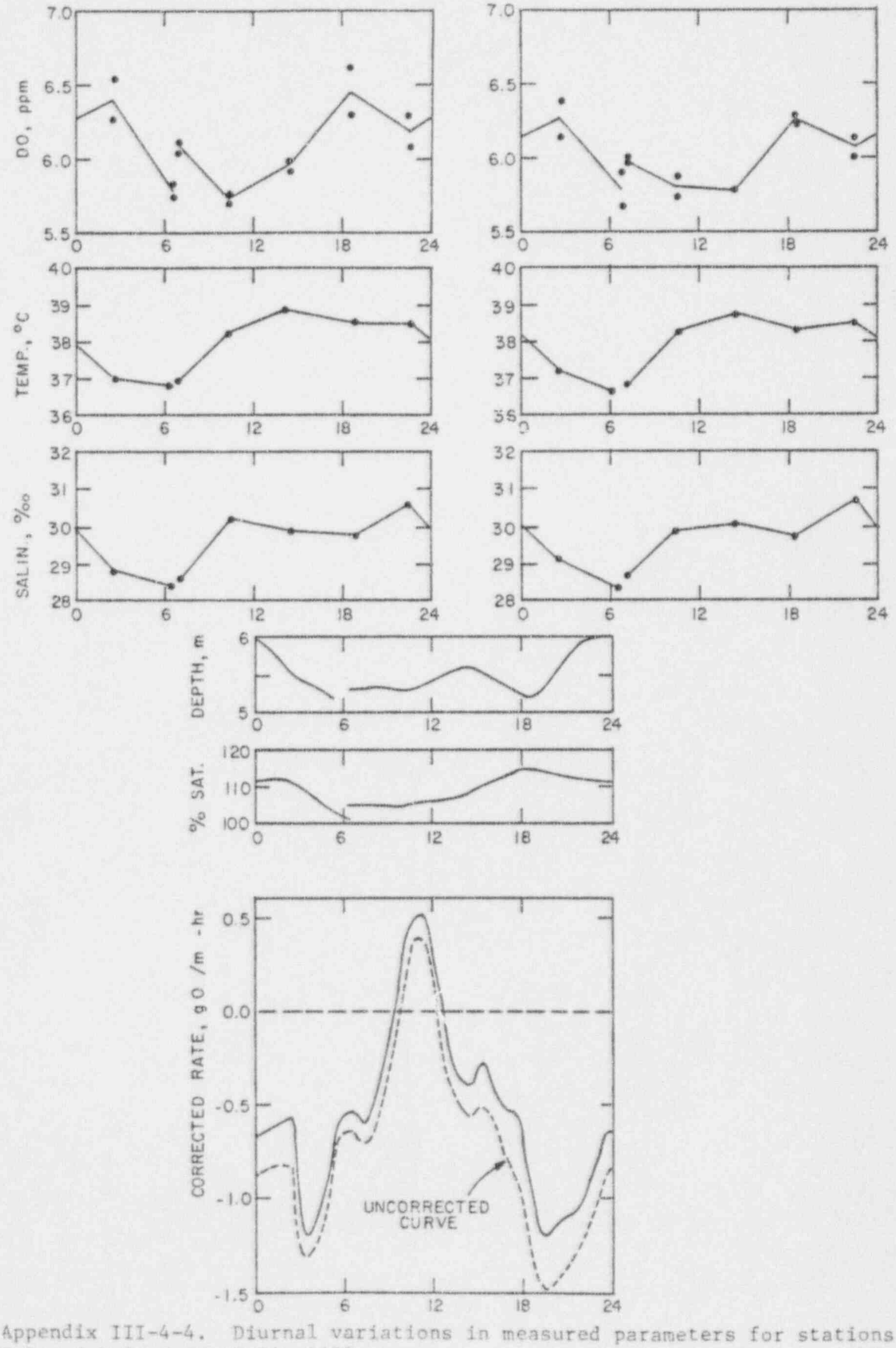
Appendix III-4-1. Diurnal variations in measured parameters for stations I-O and I-M, July 13-14, 1977. * indicates barge going through canal.



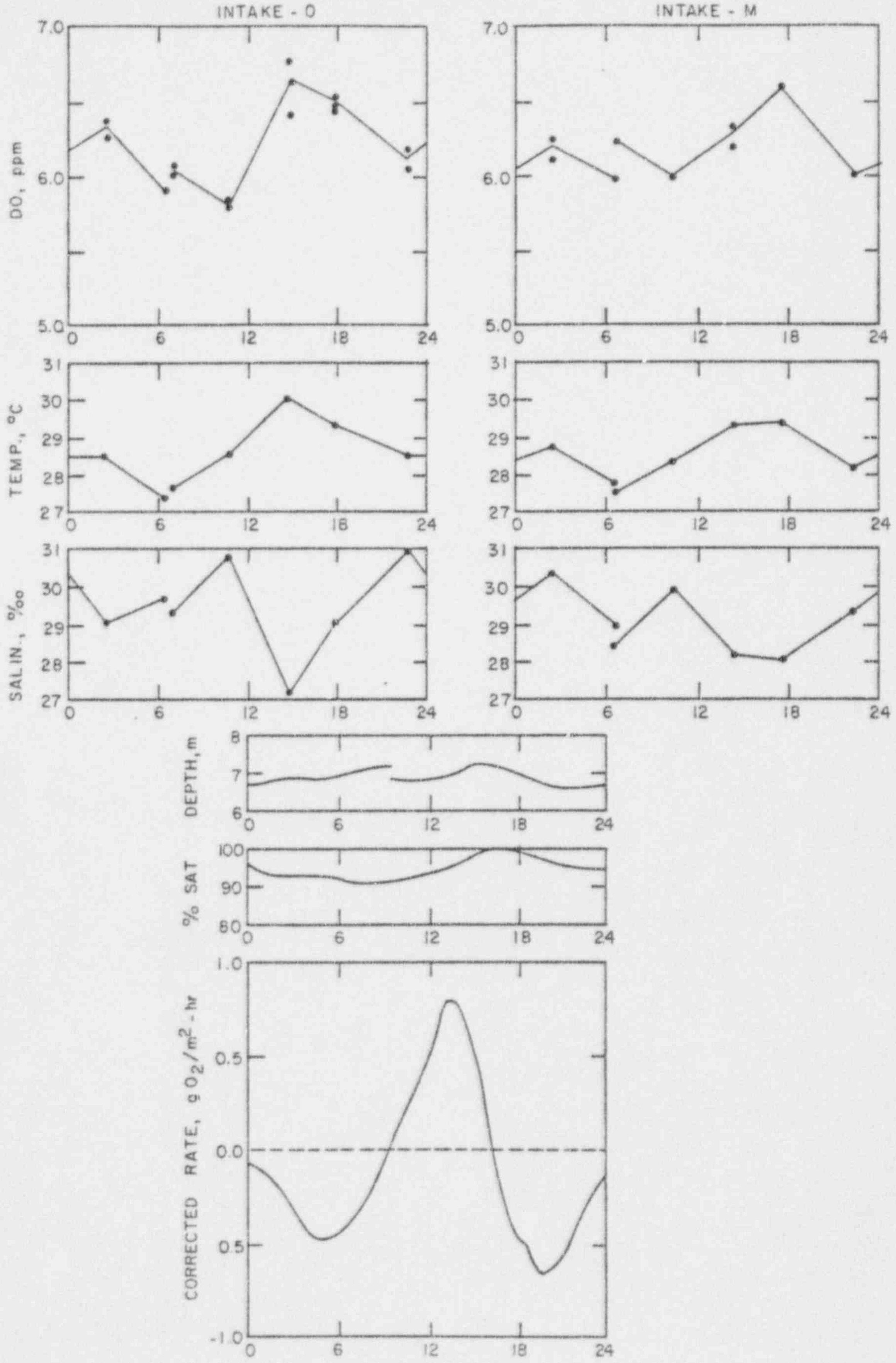
Appendix III-4-2. Diurnal variations in measured parameters for stations I-M and I-S, July 13-14, 1977.



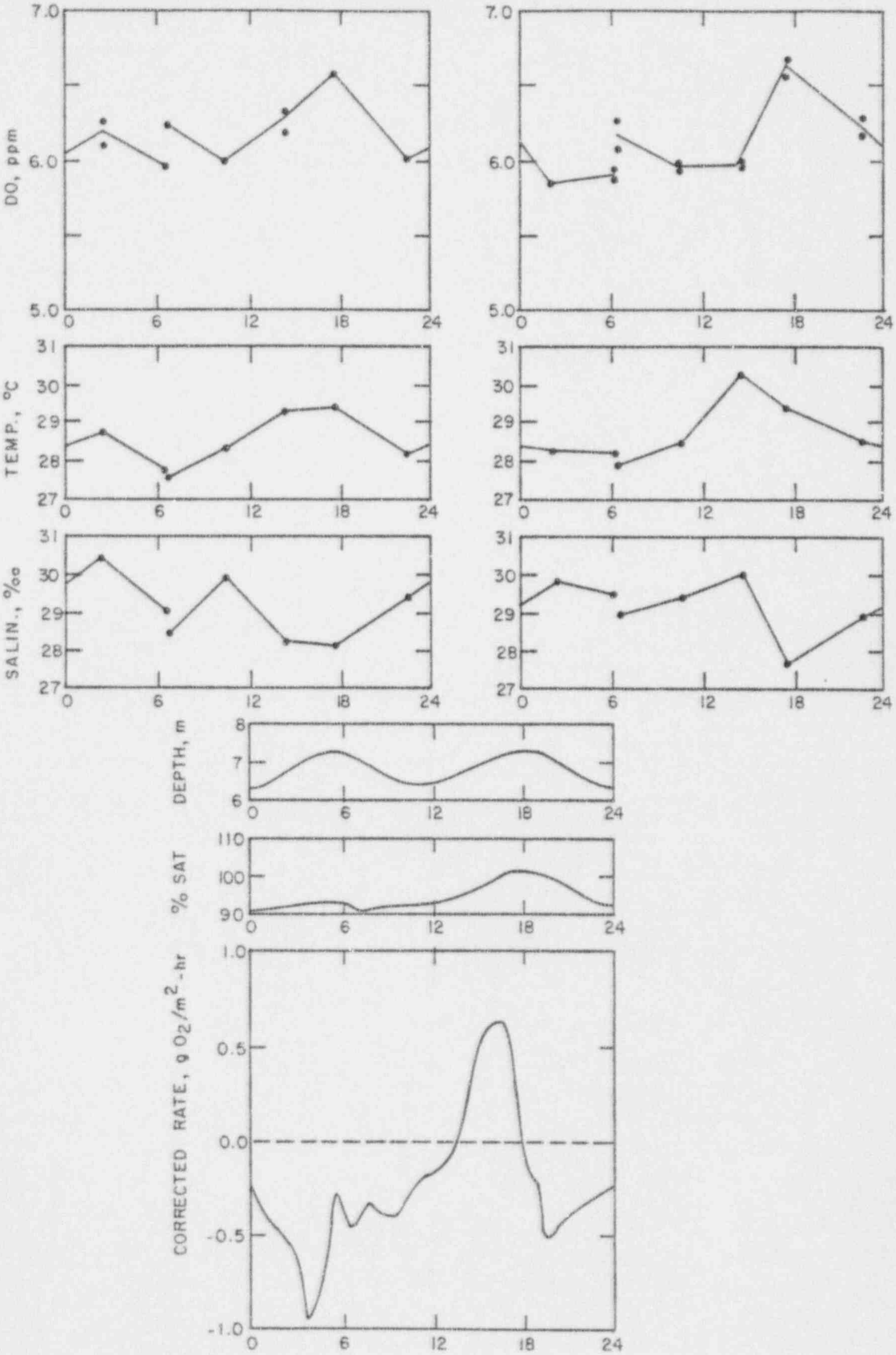
Appendix III-4-3. Diurnal variations in measured parameters for stations D-B and D-1, July 13-14, 1977.



