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ABSTRACT

Estuaries are among the most productive aquatic systems. Although human civilizations have historically depended on and benefited from estuarine resources, impacts from anthropogenic disturbances on estuarine habitats have only been recently recognized. Increased awareness of the ramifications of these disturbances led to creation of the Coastal Zone Management Act (CZMA) of 1972, which resulted in establishment of the National Estuarine Research Reserve (NERR) program. The NERR system provided an ideal network for the establishment of a national water quality monitoring program; thus, the System-wide Monitoring Program (SWMP) was initiated in 1995. The System-wide Monitoring Program of the NERR program tracks short-term variability and long-term changes in water quality variables estuarine Reserve sites nationwide. Unlike most of the existing national/regional water quality monitoring programs that collect short-term or periodic data (days to weeks), the SWMP collects long-term water quality and ecological data. Water quality variables (depth, temperature, salinity, dissolved oxygen (mg/L and % saturation), pH, and turbidity) are recorded nearly semi-continuously (every 30 minutes) throughout the entire year via unattended, automated data sondes (YSI 6000® or YSI 6600®). The long-term nature of the SWMP data set makes it possible to examine both intra-annual (seasonal) and inter-annual patterns in estuarine systems, as well as on the effects of large scale (e.g., El Niño and La Niña climatic conditions, hurricanes, Nor'easters) and localized (i.e., floods, drought) episodic events.

Proposed in 1993 and initiated in 1995, the SWMP is currently in operation at 22 Reserves in the NERR system. The Reserves represent nearly 440,000 acres of protected estuarine waters, wetlands, and uplands from the five major coastal/estuarine regions in the United States (West Coast, Northeast and Great Lakes, Mid-Atlantic Coast, Southeast Coast, and the Gulf of Mexico and Caribbean Sea). Furthermore, the NERR SWMP represents almost every recognized climatic zone (Savannah, Steppe, Mediterranean, Humid sub-tropical, Cold temperate and Polar) as well as more than 15 biogeographic zones within these major climatic zones. Within the contiguous United States, the SWMP is represented by almost every degree of geographic latitude between 26°N and 43°N, approximately 1,000 miles north to south.

Substantial efforts were made to collect, quality assure, and archive the data collected by the SWMP; however, until recently, relatively little effort had been made to analyze these data. Water quality data for 44 sites from the SWMP between 1996 and 1998 are analyzed in this report. Several important findings from this study are listed below.

- Generally, depth, salinity, and dissolved oxygen (mg/L or percent saturation) were dominated by 12.42 hour cycles at sites that experienced moderate daily tidal amplitudes (2-4 m). Twenty-four hour cycles (i.e., day-night cycle, wind, man-made perturbations) dominated sites where salinity was characterized as very low (tidal freshwater environment) or very high (marine environment), and where tidal effects were minimal.

- Twenty-four hour cycles accounted for 30-50% of water temperature variance sites at most sites and 12.42 hour cycles accounted for <20% of water temperature variance at most sites. In the summer, water temperature fluctuated by as much as 10°C over 24 hours at some sites.

- Hypoxia (DO < 28% saturation) was strongly influenced by latitude and climate. Half of the sites where hypoxia was observed (on average) for more than 20% of the first 48 hours post-deployment were located in the Gulf of Mexico and Caribbean; however, 92% of hypoxia events persisted less than 8 hours. Hypoxia was most frequently observed during summer.

- Temporal and spatial distribution of supersaturation (DO > 120% saturation) events was not as clear as the temporal and spatial distribution of hypoxic events. Supersaturation events primarily occurred in cooler months, particularly winter; however supersaturation events were observed in all seasons. Although supersaturation events sometimes co-occurred with hypoxic events during the same day, supersaturation was negatively correlated with hypoxia.

- At 92% of the sampling sites evaluated (25 of 27), aquatic respiration exceeded aquatic production. Water temperature was significantly correlated with aquatic metabolic rates at most sites; however, salinity was only significantly correlated with aquatic metabolic rates at half of the sites evaluated. Metabolic rates were not noticeably different among geographic regions; however, metabolic rates were strongly influenced by habitat type.

The synthesis results provide valuable information about how estuaries function. In addition, the findings of this synthesis revealed the short-term dynamic properties of water quality variables in shallow estuarine systems on a daily basis. Tidal cycles at most of the sites evaluated ranged from 2-4 m, resulting in nearly dry water bodies at low tide and submerged shorelines at high tide. Subsequently, daily fluctuations in temperature, salinity, and dissolved oxygen varied by as much as 10°C, 15 ppt, and > 100% saturation, respectively. The similarity in magnitude of fluctuations in water quality variables among different sites suggested that the sites in the NERR SWMP were representative of shallow water environments, but might not be representative of all water bodies within each Reserve. This synthesis also provided insight into the immediate impact on water quality and duration of the recovery period to return to pre-storm conditions in the wake of Hurricanes Bertha and Fran, two major hurricanes that catastrophically affected the mid-Atlantic coast in 1996. Had data sondes not been deployed before, during, and after these storms, this information would not have been available.

The NERR SWMP represents tremendous progress towards developing a water quality-monitoring program to monitor the health and functionality of this Nation's estuaries. Establishment of estuarine reserves and the NERR SWMP present opportunities to educate the public about water quality issues, with specific emphasis on the causes and consequences of degraded water quality. Water quality data from the NERR SWMP also provide necessary background data from which specific, experimental hypotheses can be formulated to systematically evaluate the effects of anthropogenic influences on estuarine ecosystems and the requirements to restore the functionality of these estuaries to their undisturbed conditions. Only with exhaustive, objective research can the ramifications of disturbances to natural processes occurring within estuaries be fully understood.

During the course of preparing this Synthesis Report, a list of recommendations was developed for both Reserves and future synthesis efforts. These recommendations are discussed in greater detail in the Discussion section (pp. 262-270), but are briefly presented here.

- Reserve staff should consult with physical oceanographers familiar with sampling sites to document and understand circulation patterns at the SWMP sites, as this information may directly determine how and why sampling sites are selected.

- Reserves should submit a justification of how and why sampling sites were selected and what habitat each sampling site represents.

- Reserves should compile appropriate ancillary data about sampling sites that are needed to interpret water quality data. Examples of such ancillary data include actual precipitation and flow rate data (rather than annual estimates or averages), nutrient data, and calculation of waterbody area and drainage basin area where data sondes are located.

- Reserves should agree upon and standardize data sonde deployment practices and provide the necessary training to implement these standardized practices.

- Reserves should carefully examine dissolved oxygen data for “instrument drift” to determine which records should be retained and which records should be eliminated.

- Reserves should manage their data using a readily available relational database (i.e., MS Access) and provide regular summaries of data similar to those presented in this report.

- Future analytical efforts should include an expert panel during all aspects of the project.

- Future analytical efforts should explore use of Principal Component Analysis using actual measurements for ancillary data, or appropriate multivariate analyses that incorporate both quantitative data and ordinal scale data (i.e., CART).

INTRODUCTION

In 1993, Research Coordinators representing the National Estuarine Research Reserve (NERR) system proposed a System-wide Monitoring Program (SWMP) for the purpose of collecting long-term water quality and ecological data in each Reserve in order to define baseline conditions and establish trends for the NERR system. The Research Coordinators hypothesized that the SWMP would demonstrate that the reserves represented estuarine systems with a high degree of environmental quality and, as a group, the NERRs may represent a reference condition for the Nation's estuaries. The SWMP would provide important information for defining linkages between the environmental quality of estuarine environments and adjacent human activities. This information represented a more meaningful ecological unit of measure (relatively small watersheds) across a broader spatial scale (i.e., regional and national) than was possible using data collected by ongoing regional and national monitoring programs. Although most of these existing programs focused on short-term measurements (days to weeks) collected annually or biannually for only a subset of the Nations coast, the estuaries in the NERR system represented all U.S. coastlines. In addition, the long-term nature of the SWMP data set made it possible to assess intra- and inter-annual patterns in estuarine systems.

