Entergy Nuclear Generation Company
Plymouth, MA

Study of Winter Flounder Larval Transport in Coastal Cape Cod Bay and Entrainment at Pilgrim Nuclear Power Station

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1.0 INTRODUCTION

Winter flounder (*Pleuronectes americanus*) are commercially important in Cape Cod Bay and are a dominant species collected by the entrainment monitoring program at Pilgrim Nuclear Power Station (PNPS). The objective of this study was to evaluate the impact of winter flounder larvae entrainment at PNPS through direct field measurements. An approach was applied whereby field measurements were collected to determine the relative amount of net volumetric flow and winter flounder larvae entrained into the PNPS cooling water system compared to the net volumetric flow and amount of winter flounder larvae passing PNPS in offshore Cape Cod Bay waters.

This program was designed to update the similar study completed in 2000, updated based on the suggestions and comments of federal and state agency reviewers. The results of the study confirmed those of the 2000 study in that:

- PNPS withdraws a relatively small percentage of the available net volumetric flow of water—generally less than 0.1%.
- The amount winter flounder larvae entrained by PNPS is a relatively small percentage of the net larval transport—conservatively estimated at less than 1.3%.
- Winds do not appear to have a significant influence on the density distribution of winter flounder larvae.

The field program was designed to collect sufficient measurements to determine the flux of winter flounder larvae moving along the Plymouth coast and the flux of winter flounder entering PNPS. To determine larvae flux, larvae concentration and volumetric flowrate of water were required. The field program featured determination of larval densities and water velocity measurements along the Plymouth coast in Cape Cod Bay and determination of larval densities in the PNPS cooling water system.

The field program was conducted over a four-week period and consisted of the following three elements:

- Field sampling of four stages of winter flounder larvae at six stations along three transects near the Plymouth coast in Cape Cod Bay.
- Water velocity measurements at four stations along and across the Plymouth coastline in Cape Cod Bay, using bottom mounted Acoustic Doppler Current Profiler (ADCP) units.
- Sampling of four stages of winter flounder larvae entrained into the PNPS cooling water flow.

Larvae and water velocity measurements were collected concurrently in May 2002 to support determination of larvae flux. Larvae sampling was conducted along the Plymouth coast and at PNPS during four surveys, between May 16 and 30, 2002. For each survey, larvae samples were obtained four times, twice during the day, and twice during the night, during a one-day period. Water velocity measurements were collected continuously during the month of May 2002.

The field larvae data were combined with the current measurements to determine the flux of larvae along the coast of Cape Cod Bay, for each of the four daily measurement periods. These values were then compared to the amount of larvae entrained into the PNPS cooling system, as determined from the entrainment study, during the same four daily measurement periods.

Section 2 of this report describes the field sampling program. Section 3 provides the field study results. Section 4 provides an analysis of the study results. Section 5 provides the study conclusion and an overall assessment of the entrainment by PNPS on winter flounder larvae from Cape Cod Bay.

2.0 FIELD SAMPLING PROGRAM

2.1 Winter Flounder Larvae Sampling

2.1.1 Water Column

Larval winter flounder were collected at six stations in Cape Cod Bay (Figure 2-1). Five of the six stations (A–E) were established along a single transect extending from just south of Rocky Point northeast to the 120' depth contour line of Cape Cod Bay.. The total transect length was approximately five nautical miles. The sixth station (F) was located approximately one nautical mile northeast of Rocky Point. Station F spatially complemented the A–E transect orientation to further characterize the larval populations and transport in the vicinity of PNPS in the event that the currents measured were not completely perpendicular to the primary transect formed by Stations A–E. The location of Station F was selected to provide transport information in a southerly direction across an east-west transect (C–F) and in an easterly direction across a north-south transect (A–F).The close proximity of the larvae sampling stations to the hydrodynamic measurements facilitated correlation of the acquired hydrodynamic data with biological sample data to formulate an estimate of the population of winter flounder contained in Cape Cod Bay coastal waters flowing towards and past PNPS.

The five sampling stations located along the transect were identified as Stations A through E in order of increasing distance from the shore, The approximate low-water depth at each station was as follows: Station A: 25'; Station B: 44'; Station C: 90'; Station D: 113'; Station E: 114'. Low-water depth at Station F was approximately 43'. As shown on Figure 2-1, the stations were positioned such that the inshore stations were more closely spaced than the offshore stations. Tow duration for each sample was approximately six to eight minutes, which provided sample volumes ranging from 85 to 150 cubic meters and an overall average of 120 cubic meters.

Four field surveys were completed during the month of May 2002:

- May 16–17,
- May 22–23,
- May 27–28, and
- May 29–30.

Each survey was structured to capture the ebb and flood tides of two tidal cycles on each sampling day (4 sampling events per survey, 2 predominately during the day and 2 predominately during the night). Sampling was conducted at each station using 60-cm diameter "bongo" nets rigged with 0.202-mm and 0.333-mm nylon mesh plankton nets.

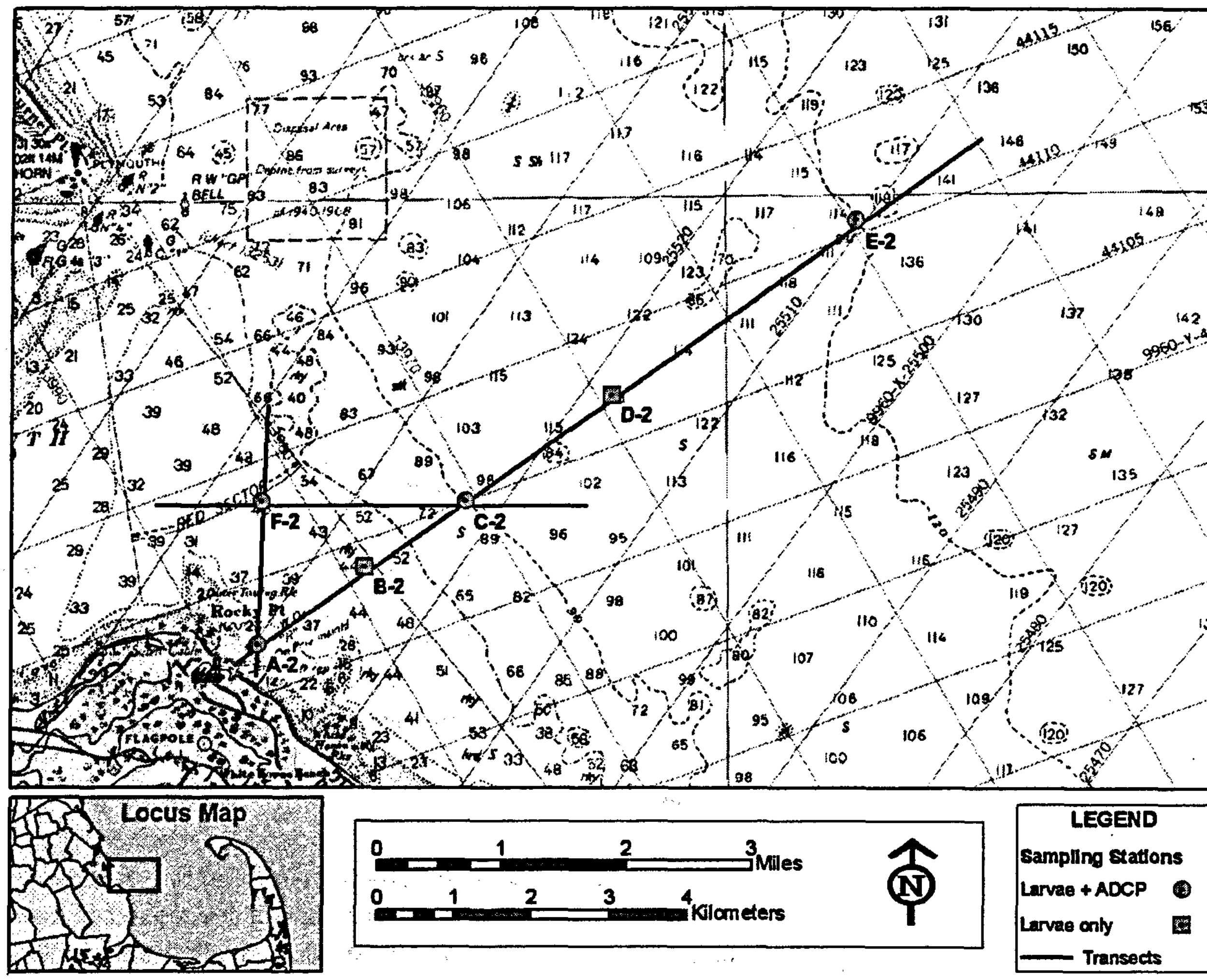


Figure 2-1 Locations of Larvae Sampling and ADCP Deployment Stations

At all six stations, A, B, C, D, E, and F, stratified oblique tows were performed, by partitioning the water column into two equal-depth layers and completing one oblique tow in each layer so that samples were obtained from surface to mid-depth and from mid-depth to bottom layer. Stations were initially located using GPS bearings but Loran C coordinates were then determined and used to locate each station for subsequent tows. Filtration volumes were determined using General Oceanics 2030R flow meters installed in the mouth of the plankton net.

After the completion of each sample tow, the net was washed down from the outside and the contents were transferred to one-liter bottles containing sufficient Formalin to produce a 10% solution with seawater. A waterproof tag listing the station, date, start and end time of the collection, the flow-meter readings, and the net was placed into each sample container. Samples were then delivered to the lab for microscopic analysis where all winter flounder larvae were identified and counted within four developmental stages. Only the 0.202-mm mesh samples were analyzed; the 0.333-mm mesh samples were archived. Due to the abundance of zooplankton samples were split in half using a plankton splitter patterned after Motoda 1959 (see also VanGuelpin *et al.* 1982). Counts were converted to larvae per 100 cubic meters of water (density) based on the flow-meter readings.

2.1.2 PNPS Discharge

In conjunction with each offshore sampling series, ichthyoplankton samples were also taken from the PNPS cooling water discharge to assess the entrainment of winter flounder larvae. Sampling was conducted near the center of the discharge canal, approximately 30 meters downstream from the headwall, which his the same location used for the routine entrainment monitoring. Samples were collected using a 60-cm diameter plankton net constructed of 0.202-mm nylon mesh. On each of the four May surveys, samples were taken every three hours for a total of eight samples per sampling event. Each collection was made by streaming the net for 10 minutes. Exact filtration volumes were determined using a General Oceanics 2030R2 flowmeter mounted in the mouth of the net.

After sample collection, the net was rinsed from the outside using seawater to wash all plankton into the cod end of the net. The sample was then transferred into a 1-liter wide mouth bottle and preserved using sufficient buffered Formalin to obtain a 10% solution. A waterproof tag listing the station, date, time of collection, and the flow-meter readings was placed into each sample container. Samples were returned to the laboratory and processed as described above for the offshore samples.

2.1.3 Larvae Sampling Method Study

To determine if stage four larvae can be more efficiently sampled with a bottom sled, additional sampling was completed during the morning of May 29, 2002. This work was done at the request of the regulatory reviewers of the larval transport study done in 2000. Samples were collected with the same 60-cm bongo net used for the above sampling program and with an epibenthic, bottom sled fitted with a plankton net. Since stage four larvae are relatively large, only the 0.333-mm mesh net was used in the bongo sampler and in the sled. Six pairs of alternating samples (*i.e.*, one sled sample, one bongo sample, one sled sample, and so on) were collected. The sled was constructed of PVC pipe identical to the one used to collect winter flounder eggs near PNPS in 1984 (MRI 1986). Tow distance for the sled averaged 750 m and was determined with GPS bearings and with a General Oceanics 2030R flowmeter mounted on the frame. Distance estimates determined by GPS and flowmeter were averaged. The bongo samples were oblique tows and confined to the lower half of the water column to correspond with the regular ichthyoplankton surveys. Sampling was conducted near shore close to PNPS in the waters bounded by Stations A, B, and F (Figure 2-1). In conjunction with each pair of sled-bongo samples an entrainment sample was collected from the PNPS discharge canal with a 0.333-60 cm plankton net for an overall total of 18 samples. Samples were preserved in Formalin, seawater solutions and processed as described above.

2.2 Hydrodynamic Measurements

The hydrodynamic measurement component of the field program was designed to support determination of the total volumetric flowrate of water along the Plymouth coast. The hydrodynamic surveys were scheduled concurrently with winter flounder larvae sampling surveys to compare with the winter flounder larval flux along the Plymouth coast.