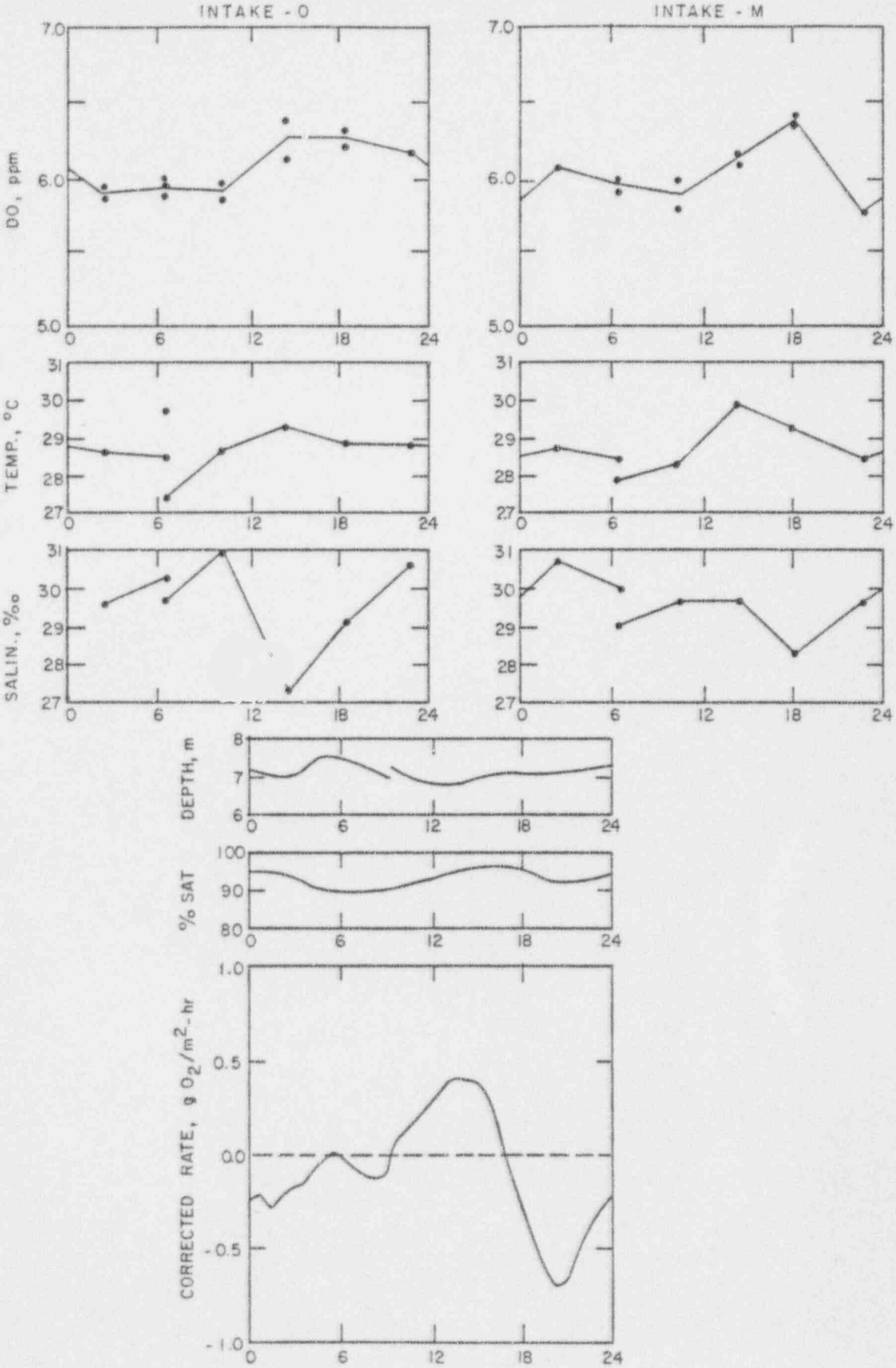
Appendix III-4-4. Diurnal variations in measured parameters for stations D-1 and D-2, July 13-14, 1977.



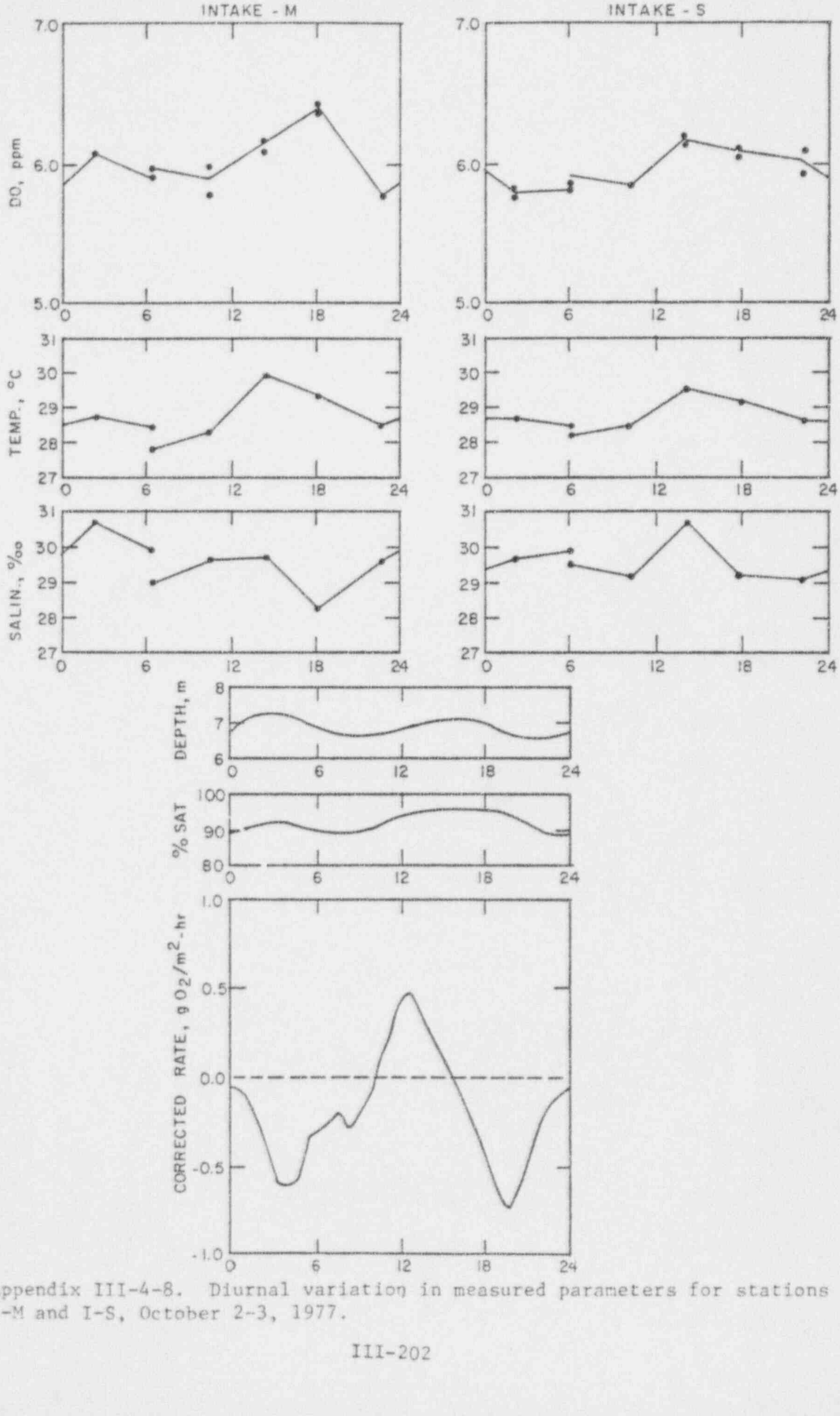
Appendix III-4-5. Diurnal variation in measured parameters for stations I-0 and I-M, October 1-2, 1977.