Initiated in 1995, the NERR SWMP identifies and tracks short-term variability and long-term changes in representative estuarine ecosystems and coastal watersheds. The first phase of the program involved monitoring a suite of water quality variables or measures that reflected the condition of estuaries. Because it was not possible to measure all environmental variables known to be important in estuaries, a few basic water quality variables (i.e., pH, salinity, temperature, dissolved oxygen, turbidity and water level) that could be measured cost-effectively in a nearly continuous manner over long time periods were chosen for study.

While these variables may or may not directly address the ecological resources at risk, they are proven indicators of environmental stress and habitat quality and are linked to a broad range of anthropogenic stresses. For example, dissolved oxygen (DO) levels are strongly influenced by point and non-point source discharges, and for that reason, the EPA has used DO as a basic measure of water quality for several decades. Increasing DO above 120% saturation and decreasing DO below 28% saturation can indicate declining water quality. The trend of DO values between hypoxia and supersaturation can be a measure of system health. Temperature controls the rate at which living resources use oxygen, and salinity is the main factor controlling the distribution, abundance and composition of biological resources in estuaries. Changes in the salinity range have been reported to be a sensitive measure of the degree to which watershed development has altered hydrographic conditions. A common perception of coastal zone environmental managers is that much is known about the salinity structure of the nation's estuaries. Reliable data on salinity distributions exist, however, for only a few of the most studied estuaries. Turbidity, a major factor controlling primary productivity in estuaries, varies greatly over short time periods and is linked to both seasonal changes in biological processes and the amount of suspended sediments in freshwater inflows. The pH of the water is an important factor controlling the availability of contaminants and nutrients to living resources. While pH varies with DO levels and salinity, influence of tidal cycles and diel cycles on pH are poorly understood and have been measured in relatively few estuarine systems.

The system-wide water quality monitoring database collected by the NERR program is one of the most intensive and extensive ever collected for estuaries. The database includes two sites in each of 22 Reserves collected over several years at half-hour intervals. The 22 Reserves represent all geographical regions of the country and a broad range of estuarine habitats and types. Considerable effort and expense were required to collect, quality assure, and archive these data. These data represent valuable scientific information for advancing the understanding of how estuaries function and change and may enable scientists to eventually predict how estuarine systems will respond to changes in climate and human-induced perturbations.

Synthesis Goals

The goals of this project were to conduct a detailed analysis of the NERR water quality monitoring data collected between 1996-1998 in order to:

- Provide a characterization of the water quality for each NERR site (i.e., extent and severity of naturally occurring hypoxia, temperature, and salinity range)
- Determine the degree to which the SWMP is producing important scientific information about the water quality of the Nation's estuaries.
- Determine if the program could be modified to be more effective or efficient or to obtain more ecologically relevant water quality information.

Results obtained during this project provided information for characterizing water quality at each of the NERR sites and for making national comparisons. Additional benefits of this project included assessment of the value of the SWMP water quality monitoring element, modification of the existing sampling design to make it more efficient and effective and plans for the next phases of the SWMP monitoring effort. The specific objectives of the project were to:

- Determine the frequency, duration, and periodicity in hypoxia and other key water quality indicators at each site and among sites within each NERR.
- Compare key indicators of water quality stress, with an emphasis on hypoxia, among NERR systems and regions.
- Classify sample sites and reserves into groups based on their similarity/ dissimilarity in key water quality indicators and site characteristics.
- Characterize water quality conditions at sites individually, regionally, and nationally.
- Prepare a synthesis for broad distribution that evaluates the status of hypoxia in the NERR SWMP.

- Develop a Technical Report for distribution to the Reserve staff and other research scientists that presents the results of statistical analyses and includes recommendations for improving the efficiency or effectiveness of the sampling design.

- Conduct a workshop for NERR researchers that presents and discusses major findings in the Technical Report, reviews recommendations, and trains them to apply the analytical protocols developed for evaluating water quality data.

Findings of the Expert Panel

A workshop was convened in November 1999 in Charleston, SC, to develop a detailed analytical plan for the synthesis of the NERR monitoring data. An expert panel of scientists, experienced in the collection, analysis, and interpretation of water quality data, was assembled at the workshop. Members of the Expert Panel included Dennis Allen (University of South Carolina/ North Inlet-Winyah Bay NERR), Walter Boynton (University of Maryland Chesapeake Biological Laboratory, Chesapeake Bay Laboratory), Loren Coen (South Carolina Marine Resources Research Institute), Don Edwards (University of South Carolina), Holmes Finch (University of South Carolina), John Grego (University of South Carolina), Fred Holland (South Carolina Marine Resources Research Institute), Todd Hopkins (Florida Department of Environmental Protection/ Rookery Bay NERR), Richard Langan (University of New Hampshire/ Great Bay NERR), Chris Nietch (University of South Carolina), George Riekerk (South Carolina Marine Resources Research Institute), Steve Ross (North Carolina NERR), Denise Sanger (South Carolina Marine Resources Research Institute), Tammy Smalls (Centralized Data Management Office), Kevin Summers (United States Environmental Protection Agency), and Elizabeth Wenner (South Carolina Marine Resources Research Institute/ ACE Basin NERR).

Identification of Key Variables

The panel concluded that five variables were critical for inclusion in the statistical analyses to be conducted for this project: (1) DO (% sat), (2) DO (mg/l), (3) salinity, (4) temperature, and (5) depth. They suggested that turbidity and pH were also potentially important variables that may be used in future analyses following protocols developed by this project. Because of quality assurance concerns about the reliability of the turbidity and pH data, and the recent implementation of turbidity data collection, these two variables were recommended for exclusion from this project at this time.

In addition to prioritizing the water quality variables, the panel discussed other metrics that could be calculated using the existing data. Three calculated metrics that were determined to be particularly important and recommended for inclusion in the analysis were: (1) The percent of time DO values were less than 28% saturation; (2) The percent of time DO values were greater than 120% saturation; and (3) The duration of hypoxic events. The first metric defines the total amount of time each site experienced hypoxia, and the second metric defines the total amount of time each site experienced supersaturation. There has generally been little documentation of extent and severity of supersaturation events in estuarine water or an assessment of the value of this information for the identification of algal blooms or other environmental problems. Supersaturation, however, frequently occurs at NERR sites and is potentially as stressful to biota as low DO levels. Therefore, the panel felt it was important to evaluate occurrence of supersaturation events. The third metric defines the amount of time that each hypoxic event persisted at each site.

Potential Stratification Changes

Stratification of the NERR sites for summarization of the data was discussed. Potential *a priori* stratification schemes identified included classification by geographic region, salinity regime, tidal regime, and amount of development (i.e., reference vs. impacted). The panel decided that *a priori* stratification for summarization and analysis of the data was unnecessary. They recommended allowing the analytical results to define any strata that occurred, including conducting specific analyses to classify sites using multivariate methods. The critical step for conducting classification analyses was development of a data matrix (ecological attributes by site) that would provide the input data for these analyses.

Completeness and Quality of the Data

The completeness of the existing water quality data for the 22 NERRs is variable among years and sites. In general, most sites have relatively continuous data for some years and large data gaps for other years. The data gaps are due to equipment failure, staffing problems, or weather (i.e., meters are not deployed at some sites in winter due to ice formation). A major topic of discussion at the workshop was whether data gaps should be corrected by estimating the values for missing data or whether analyses should only focus on available data. The panel recommended that data gaps did not need to be filled to address the goals of the project and that only the data that were collected should be included in statistical analyses.