The hydrodynamic field program consisted of two components, a long-term survey and a synoptic survey. Continuous long term ADCP measurements of current velocity were made at four stations for a period of one month (designated locations A, C, E and F in Figure 2-1) for a period of one month. The boat-based synoptic survey featured the collection of time series (complete tidal cycle) of hydrodynamic measurements along the entire length of Transect A–E. The long-term and synoptic surveys successfully collected the data required to support the study and are described below.

2.2.1 Long-term Hydrodynamic Survey

Hydrodynamic measurements were continuously collected at four locations (A, C, E, and F see Figure 2-1). At each hydrodynamic sampling location, the following measurements were collected for a period of one month.

- Water velocity measurements were recorded throughout the water column using a bottom-based acoustic Doppler current profiler (ADCP). The ADCP measures the magnitude and direction of water movement through transmission of acoustic signals and interpretation of Doppler frequency shifts in acoustic returns. ADCP measurements were acquired at one-meter intervals throughout the full depth of the water column.
- Sea surface elevation using a tide gauge (pressure transducer).

Two problems were encountered with the long-term hydrodynamic data collection, that were not able to be discovered until the instruments were recovered from the seafloor:

- The instrumentation package for Station E was spun upside down, resulting in the inability to record data that is applicable to the study. To overcome the resultant loss of data at Station E an additional set of synoptic ADCP measurements were performed between Stations C and E to gather data for correlation of water flowrate along the portion of the transect between those stations. This additional information can be found below.
- The instrumentation for Station F lost power midway through deployment, so the hydrodynamic measurements only coincide with the first survey of flounder larvae sampling.

A description of long-term survey deployments, equipment, and data collection is provided in Table 2-1 for each location.

Processing, analysis and application of the long-term hydrodynamic measurement data is described in Section 3.

Table 2-1 Long-Term Hydrodynamic Survey Deployment Description

		Station A	Station C	Station E	Station F
Deployment Information	Instrument deployment coordinates	41° 56.906'N 70° 34.413'W	41° 57.907'N 70° 32.456'W	41° 59.835'N 70° 28.805'W	41° 57.906'N 70° 34.355'W
Deployment Information	Instrument deployment depth	27 feet	97 feet	120 feet	48 feet
Deployment Information	Deployment date/time	5/7/2002 at 12:53	5/7/2002 at 12:14	5/7/2002 at 11:34	5/7/2002 at 13:07
Deployment Information	Recovery date/time	6/18/2002 at 13:00	6/18/2002 at 14:11	7/2/2002 at 14:08	6/18/2002 at 13:36
Deployment Information	Deployment duration	42 days	42 days, 4 hours	55 days, 2 hours	42 days
Deployment Information	Data record duration	42 days	42 days, 4 hours	None	18 days, 15 hours
Equipment and Data Collection Configuration	Water velocity meter specification	RD Instruments, Workhorse Sentinel ADCP, 1200kHz frequency (serial #0216)	RD Instruments, Workhorse Sentinel ADCP, 600kHz frequency (serial #1302)	RD Instruments, Workhorse Sentinel ADCP, 600kHz frequency (serial #1301)	RD Instruments, Workhorse Sentinel ADCP, 600kHz frequency (serial #0633)
Equipment and Data Collection Configuration	ADCP water velocity data collection	Recorded every 10 minutes throughout the water column	Recorded every 10 minutes throughout the water column	Recorded every 10 minutes throughout the water column	Recorded every 10 minutes throughout the water column
Equipment and Data Collection Configuration	Tide gauge specification	Coastal Macrowave Non-directional Wave Gauge (serial #10654)	Coastal Macrowave Non-directional Wave Gauge (serial #10683)	Coastal Macrowave Non-directional Wave Gauge (serial #10684)	Coastal Macrowave Non-directional Wave Gauge (serial #10658)
Equipment and Data Collection Configuration	Tide gauge data collection	Water level measurements recorded every 10 minutes	Water level measurements recorded every 10 minutes	Water level measurements recorded every 10 minutes	Water level measurements recorded every 10 minutes

2.2.2 Synoptic Hydrodynamic Survey

Synoptic, boat-based water velocity measurements were collected using an ADCP instrument on 18 June 2002. The boat-based ADCP survey featured measurement of water velocities (direction and magnitude) at one-meter intervals throughout the water column. Two transits of Transect A–E were performed, once each during ebb and flood tide. The ADCP unit was rigidly mounted in a frame suspended over the side of the survey vessel. The synoptic survey transits were performed at the times indicated below:

- Ebb tide survey date/time: 18 June 2002 from 10:31 to 12:25
- Flood tide survey date/time: 18 June 2002 from 15:52 to 17:17

The synoptic survey achieved the 100% data collection goal. Processing, analysis and application of synoptic hydrodynamic measurement data is described in Section 3.

2.2.3 Additional Synoptic Velocity Data

Additional synoptic velocity measurements along the transect between Stations C and E were collected using an ADCP instrument on 10 September 2002. These additional transects were performed to capture hydrodynamic information that was not recovered during the original deployment. This second boat-based survey was performed similarly to the Synoptic Hydrodynamic Survey. Water velocities (direction and magnitude) at one meter intervals were collected throughout the water column by an ADCP unit that was mounted in a frame suspended over the side of the survey vessel. Records of the transits are presented in Table 2-2. Processing, analysis and application of the additional synoptic velocity data is described in Section 3.

Table 2-2 Additional Synoptic Hydrodynamic Data Collection

Tow Number	Direction	Tide Cycle Position	Start Time	End Time
3	West to East (C–E)	Ebb low slack	7:51	8:40
4[1]	East to West (E–C)	Flood just after slack	8:45	9:52
5	West to East (C–E)	Flood	9:53	10:50
6	East to West (E–C)	Flood	10:53	11:46
7	West to East (C–E)	Flood	11:49	12:43
8	East to West (E–C)	Flood	12:44	13:35
9	West to East (C–E)	Flood to high slack	13:37	14:30
10[1]	East to West (E–C)	Ebb just after slack	14:39	15:38
11	West to East (C–E)	Ebb	15:39	16:28
12[2]	East to West (E–C)	Outgoing Tide	16:29	16:54

[1] Transect interrupted briefly due to ADCP frame displacement
[2] Transect terminated prematurely due to ADCP frame displacement/rough seas

2.3 Water Column Monitoring

Measurements of temperature (± 0.1° C), salinity (± 0.1 o/oo), and dissolved oxygen (± 0.1 ppm) were recorded at each station immediately preceding the surface ichthyoplankton tow using a Hydrolab Quanta instrument. Readings were recorded at surface, mid-depth and at a depth within 1-meter of the bottom.

3.0 STUDY RESULTS

3.1 Winter Flounder Larvae Sampling Results

Densities of larval flounder per 100 m^3 of water by developmental stage for each sample appear in Appendix A. Larval flounder were present on each sampling occasion (Figure 3-1 to Figure 3-4). The percentages of each of the four larval stages that were found in each sampling event are presented in Figure 3-5.

3.1.1 Water Column

Averaged over all samples taken within each of the four surveys, larvae observed in the water column were most abundant during the May 16 series and least abundant during the May 22 series, and found in nearly equal numbers during the latter two series. Overall mean densities for May 16, 22, 27, and 29 were 74.1, 23.8, 24.4, and 40.7 per 100 m^3 of water, respectively.

Summarized across stations and events for each survey, the percentages of each larval stage observed are given in Table 3-1. Stage 1 larvae comprised approximately one quarter of the total during the first survey, with percentages dropping consistently through subsequent surveys. Stage 4 larvae were only observed during Surveys 3 and 4, and then at less than one percent of the total. Stage 2 and 3 larvae make up the bulk of the population, with Stage 2 dominating in Surveys 1 and 2, and Stage 3 in Surveys 3 and 4.

Table 3-1 Water Column Larval Stage Percentages Summarized For Each Survey

		Survey			
		16-May	22-May	27-May	29-May
Percent of Total Larval Count	Stage 1	23	12	8	2
	Stage 2	52	59	27	19
	Stage 3	26	29	64	79
	Stage 4	0	0	<1	<1