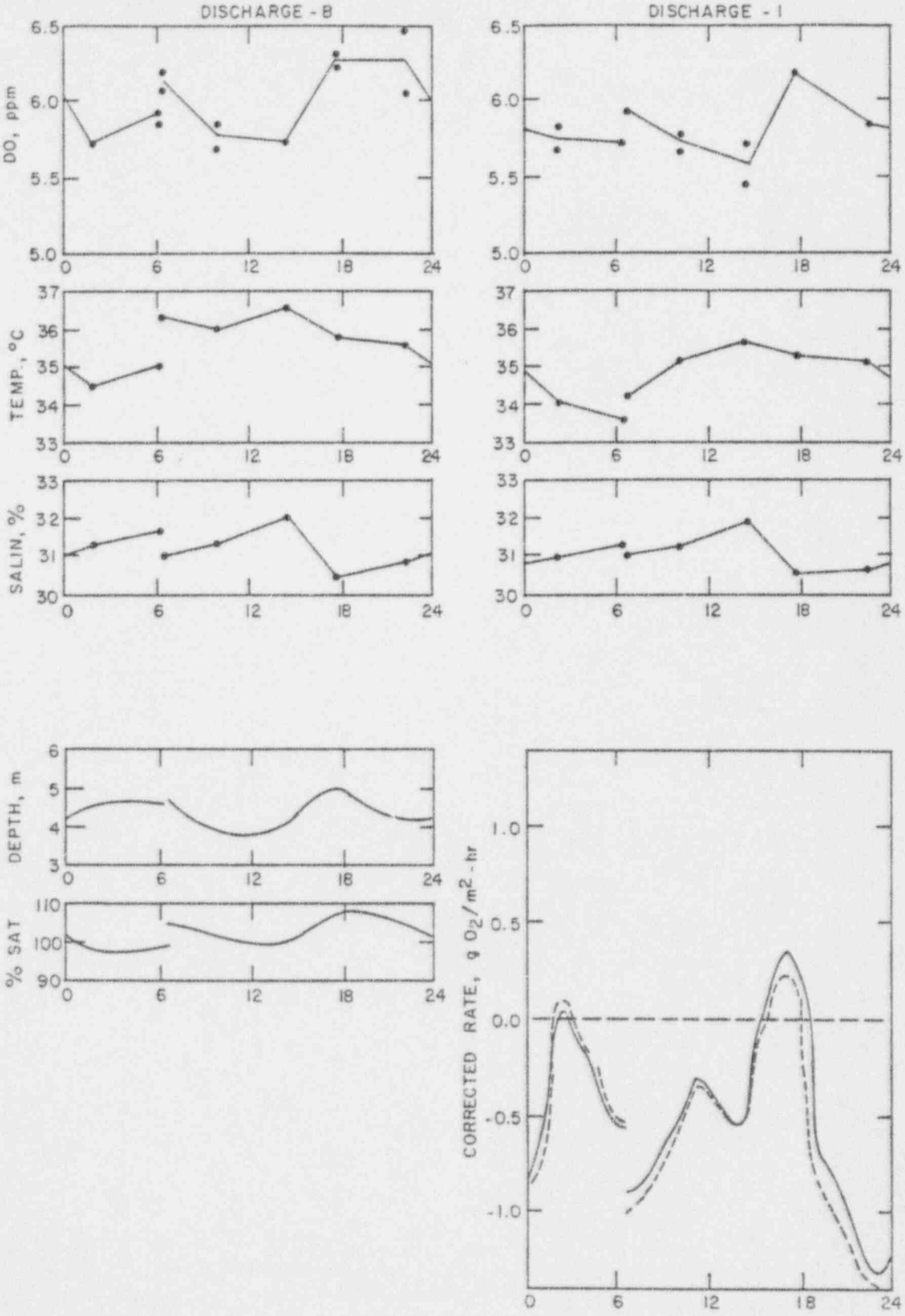
Appendix III-4-6. Diurnal variation in measured parameters for stations I-M and I-S, October 1-2, 1977.



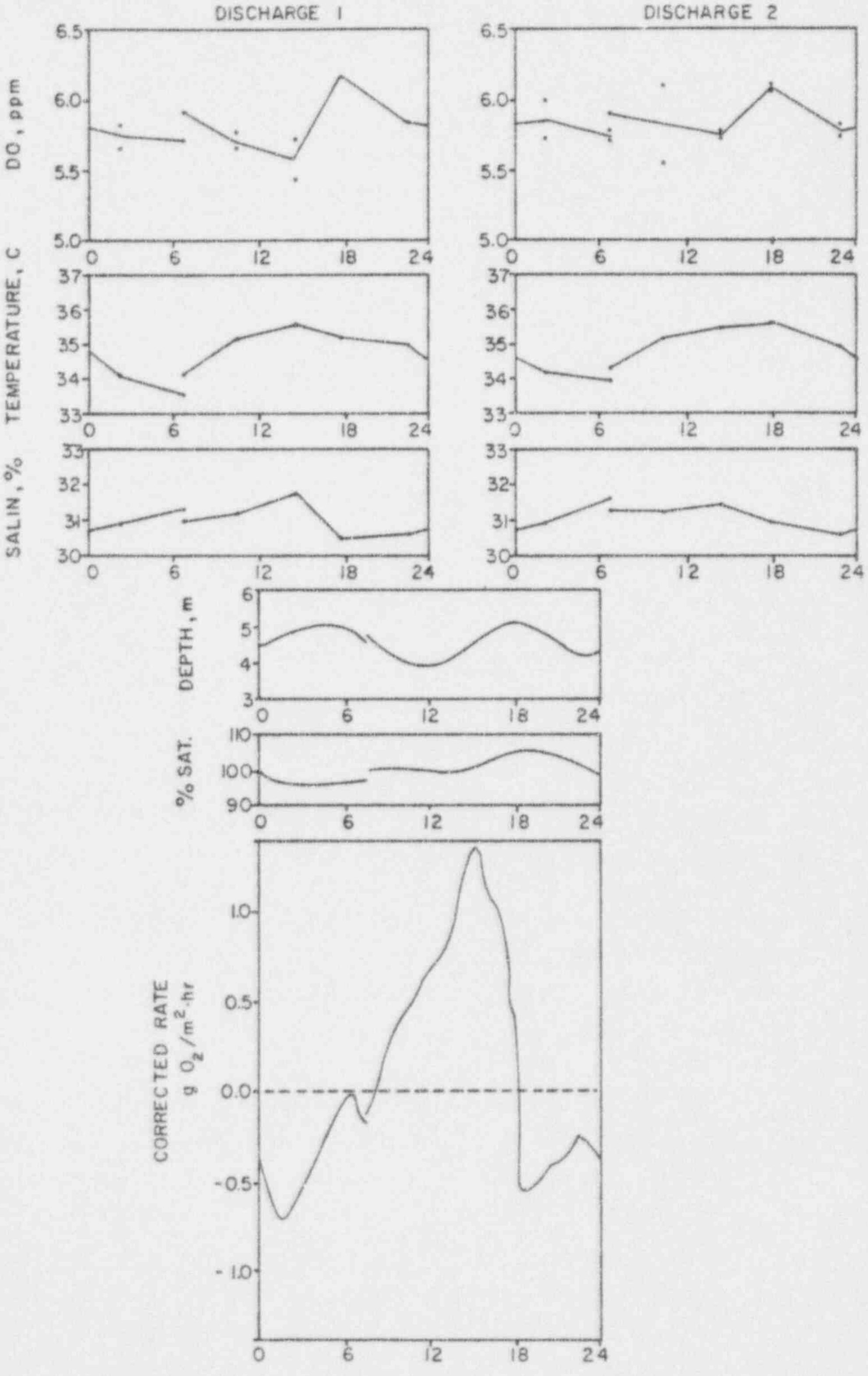
Appendix III-4-7. Diurnal variation in measured parameters for stations I-O and I-M, October 2-3, 1977.



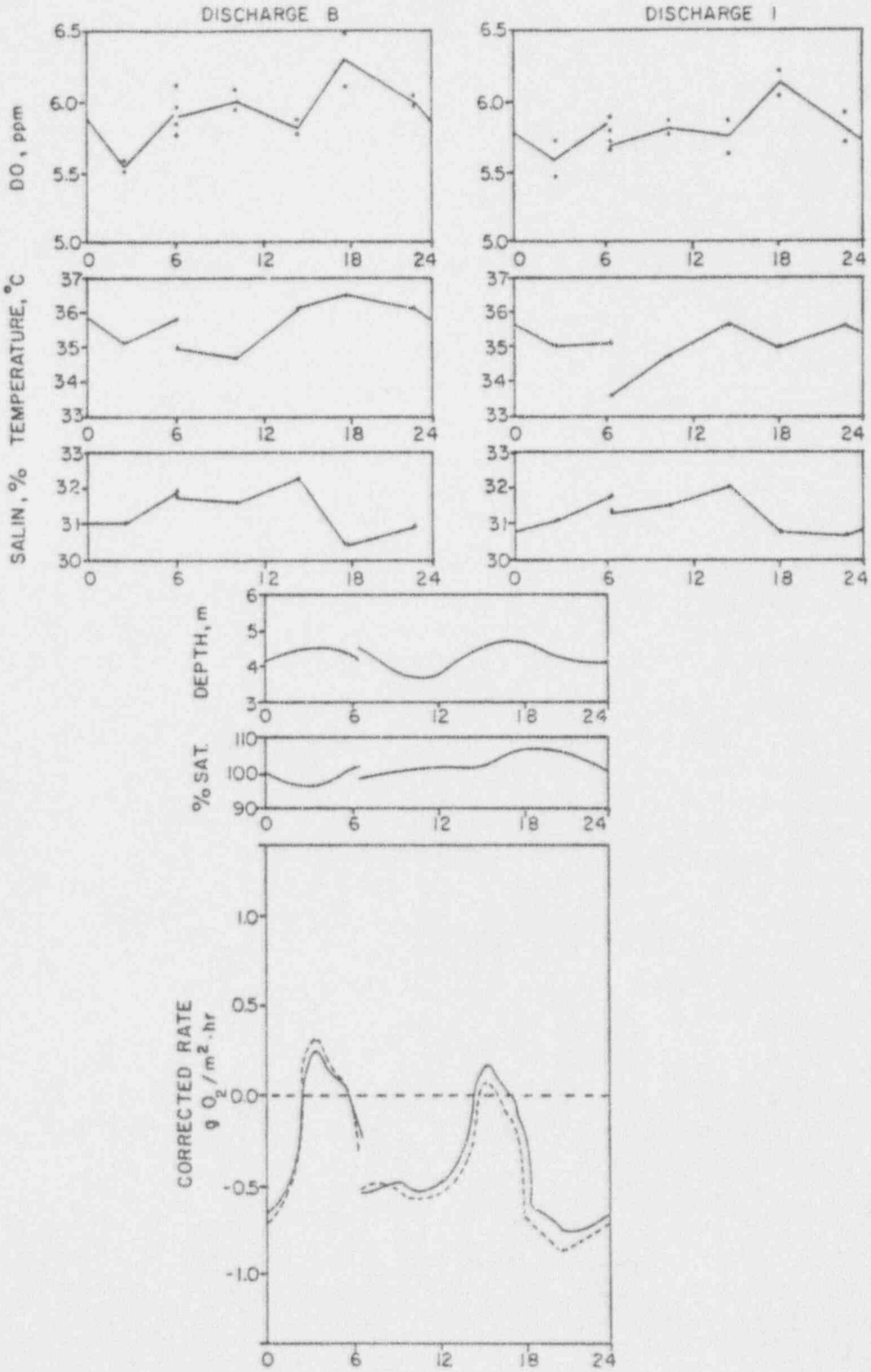
Appendix III-4-8. Diurnal variation in measured parameters for stations I-M and I-S, October 2-3, 1977.