Another important data quality issue discussed was the apparent systematic downward “drift” in the DO values at many sites 3-5 days after deployment of the meters. The cause of DO “drift” was thought to be fouling by living organisms of the membrane covering the oxygen probe. The DO “drift” biases estimates of central tendency (e.g., mean, median), variance, and the percent of time DO was below 28% saturation. The panel recommended pre- and post-calibration values be obtained and used to correct for DO drift using standard methods and criteria. The panel further recommended that the unreliable DO data resulting from “drift” (i.e., the records most affected by “drift”) should be excluded from analyses. In addition, the extent of drift for each reserve should be determined and evaluated if time allowed.

Summarization/Evaluation of the Existing Data

The panel recommended that the general summarization of data should include scatter plots and frequency distributions of raw data and the percent of time below or above critical levels. In addition, the dynamics of the data should be analyzed using harmonic regression analysis. Fourier analyses were not recommended because of the large data gaps. Harmonic regressions, ANCOVA using trigonometric functions to adjust for known periodicity in the data (12.42 and 24 hour cycles), partition the variance within each data set into known cycles. This procedure allows the relative importance of various sources of periodicity, as well as interactions among sources, to be evaluated and compared for parameters (e.g., DO mg/L) after adjusting for known periodicity among reserves and sites (treatments). Harmonic regressions include an evaluation of interactions among treatments and co-variates as well as a determination of the magnitude of random error in the signal. The net result of harmonic analysis would be to identify systems that tended to be physically dominated by 12.42-hour cycles, 24-hour cycles, or interaction between these two cycles.

The panel recommended that analyses (harmonic and other) should first summarize and compare data by season and month within a reserve. Comparisons between reserves would depend on the quantity (completeness) and quality of the data available and would occur after conditions within each reserve had been defined. The main questions to be addressed included: (1) What are the basic water quality characteristics for each site; (2) How "good" were the data for each site (i.e., do they represent conditions that occur at the site); and (3) How do water quality conditions compare among sites? The panel also recommended that a summarization and analysis of water quality data should utilize readily available and user-friendly software such as Microsoft Excel and that a technical training manual be prepared to illustrate data management and graphical methods. Details about harmonic regression analysis and associated statistical programs should be included in the technical report for the project.

Representativeness/Characterization of NERR Sites

The panel concluded that NERR sampling sites are representative of the processes that occur at each site, but not necessarily representative of conditions in a particular reserve or of the NERR system as a whole. The panel recommended comparisons of NERR sites with other programs that collect similar data (i.e., EMAP, National Coastal Monitoring Program, C-GOOS, National Assessment of Eutrophication) to determine if NERR sites could be potential reference areas for other programs.

The panel concluded the NERR water quality data were likely to be important for defining water quality conditions in relatively undisturbed/undeveloped systems. The panel knows of no other multi-regional, multi-year water-quality monitoring program that collects measurements as frequently as the NERR program. Because of these unique attributes, the NERR SWMP may likely provide baseline information that would provide information for defining baseline conditions at sites.

Metabolic Status of NERR Sites

The panel recommended that the status of the NERRs should be addressed using results of the previously discussed analyses, particularly the harmonic analysis and metrics using percent of time. In addition, determination of the metabolic properties of each site was suggested as a means of providing information for a status assessment of NERR sites. Production/respiration (P/R) analyses determine if a system is autotrophic or heterotrophic by computing net production and nighttime respiration from semi-continuous DO measurements. P/R analyses would be done at a few of the reserve sites having nutrient data that would facilitate the interpretation of results.

Alternative Sampling Approaches

The panel agreed that it was too early in the project to discuss alternative sampling approaches; however, the following topics were recommended for examination after the existing data had been thoroughly analyzed. First, should duration of deployment vary among geographical location and/or among sites within reserves? Second, are there critical time periods when data must be collected which may vary among geographical locations and sites within reserves? Third, what changes to the sampling design would make the SWMP more efficient or effective? Many panel members were of the opinion that if the goal of the SWMP is to understand the long-term dynamics of water quality variables within reserves, then it might be useful to keep sampling methods and the sampling design relatively similar to the approach currently being used.

Trends Assessment
The panel concluded that the amount of data available (i.e., 3 years) was not sufficient to determine trends in water quality for sites. This project may be able to provide recommendations for trend analysis activities in the future, based on the results of the analyses that will be conducted. The panel recommended that the following topics be examined once the 1996-1998 SWMP data have been synthesized: (1) Determine what trends are likely to be important; (2) Consider the use of average values in trend assessment; and (3) Assess the importance of amplitude changes over short time periods when defining trends.

METHODS

Data Collection and Management

Collecting long-term trend data that captures natural variability requires adequate temporal and spatial coverage. To address the temporal coverage, the National Estuarine Research Reserve System-Wide Monitoring Project employs Yellow Springs Instrument Co. (YSI^{TM}) model 6000 or 6600 UPG data sondes to collect water quality data. These data loggers record at 30-minute intervals, relay measurements to internal memory, can run unattended for weeks at a time, and operate in depths from a few cm to greater than 150 m. The attached dissolved oxygen, conductivity, turbidity, temperature and pH sensors can be quickly replaced in the field, if necessary. The dissolved oxygen sensor provides accurate readings without the use of an auxiliary stirrer and with little drift for extended periods, although deployment duration may differ among sites based on differences in fouling and water flow. The turbidity probe features a mechanical cleaner for the optical face, thereby preventing fouling in long-term deployments. The data logger interfaces with a PC or laptop, as well as to real-time data collection platforms using telemetry systems. Built-in software exports data to spreadsheet programs and generates basic statistics and plots.

For spatial coverage, each Reserve deploys a minimum of two data loggers. At half of the Reserves, one data sonde is deployed at a reference location and serves as a long-term control and additional loggers are deployed at other locations to monitor conditions related to specific non-point source concerns (Table 1) within the Reserve (Trueblood et al. 1996). With the exception of two Reserves (North Carolina and Waquoit Bay) where the data sondes are deployed at sites with minor anthropogenic disturbances, data sondes at the remaining Reserves are deployed at impacted sites only. In addition to the data sondes, many NERR sites deploy additional water sampling instruments and measure other water quality variables, such as nutrients. Standardized protocols developed by the Reserves assure that sampling, processing and data management techniques are comparable among sites. A Centralized Data Management Office (CDMO) at the Belle W. Baruch Institute for Marine Biology and Coastal Research of the University of South Carolina provides additional quality control for data and metadata.

Table 1. Types of non-point source pollution categories addressed at different National Estuarine Research Reserves (NERR). Blank spaces indicate non-issues for the respective Reserve.

NERR	**Urban**	**Agricultural**	**Boating**	**Wetland Restoration**
ACE Basin	X			
Apalachicola				X
Chesapeake Bay MD	X			
Chesapeake Bay VA	X			
Delaware Bay	X	X		
Elkhorn Slough		X		
Great Bay	X	X		
Hudson Bay	X			
Jacques Cousteau				
Jobos Bay		X		
Narragansett Bay			X	
North Inlet				
North Carolina				
Old Woman Creek		X		
Padilla Bay		X		
Rookery Bay		X		
Sapelo Island	X	X		
South Slough				X
Tijuana River	X			
Waquoit Bay	X			
Weeks Bay	X			
Wells	X			

Site Summaries and ancillary data

In an effort to characterize sites at each Reserve where water quality data were collected, a standardized form requesting information on sites was sent to each Research Coordinator. To supplement written descriptions of each site, maps showing location of water quality sampling sites were obtained from the NOAA Estuarine Reserves Division. Information requested included:

- Latitude and longitude
- Salinity range and mean for site
- Tidal frequency, range and mean for site area
- Creek or water body dimensions (length, mean depth, mean width)
- Distance meter is above the bottom
- Creek bottom habitat at site
- Dominant marsh plants and submerged aquatic vegetation near site
- Dominant upland vegetation
- Upland land use
- Activities potentially impacting the site

Data Review and Protocols for Deletion

Data from each of the 22 NERR sites were downloaded from the CDMO FTP site. Data were then imported into MS Access to obtain a continuous time series for all three years. Queries were run to detect duplicate data and verify the number of records for each day. There were 52,608 possible records for each site within a reserve. As data were reviewed, it became evident that a complete QA/QC would be necessary on all data received. Scatter plots of yearly data were graphed for each of the five key variables at each site. If graphs indicated that data were suspect or unusual from the graphs, then the Anomalous Data section of the metadata was consulted to determine if the Reserve also felt the data were suspect. If the Reserve considered the data suspect, then those data were deleted. If data were suspect or atypical and the Reserve did not make note of suspect data in the Anomalous Data section of the metadata, a second opinion was sought to determine if the data were unusual enough to delete. In both instances, the whole deployment was deleted unless an event occurred that subsequently altered records after the event, in which case data were deleted from the onset of this event until the end of the deployment.