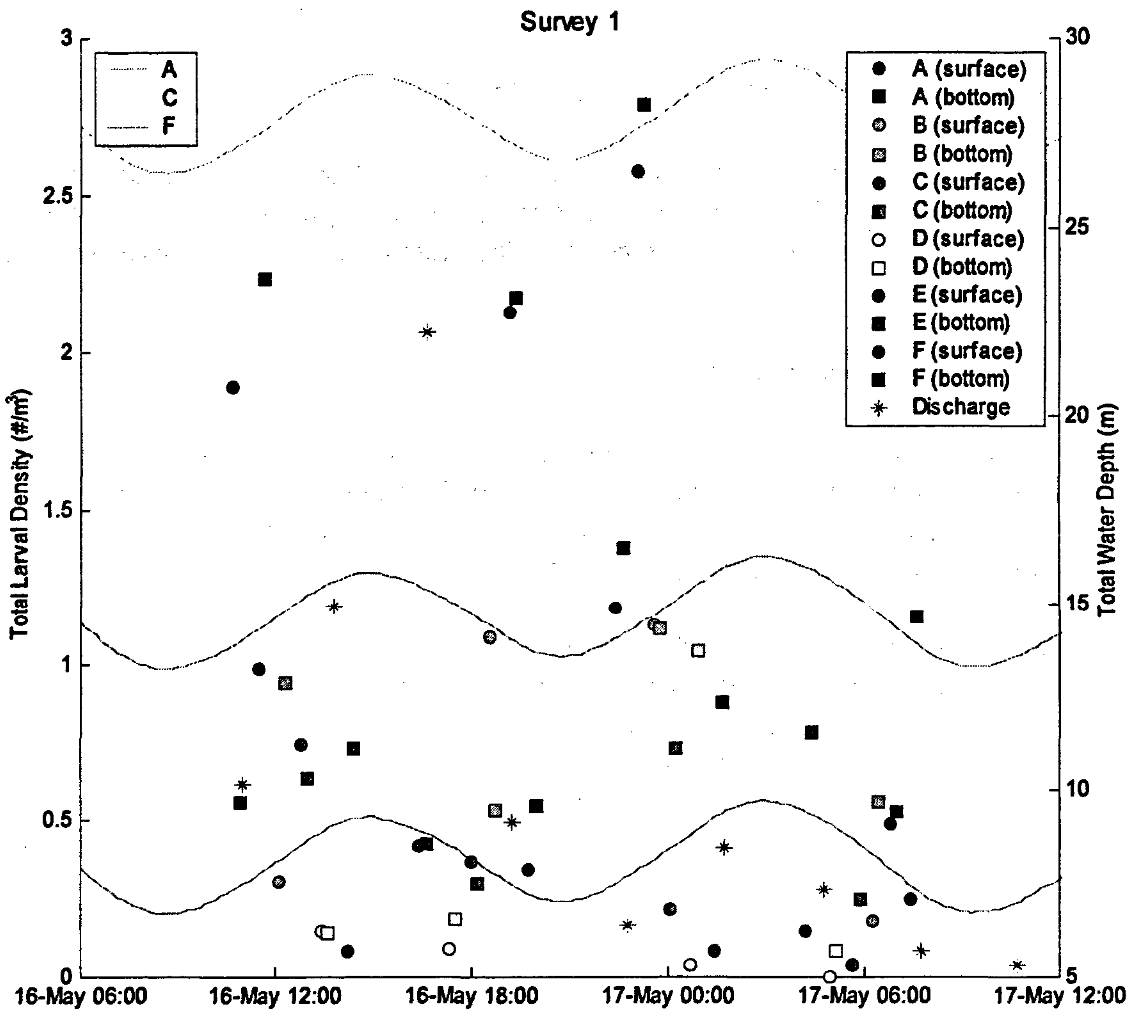


Figure 3-1 Total Larval Densities For Sampling Survey 1

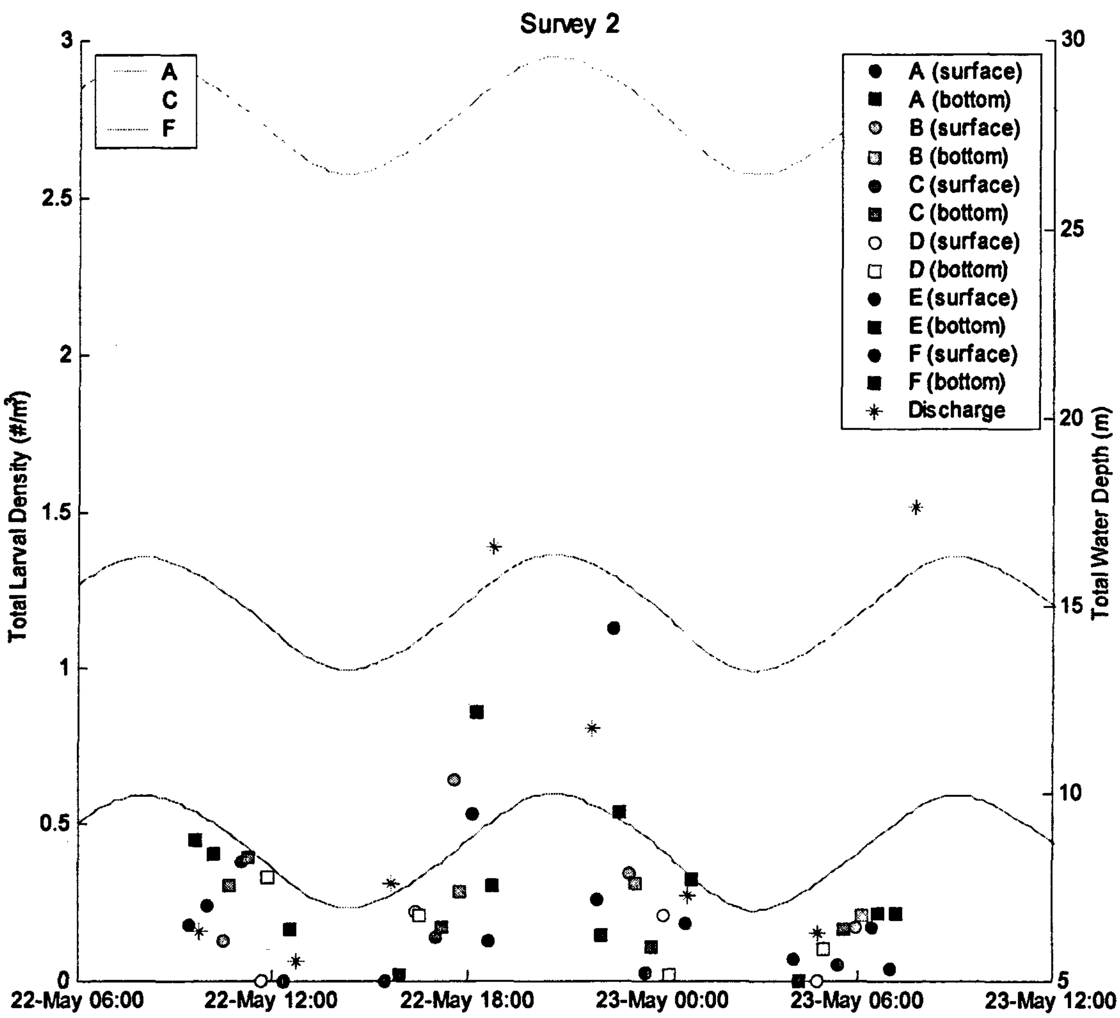


Figure 3-2 Total Larval Densities For Sampling Survey 2

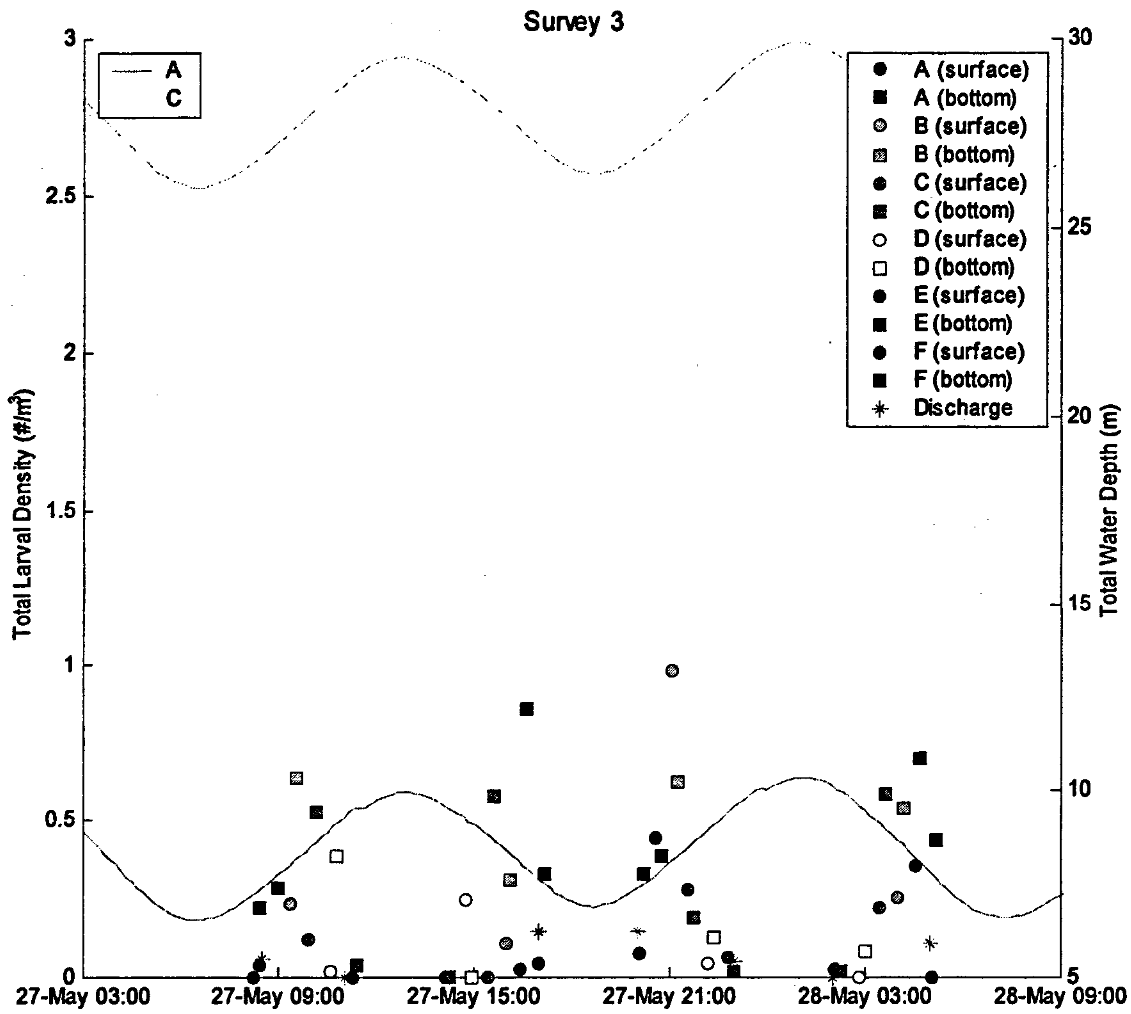


Figure 3-3 Total Larval Densities For Sampling Survey 3

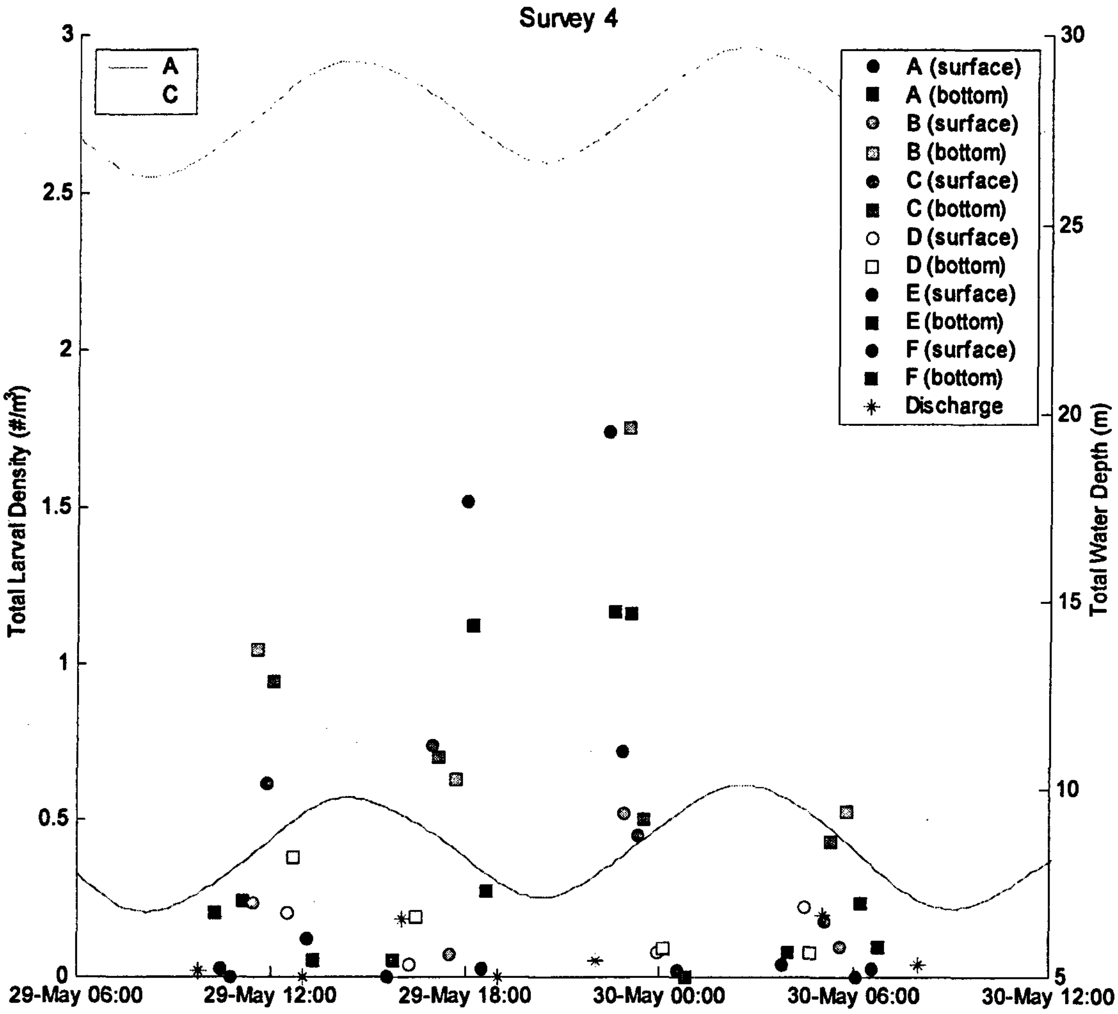


Figure 3-4 Total Larval Densities For Sampling Survey 4

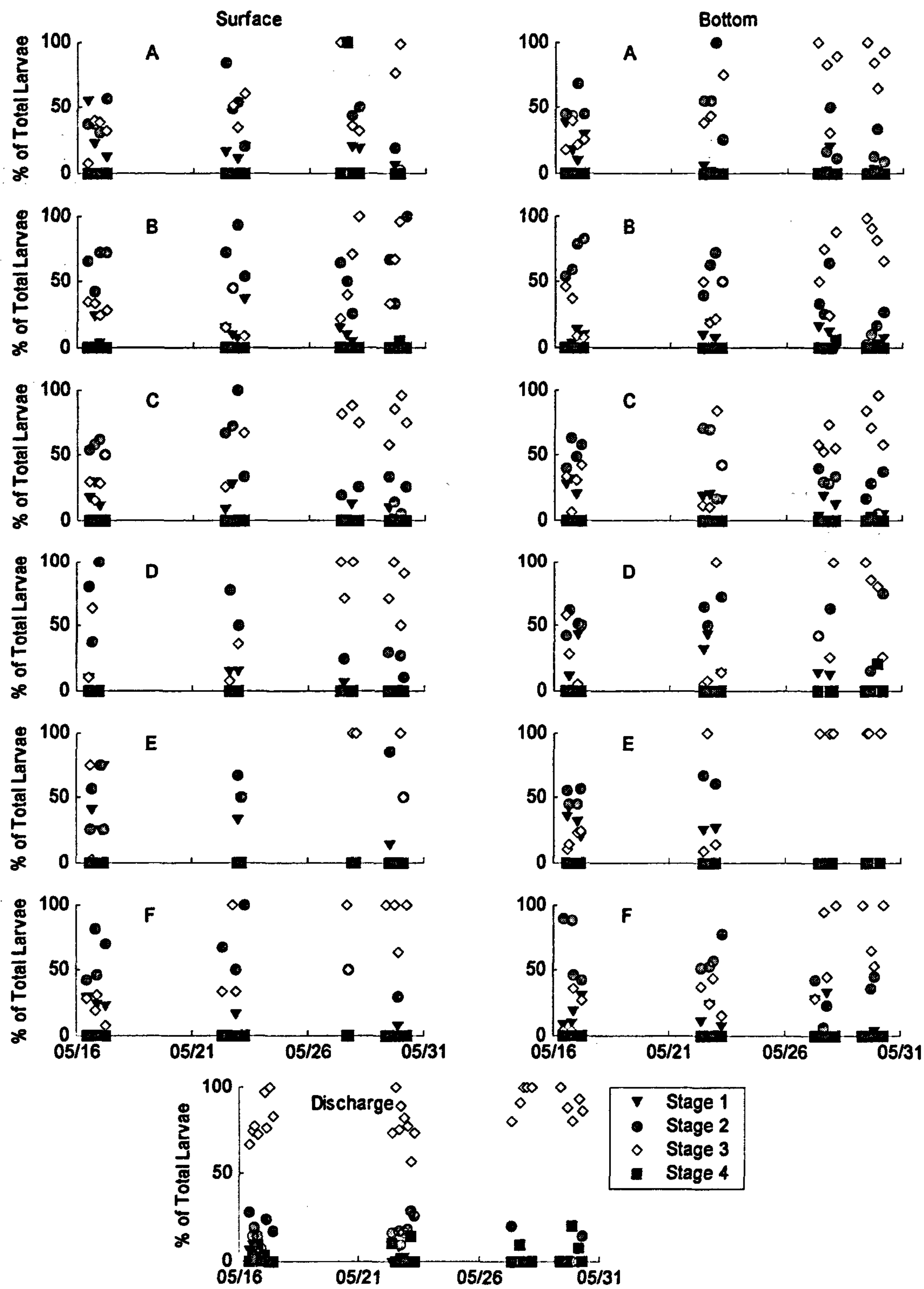


Figure 3-5 Larval Stage Percentage of Total Count

3.1.2 PNPS Discharge

Mean densities of flounder larvae observed in the PNPS discharge were 59.2, 58.3, 7.1, and 12.1 per 100 m^3 of water for the May 16, 22, 27, and 29 series, respectively.

The percentages of larval stages observed in the PNPS discharge are summarized in Table 3-2. During each survey, Stage 3 larvae were consistently observed at the highest percentage compared to the three other stages. During Surveys 3 and 4, Stage 1 larvae were not observed, suggesting that the spawning season ended earlier in May. There was a sharp decrease in Stage 2 larvae between Surveys 2 and 3. Stage 4 larvae made up between two and seven percent of the total in all four Surveys.

Table 3-2 Discharge Larval Stage Percentages Summarized For Each Survey

		Survey			
		16-May	22-May	27-May	29-May
Percent of Total Larval Count	Stage 1	5	1	0	0
	Stage 2	16	17	4	1
	Stage 3	78	80	98	90
	Stage 4	2	7	3	6

3.1.3 Larvae Sampling Method Study

The average densities obtained with the bottom sled are presented in Table 3-3. Overall, the sled yielded approximately 10 times more larvae than the bongo net when standardized to 100 m3 of water. Both methods of sampling yielded similar percentages of the four larval stages, stage 3 larvae accounting for 96 and 99% of the catch in the bongo net and sled, respectively. The PNPS samples also had developmental stage percentages similar to the water column samples with stage 3 larvae accounting for 90%, but had the lowest average density. Densities of Stages 2, 3, and 4 larvae were all greater in the sled than in the net samples although stage 2 larvae were uncommon by the end of May when the sled was used. Densities of Stage 3 larvae in the sled samples were 10 times higher than in the bongo net samples and 70 times higher than in the PNPS samples. There were no Stage 4 larvae collected in the bongo net samples. Single individuals were taken in the sled and at PNPS.

Table 3-3 Larvae Sampling Method Study Results

	Bongo Net		Bottom Sled		PNPS	
	#/100m3	% of total	#/100m3	% of total	#/100m3	% of total
Stage 1	0.00	0%	0.00	0%	0.00	0%
Stage 2	1.12	4%	3.23	1%	0.28	7%
Stage 3	24.30	96%	278.58	99%	3.80	90%
Stage 4	0.00	0%	0.47	0.2%	0.15	4%
Total	25.41		282.28		4.24	

3.2 Hydrodynamic Monitoring Results

3.2.1 Long-term Hydrodynamic Survey

Hydrodynamic data from each of the three locations was inspected, processed, and exported for further analyses using RD Instruments WinADCP software. The conversion of the water velocity vectors (magnitude and direction) to velocity normal to the transect results in velocities and water flowrates being reported such that positive values are flowing North and/or West, and negative values are flowing South and/or East.

Over the duration of the ADCP deployment, observed velocities perpendicular to the study transect ranged, in meters per second:

- from 0.398 (North) to -0.472 (South) with an average of 0.003 at Station A,
- from 0.326 (North) to -0.419 (South) with an average of -0.028 at Station C

Hydrodynamic data are provided in Appendix C.

3.2.2 Synoptic Hydrodynamic Surveys

Data from the two boat-based ADCP tows was inspected using RD Instruments WinRiver software, and exported for further analysis. The ADCP transect tows of June 18, 2002 are presented in Figure 3-6 and Figure 3-7. These figures show the velocity normalized perpendicular to the A–E transect, with positive values flowing northwest, and negative values flowing southeast. The results of the synoptic surveys show that the current profiles vary across the transect, however, the placement of the three fixed ADCP stations should capture the major flow regimes.