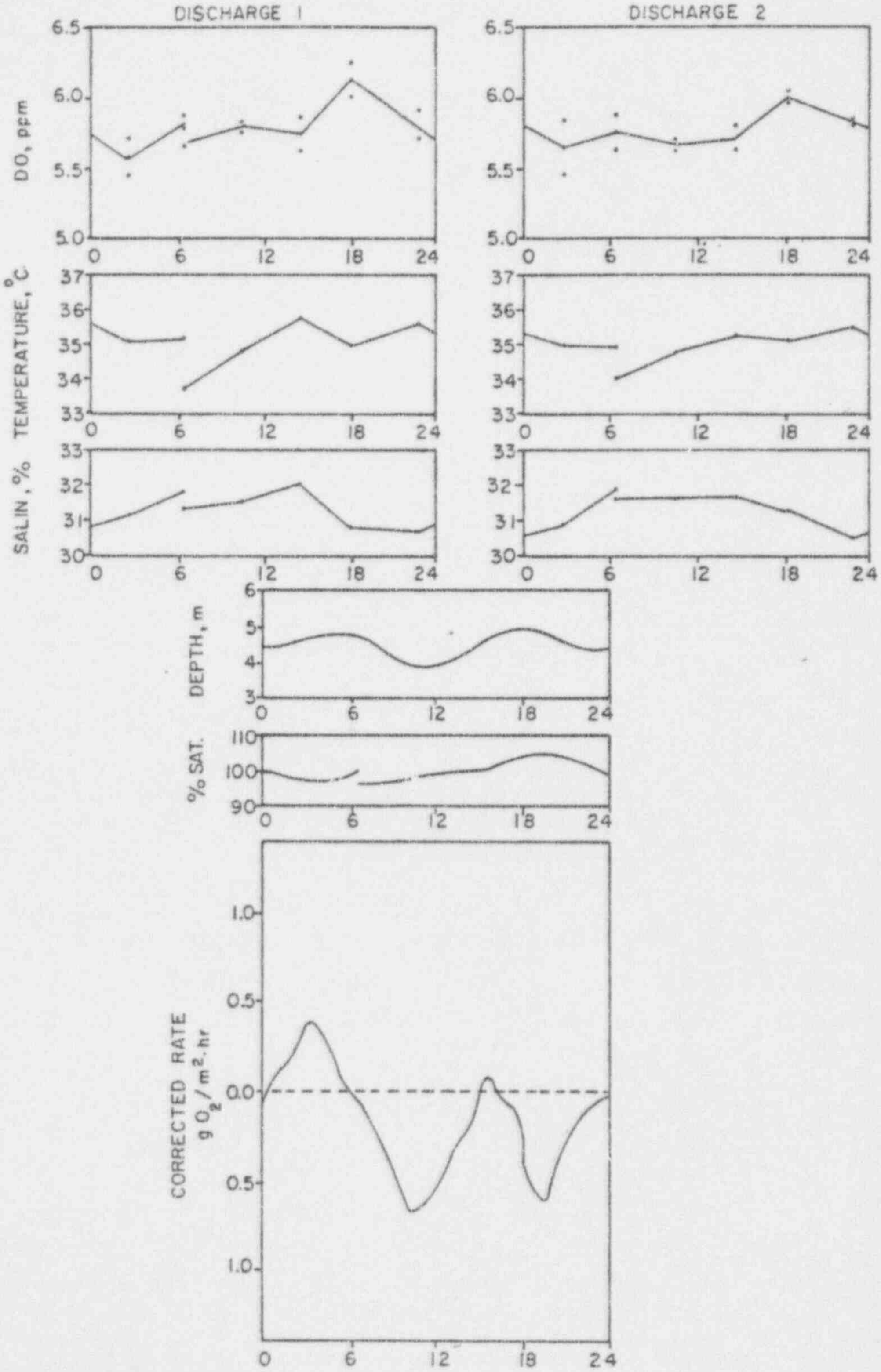
Appendix III-4-9. Diurnal variations in measured parameters for stations D-B and D-1, October 1-2, 1977.



Appendix III-4-10. Diurnal variation in measured parameters for stations D-1 and D-2, October 1-2, 1977.



Appendix III-4-11. Diurnal variation in measured parameters for stations D-B and D-1, October 2-3, 1977.



Appendix III-4-12. Diurnal variation in measured parameters for stations D-1 and D-2, October 2-3, 1977.

Appendix III-4-13. Mean percent saturation of water with dissolved oxygen at point of discharge, intake screens and outer bay during dawn-dusk-dawn sampling. The mean percent is based upon three water samples.

Date 1977	Station - Outer Bay		Station - Discharge Canal		Station - Intake Screens	
	Time	Mean % saturation	Time	Mean % saturation	Time	Mean % saturation
April 6	0810	89.3	0700	91.5	0720	78.0
April 6	1835	105.5	1800	---	1830	---
April 7	0731	99.2	0700	98.0	0725	90.5
April 7	1826	111.2	1800	105.4	1815	97.2
April 8	0737	98.9	0710	102.8	0725	96.3
April 25	0824	87.9	0845	87.9	0810	91.0
April 25	1857	103.8	1820	103.8	1830	97.3
April 26	0757	91.0	0800	96.5	0745	88.2
April 26	1903	100.5	1900	101.2	1850	95.4
April 27	0800	88.6	0805	99.2	0748	91.6
May 16	0905	101.2	0810	102.8	0830	100.5
May 16	1955	119.9	1925	122.9	1900	112.5
May 17	0820	106.3	0800	121.5	0730	105.1
May 17	1930	124.5	1910	124.9	1855	118.1
May 18	---	---	0730	110.5	0755	106.5
May 30	0830	92.0	0745	103.9	0720	94.4
May 30	1935	111.7	1915	108.1	1900	96.0
May 31	0820	93.6	0735	108.0	0713	97.2
May 31	---	---	1920	107.3	1905	98.5
June 1	0803	93.7	0726	120.3	0707	105.8
June 17	---	---	0710	98.5	0730	86.5
June 17	---	---	1835	104.0	1805	89.0
June 18	0815	83.9	0745	107.9	0835	92.0
June 18	1940	112.8	1920	114.8	2000	106.1
June 19	0740	83.5	0720	107.2	0805	92.4
June 30	0725	93.5	0820	104.3	0625	101.5
June 30	1855	119.7	1745	116.2	1940	112.6
July 1	0730	92.6	0810	105.1	0645	97.0
July 1	1810	107.9	1855	102.8	1720	100.4

Appendix III-4-14 (cont.)

Date 1977	Station - Outer Bay		Station - Discharge Canal		Station - Intake Screens	
	Time	Mean % saturation	Time	Mean % saturation	Time	Mean % saturation
July 2	0735	85.9	0655	94.0	0820	85.2
July 13	---	---	0647	110.7	0650	55.6
July 13	---	---	1815	117.7	1815	105.9
July 14	---	---	0620	107.0	0644	91.1
August 9	0752	83.4	0710	96.4	0837	85.6
August 9	1835	100.9	1750	96.5	1920	96.9
August 10	0727	85.8	0647	90.9	0834	83.5
August 22	0745	90.2	0650	89.2	0850	85.2
August 22	1720	114.8	1635	97.6	1820	109.0
August 23	0730	97.2	0635	91.6	0830	86.5
August 23	1755	130.4	1700	109.2	1900	117.6
August 24	0715	97.4	0625	98.2	0755	96.8
September 8	0735	97.7	0620	115.5	0835	95.7
September 8	1735	112.1	1645	127.6	1840	105.2
September 9	0750	93.0	0710	105.3	0835	94.6
September 19	0800	93.8	0720	109.3	0850	90.9
September 19	1830	110.0	1750	117.1	1930	102.8
September 20	0745	92.3	0650	105.5	0845	93.9
September 20	1805	110.4	1715	118.2	1905	103.2
September 21	0805	90.8	0710	107.3	0857	91.8
October 17	0810	91.6	0730	109.5	0850	88.8
October 17	1720	103.3	1640	109.9	1800	94.7
October 18	0755	93.1	0710	110.2	0845	91.3
October 18	1745	105.4	1700	111.0	1830	94.4
October 19	0800	95.2	0710	109.1	0840	91.6
November 1	0550	94.1	0815	108.1	0710	91.2
November 1	1645	101.7	1745	105.1	1630	92.0
November 2	0710	96.2	0755	105.9	0615	93.5
November 14	0720	97.3	0635	115.9	0835	94.1
November 14	1645	105.7	1610	113.1	1725	96.8
November 15	0715	98.4	0630	115.0	0815	95.6
November 15	1710	108.8	1630	118.3	1750	101.8
November 16	0705	100.6	0630	113.2	0755	96.7
November 29	0735	95.5	0655	107.2	0835	90.5

Appendix III-4-15 (cont.)

Date 1977	Station - Outer Bay		Station - Discharge Canal		Station - Intake Screens	
	Time	Mean % saturation	Time	Mean % saturation	Time	Mean % saturation
November 29	1700	103.0	1630	110.1	1755	98.7
November 30	0705	93.2	0630	106.2	0805	93.9
November 30	1700	97.3	1620	113.9	1745	101.9
December 1	0700	91.8	0620	110.8	0750	96.1

APPENDIX III-5

STUDIES OF FLORIDA GULF COAST SALT MARSHES RECEIVING THERMAL DISCHARGES

III-5-1

STUDIES OF FLORIDA GULF COAST SALT MARSHES RECEIVING THERMAL DISCHARGES

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ABSTRACT

Two Florida Gulf Coast salt marshes were studied over an annual cycle to document marsh-ecosystem response to thermal additions from an electricity-generating station. The overall marsh metabolism, including plant production and respiration, and selected animal-population numbers were chosen as indicators of the impact of thermal additions. Water temperatures in the thermally affected marsh averaged 3 to 6°C warmer than in the nearby control marsh. The maximum water temperatures recorded during the summer were 37° in the thermal marsh and 32°C in the control marsh. The apparent net production calculated from measurements of monthly changes in *Spartina alterniflora* live and dead standing crops, including estimates of decomposition and export during the spring growing season (February–May), was 547 g (dry weight)/m^2 in the thermal marsh, compared with 282 g (dry weight)/m^2 in the control marsh. The community metabolism measurements performed with CO_2 gas-analysis equipment in March 1973 indicate community respiration of 5.71 g C m^{-2} day^{-1} in the thermal marsh and 2.21 g C m^{-2} day^{-1} in the control marshes. The overall effect of higher water temperature appears to be higher levels of organic-matter turnover and metabolism with a ratio achieved between production and respiration which is similar to control marshes. Population comparisons indicate no significant difference in snail numbers, although fiddler crabs appear to be less numerous in the thermally affected marsh.

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This paper provides information to land planners on the structure and function of a Florida salt-marsh coastal ecosystem and its condition after 5 years of adaptation to thermal loading from a contiguous electricity-generating station. Decision-makers and coastal-zone resource managers are responsible for interfacing man's high-energy systems, which are subsidized by large quantities of fossil fuels, with the natural coastal ecosystems maintained by natural energies. Planning success can be ensured if the evolving systems containing both man and nature are designed to provide that combination which maximizes the value of the region under consideration (H. T. Odum, Littlejohn, and Huber, 1972; and Bayley and Odum, 1973). Such a goal in planning requires knowledge of the

structure and function of natural ecosystems, their role on a regional scale, and their response and adaptation to man-induced perturbations; decisions of resource allocation without such knowledge are tenuous.