Graphs were particularly useful for detecting erroneous transposing of data. Erroneous transposition was obvious when data were lower or higher than what is usually found at that site. By adding deployment and retrieval times to the data and plots, we were able to detect data that were not removed at the beginning and end of a deployment, even when the meter was not in the water. Several criteria were used in review of the data. If data for at least two variables (usually salinity and depth) indicated the probes were exposed or partially exposed due to a meter change or low tide, then all data were deleted for that time period. If the temperature data were determined to be suspect and were deleted, then corresponding records of specific conductivity, salinity, and DO (mg/l) were also deleted (McDonald 1996). Similarly, if data for specific conductivity and salinity were determined to be suspect and were deleted, then records for DO (mg/l) were also deleted.

The data were also reviewed for occurrence of negative numbers. If depth and temperature data were negative, they were retained. Because salinity and DO data cannot be negative, those records were changed to zero. In some cases, the DO data were negative for long periods of time, suggesting that the meter was not functioning properly. Those data were evaluated to determine if deletion was appropriate. Notation was made in the Access database for all cases in which data were deleted. All deletions were annotated and compiled in electronic files and sent to the Reserves and the CDMO.

Data Analysis and Synthesis

Sampling interval

A two-sample t-test was used to compare daily mean, minimum and maximum DO (% saturation) at 30-min and 4-h sub-sampled intervals during deployments in July-August 1997 and 1998 at Big Bay Creek and St. Pierre Creek in the ACE Basin NERR to determine the effects of sampling interval on accuracy of estimates of mean, minimum, and maximum values.

Effect of deployment period on dissolved oxygen (% saturation)

Potential drift in dissolved oxygen (% sat) due to fouling necessitated determination of whether noticeable differences in hypoxia and supersaturation occurred over an entire deployment. Hypoxia and supersaturation, expressed as percent of time per deployment, were evaluated at 1, 2, 4, 7 and 14-day intervals for July-August 1997 and 1998 data. Line graphs were created in MS Excel to evaluate decay/increase in DO (% saturation) readings with respect to time post-deployment and these relationships were subsequently subjected to regression analysis. One-way Analysis of Variance (ANOVA) was used to test for significant differences in mean hypoxia and mean supersaturation for 1, 2, 4, 7, and 14-day treatment intervals. Linear regression analysis was used to determine whether there was a significant relationship between supersaturation and hypoxia (% of deployment with condition) and deployment duration. Data for analyses were not available for the following sites: Chesapeake Bay MD (Jug Bay-1997; Patuxent River-1997, 1998), Chesapeake Bay VA (Goodwin Island-1997), Jobos Bay (Stations 9 & 10-1997), Narragansett Bay (T-wharf-1998), Rookery Bay (Blackwater River-1997; Upper Henderson-1998), South Slough (both sites/years), Week's Bay (Fish River-1998), and Waquoit Bay (both sites/years).

Descriptive Analyses by Reserve Site

Water depth (m), temperature (°C), salinity (ppt), dissolved oxygen (mg/L and % saturation), and deployment duration for each site at each Reserve were summarized independently using a suite of graphical data analysis techniques, which are summarized in Table 2.

- Scatter plots for depth, temperature, salinity, and DO were created for each year of data at each site for detection of erroneous data and outlying data points.

- Histogram plots for depth, temperature, salinity, and DO were created for each year of data at each site to examine the frequency distribution of data at each site and inter-annual variability.

- Box plots of central tendency (mean, minimum, maximum, 90th percentile, and 10th percentile) were created for depth, temperature, salinity, and DO for each deployment at each site to examine seasonal and inter-annual variability.

- Bar graphs for hypoxia (<28% sat) and supersaturation (>120% sat) events were created for each deployment at each site to examine seasonal and inter-annual variability.

- Bar graphs for deployment duration were created for each site to examine the extent and duration of seasonal monitoring at each NERR site.

Reserve Comparisons

Frequency of hypoxia (<28% saturation) and supersaturation (>120% saturation) events were compared within and among reserves, within and between seasons, and between years. Duration of hypoxia among reserves was also examined. Mean daily salinity and daily salinity range were compared among reserves within and between seasons. SPSS® was used for statistical testing.

- A two-sample t-test was used to determine whether hypoxia, supersaturation, mean daily salinity, and daily salinity range between June 21st and September 21st (1997, 1998) differed among sites within Reserves. If variances were heterogeneous by Levene's test, then a two-sample t-test for unequal variances was used. Incomplete data for Chesapeake Bay MD (Patuxent River), South Slough (both sites), and Waquoit Bay (Metoxit Point) resulted in partial exclusion from analysis.

- A two-way ANOVA was used to compare hypoxia, supersaturation, mean daily salinity, and daily salinity range at Reserve sites between seasons for 1997 and 1998 data. Seasons were defined as winter (Jan-Mar), spring (Apr-Jun), summer (Jul-Sep), and fall (Oct-Dec). If variances were heterogeneous by Levene's test and were not homogeneous following $\log_{10}$ transformation, a two-sample t-test for unequal variances was used to determine whether variables were significantly different between sites. A one-way ANOVA was used to determine if seasonal differences in variables occurred at each site. If variances were heterogeneous for the one-way ANOVA, then a Kruskal-Wallis test was used to test the hypothesis of no seasonal differences. Incomplete supersaturation data resulted in exclusion of the Winchester site (South Slough) and both Chesapeake Bay-MD NERR sites from analyses. Incomplete hypoxia data resulted in exclusion of the following sites from analyses: Jobos Bay (Station 10); Sapelo Island (Marsh Landing); Week's Bay (Fish River); and both sites at the Chesapeake Bay-MD, Great Bay, Waquoit Bay, and Jacques Cousteau-Mullica River NERRs.

- Pearson's correlation analysis was used to determine if hypoxia and supersaturation events in July-August 1997 were correlated with hypoxia and supersaturation events July-August 1998. Incomplete data for the following sites resulted in exclusion from analysis: Narragansett Bay (T-wharf); Week's Bay (Fish River); Waquoit Bay (Metoxit Point); Chesapeake Bay VA (Goodwin Islands); and both sites from Chesapeake Bay MD, Jobos Bay, Rookery Bay, and South Slough.

- Hypoxic events for each site were sorted into one of six time bins (<4 h, 4-8 h, 8-12 h, 12-16 h, 16-20 h, 20-24 h, and >24 h) to examine the duration of hypoxia at sites in the SWMP. Deployments with missing data were excluded from analysis. Because not all sites collected similar quantities of data during the same time of year, calculations based on the frequency and duration of actual hypoxic events were made to predict annual frequency and duration of hypoxia at sites in order to compare sites using the same scale.

System-wide analysis

Representative values for depth, salinity, temperature, and dissolved oxygen (% saturation) were calculated in order to compare all 44 sites in the NERR system. Mean depth and mean salinity were calculated as the average of monthly mean values between 1996 and 1998 for all months with data. Mean annual frequency of occurrence that sites experienced warm ($\geq 25°C$) and cold ($\leq 10°C$) water temperatures was used to compare water temperature among sites, rather than a single mean value. Similarly, mean occurrence of summer (Jul-Aug 1997 and 1998) hypoxia and supersaturation during the first 48 hours post-deployment was used to compare DO among sites. Hypoxia and supersaturation were correlated (Pearson's R) with each other as well as with water depth, water temperature, salinity, and latitude using SPSS®.