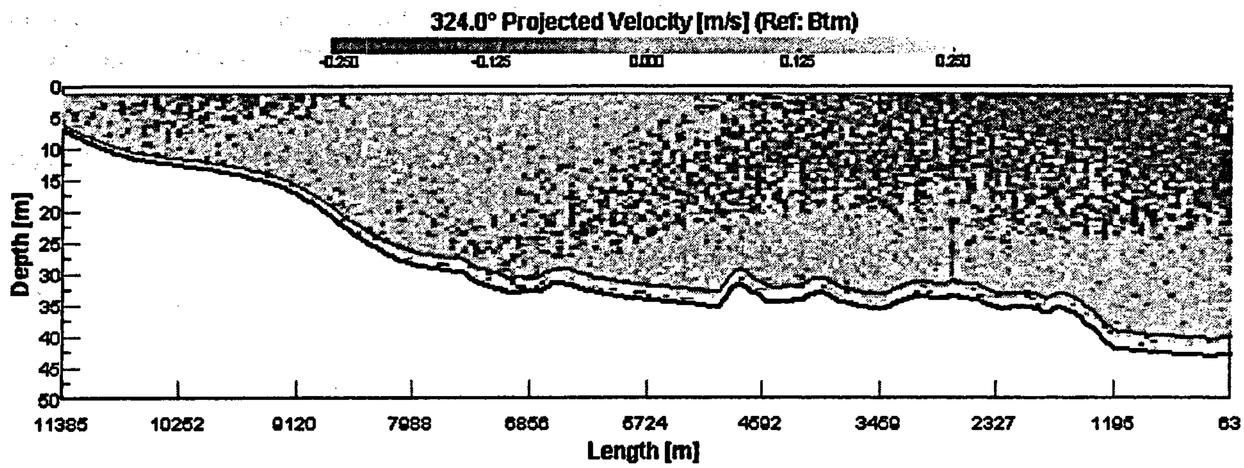


Figure 3-6 Velocity Normal to Transect A–E: Tow 1 June 18, 2002 (10:31-12:25)

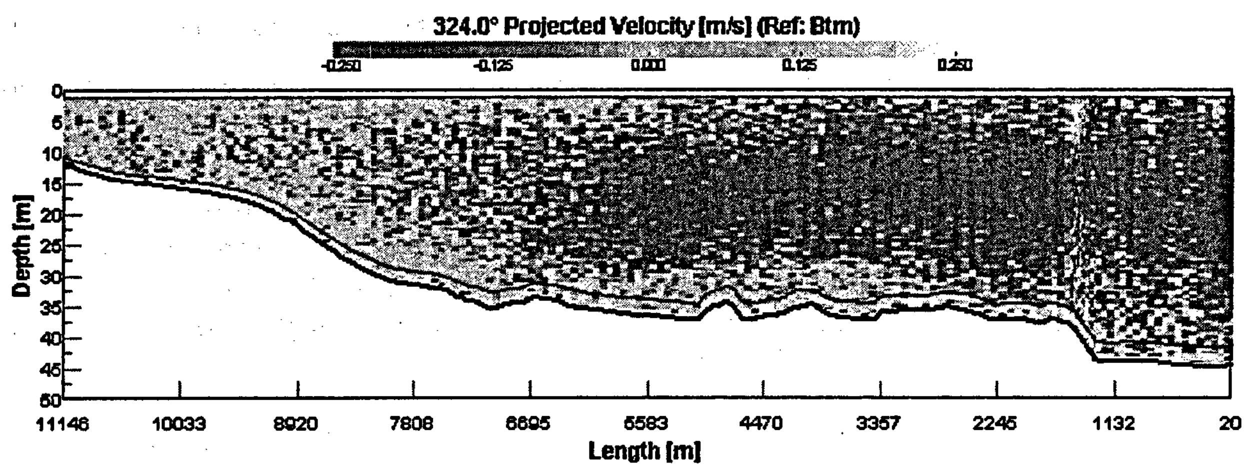


Figure 3-7 Velocity Normal to Transect A–E: Tow 2 June 18, 2002 (15:52-17:17)

3.2.3 Quantify Flow Variability Across Transect

To assess the ability of the volumetric water flowrate analysis to accurately represent the flow across the relatively long transect with only three ADCP recording stations, a comparison of the volumetric water flowrate determined by the method to be applied to the long-term ADCP data, and of the volumetric water flowrate measured directly for the synoptic ADCP surveys was performed.

The two ADCP transits described above were not exactly the same length as the transect applied to the long-term ADCP data. To accommodate this discrepancy, the volumetric water flowrate method was applied in the following manner:

- The locations of long-term ADCP stations A and C (station E was not included since that long-term ADCP instrument failed to record data) were expressed as a percentage of total transect length,
- Equivalent stations A and C for the ADCP transit data were determined by taking the above percentages of the total transit lengths,
- The total depth reported by the ADCP at the equivalent stations was divided into halves, and the ADCP velocity normal to the transect at each equivalent station was averaged over each of the two depth segments,
- The average North velocity at the two depths for station B was determined as the average of the normal velocities at stations A and C,
- For each depth segment of each of the five stations, the average North velocity was multiplied by depth of the segment and by the corresponding width of the transect to determine the volumetric water flowrate in each of 10 sections of the total cross-sectional area, and
- The sum of the 10 volumetric water flowrates is the total volumetric water flowrate for the transect.

The total volumetric water flowrate for each of the ADCP transits was also independently determined by RD Instruments WinRiver software. This volumetric water flowrate is determined as the sum over all ADCP bins of the product of the depth of the bin, the width of the bin, and the velocity normal to the transect recorded for the bin. The results of the volumetric water flowrate calculations by both methods, for each of the two synoptic ADCP surveys, are presented in Table 3-4.

Table 3-4 Comparison of ADCP Flowrate Calculation Methods

Tow Number	Transit Length Used/Total (m)	Flowrate By 10 Discrete Average Segments (m3/s)	Flowrate By Continuous Measurement (m3/s)	Percent Difference
1	4,918/11,385	1,357	4,797	72%
2	4,815/11,146	-4,747	-6,317	25%

The percent differences between the two methods for both of the ADCP surveys shows that the deployment of the stationary ADCPs and the volumetric water flowrate calculation method used in the study provides a conservatively low estimate of the net water velocity and flowrate across the study transect.

3.2.4 Extra Synoptic Hydrodynamic Surveys

Data from the nine extra boat-based ADCP tows was inspected using RD Instruments WinRiver software, and exported for further analysis. The flowrate across the transects collected as the extra synoptic ADCP velocity data is summarized in Table 3-5. Figure 3-8 presents a representative view of the velocity data collected during the extra synoptic survey. Consistent with the original synoptic survey, this data shows variation in currents across the transect, with distinct flow regimes in the surface and bottom halves of the water column.