Florida is currently experiencing intensive growth and development within its coastal zone, and a by-product of urbanization is waste heat from industrial-plant processes and electricity-generating stations. One of the aspects of importance to planners in Florida is the interaction of thermal plumes entering coastal salt marshes. Murray and Reeves (1972) point out that more saline water is used for cooling purposes in Florida than in any other state. They estimate that 9.3 × 10^9 gal of heated water per day are returned to Florida's estuaries. As of this writing approximately 25 coastal power plants are in operation and roughly 20% are sited in or near tidal salt marshes (Florida Division of State Planning, 1973). Eighteen percent, or 529,000 acres, of the Florida Gulf Coast estuarine zone described by McNulty, Lindall, and Sykes (1972) is occupied by tidal salt marshes. A comparison of the areal extent of marshes in Florida to other eastern states (Teal and Teal, 1969; and Day et al., 1973) reveals Florida as second only to Louisiana in total tidal marsh acreage. Because of the recognized importance of coastal marshes in supporting marine food chains, in building up the land, in serving as greenbelts, and in providing shelter from storm surges, questions arise as to the impact of thermal discharges on the marshes. Under new regimes of elevated temperature, are the basic structural and functional processes of the marsh ecosystem altered? What are the self-designing adaptations used by the new system for its long-term survival? What is the value of the new, adapted system to the larger system of man and nature?

Indexes of overall community structure and metabolism were chosen as parameters for evaluating the effect of thermal discharges. Discussion in this paper is limited to effects on *Spartina alterniflora*. Monthly harvest samples of *Spartina* standing crop, in situ infrared gas-analysis measurements of metabolism, and litter-bag experiments were undertaken to investigate the effect of heated effluents on standing crop and net production, respiration and total metabolism, and decomposition, respectively. Comparisons were made of the above parameters between thermally affected and control marshes to determine the level or quantity of biological activity in each. If differences in community metabolism are observed, insight may be gained as to whether thermal plumes act as a stress or a supplementary energy source to the marsh community. In addition, surveys of the population densities of marsh snail, *Littorina*, and fiddler crab, *Uca*, were made in each marsh to obtain information about the ability of these two invertebrates to tolerate elevated temperatures.

SITE

Studies were carried out at the Florida Power Corporation Crystal River site near Crystal River, Fla. (Fig. 1). Florida's Gulf coastline is a low-energy coast of

III-5-2

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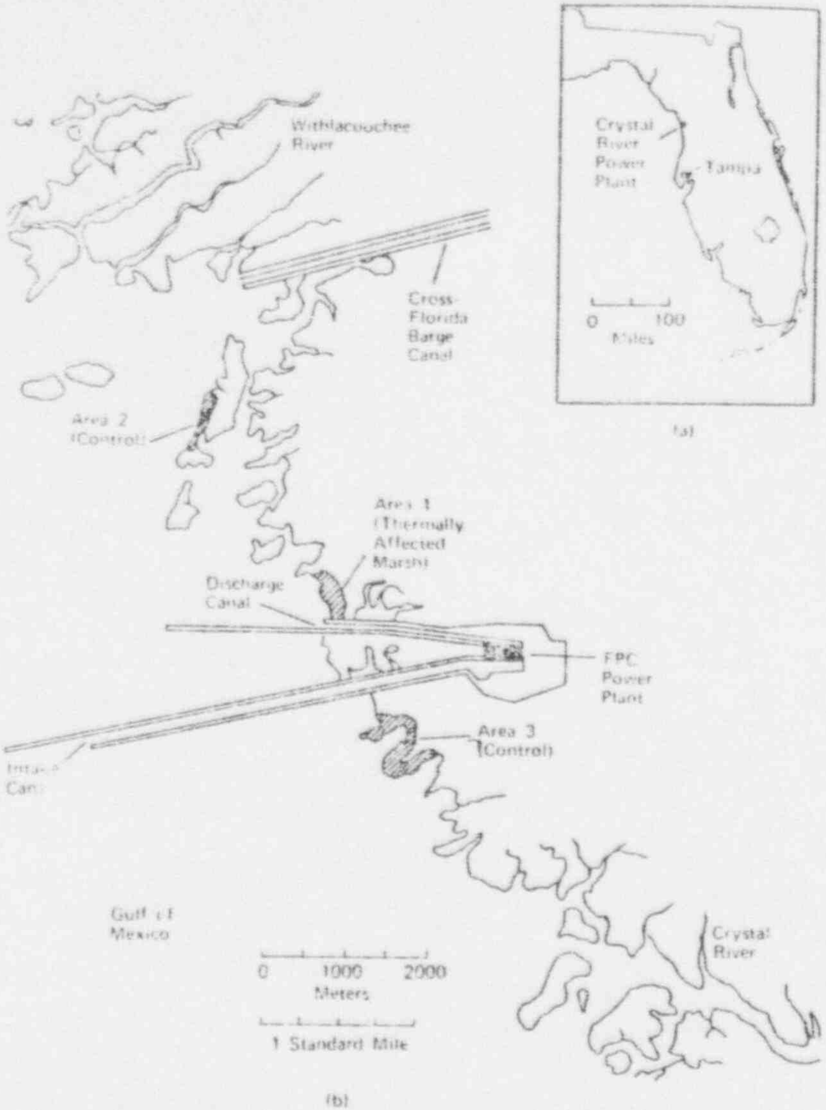

Fig. 1 (a) Location of the Florida Power Corporation Crystal River site. (b) Details of the marsh ecosystem in the vicinity of the plant, including experimental study areas.

mixed tides (tides are semidiurnal, but highs and lows during the same day are of unequal amplitude); the mean tidal range at Crystal River is 0.76 m (2.5 ft). In 1972 and 1973 two oil-fired steam plants, with a combined maximum capacity of 897 MW, were located at the landward edge of the salt marsh. Seawater from the Gulf of Mexico was used as condenser coolant at a rate of 2420 m^3/min (640,000 gal/min) in a once-through cooling scheme. Seawater is circulated through a system of two canals dredged through the marshes; water is drawn from offshore, passed through the condensers with a maximum temperature rise of 6°C, and discharged into a shallow estuarine bay (Fig. 1). During periods of high tide, the thermal effluent is backed up into the marshes to the north of the mouth of the discharge canal.

An area of marsh immediately north of the mouth of the discharge canal was designated as the thermally affected study area (area 1 in Fig. 1) on the basis of hydrological studies by Carder (1971, 1972). Carder demonstrated that a significant portion of the thermal plume is pushed onto these marshes by high tides and that elevated temperatures in the marshes bordering the bay are highest there. Two control areas (areas 2 and 3 in Fig. 1) were established for comparative purposes in areas beyond the influence of the plume to the north and south of the canal complex. Water-temperature measurements obtained in the thermally affected marsh averaged 3 to 6°C warmer than similar measurements in the nearby controls. The maximum water temperature observed on the thermal marsh by Carder and confirmed with independent measurements during this study was 37°C in the summer.

Both the designated control areas and the thermally affected marsh appear to be typical of the marshes in the Crystal River vicinity. They are characterized by approximately the same elevations and floristic compositions, with *Spartina* commonly found at the seaward edge of the marsh and along creek banks. The control areas and the marsh are washed by the tides twice a day.

METHODS

Field collections and measurements began in June 1972 in the thermally affected marsh and in September 1972 in the control marshes. The clip quadrat, or harvest method, was used to estimate standing crop and, later, to estimate net production of *Spartina*. This method is applicable to vegetation that exhibits an annual pattern of minimum standing crop in the spring, with accumulated live standing crop reaching a maximum in late summer (E. P. Odum, 1971; and Keefe, 1972). The amounts of live and dead standing crops were monitored throughout the growing season, and the sum of the increases in the amounts of live and dead organic materials is indicative of net community production. Estimates of losses to herbivory and export of materials permitted calculations of net community production and the refinement of estimates of net primary production. Nine randomly selected samples of aboveground vegetation (quadrat size = 0.25 m^2) were removed at 4- to 6-week intervals from the thermally affected and the control marshes. Collections from each control area were taken at every sampling interval and pooled to achieve a composite control sample size of nine quadrats. Each sample was separated by species and live and dead fractions, dried to constant weight at 70°C, and weighed; the results were multiplied by 4 for conversion to grams (dry weight) per square meter of marsh surface. Stem densities, expressed as stems per square meter, were obtained by counting live and dead stems contained within each quadrat sampled.

In situ gas-exchange measurements were made in the field during early March 1973 to obtain comparative information concerning the levels of total metabolism of both marsh communities. This method estimates total metabolism by monitoring the concentration of CO_2 in air entering and leaving a rigid transparent chamber that enclosed the marsh grass canopy and was sealed at the mud surface. Since this technique enclosed a portion of the entire community, results showed the integrated response of both producing (CO_2 fixing) and consuming (CO_2 releasing) components of the system. Production included contributions of the higher plants, periphyton, and mud algae. Consumption or respiration of the higher plants, algae, microbes, and animals living in or on the dead plants and mud surface constituted total-system respiration. These measurements represent metabolism of the entire community and the soil. Experiments were conducted for 6 days (March 3–9) in area 1 and for 5 days (March 11–16) in area 3. Since gas-analysis techniques monitor only the metabolism of the system exposed to air, concurrent measurements by other techniques must be made of that portion of the system covered by water to estimate total metabolism during high tides. No sampling of the water column was performed in March.

Details of the complete sampling apparatus, including sensors, pumps, valves, recorders, and timers, have been described by H. T. Odum (1970) and Lugo (1969). Calculations of diurnal rates of photosynthesis and respiration were performed using the techniques and formulas outlined by Odum (1970). A brief mention of the gas-analysis methods in this paper will suffice because of the large amount of data collected and the necessarily limited interpretation allowed as of this writing. These initial reported values are important for interpretation of the other field measurements, but they should be considered by themselves as preliminary. Final results of these experiments will be published at a later date.

Studies of decomposition rates of *Spartina* in the thermally affected and the control areas were begun in February 1973. Fresh live plant material was gathered and allowed to air dry for approximately 1 week. Litter bags measuring 15 cm wide and 70 cm long were constructed of 1.0-mm-mesh plastic window screening. The bags were sealed by folding the edges twice and stapling them at 5-cm intervals to prevent leakage of plant materials via tidal action. Each of 30 bags was filled with approximately 50 g of air-dried whole plants. Material in each bag was individually weighed to the nearest 0.1 g prior to filling.