Hierarchical cluster analysis was used to detect groupings in the data based on a survey of 14 site attributes designed to characterize reserve sites with respect to watershed input attributes and water body (where sites were located) filtering capabilities (Appendix A). Additional attributes were included in the data based on analysis of water quality at each of the sites. Squared Euclidean distance was used as the measure for clustering sites based on attributes, while attributes were clustered using Pearson correlation. A resulting dendrogram indicated how the clusters were formed and provided a measure of the linkage distance for clustering.

Table 2. Summary of analytical techniques for characterizing water quality data.

Analysis	Technique	Parameters	Sites
Sampling Interval	t-test	Daily Min, Max, and Mean for DO (% sat)	2
DO vs. Deployment	Line graph	DO Extremes, Deployment Duration	42*
	ANOVA	DO Extremes, Deployment Duration	44
	Regression	DO Extremes, Deployment Duration	44
Descriptive	Scatter	Depth, Temperature, Salinity, DO (both)	44
	Histogram	Depth, Temperature, Salinity, DO (both)	44
	Box plot	Depth, Temperature, Salinity, DO (both)	44
	Bar graph	Hypoxia, Supersaturation	44
	Bar graph	Deployment Duration	40
Reserve comparisons			
(Summer)	t-test	Salinity (range, mean), DO Extremes	44#
(Seasonal)	ANOVA/KW	Salinity (range, mean), DO Extremes	44#
	Bar graph	Salinity (range, mean), DO Extremes	44#
(Inter-annual)	Rank testing	Hypoxia, Supersaturation	44#
	Bar graph	Hypoxia, Supersaturation	44#
(Duration)	Bar graph	Hypoxia	44
	Bar graph	Hypoxia (by region)	44
System Comparisons			
	Bar graph	Depth (mean)	44
	Bar graph	Salinity (mean, min, max)	44
	Bar graph	Temperature Extremes	44
	Scatter	DO Extremes vs. temperature, salinity, depth	44
	Scatter	DO Extremes vs. each other vs. latitude	44
	Correlation	DO Extremes vs. other parameters	44
	Cluster	Attributes survey, all parameters	44

* See text (*Effect of Deployment on Dissolved Oxygen*) for listing of sites with unavailable data.
# See text (*Reserve Comparisons*) for listing of sites partially excluded from analyses.

Periodicity (Harmonic Regression Analysis)

The first challenge of this aspect of the data analysis was to find effective ways to look at the data with fitted models. Because data were collected every half-hour for three years, each of the 220 series (22 reserves, 2 sites each, 5 parameters) could have length on the order of 50,000 observations. Simple time plots of such data sets were too dense to reveal patterns, with the possible exception of annual periodicity. To allow for more effective visual evaluation, two interactive graphical functions (*microscope* and *plot.week*) were written in Splus®.

In *microscope*, the data were initially plotted in their entirety over time. The user may then select a sub-segment of the full data record to plot in greater detail. In *plot.week*, the data for the first week were plotted over time. The user may advance the plot to the next week's data, and so on until the series ends. Both functions can control vertical axes to allow comparability of multiple plots, and both can superimpose fitted curves on the raw data.

Harmonic regression (Bliss 1970) was used to describe the cyclic phenomena in the data and as a basis for comparing aspects of known periodicity between sites and reserves. These are methods of approximating a periodic function of known period p (i.e., 12.42 h) with weighted sums of sine and cosine waves for periods p, p/2, p/3, etc. The fractions p/2, p/3, etc. (and also their sine and cosine terms) are referred to as the harmonics of the principal period (p). The weights are usually determined by multiple regression (ordinary least squares). The technique works surprisingly well if the periodic function of interest is fairly smooth. Effects of multiple principal periods can also be modeled simply by adding terms and harmonics for each principal period.

Initial analyses attempted to model the entire data series with a large single multiple regression model using multiple harmonics of the 12.42 hour (T), 24 hour (D), 29.5 day (L), and 365.24 day (A) periods. These models also allowed for shifts in mean level of the series whenever new meters were deployed, and for deployment-specific trends. These models did not fit entire series well, even with many harmonic terms for each principal period. Simpler models did, however, fit individual deployment series well (typically on the order of 10-25 days in duration, about 500-1500 observations). The fit using similar models suggested that deployment effects on the response variable are much more complicated than simply a shift in mean level with a trend.

Lunar terms (29.5 d and harmonics) effectively accounted for spring-neap cycles, as well as having the useful property of correcting non-stationarity (i.e., breakpoints, trends) in the data; however, lunar terms created a co-linearity problem for very short deployment series. Because short series resulted in unstable coefficients, only deployments > 10 d in length were included in the harmonic regression analyses. In addition, some deployments were excluded from analyses because the data were essentially constant (usually zero) and there was no way to fit any model to a constant series.

A two-tiered approach to the analysis was ultimately selected. In the first tier, each deployment's data were modeled with its own harmonic regression. From each such fit, 35 descriptive measures were computed (Table 3). This resulted, for each variable and site, in a three-year series of approximately biweekly values for the given descriptive (one value for each deployment). After experimenting with different numbers of harmonic terms on a large number of representative series and variables, the following 37-term multiple regression model was settled upon for each of the "first-tier" analyses, approximately 10,000 deployment-level regressions:

- Intercept (1 term)
- Principal terms and three harmonics for 12.42 hour effects (8 terms)
- Principal terms and three harmonics for 24 hour effects (8 terms)
- Principal terms and three harmonics for 29.5 day effects (8 terms)
- Pair-wise cross- products of principal harmonics between T, D, and L terms (12 terms)

The cross-product terms (at least, between T and L terms) were suggested physically because tidal cycle amplitudes varied according to a lunar cycle. Perhaps more significantly, the visual fit of the models was noticeably enhanced, especially at data extremes, by the use of cross-product terms in the regressions. Because the quality of the data was expected to be best early in the deployment, the first complete 12.42 hour cycle and 24 hour cycle were generated and their amplitude (max - min) calculated. Later profiles changed during the deployment due to cross products with the lunar terms.

In the second tier of analysis, these “descriptives” were modeled for annual periodicity and overall averages and compared between sites and reserves via analysis of variance with pre-planned multiple comparisons. If a sufficient number of deployments (≥ 10) for a given site and water quality variable remained after the first stage analysis, these deployments were subsequently examined for annual periodicity in the second stage. A period of 365.24 days (with four harmonics) was used in a second harmonic regression model for each of a subset of 27 deployment descriptive variables, for each water quality variable, at each site (> 5000 regressions, but ≤ 60 observations each). This model was fit using least squares and annual periodicity tested using an F-test for overall model significance. If annual periodicity was detected, fitted values were calculated.

The stage-two harmonic regression fits included the following items for each site, water quality variable, and deployment descriptive variable: (1) p-value for overall annual harmonic fit; (2) estimated amplitude of the annual cycle after gap removal (amplitude = 0 if no annual periodicity present); (3) mean of fitted values after gap removal (ordinary sample mean if no annual periodicity present); (4) standard error of the mean; and (5) the number of deployments analyzed. These summary data were passed to the final stage of analysis, which featured inter-site graphical summaries and multiple comparisons between sites within reserves. Conspicuously absent from these summaries are descriptives based on first-cycle profiles (descriptive variables 27-33, Table 3). Large standard errors accompanied these "first cycle" descriptive means, and it was decided that they were probably not reliable for this reason. Within reserves, sites were compared with pre-planned multiple comparisons with an error rate of 0.05 using the Šidák (1967) method (see Hsu 1996), which gives exact inference in this setting. Reserves were not formally compared, as the large number of tests so performed would render these comparisons uselessly conservative if the overall error rate was controlled.