Table 3-5 Extra Synoptic ADCP Data Summary

Tow Number	Depth	Portion of Transect Total Flowrate (m^3/s) + N/W – S/E				
		C_2	D	E_1	Total	
3	Surface	-342	2465	963	3086	2486
	Bottom	-399	-477	275	-601	
4	Surface	-1952	-4393	87	-6258	-4424
	Bottom	-659	679	1814	1835	
6	Surface	-2223	-6998	-3404	-12625	-15004
	Bottom	-480	-499	-1400	-2379	
6	Surface	-2088	-8169	-3661	-13918	-18502
	Bottom	-626	-1690	-2268	-4584	
7	Surface	-2490	-6909	-1641	-11040	-17896
	Bottom	-735	-2412	-3710	-6856	
8	Surface	-1492	-3503	-1467	-6462	-18955
	Bottom	-1618	-6051	-4825	-12494	
9	Surface	-1108	-459	1098	-470	-5767
	Bottom	-1605	-4326	634	-5298	
10	Surface	1751	4655	2054	8460	3624
	Bottom	-1330	-2296	-1211	-4836	
11	Surface	1029	7109	4822	12959	15934
	Bottom	-692	1160	2506	2975	

C_2 refers to the eastern half of the Station C box
E_1 refers to the western half of the Station E box

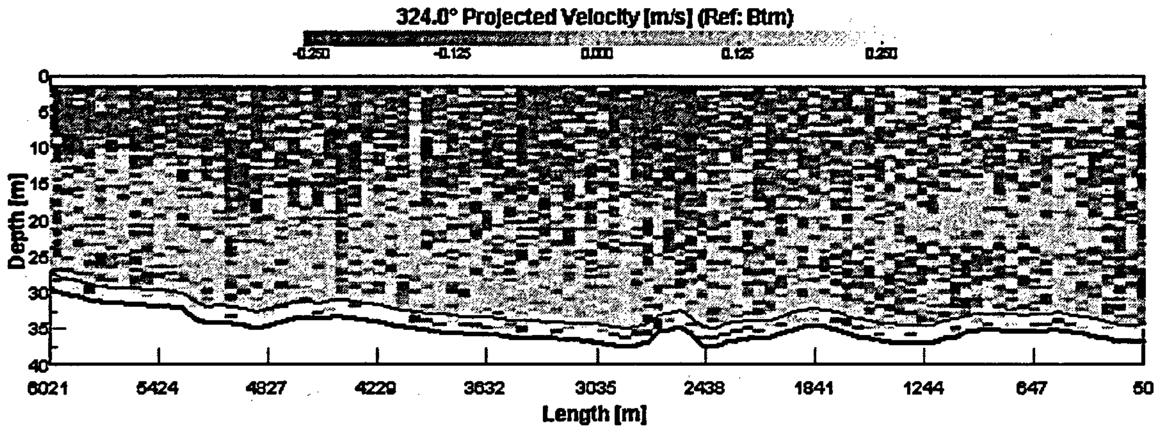


Figure 3-8 Velocity Normal to Transect A–E: Extra Synoptic Tow 6 September 10, 2002

3.3 Water Column Monitoring Results

Water temperature, salinity, and dissolved oxygen data recorded at each station are tabulated in Appendix B. The most significant variation observed during the study was in temperature values. Temperature readings are mapped on Figure 3-9, for each station, surface and bottom, of the four surveys. Based on average readings across all stations for each survey, surface water temperatures ranged from 9.7° C on the first survey to 12.5° C on the fourth. Bottom readings ranged from 8.2° C on the first to 7.6° C on the fourth however bottom readings actually averaged somewhat higher (8.7° C) on the second survey. Along the sampling transect both surface and bottom water averaged higher at inshore Station A than further offshore, the difference between locations being more pronounced in bottom water due to the increasing depth along the transect.

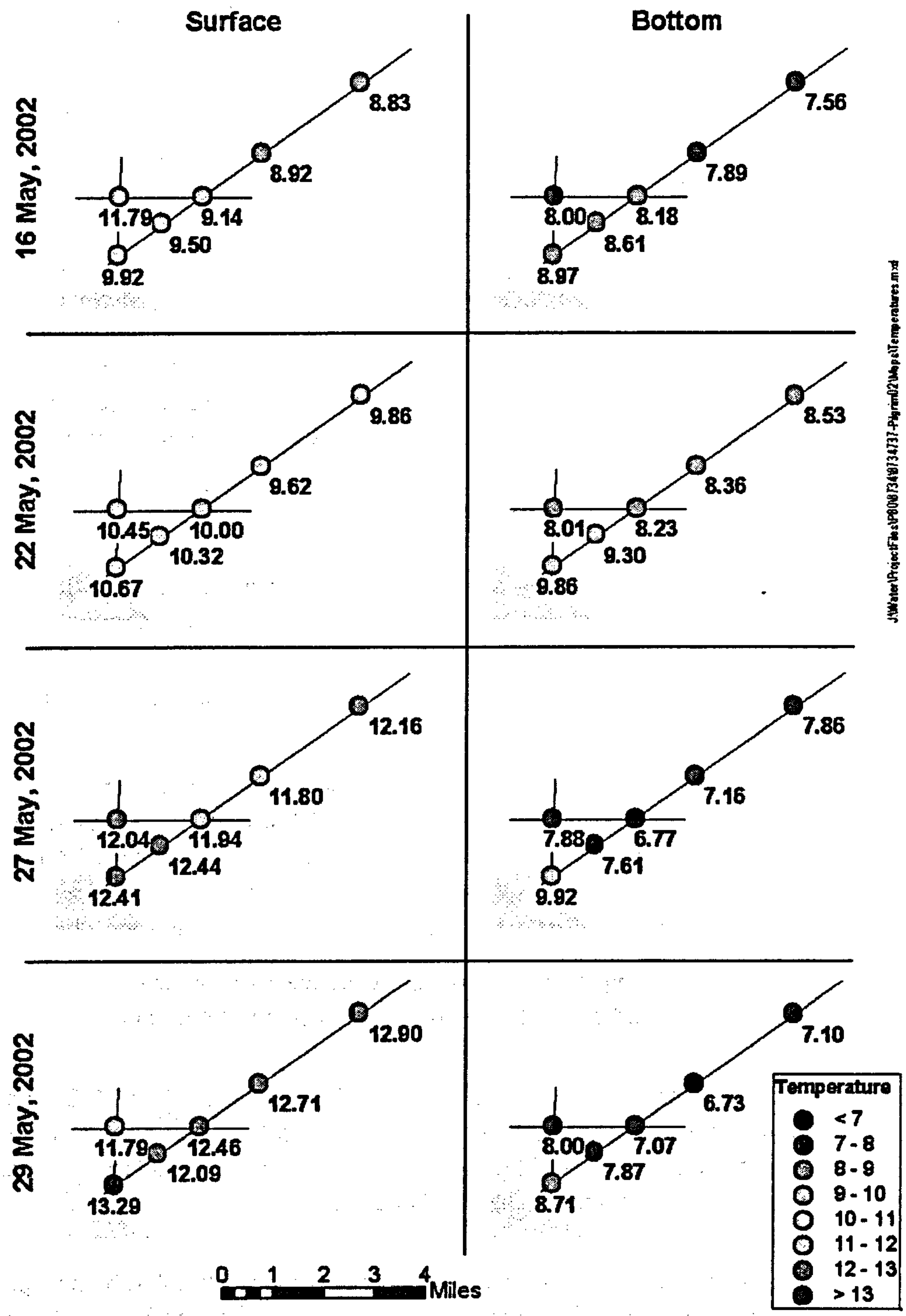


Figure 3-9 Maps of Mean Surface and Bottom Water Temperatures

4.0 DATA ANALYSIS AND ASSESSMENT

The data discussed above were analyzed to allow a determination of (1) the percentage of net volumetric flow in nearby coastal Cape Cod Bay waters withdrawn by PNPS and (2) the percentage of winter flounder larvae in the net coastal flow entrained by PNPS. This allows an evaluation of the overall effect of winter flounder larvae entrainment at PNPS.

A separate calculation of the percentage of coastal flow withdrawn and larvae entrained by PNPS was performed for each of the four sampling events for which the sampling study was conducted. In addition, the volumetric flow analysis was performed over the entire monthly period that the hydrodynamic measurements were conducted. The larval analysis was performed for each of the four winter flounder larvae life stages and for total larvae. Details of the analysis procedures and results are discussed below.

4.1 Volumetric Water flowrate Analysis

In order to correlate the four continuous-depth ADCP stations with the six discrete-depth larvae sampling stations, the ADCP water velocity data was processed in the following manner:

- The flow across three transects, A–E, A–F, and C–F, was analyzed, with the main focus being on Transect A–E.
- At each ADCP station, the water column was divided into halves based on total depth at the time of the reading. The component of the ADCP velocity normal to the transect was averaged over each half of the water column, for each 10-minute ensemble of data. Figure 4-1 to Figure 4-4 contain plots of water depth and the average velocities across Transect A–E for the surface and bottom depth intervals at ADCP stations A and C during each larvae sampling period.
- For larvae sampling station B, velocities were estimated by the average of the transect normal velocities at the adjacent stations (*i.e.*, B is average of A and C).
- For Stations D and E, the extra synoptic ADCP data (Section 3.2.2) was used to develop a linear regression between the flowrate across the area represented by those stations and that represented by Station C. This regression was used to estimate the flowrates across the portion of the transects represented by Stations D and E.
- The flowrate of water across the transect was then calculated by multiplying each of the 10 transect velocity series by the estimated cross-sectional area of the transect represented by that value. The cross-sectional areas were determined for each segment by multiplying one-half of the water depth at the station by one-half of the combined distance to the two adjacent stations.

- In order to correlate the ADCP time series with the discrete larvae sampling events, the ADCP-based water flowrate data was averaged over the duration of each tidal phase. The tidal phase was defined as the time between the maximum and minimum tide heights at the station. The sum of the flowrates during the four tidal phases also was the basis for daily estimates of water flowrate across the study transect.