The bags were placed at six randomly selected locations (three in the thermally affected marsh and three in the control area). *Spartina* has been

observed to decompose while remaining in a vertical position on the marsh; leaf and some stem parts gradually decay until, eventually, only the shortened bare stem remains. Finally the stem weakens at the base of the marsh surface and falls over. Natural conditions were simulated as closely as possible by constructing T-shaped wooden frames and driving them into the substrate. The litter bags were suspended from the crosspiece, positioned approximately 1 m above the mud surface, and the bottom of each bag was pinned to the mud surface with a metal stake. Thus the bags remained upright, with only the bottom of the bag containing the base of the plant stems in direct contact with the substrate. One frame was placed at each of the six locations, and five bags were suspended from each frame (15 bags in the thermally affected marsh and 15 in the control areas).

Before the bags were placed in the field, four representative samples of air-dried material were dried to constant weight at 70°C in a drying oven to determine the percent moisture of the initial samples. All samples gave results consistent within 5%. This information was used to calculate the initial ovendry weight of the plant material in each of the 30 bags. Four bags were randomly retrieved from each area at 6- and 10-week intervals. Plant material was removed from the bags, dried to constant weight at 70°C, and weighed to the nearest 0.1 g; the results were expressed as percent dry weight remaining. Every bag retrieved was intact, and there was no evidence of contamination by soil organic matter. Nearly every bag examined contained amphipods and fungi, indicating that, despite the small mesh size, some macrodecomposers were able to enter the bags.

In conjunction with the studies of structure and metabolism, an effort was made to census two conspicuous invertebrate populations of the marsh system. A comparison of the numbers of animals present may serve as an indicator of animal adaptation to elevated temperatures. During the monthly standing-crop harvests, counts were taken of the number of marsh periwinkles, *Littorina irrorata*, and fiddler crab, *Uca* sp., burrows in each quadrat. Mean numbers were then calculated and expressed as number of snails or crab burrows per square meter. No attempt has been made to monitor size classes and metabolism or to correlate the number of crab burrows per area to the actual number of crabs inhabiting a unit area of marsh.

RESULTS

The results of the various experiments are given under headings of *Spartina* standing crop, total or gross metabolism, decomposition, and animal populations.

Spartina Standing Crop

Standing-crop data for an annual growth cycle in the thermally affected marsh are shown in Fig. 2. Monthly trends are similar to those found by other

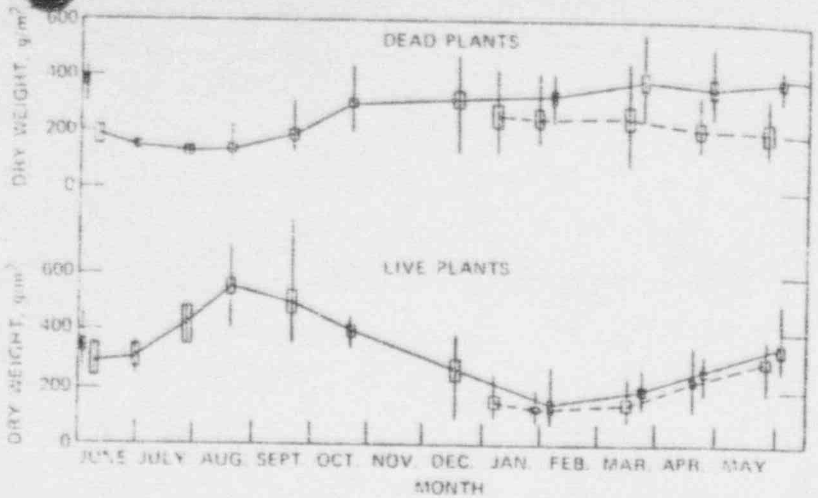

Fig. 2 Annual *Spartina* standing crop in the thermally affected marsh, including a comparison with standing crops from control areas during February–May. ——, thermally affected marsh, - - -, control areas. Vertical lines represent ±1 standard error around the mean of nine samples. The community net production (June 1972–June 1973) was estimated by summing Δ live + Δ dead: 551.7 g m⁻² year⁻¹.

researchers in southeastern U. S. marshes (Morgan, 1961; Marshall, 1970; and Day et al., 1973). However, the calculated net gain of biomass during the growing season of 550 g (dry weight)/m^2 obtained in this study is low. Figure 2 and Table 1 compare winter and spring standing-crop levels in the thermally affected and control marshes. Trends of the changes in standing-crop levels over time are similar in both areas. The minimum live standing-crop values for both marshes were observed in February; maximum dead standing crop occurred in both areas during March. A nonpaired t-test was performed to test for differences between means of monthly live and dead standing crops on both marshes. Results showed no significant differences in live material at the 95% confidence level except during March. Differences in dead material were all significant.

Incremental changes in *Spartina* live and dead standing crop during the growing season (including appropriate corrections for in situ consumption of dead material, tidal export, and herbivory) can be used to estimate net primary production. These processes are summarized in a simplified energy diagram (Fig. 3) that represents the mechanisms of energy capture, production of organic matter, respiration, transformation of living material to a dead status, and decomposition. *Spartina* net production during an interval of time is shown in Fig. 3 to be equal to the change in live standing crop ($\dot{Q}_1$) plus the fraction of live material removed by herbivores (H) plus the amount of live material which dies and is transferred to the dead compartment ($\dot{Q}_2 + R_M + L$).

TABLE 1

COMPARISON OF *Spartina* NET PRODUCTION IN THERMALLY AFFECTED AND CONTROL MARSHES

Date	Live standing crop, g(dry wt)/m²	Δ live between sampling periods	Dead standing crop, g(dry wt)/m²	Δ dead between sampling periods	Loss of dead* through decomposition, g(dry wt)/m²	Net production (Δ live + Δ dead + decomp.)‡
Thermally Affected Marsh						
Feb. 6	144.9	+55.1	337.4	+59.0	111.8	225.6
Mar. 23	200.0	+58.5	396.4	(−49.8)†	70.0	128.5
Apr. 26	258.5	+89.8	346.6	+34.3	68.6	192.7
June 3	348.3		380.9			
Subtotals		203.4		93.3	250.1	
Summation of monthly biomass increments through June 3: 546.8						
Control Marsh						
Feb. 6	132.0	+17.0	245.2	+2.0	62.9	81.9
Mar. 23	149.0	+75.6	247.2	0.0	23.5	99.1
Apr. 26	224.6	+74.2	247.2	(−37.2)†	26.3	100.5
June 3	298.8		210.0			
Subtotals		166.8		+2.0	112.7	
Summation of monthly biomass increments through June 3: 281.5						

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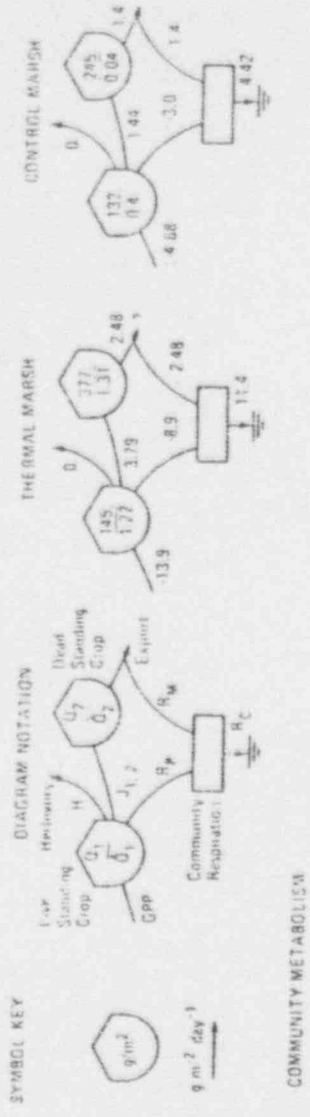
*Decomposition was calculated by multiplying the dead standing crop at the beginning of the time interval by the average daily decomposition rate during that interval (Fig. 5) by the number of days in the time interval.

†Numbers in parentheses are not included in the production estimates.

‡Herbivory was assumed to be zero during sampling period.



COMMUNITY METABOLISM

Gross production, GPP:	$(Q_1 + Q_2 + E) + R_c$	$(1.22 + 1.31 + ?) + 11.4 = \underline{13.9}$	$(0.4 + 0.04 + ?) + 4.42 = 4.90$
Net production, NPP:	$Q_1 + Q_2 + E$	$(1.22 + 1.31 + ?) = \underline{2.5}$	$(0.4 + 0.04 + ?) = 0.4$
Respiration, R_C:	$R_p + R_M$	$\underline{11.4}$	$\underline{4.42}$
NPP/GPP:	$\frac{Q_1 + Q_2 + E}{(Q_1 + Q_2 + E) R_C}$	$2.5/13.9 = \underline{0.18}$	$0.4/4.90 = \underline{0.08}$
Biomass/GPP, days:	Q_1/GPP	$\sim 145/13.9 = \underline{10.4}$	$\sim 132/4.9 = \underline{27.0}$

Spartina METABOLISM

Gross production, GPP:	$Q_1 + H + (Q_2 + R_M + E) + R_p$	$1.22 + 0 + (1.31 + 2.48) + 8.9 = \underline{13.9}$	$0.4 + 0 + (1.4) + 3.0 = \underline{4.8}$
Net production, NPP:	$Q_1 + H + (Q_2 + R_M + E)$	$1.22 + 0 + (1.31 + 2.48) = \underline{5.01}$	$0.4 + 0 + (0.4 + 1.4) = \underline{1.8}$
Respiration, R_p:	R_p	$>\underline{8.9}$	$>\underline{3.0}$
NPP/GPP:	$\frac{Q_1 + H + (Q_2 + R_M + E)}{Q_1 + H + (Q_2 + R_M + E) + R_p}$	$5.01/13.9 = \underline{0.36}$	$1.8/4.8 = \underline{0.38}$
Biomass/GPP, days:	Q_1/GPP	$\sim 145/13.9 = \underline{10.4}$	$\sim 132/4.8 = \underline{27.5}$

Fig. 3 Energy diagrams summarizing the observed movement of organic material measured in the thermally affected and control marshes during the February–March period. Quantities displayed on the diagrams are in units of grams (dry weight) of organic matter per square meter for tanks (converted from Table 2 by multiplying grams of carbon by 2) and grams per square meter per day for pathways. Below the diagrams are equations defining net and gross production which are derived from relations implicit in the diagrams.

Table 1 is a comparison of net production estimates between [illegible]shes, based on the procedure outlined above. Herbivory was assumed to be zero during the time span of Table 1, based on observations of negligible leaf damage. During the 3-month interval examined, the thermally affected marsh had almost twice the net production of the control marshes (547 g/m² vs. 282 g/m²).