Table 3. Summary variables computed for deployment-level harmonic regressions.

No.	*Description of Summary Measure*	*Acronym / var. name*
1.	NERR site No.	site
2.	Water Quality Variable No.	qualvar
3.	Root mean square error	rse
4.	Model R^2	R2
5.	Model F statistic	Fstat
6.	Model error df	dfe
7.	Number of observations	nobs
8.	Model intercept	yhatint
9.	Median of raw response variable data	rawmed
10.	Mean of raw response variable data	rawmean
11.	Range of raw response variable data	rawrange
12.	Std. Deviation of raw response variable data	rawstdev
13.	Coded Date/time of first observation of deployment	startdate
14.	Coded Date/time of last obs. of deployment	enddate
15.	Maximum model predicted value	yhatmax
16.	Minimum model predicted value	yhatmin
17.	Mean model predicted value	yhatbar
18.	Median model predicted value	yhatmed
19.	90th percentile of model predicted values	q90yhat
20.	10th percentile of model predicted values	q10yhat
21.	Partial SS for T terms	SST
22.	Partial SS for D terms	SSD
23.	Partial SS for TD crossproduct terms	SSTD
24.	Partial SS for T,D, and crossproduct terms	SSTDI=SST+SSD+SSTD
25.	Partial SS for T and crossproduct terms	SSTI=SST + SSTD
26.	Partial SS for D and crossproduct terms	SSDI=SSD+SSTD
27.	First full 12.42 hour cycle amplitude	tidal.amp
28.	First full 24 hour cycle amplitude	day.amp
29.	First cycle total amplitude from T & D terms	to.amp
30.	Percent of total amplitude from D amplitude	day.pct.amp
31.	Percent of total amplitude from T amplitude	tidal.pct.amp
32.	First cycle time of day for D maximum	dtmax
33.	First cycle time of day for D minimum	dtmin
34.	Percent of SSTDI due to T terms	tidal.pct.var
35.	Percent of SSTDI due to D terms	day.pct.var

Production and Respiration (P/R)

Use of diel oxygen curve data to calculate primary production, respiration and net ecosystem metabolism (NEM) was first proposed in the 1950's (Odum 1956). Since then, these calculations have been applied to a wide variety of aquatic systems, including many estuaries (Odum and Hoskins 1958, Nixon and Oviatt 1972, Kemp and Boynton 1980, Oviatt et al. 1986, D'Avanzo et al. 1996, Swaney et al. 1999). This method underestimates production and respiration for inter-tidal sites because atmospheric oxygen exchanges directly with sediments or macrophyte beds, rather than into the water column, at low tide; however, this method is one of the few ways to determine an integrated measure of metabolic rates for the entire aquatic system. Similarly, metabolic rates in emergent vegetation such as marshes and forests are not captured by this technique. In this study, dissolved oxygen data from the NERR SWMP (January 1996 to December 1998) was used to calculate primary production, respiration, and net ecosystem metabolism. Data from two sites at each of 14 Reserves were analyzed. Sites included in these calculations were those for which data on water volume nutrient and chlorophyll concentrations were available. Sites were selected to represent as many regions and habitats as possible (Table 4).

Oxygen is produced as a product of photosynthesis, which causes oxygen concentrations to generally increase during the day. At night, dissolved oxygen concentration decreases due to respiration. Diffusion of oxygen across the air-water interface also affects the water column oxygen concentrations. Diffusion, or air-sea exchange, was estimated by multiplying the exchange coefficient by the percent saturation (DO_{sat}). We assumed that the exchange coefficient was 0.5 g O_2 m^{-2} hr^{-1} when the oxygen concentration was zero.

$$\text{Air-sea exchange} = \left(1 - \frac{DO_{\text{sat, t2}} + DO_{sat,t1}}{200}\right) * 0.5 * \text{dt} \qquad (1)$$

Estimation of oxygen exchange using this formula is reasonable under most conditions; however, because the rate of diffusion is dependent on wind speed (Copeland and Duffer 1964, Hartman and Hammond 1984, Marino and Howarth 1993), oxygen exchange may be underestimated during periods of high winds and overestimated during calm periods. For each time interval, oxygen flux was calculated as the change in oxygen concentrations (DO) minus air-sea exchange.

$$\text{Oxygen flux} = (DO_{t2} - DO_{t1}) - \text{Air-sea exchange} \qquad (2)$$

Net production was calculated as the sum of oxygen fluxes during daylight hours. Net respiration was calculated as the sum of oxygen fluxes at night. Net production and net respiration were used to calculate gross production and total (day + night) respiration rate. Constant respiration was assumed during the day and night; thus, night respiration divided by total number of night hours represented the hourly respiration rate. Total respiration was calculated as the hourly respiration rate multiplied by 24. Gross production was equal to net production plus daytime respiration and was calculated by adding net production to the hourly respiration multiplied by the number of daylight hours. Net ecosystem metabolism (NEM) was calculated by subtracting total respiration from gross production and was reported in terms of oxygen and carbon units. Oxygen was converted to carbon assuming a photosynthetic quotient of 1.25 and a respiration quotient of 1.0 (Kemp et al. 1997).

A major assumption of the diel oxygen curve method is that water masses passing by the sensor are laterally and vertically homogenous (i.e., they have the same metabolic history). In areas where physical processes such as advection and diffusion mask site-specific biological processes, metabolic rates will likely be underestimated (Kemp and Boynton 1980). Deployments for which gross production estimates were less than zero and/or total respiration estimates were greater than zero failed to meet this assumption and were excluded from calculation of photosynthesis and respiration. To determine how effective the diurnal curve technique was at estimating metabolic rates, the percent of observations meeting the assumptions was determined for each site.

The effect of instrument drift (i.e., due to fouling) on metabolic rates (gross production, total respiration and net metabolism) was determined for each site using a paired t-test comparing the record for the entire deployment to the first 2 days of the deployment. If instrument drift was determined to be significant, then only the first 2 days of deployment were used for the subsequent statistical analyses. Average and standard error of metabolic rate estimates were calculated for each site. Correlation analysis was used to determine relationships between temperature and salinity and metabolic rates for each site. Daily rates of gross production and total respiration were compared using a paired t-test. If production and respiration rates were significantly different from one another, net metabolism was significant. Results are reported as non-significant when $p>0.05$.

Table 4. Summary of dominant habitat near 27 sites used in ecosystem metabolism analysis.

Reserve	Site	Dominant Habitat near site
ACE	Big Bay	Salt marsh
	St Pierre	Salt marsh
Apalachicola	Surface	Estuarine
	Bottom	Estuarine
Chesapeake Bay MD	Jug Bay	Fresh marsh
	Patuxent River Park	Fresh marsh
Chesapeake Bay VA	Goodwin Island	Eelgrass
	Taskinas Creek	Brackish marsh
Elkhorn Slough	Azevedo Pond	Uplands
	South Marsh	Salt marsh
Great Bay	Great Bay Buoy	Estuarine
	Squamscott River	Estuarine
Hudson River	Sawkill	Uplands
	Tivoli South Bay	Fresh marsh
Jobos Bay	Station 9	Mangrove
	Station 10	Mangrove
Narragansett Bay	Potters Cove	Estuarine
	T-wharf	Estuarine
North Inlet-Winyah Bay	Oyster Landing	Salt marsh
	Thousand Acre Creek	Salt marsh
Padilla Bay	Bay View	Eelgrass
	Joe Leary Slough	Upland
Rookery Bay	Upper Henderson	Mangrove
	Blackwater River	Mangrove
Weeks Bay	Fish River	Estuarine
	Weeks Bay	Estuarine
Waquoit Bay	Central Basin	Macroalgae

RESULTS

Sampling Interval

A comparison in daily mean, minimum and maximum DO (% saturation) was made between 30-min and 4-h sub-sampled intervals during deployments in July-August 1997 and 1998 at Big Bay Creek and St. Pierre Creek in the ACE Basin NERR. A two-sample t-test indicated no significant difference in mean DO (% saturation) between 30-min and 4-h sub-samples (Table 5). Minimum DO (% saturation) was significantly greater during 4-h sampling intervals at Big Bay Creek in July-August 1998, while maximum DO (% saturation) was significantly greater during 30-min. sampling intervals at St. Pierre Creek in 1997.