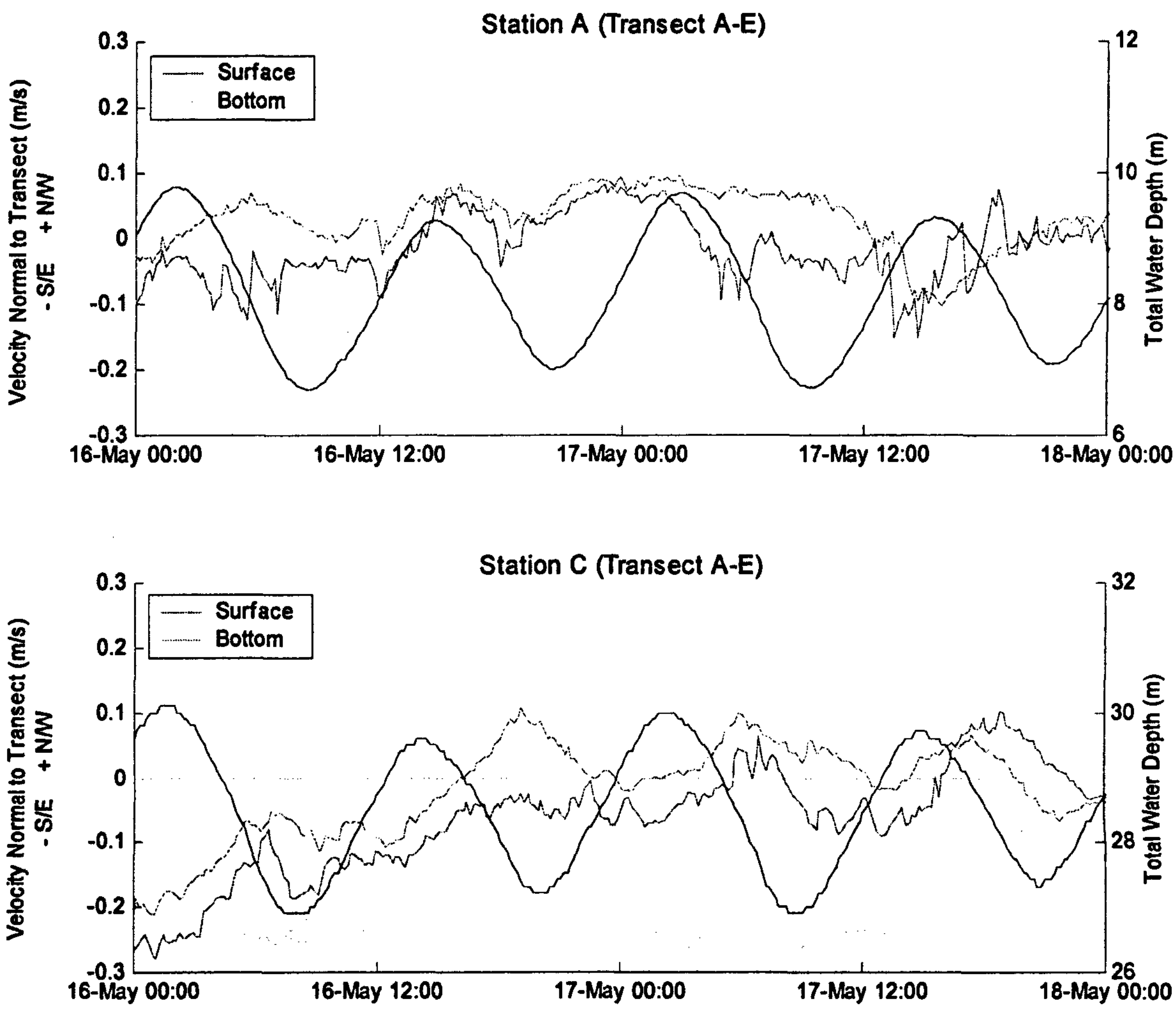
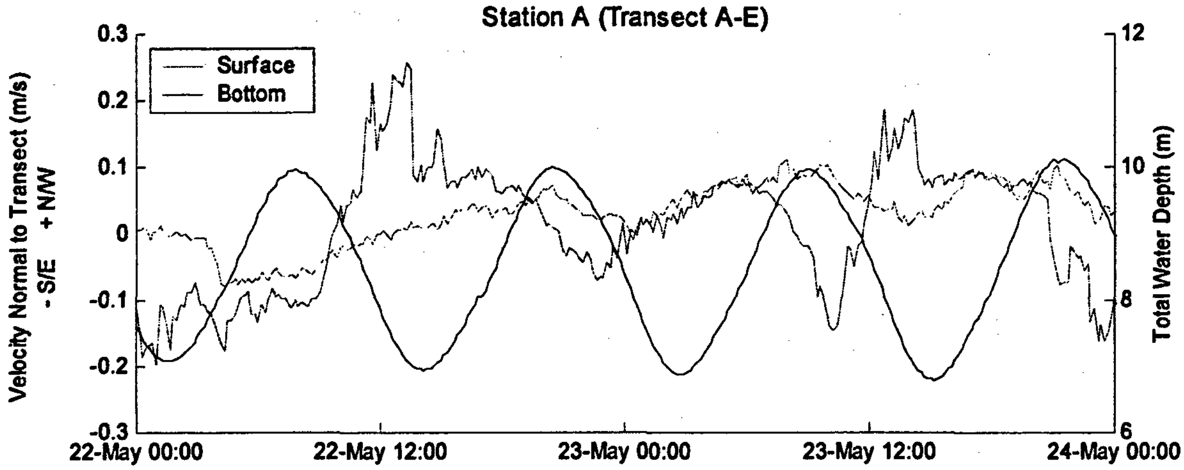


Figure 4-1 Transect A-E Water Velocities During Sampling Survey 1



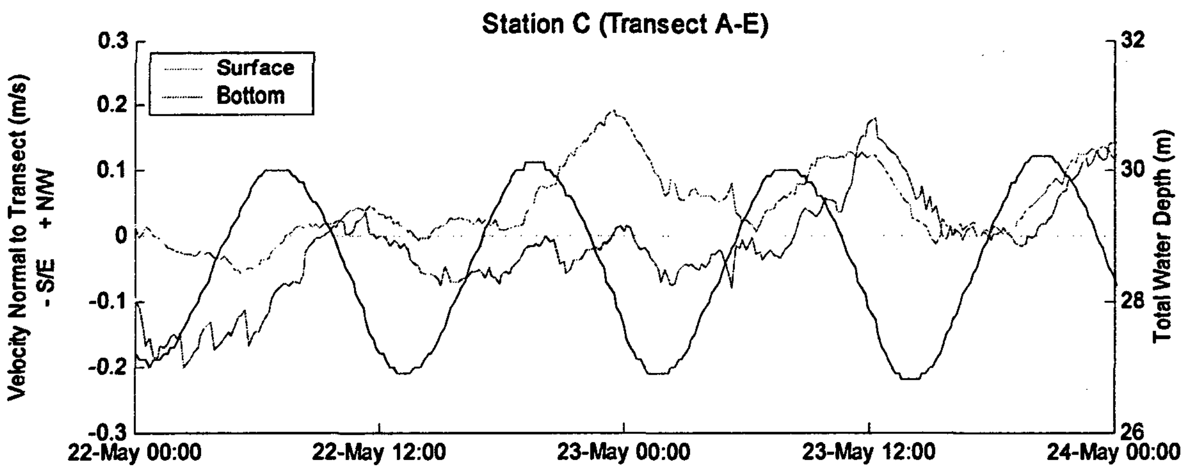
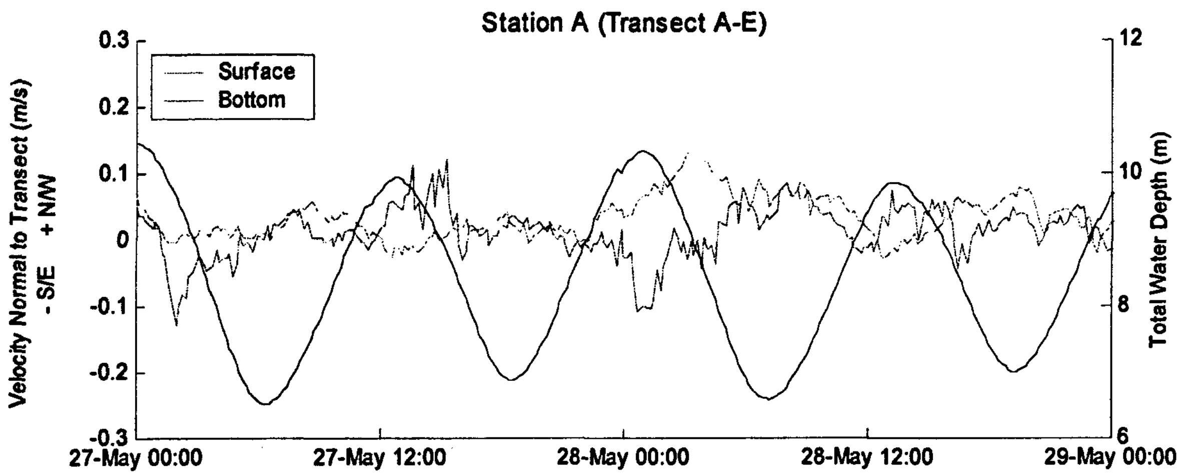