Stem-density determinations for both marshes (Fig. 4) showed that thermally affected marshes contain greater numbers of live and dead stems per square meter than do control marshes. Since live-plant standing crops for both marshes were nearly identical, the higher density of stems suggested a dwarfing of stem size in the thermal marsh. With the data for February from Figs. 2 and 4, the mean weight per stem values for live plants were calculated to be 0.78 and 0.94 g per stem in the thermal and control areas, respectively. Mean weight per stem figures for both marshes were subjected to a nonpaired t-test, and the differences in population means were found to be statistically significant at the 95% confidence level.

Total Metabolism

Table 2 summarizes metabolism measurements made in the thermally affected and control marshes using gas-analysis techniques. Values are for daytime photosynthesis, nighttime respiration, diel total metabolism, solar insolation, and mean daily air temperature. Rates of total community metabolism were similar in both thermally affected and control marsh communities; mean rates were near 7 to 8 g C m^{-2} day^{-1}, which represents about 12 to 16 g of organic matter or 56 to 64 kcal m^{-2} day^{-1}. A t-test showed no statistically significant differences between the means at the 95% confidence level. Significant differences were indicated in the nighttime respiration rates between the two marshes. During the March sampling the thermally affected marsh exhibited daily respiration that was twice that of the control marsh (5.71 vs. 2.21 g C m^{-2} day^{-1}). In data examined thus far, variations in total metabolism from day to day may have been due to differences in solar insolation, ambient air temperature, and irregularities of the tidal cycle.

Decomposition

Results of the decomposition experiments are given in Fig. 5. After 6 weeks there was an indication of slightly higher losses of material from bags placed in the thermally affected areas, but a t-test revealed no significant difference at the 95% confidence level. However, after 10 weeks there was a statistically significant higher loss of material from the thermally affected marsh. After 10 weeks 67% of the original material remained in the control areas and only 56% in the thermally affected marsh; these values correspond to a mean loss per day of 0.45 and 0.63%, respectively.

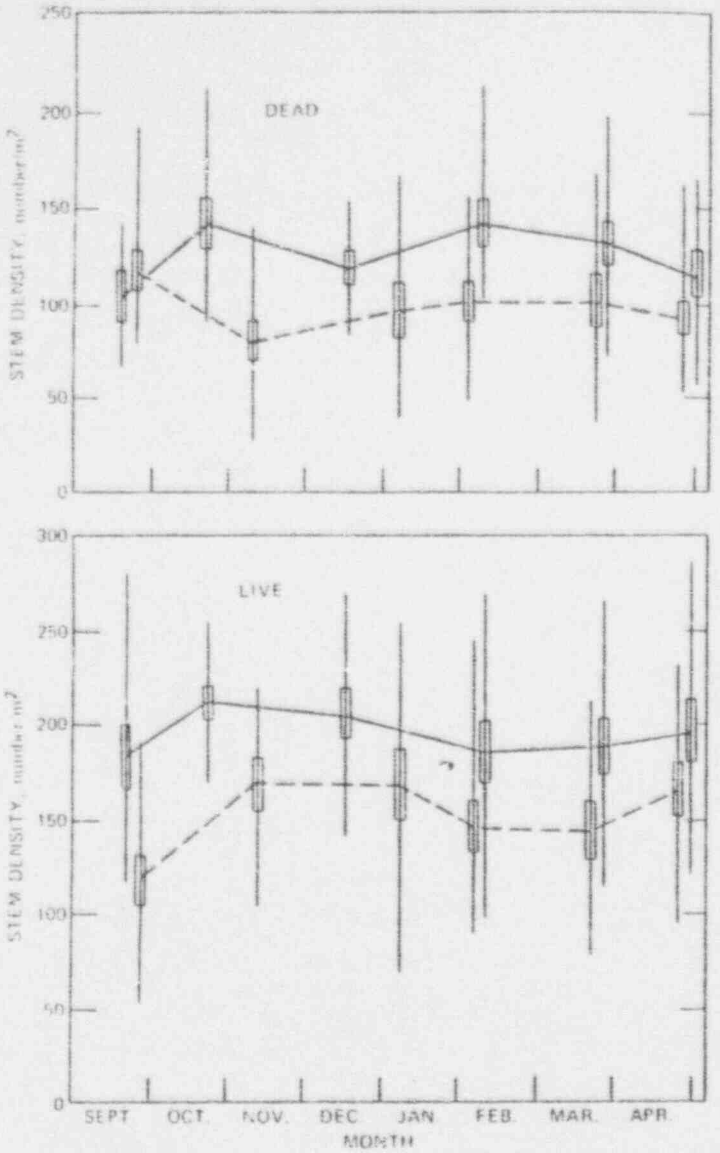


Fig. 4 Comparison of *Spartina* stem densities in thermally affected (—) and control (- - -) marshes. Vertical lines represent the range, and bars represent ±1 standard error around the mean of nine samples.

TABLE 2

CO$_2$ GAS-EXCHANGE MEASUREMENTS OF TOTAL METABOLIS
IN THERMALLY AFFECTED AND CONTROL MARSHES

			Metabolism, g C m^{-2} day^{-1}		
Date	Mean daily air temp., °C	Solar radiation, kcal m^{-2} day^{-1}	Net daytime production (P)	Nighttime respiration (R)	Gr metal (P +
			Thermally Affected Marsh		
Mar. 3–4	22.0	4590	1.35	6.20	
Mar. 3–4	22.0	4590	2.40	4.71	
Mar. 8–9	23.0	2064	1.25	2.79	
Mar. 8–9 values corrected to March 3–4 solar radiation levels: 4590/2064 = 2.224)			2.78	6.21	
		Mean	2.18	5.71	
			Control Marsh		
Mar. 12–13	27.2	5050	3.79	2.55	
Mar. 14–15	25.8	5094	3.96	2.22	
Mar. 14–15	25.8	5094	4.57	1.86	
		Mean	4.77	2.21	

Animal Populations

Estimates of population densities of *Littorina* and *Uca* burrows prese the two marshes are summarized in Tables 3 and 4. Crab burrows were co only at low tides, which accounts for gaps in the data. Snail populations patchy, which was manifested by the large standard errors. Mean annual densities were quite similar in both marshes; however, crab burrows were numerous in the control marshes.

DISCUSSION

On the basis of a review of marsh-productivity literature, Keefe (1972) an apparent latitudinal variation in *Spartina* standing crop and net produ inferred from seasonal increments of standing crop. Standing crop anc production tend to increase from north to south. However, *Spartina* sta crop and the resultant seasonal change in standing crop (550 g m^{-2} year^{-1}) during this study at Crystal River, which is near the southern lin grass-dominated salt marshes, are low when compared to studies identific Keefe. Estimates of net production by others range from approximately 5 600 g m^{-2} year^{-1} (Morgan, 1961; and Williams and Murdock, 1969) to 2

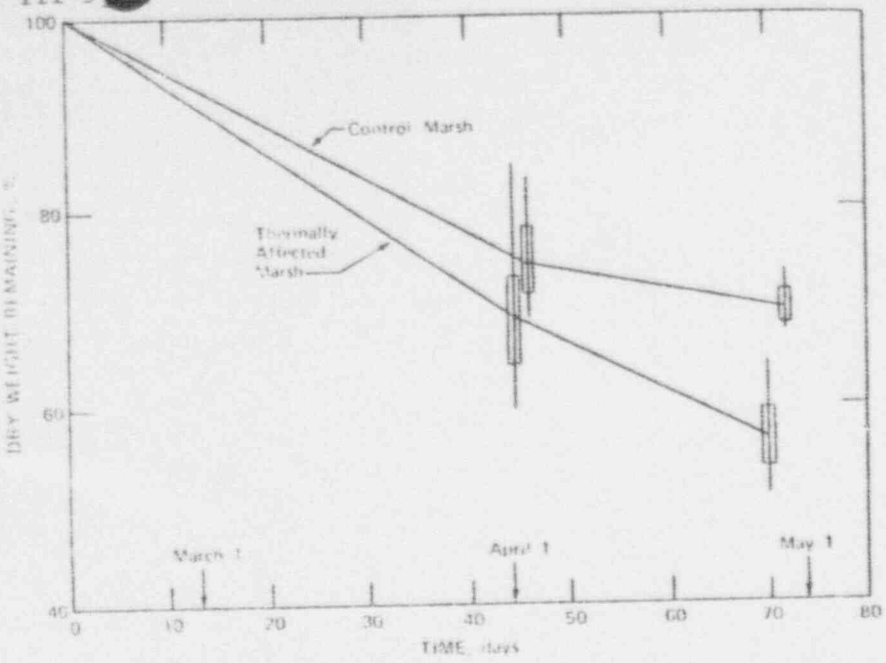


Fig. 5 Comparison of *Spartina* decomposition rates in thermally affected and control marshes. Vertical lines represent the range, and bars represent ±1 standard error around the mean of four samples.

TABLE 3

POPULATION ESTIMATES OF SNAILS, *Littorina irrorata*, IN THERMALLY AFFECTED AND CONTROL MARSHES

Month	Thermally affected marsh		Control marsh	
	Number/m² ± 1 S.E.	N	Number/m² ± 1 S.E.	N
August	3.11 ± 2.19	9	No data	
September	2.67 ± 2.21	9	No data	
October	7.11 ± 2.47	9	2.0 ± 2.0	2
November	No data		6.5 ± 2.82	8
December	3.56 ± 1.82	9	No data	
January	No data		3.4 ± 3.43	7
February	5.78 ± 2.22	9	0.0	6
March	2.29 ± 1.19	7	3.43 ± 1.84	7
April	1.33 ± 1.33	3	6.4 ± 1.60	5
Annual mean	3.69 ± 0.77		3.62 ± 1.03	

TABLE 4

DENSITIES OF FIDDLER CRAB, *Uca* sp., BURROWS IN THERMALLY AFFECTED AND CONTROL MARSHES

Month	Thermally affected marsh		Control marsh	
	Number/m² ± 1 S.E.	N	Number/m² ± 1 S.E.	N
September	313 ± 36.6	7	No data	
October	425 ± 23.8	8	634 ± 66.0	2
November	No data		485 ± 40.6	7
December	278 ± 29.9	9	No data	
January	No data		340 ± 41.8	9
February	331 ± 42.0	9	319 ± 20.6	8
March	332 ± 32.1	4	406 ± 20.7	4
April	No data		327 ± 75.5	4
Annual mean	336 ± 24.3		419 ± 50.2	

m^{-2} $year^{-1}$ (Day et al., 1973). Low apparent productivity at Crystal River may be due to one or more factors. The nutrient concentration of nearshore waters that flush the marshes is low. For example, total phosphorus concentrations in these waters annually average between 1.0 and 1.5 μg-atom/liter, which is similar to open Gulf waters (McKellar, 1973). Tides provide an important energy subsidy to marshes (E. P. Odum and Fanning, 1973), and the tidal fluctuations at Crystal River are small in amplitude relative to the tidal range of the Atlantic coast. Perhaps the mild winters and more regular seasons characteristic of Florida account in some measure for a smaller fluctuation of standing crop than is typical of northern marshes.