Table 5. Results of t-tests to determine significant differences in mean, minimum and maximum DO (% saturation) between 30 min. and 4 h sampling intervals. Analyses are based on homogeneous variances.

Big Bay Creek	30 min.	4 h	p
1997			
mean	68.86	69.07	0.94
min.	36.81	46.02	0.13
max.	93.76	91.25	0.32
1998			
mean	60.47	61.48	0.78
min.	25.72	36.56	0.03*
max.	80.83	81.45	0.89
St. Pierre Creek	30 min.	4 h	p
1997			
mean	81.52	81.32	0.94
min.	40.15	48.43	0.05
max.	110.04	105.56	0.01*
1998			
mean	85.73	87.38	0.69
min.	53.98	59.17	0.35
max.	104.84	103.6	0.82

* significant at p=0.05

Effect of deployment period on dissolved oxygen (% saturation)

Hypoxia (% of time DO < 28% saturation) and supersaturation (% of time DO > 120% saturation) were compared among 1, 2, 4, 7 and 14-day deployments at each site during July-August 1997 and 1998. Graphical examination of dissolved oxygen over time consistently revealed a marked increase in hypoxia with increasing deployment duration at 11 sites (Chesapeake Bay VA (Taskinas Creek); Narragansett Bay (T-wharf); Old Woman Creek (State Route 2); Tijuana River (Tidal Linkage); Weeks Bay; Waquoit Bay (Central Basin); Hudson River (Tivoli South); North Carolina (Zeke's Island); Jobos Bay (Station 9); and both Sapelo Island sites). This suggested decay in dissolved oxygen readings over time due to instrument drift. Independent data to validate this trend were available for relatively few sites. Therefore, regression analysis was used to determine whether a relationship existed between hypoxia and time intervals post-deployment. Regression analysis indicated a significant quadratic relationship between percent of time that DO < 28% saturation and deployment duration for both years (Figure 1). Analysis of variance indicated a significant difference in average hypoxia among deployment duration intervals at sites measuring dissolved oxygen in summer 1997 (df= 4/170, f=0.946, p=0.008) and 1998 (df= 4/180, f=0.186, p=0.02).

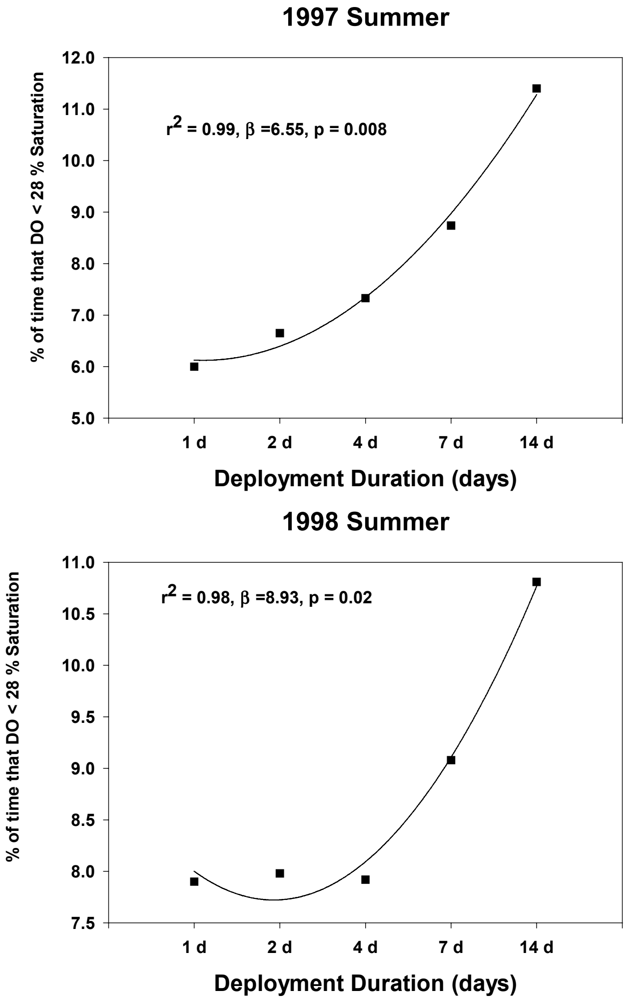


Figure 1. Regression of hypoxia (% of time) versus deployment duration.

When the effect of deployment duration on percent of time that DO was supersaturated (>120% saturation) was examined among reserve sites, most sites showed a decrease in supersaturation over deployment duration in one or both years (1997 and 1998). Sites showing decreases in supersaturation over time included Wells (Inlet site), North Inlet-Winyah Bay (Oyster Landing), Elkhorn Slough (Azevedo Pond), Weeks Bay, Apalachicola (East Bay Bottom), Jobos Bay (Station 9), Tijuana River (Tidal Linkage), ACE Basin (Big Bay Creek), and Sapelo Island (Flume Dock). Sites showing an increase in supersaturation with deployment duration included Narragansett Bay (Potter's Cove), Great Bay, Padilla Bay (Bayview Channel), Delaware Bay (Blackbird Landing), and Hudson River (Tivoli South Bay). Regression analysis indicated a significant relationship between percent of time with supersaturation conditions and deployment duration for both 1997 and 1998 (Figure 2). Analysis of variance indicated no significant difference in mean frequency of supersaturation among deployment periods in July-August 1997 (df = 4/170, f = 0.14, p= 0.967) or 1998 (df= 4/180, f= 0.49, p= 0.737). The examination of percent of time variables in relation to deployment duration at individual sites and in the regression analysis for all sites combined suggests a bias is introduced by instrument drift for percent of time variables. In order to minimize bias due to drift, further analyses using percent of time DO variables included data up to 48 h post-deployment only.

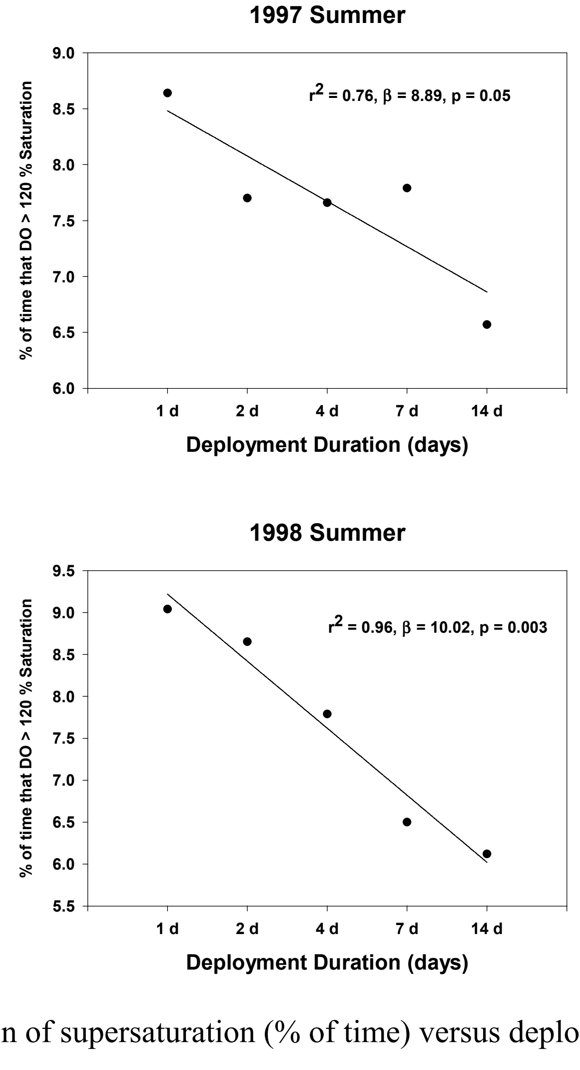


Figure 2. Regression of supersaturation (% of time) versus deployment duration.