Figure 4-2 Transect A-E Water Velocities During Sampling Survey 2



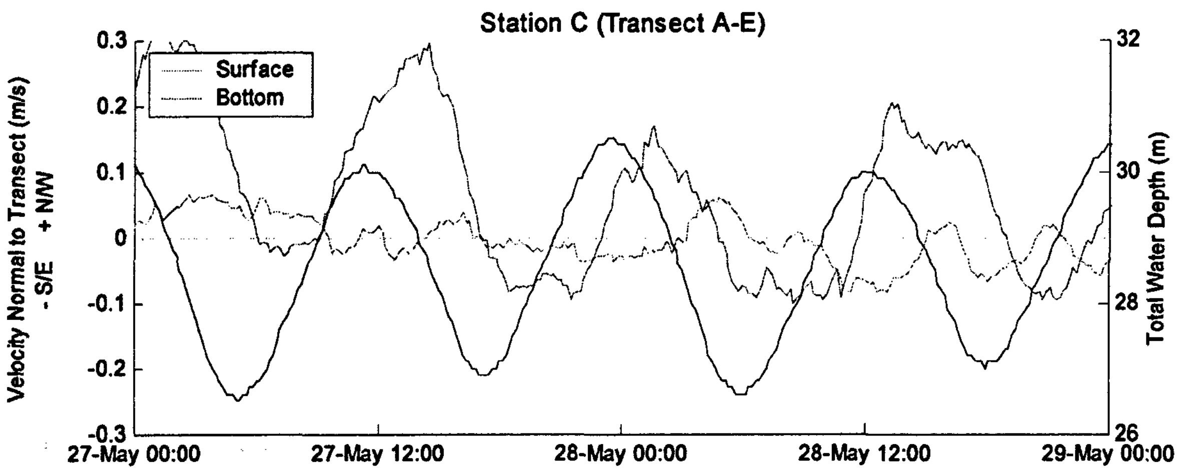


Figure 4-3 Transect A-E Water Velocities During Sampling Survey 3

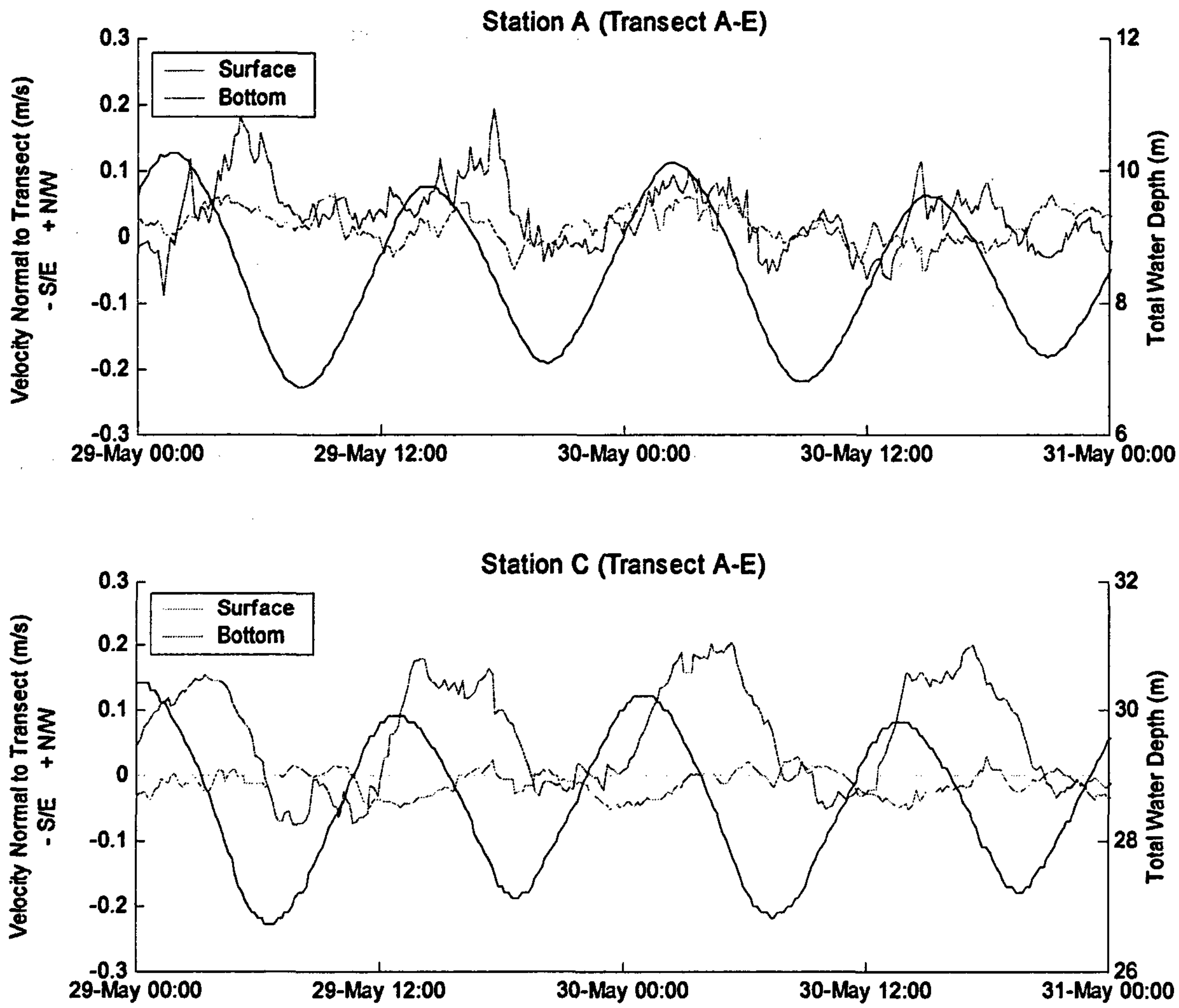


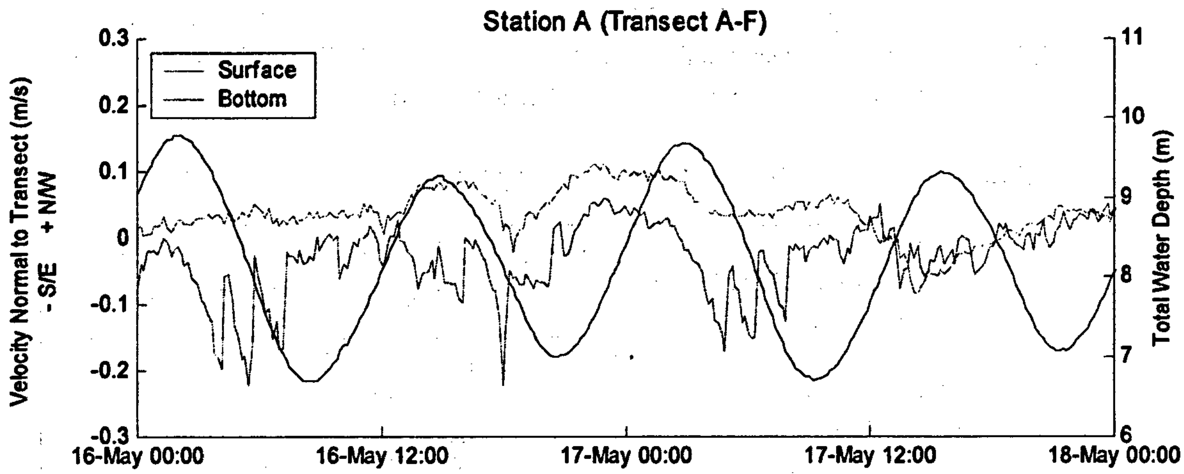
Figure 4-4 Transect A-E Water Velocities During Sampling Survey 4

Table 4-1 compares the daily water flowrates during the sampling events with the average daily water flowrate during the study period, May 7-31, 2000. The percentage of the volumetric flow withdrawn by PNPS (with both pumps operating at the rated total maximum of 19.56 m^3/s) to range from 0.04% to 1.71% for the four larvae sampling days, and to be 0.66% for the entire monthly study period.

Table 4-1 Analysis of Volumetric Flow in Bay Study Area Compared to PNPS Withdrawal

	May 16	May 22	May 27	May 29
Net Volumetric Flow (m^3) in Bay Study Area for 1 Day	1,141	36,240	53,013	54,699
% of Volumetric Flow in Bay Study Area Withdrawn by PNPS* in 1 Day	1.71%	0.05%	0.04%	0.04%
* With both pumps operating at the rated total maximum of 19.56 m^3/s				

The velocities across Transects A–F and C–F were analyzed only for larvae sampling Survey 1, because of the premature failure of the instruments at Station F. Figure 4-5 and Figure 4-6 contain plots of water depth and the average velocities across Transect A–F at Stations A and C and C–F at Stations C and F, respectively, for the surface and bottom depth intervals.



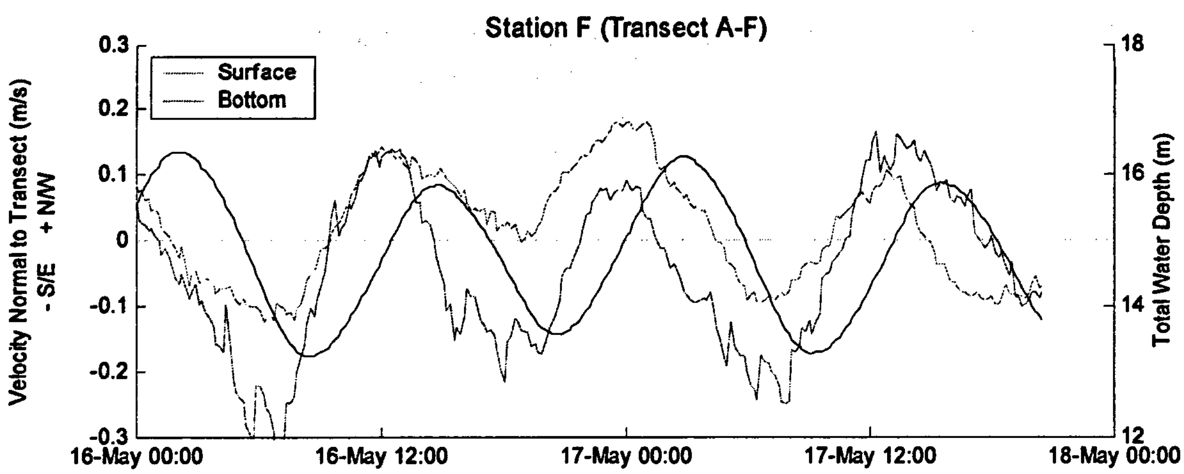
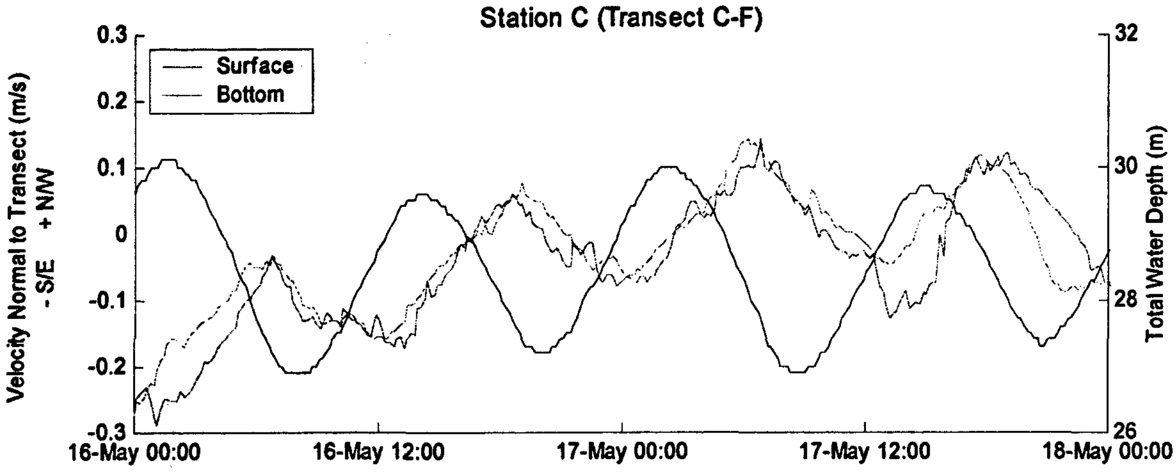


Figure 4-5 Transect A-F Water Velocities During Sampling Survey 1



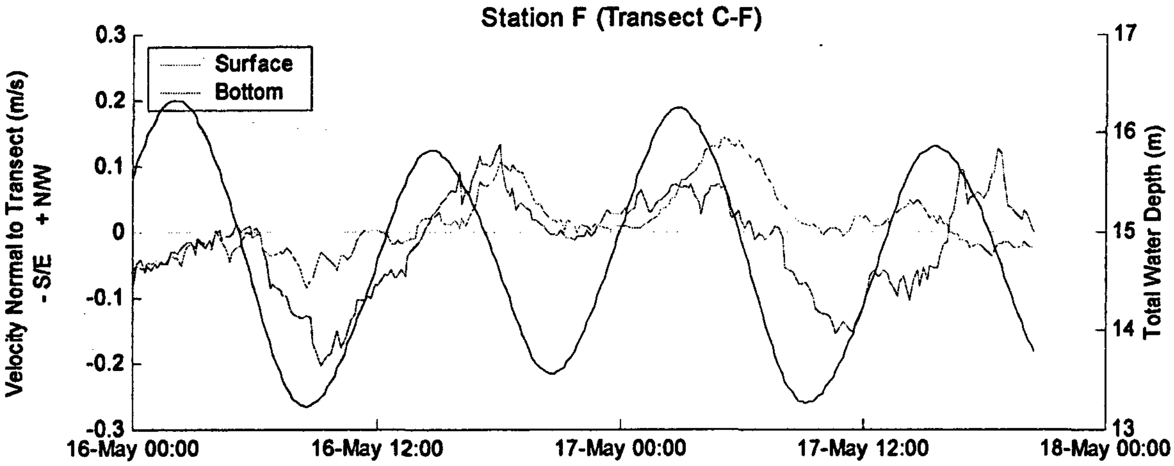


Figure 4-6 Transect C-F Water Velocities During Sampling Survey 1

An inspection of the complete time series of hydrodynamic data (Figure 4-7) shows that the selection of the larvae sampling days may have contributed significantly to the average daily flow values, including direction of net flow. For example, if each of the first three sampling events taken place one day earlier, and the fourth seven days following the third, the average velocities would have been strongly south/west for each event except the third.

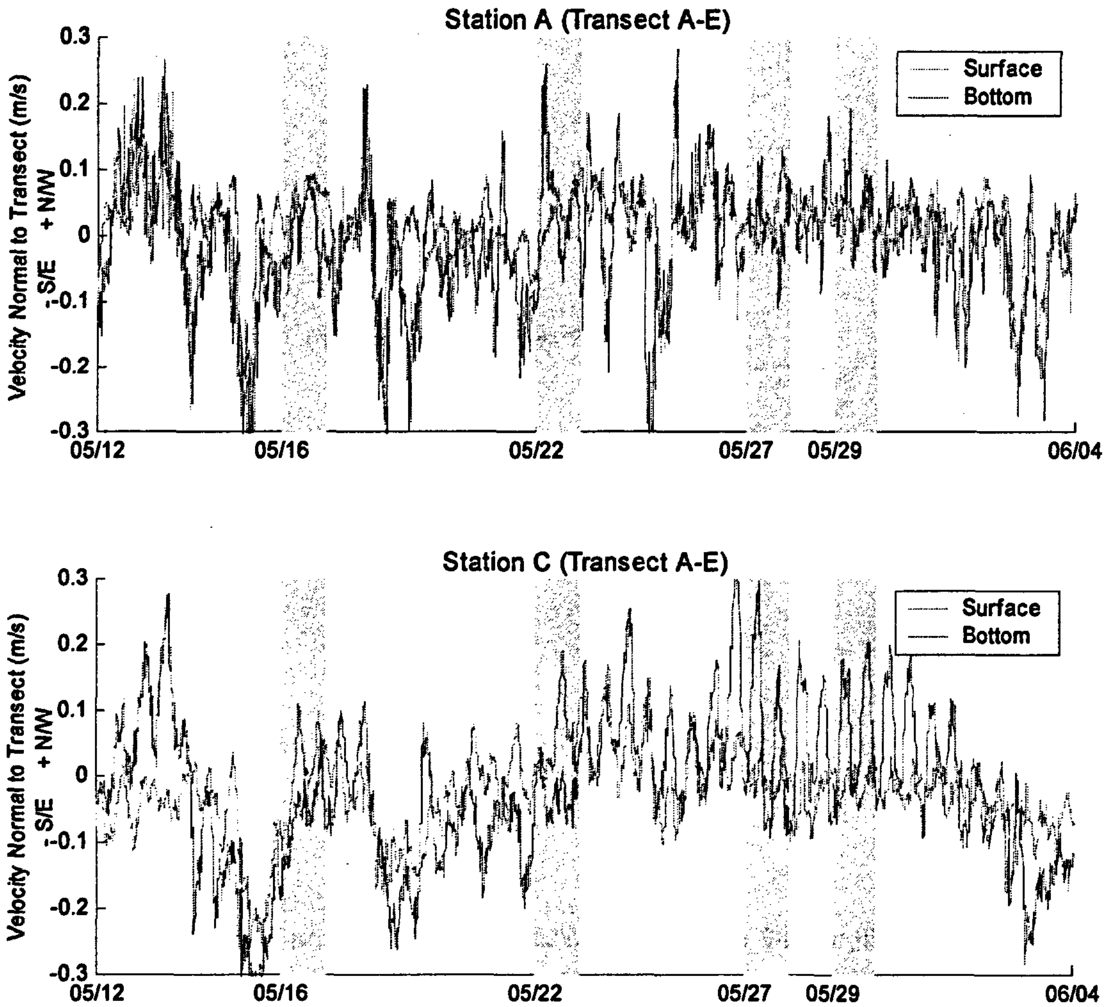


Figure 4-7 Complete Time Series for Transect A–E Water Velocities

4.2 Larval Transport and Entrainment Analysis

4.2.1 Larval Transport Analysis

The flux or transport of winter flounder larvae flowing along the coast was determined for each of the four study days using larvae density and hydrodynamic measurements (Figure 4-6). This approach integrated current velocity, water depth and larval stage density over the cross-sectional area of the transect over the time of each tidal phase.