Examination of the energy diagrams in Fig. 3 aids the interpretation of the various growth and adaptation trends observed in the standing crop, metabolism, and decomposition experiments. The energy diagrams portray the essential process of organic-matter production and the eventual fate of this matter in the *Spartina* marsh ecosystem. The two storage "tanks" or modules denote the standing crop of live and dead material; the lines or pathways correspond to the dominant fluxes of organic matter from the storage compartments. Values displayed on the storages and pathways were those obtained from the field sampling program, including respiration values from gas analysis for the February–March period; all previously quoted values for the period are expressed as grams (dry weight) of organic matter per day in Fig. 3. Decomposition of dead standing crop, which represents both in situ decomposition and export, is denoted by a single value, which was measured by litter bags. Exact values are yet to be determined for export, and this flow is labeled with a question mark. Flows entering a storage tank must equal the sum of all outflows plus the change of the level within the tank during the time interval considered. Net production and gross production, both for the community and *Spartina*, are defined in Fig. 3 by equations derived from the energy diagrams. For example, *Spartina* net production is equal to the summation of the change in live standing crop, loss to herbivores, and the quantity of live material which dies and is transferred to the dead standing compartment. The flux of live material into the dead standing compartment is "back calculated," using the observed increases in the dead standing crop and the combined estimates of in situ decomposition and export rates obtained from the litter-bag studies.

The data in Table 1 and Figs. 2 and 3 show that February–March increase of live standing crop of *Spartina* are three times as great in the thermally affected marsh as in the control area. Thus increased water temperatures apparently hasten the beginning of the growing season. Subsequent standing-crop increments during the remainder of the spring season are similar for both marshes; the overall increase of live standing crop in the thermal marsh is 22% greater than in the controls. Anderson (1969) made a qualitative observation that live *Spartina* growing near the discharge of a power plant in Maryland appeared more robust than that in nearby marshes which received ambient waters.

The change in dead standing crop in the thermal marsh contributes 26% of the estimated net production during February and March and 17% throughout the growing season. These figures are significant when compared to the control marsh, where there is essentially no gain in dead standing crop during the growing season. Owing to higher dead standing crops and higher decomposition rates (Fig. 5), the total loss of material through decomposition and export is twice as high in the thermal marsh as in the control areas. The contribution from decomposition to the estimated net production during the spring season is approximately 50% in the thermal marsh and 40% in the controls.

Comparison of changes in dead standing crop and losses from decomposition and export reveals the thermally affected marsh processes, or turns over, a larger portion of material from the live compartment. Ratios of biomass to gross production calculated in Fig. 3 show the turnover time of the thermal marsh to be one-third that of the control marsh. The net effect of monthly standing-crop changes and decomposition is greater production of plant material in the thermal marsh (546.8 vs. 281.5 g/m^2) during the spring period.

Community metabolism measurements by gas analysis corroborate the findings of higher metabolic activity in the thermally affected marsh. Total 24-hr, or gross, metabolism appears slightly higher in the thermal marsh; however, nighttime respiration is significantly higher, 5.7 g vs. 2.21 g/m^2. Disparities, unresolved as of this writing, exist in the daytime net production values for the two marshes. Metabolic measurements indicate higher photosynthesis in the control marshes. Few direct measurements of metabolism have been attempted in salt marshes. Teal and Kanwisher (1961) measured the respiration of mud, *Spartina* stems, and the entire marsh community in productive Georgia marshes. Teal (1962) found *Spartina* to exhibit the following mean yearly metabolism: gross, 2.3 to 8.3 g C m^{-2} day^{-1}; net, 0.9 to 3.08 g C

m^{-2} day^{-1}; and respiration, 1.74 to 3.89 g C m^{-2} day^{-1}. He summarizes total community metabolism as: gross, 14.0 g C m^{-2} day^{-1}; net, 1.4 g C m^{-2} day^{-1}; and respiration, 11.2 g C m^{-2} day^{-1}. During this study metabolism rates obtained by gas analysis in March fall into the range of values calculated by Teal. Gas metabolism data from Crystal River are still being interpreted, and results and conclusions based on these data should be considered preliminary.

As was shown in the preceding paragraph, respiration of the marsh community increased in areas that received thermal discharges. However, it is more meaningful to compare the ability of the two marsh communities to compensate for increased respiratory demands by simultaneous, proportional increases in net production. The ratio of net production to gross production indicates the fraction of the total community metabolic budget which is available for net production. Values of this ratio during the February–March period are given for both marshes in Fig. 3. Note the similarity of this ratio for both marshes, implying that net production remains nearly a constant percentage of the marsh metabolic budget. Identical calculations, not reported in Fig. 3, were made using the entire spring growing season production estimates given in Table 1 (together with March respiration measurements), and similar ratios between marshes were found to exist through June 3.

The adaptations observed in the thermal marshes at Crystal River are consistent with Lotka's (1922) principle that surviving ecosystems are those which maximize the flow of energy through the system. The thermal marsh is apparently using some of the potential energy contained within the thermal discharges to carry on higher levels of metabolism. The mechanism through which production and respiration are accelerated under regimes of elevated temperature is still unclear, but one possibility is increased organic-matter decomposition and concurrent nutrient regeneration. Higher temperatures tend to accelerate decomposition and respiration, but, for a system to remain viable, it must achieve a balance between disordering outflows and production (or inflows). Models described by Odum (H. T. Odum, this volume) illustrate theoretical "push–pull" effects of temperature on ecosystem behavior. Chemical reaction rates and recycling of materials proceed faster at elevated temperatures; therefore increased production observed in an adapted system, which contains a finite stock of materials necessary for production, such as nutrients, may be due to increased recycle and subsequent uptake of these materials.

No nutrient determinations have yet been made on live and decaying plant material during this study, but Ustach (1969) has shown that radioisotopes of chromium, cesium, and zinc are rapidly leached from dead *Spartina* at a rate that exceeds the loss of dry weight. The biogeochemical cycling of cesium is similar to that of potassium, and the behavior of chromium and zinc may indicate the fate of micronutrients (molybdenum and zinc) necessary for plant function. Ustach also suggests the role of increased environmental temperature in augmenting decomposition rates. Phosphorus, calcium, and other macronutrients are lost in forest litter in proportion to the reduction in dry weight (Ewel, 1968)[illegible]eater decomposition rates in areas of elevated temperature may quickly release a larger fraction of the bound nutrients, which are reused by *Spartina* for further production. The larger amounts of dead material on the thermal marsh may be an adaptation by that system for concentrating and transferring a greater fraction of nutrients normally bound in live plant tissue to a compartment where they are quickly made available through decomposition for reuse.

Results of the stem-density measurements also reveal a possible adaptation to elevated temperatures. The inverse size–metabolism principle (H. T. Odum, 1956) may help to explain the presence of smaller "dwarfed" plants in the thermal marsh. A smaller plant with its higher metabolism per unit weight and more rapid turnover may process the same energy and material flows with less structure and biomass (H. T. Odum, McConnell, and Abbott, 1958). In areas where elevated temperature provides an additional energy source, small organism size may have selective advantage by allowing the processing of proportionally more energy for production, respiration, and recycling of products of respiration.

The types of animals present and their numbers also provide information about the structure of an ecosystem. *Littorina* migrate up and down the *Spartina* stems in rhythm with the tide. As adults they have the ability to avoid the hot water for much of the time, which may explain why no significant differences are found in the mean annual numbers between the two marshes. *Littorina* have a waterborne larval stage, so the density figures also suggest no unusual mortalities during infancy when they are directly exposed to the elevated water temperatures. Mean annual fiddler crab burrow numbers are lower in the thermally affected marsh. Measurements of sediment temperature were taken during winter and spring with a thermistor-type soil temperature probe. Temperatures to a depth of 70 cm were 2 to 3°C warmer in the thermally affected marsh. Since these crabs spend a significant amount of time in their burrows, it is conceivable that higher substrate temperatures may limit their ability to adapt and survive in the thermal marsh. Fiddler crabs may normally be important members of the community for expediting the breakdown of detritus and facilitating nutrient regeneration. If they are present in fewer numbers after ecosystem adaptation to higher temperatures, perhaps the service previously carried out by the crabs is now being performed by other organisms to ensure the long-term survival of the marsh ecosystem.

In summary, the apparent effect of increased water temperatures on salt-marsh structure and function is to accelerate biological and chemical processes. The salt marsh has self-designed mechanisms to utilize the potential energy of the thermal discharges for compensating increased respiration demands with some proportional increases in production. Estuarine ecosystems may possess an inherent ability to adapt to such pertubations because of the natural fluctuations of temperature, salinity, waves, etc., in the coastal zone. The results of this study indicate that man should not continuously seek to apply costly

technology to minimize his waste products. Instead, he should under certain circumstances recognize the natural ecosystems that have the necessary flexibility to serve as effective interfaces in processing and putting his wastes to use at no cost to him.

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POPULATION ECOLOGY OF PARASITES IN TURTLES FROM THERMALLY ALTERED AND NATURAL AQUATIC COMMUNITIES

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ABSTRACT

The influence of thermal loading on parasite population biology was examined in emydid turtles from several types of aquatic habitats on the Savannah River Plant area, Aiken, S. C. Host populations from natural, thermally altered, and post-thermal recovery ponds and river swamps were compared in terms of percent incidence of parasitic infection, frequency distribution of the infection, and mean parasite burden. Different groups of parasites reacted dissimilarly to thermal modification of habitat. Nematode levels increased in heated river swamps but decreased in heated ponds when compared with similar natural habitats. Trematodes were adversely affected, but certain species of Acanthocephala increased in heated habitats. Thermal modification resulted in protracted (at least 9 years) change in parasite population levels after final thermal input.

Although general interest in the biological effects of thermal pollution has increased in recent years, the impact of thermal effluent on population biology of parasitic organisms has received little attention from either an applied or a theoretical viewpoint. The increased incidence of two bacterial diseases, columnaris (Stroud and Douglas, 1968) and furunculosis (McCraw, 1952), in heated areas of the Columbia River, is frequently mentioned in the thermal literature, but, other than these isolated cases, no studies in the United States have dealt with parasite populations in thermally manipulated ecosystems.

The present study examines parasite population and community ecology in the yellow-bellied turtle, *Pseudemys s. scripta*, from natural and heated areas and in previously heated areas presently undergoing post-thermal succession.