The calculation was performed for each of the four winter flounder larval stages and the total winter flounder larvae concentration at each of the four 6-hour tidal periods that constituted one 24-hour period. The net larval flux over a given 6-hour tidal period was determined by multiplying the concentration of larvae (larvae/m^3) times the flowrate of water (m^3/s) to yield larvae/second over the 6-hour period. For each study day, the net larval flux was determined by taking the sum of the net larval flux over all the 6-hour tidal periods.

4.2.2 Larval Entrainment Analysis

The number of winter flounder larvae entrained by PNPS during each of the four sampling events was determined from the station flow rate and the eight larval entrainment samples collected during the day specifically for this study. The calculation was performed for each of the four winter flounder larval stages, by multiplying the number of larvae for each stage entrained by the station by the station flow rate for the 6-hour tidal cycle over which the ambient flounder samples were collected. The sum of each of the 6-hour periods became the total entrainment per day.

The percentage of each larval stage entrained was determined by dividing the number of larvae entrained during the day by the number of larvae carried past the station in the net longshore current (and then multiplying by 100 to obtain a percentage). The larval entrainment results are presented in Table 4-2. These calculations were performed for each of the three transects performed in the study area (A-E, C-F, and A-F).

In general, the results in Table 4-2 indicate that PNPS entrains a very small percentage of the winter flounder larvae in the coastal flow of Cape Cod Bay. The percent entrained during Survey 1 is high relative to subsequent Surveys due to the low net volumetric flow of water observed for that time period (Table 4-1). These results are similar to those of the larvae transport study performed in 2000 (ENSR and MRI, 2000).

Table 4-2 Larval Flux and Entrainment Results Transect A–E

		Survey 1	Survey 2	Survey 3	Survey 4
Stage 1	PNPS Larvae/day	4.59E+04	1.24E+04	0	0
	Bay Larvae/day	3.51E+07	2.22E+07	6.87E+06	4.34E+06
	% Entrained	0.13	0.06	0	0
Stage 2	PNPS Larvae/day	1.68E+05	1.81E+05	5.58E+03	1.27E+03
	Bay Larvae/day	4.75E+07	5.85E+07	2.85E+07	4.37E+07
	% Entrained	0.35	0.31	0.02	0.003
Stage 3	PNPS Larvae/day	7.92E+05	8.27E+05	1.22E+05	1.06E+05
	Bay Larvae/day	3.02E+06	2.81E+07	7.60E+07	1.26E+08
	% Entrained	26.22	2.94	0.16	0.08
Stage 4	PNPS Larvae/day	1.85E+04	7.67E+04	3.36E+03	5.67E+03
	Bay Larvae/day	0	0	6.49E+05	1.41E+05
	% Entrained	NA*	NA*	0.52	4.03
Total	PNPS Larvae/day	1.02E+06	1.04E+06	1.25E+05	1.18E+05
	Bay Larvae/day	7.96E+07	1.09E+08	1.12E+08	1.76E+08
	% Entrained	**1.28**	**0.95**	**0.11**	**0.07**

* Stage 4 observed in PNPS discharge, but not in water column

Based on this analysis, it is concluded that the percentage of winter flounder larvae transported in coastal Cape Cod Bay waters that is entrained by PNPS may be conservatively estimated at less than 1.3%. Though the results in Table 4-2 indicate higher entrainment percentages for Stages 3 and 4 larvae, it is likely that the actual entrainment rate for these larval Stages is similar to the total larvae entrainment rate of 1.3% or less. This is because of the skewed results caused by the net sampling method in the bay, as discussed in Sections 3.1.3 and 4.2.3.

The transport of larvae across transects A–F and C–F were compared to determine the relative effects of East-West and North-South flow near PNPS. These results, contained on Table 4-3, were calculated in the same manner as those for Transect A–E. These results confirm those of Transect A–E. For both of the supplemental Transects, the percent of larvae entrained is less than one percent. It is important to note that the supplemental Transects have much less cross-sectional area, and therefore, less volumetric flow of water and subsequent larval transport.

Table 4-3 Larval Entrainment for Transects A–F and C–F for Survey 1

		A–F	C–F
Stage 1	PNPS Larvae/day	4.59E+04	
	Bay Larvae/day	2.70E+07	3.55E+07
	% Entrained	0.17	0.13
Stage 2	PNPS Larvae/day	1.68E+05	
	Bay Larvae/day	7.62E+07	5.41E+07
	% Entrained	0.22	0.31
Stage 3	PNPS Larvae/day	7.92E+05	
	Bay Larvae/day	3.91E+07	4.22E+07
	% Entrained	2.03	1.88
Stage 4	PNPS Larvae/day	1.85E+04	
	Bay Larvae/day	0	0
	% Entrained	NA*	NA*
Total	PNPS Larvae/day	1.02E+06	
	Bay Larvae/day	1.42E+08	1.32E+08
	% Entrained	0.71	0.77

* Stage 4 observed in PNPS discharge, but not in water column

4.2.3 Larvae Sampling Method Study

The results of the bottom sled larvae sampling study (Table 3-3) show that Stage 3 larvae were sampled in much greater numbers using the bottom sled than the bongo net indicating that these older larvae were abundant near the bottom. The dramatically high number of stage 3 individuals very near bottom was unexpected since these larvae had not yet visibly begun to metamorphose. Results suggest that these larvae begin to move toward the bottom before the left eye begins to migrate. No Stage 4 larvae were collected in the bongo net; one each was collected in the sled and at PNPS, an insufficient number to provide conclusions on these fish.

These results indicate that use of the standard bongo net towed obliquely through the water column provides stage 3 larval density values that are much lower than actual larval densities near bottom. In addition, though no Stage 4 larvae were sampled in the Bay during Rounds 1 and 2, the bottom sled study results indicate that Stage 4 larvae were likely present during these sampling rounds. This is consistent with the fact that the bongo net can only be towed to within a meter or so of the bottom to avoid hitting rocks and other bottom contours. As a result, the Stages 3 and 4 larvae transport values in the bay reported in Table 4-2 and Table 4-3 are skewed low, likely by an order of magnitude for the bottom layer.

Therefore, the percentages of Stage 3 larvae entrained, as shown in Tables 4-2 and 4-3, are overestimated. Because of the difficulty in collecting representative Stage 4 samples in the Bay, it is difficult to quantitatively estimate the percentage of Stage 4 larvae entrained during the study. However, because Stage 4 larvae tend to stay near the bottom. it is unlikely that PNPS entrains a higher percentage of Stage 4 larvae than other larval stages. This indicates that the Stage 4 entrainment rate should be less than the average larval entrainment rate, *i.e.* less than 1.3%.

4.3 Analysis of Wind Effect on Larval Variability

An analysis of winter flounder larvae variability was performed to evaluate the effect of wind speed and direction on the distribution of larval densities as discussed below.

There is a potential that localized winds may control the larval density distribution by transporting water to or from shore depending on whether the wind is onshore or offshore. In order to evaluate the relationship between wind speed and direction and larval density distribution, a correlation analysis was performed by plotting winter flounder larval densities for the each of the larvae sampling stations versus wind speed as recorded at PNPS (with offshore winds specified as positive and onshore winds as negative). If a correlation between winds and larvae distribution existed, it would be expected that nearshore densities would decrease for an offshore wind and increase for an onshore wind, with the opposite effect for the furthest offshore station. The results of the analysis (shown on Figure 4-8) indicate that there is essentially no correlation between winds and the larval density distribution. It should be noted that the winds during the sampling events were predominantly offshore.

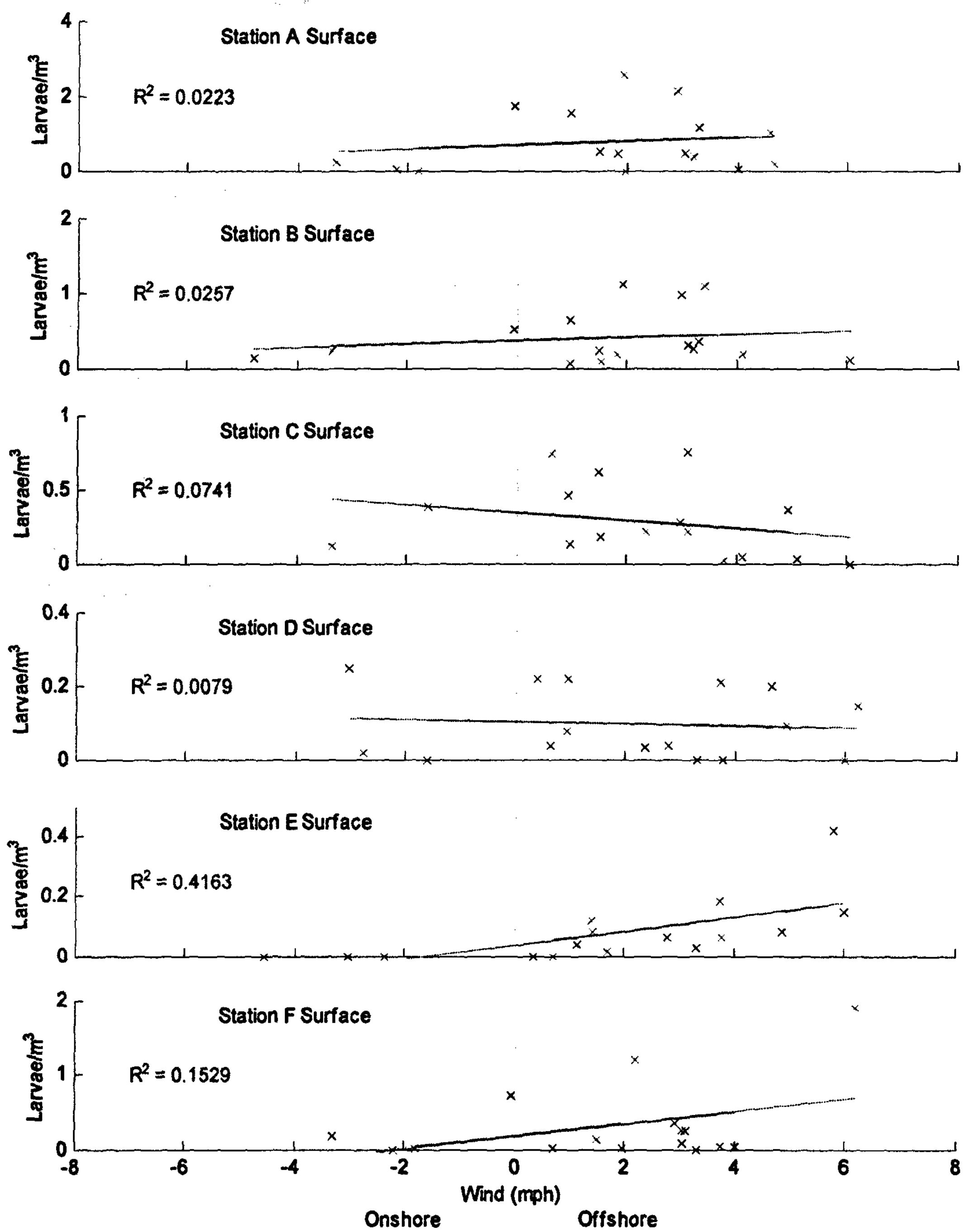


Figure 4-8 Correlation of Wind and Larvae Observations

5.0 CONCLUSIONS

The study results show that:

- PNPS withdraws a relatively small percentage of the available net volumetric flow of water—generally less than 0.1%.
- The amount winter flounder larvae entrained by PNPS is a relatively small percentage of the net larval transport—conservatively estimated at less than 1.3%.
- Winds do not appear to have a significant influence on the density distribution of winter flounder larvae.

These results are similar to those of the larvae transport study performed in 2000 (ENSR and MRI, 2000). The results also confirm the conclusion in the March 2000 316 Demonstration Report that entrainment at PNPS has not had any adverse impacts on the integrity of the winter flounder population. In fact, based on these results, the potential impact to the winter flounder population (less than 1.3%) is less than that stated in the 316 Demonstration (less than 5%).

6.0 REFERENCES

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