Descriptive analyses by reserve site

Water depth (m), water temperature (°C), salinity (ppt), and dissolved oxygen (mg/L and % saturation) data collected between January 1996 and December 1998 were analyzed individually for 44 sites in the National Estuarine Research Reserve's System-Wide Monitoring Program (Figure 3). In the site summaries that follow, the percent of data for each water quality variable included in analyses are stated accordingly. Percentages were calculated as the total number of actual observations relative to the total number of possible observations (48 observations/day x 365(6) days/year = 52,608 observations possible). Reasons for exclusion of data from analyses included deletion of erroneous data and no data collection.

Spatial and temporal data collection was greatest along the Southeast coast, with full coverage from January 1996 to December 1998 at these reserves (Table 6). Along the West Coast, the Mid-Atlantic Coast and the Gulf of Mexico and Caribbean, 75% of sites collected data in all seasons and almost all months examined. The Northeast Coast and Great Lakes reserves typically only collected data between spring and fall; however, some winter data were collected at sites in the Narragansett Bay, RI, and the Wells, ME, reserves.

Descriptive statistics (mean, min, max, and frequency of occurrence) were used to characterize sites with respect to water quality parameters. Minimum and maximum values observed for each parameter at each site between 1996-1998 are summarized in Table 7. Negative water depths were observed in all five geographic regions, while water depths greater than 5 m were only observed in the Northeast. Water temperature ranged from below 0°C (all regions except for the Gulf of Mexico and Caribbean Sea) to 45.9°C (ACE Basin-St. Pierre Creek) in the Southeast. Minimum and maximum salinity varied from 0 to 53.8 ppt and dissolved oxygen varied from 0-35.2 mg/l and 0-489.1 % saturation. Because temperature, salinity, and pressure affect dissolved oxygen (mg/L) concentration, and in order to compare dissolved oxygen between sites and reserves using the same scale, only percent saturation of dissolved oxygen was discussed in the site summaries.

Deployment-level harmonic regression analysis models were fit separately for each of five water quality variables at each of the 44 sites (Table 8). Mean sums of squares for each of the three model components (12.42 hour cycles, 24 hour cycles, and interaction between these cycles) were computed for each water quality variable at each of the 44 sites (Table 9). Percent of variance attributed to each of these three model components for a given water quality variable is presented for each variable in the site summaries; however, because tidal periods may differ among sites, interpretation of the variance attributed to these cycles is best left to personnel at each site.

Respiration, production, and net ecosystem metabolism were computed for 27 sites from all five geographic regions included in this study (Table 10). All but three sites (Great Bay Buoy; Chesapeake Bay VA-Goodwin Island; and Waquoit Bay-Central Basin) were determined to be net heterotrophic; however, sites exhibited considerable seasonal variability with regards to heterotrophic vs. autotrophic condition. Individual metabolism calculations, as well as a graphic showing temporal tendency towards heterotrophic vs. autotrophic conditions, appear with each site summary.

Figure 3. Geographic distribution of National Estuarine Research Reserves participating in water quality monitoring, 1996-1998.

Table 6. Temporal and spatial distribution of water quality sampling effort (months) at NERR sites, 1996-1998.

Site	1996	1997	1998	Total	Seasons
ELKAP	12	12	12	36	wi, sp, su, fa
ELKSM	12	12	12	36	wi, sp, su, fa
PDBBY	12	11	12	35	wi, sp, su, fa
PDBJL	12	12	12	36	wi, sp, su, fa
SOSSE	9	8	2	19	wi, sp, su, fa
SOSWI	8	7	7	22	sp, su, fa
TJROS	12	11	12	35	wi, sp, su, fa
TJRTL	0	8	12	20	wi, sp, su, fa
GRBGB	8	8	8	24	sp, su, fa
GRBSQ	0	5	8	13	sp, su, fa
HUDSK	4	9	9	22	sp, su, fa
HUDTS	9	8	9	26	sp, su, fa
NARPC	12	12	12	36	wi, sp, su, fa
NARTW	4	12	0	16	wi, sp, su, fa
OWCSU	7	7	7	21	sp, su
OWCWM	7	7	7	21	sp, su
WELHT	9	10	9	28	sp, su, fa
WELIN	12	12	12	36	wi, sp, su, fa
WQBCB	3	8	5	16	sp, su, fa
WQBMP	0	0	2	2	fa
CBMJB	6	5	4	15	sp, su
CBMPR	6	5	4	15	sp, su
CBVGI	0	3	12	15	wi, sp, su, fa
CBVTC	12	12	12	36	wi, sp, su, fa
DELBL	11	12	12	35	wi, sp, su, fa
DELSL	11	12	12	35	wi, sp, su, fa
MULB6	5	12	12	29	wi, sp, su, fa
MULBA	3	12	12	27	wi, sp, su, fa
ACEBB	12	12	12	36	wi, sp, su, fa
ACESP	12	12	12	36	wi, sp, su, fa
NIWOL	12	12	12	36	wi, sp, su, fa
NIWTA	12	12	12	36	wi, sp, su, fa
NOCMS	12	12	12	36	wi, sp, su, fa
NOCZI	12	12	12	36	wi, sp, su, fa
SAPFD	12	12	12	36	wi, sp, su, fa
SAPML	12	12	12	36	wi, sp, su, fa
APAEB	12	12	12	36	wi, sp, su, fa
APAES	12	12	12	36	wi, sp, su, fa
JOB09	11	8	7	26	wi, sp, su, fa
JOB10	11	5	6	22	sp, su, fa
RKBBR	0	0	11	11	sp, su, fa
RKBUH	2	12	12	26	wi, sp, su, fa
WKBWB	12	12	12	36	wi, sp, su, fa
WKBFR	12	12	12	36	wi, sp, su, fa

Table 7. Minimum and maximum values for water quality variables, 1996-1998.

Site	Depth	Temperature (°C)	Salinity (ppt)	DO (% sat)	DO (mg/L)
ELKAP	-0.1 / 1.1	-1.3 / 35.6	0.5 / 39.2	0 / 403.6	0 / 25.7
ELKSM	0 / 2.8	5.5 / 24.4	8.3 / 39.2	0 / 234.6	0 / 20.5
PDBBY	-0.1 / 4.3	-1.5 / 23.5	19.2 / 32.2	12.6 / 225.5	1.2 / 19.0
PDBJL	-0.2 / 2.0	-0.6 / 28.2	0 / 28.0	0 / 194.9	0 / 15.2
SOSSE	0 / 2.3	0 / 27.0	0 / 31.3	0 / 230.2	0 / 19.2
SOSWI	0 / 3.3	1.2 / 25.0	0 / 32.8	10.9 / 149.0	0.9 / 13.6
TJROS	0.1 / 2.04	7.5 / 30.3	0.3 / 40.2	0 / 449.6	0 / 32.8
TJRTL	-0.1 / 1.7	7.5 / 32.1	0.4 / 35.2	0.2 / 462.0	0 / 32.0
GRBGB	2.6 / 6.1	2.2 / 25.3	1.3 / 30.9	45.1 / 168.1	3.3 / 14.5
GRBSQ	0.4 / 6.1	0.8 / 27.0	0 / 29.9	45.2 / 147.3	3.5 / 13.4
HUDSK	0.4 / 1.1	0.1 / 24.3	0.1 / 0.2	18.9 / 122.1	1.6 / 16.4
HUDTS	-0.1 / 2.2	0 / 29.8	0 / 0.1	8.3 / 154	0.7 / 17.0
NARPC	0.6 / 4.0	-1.3 / 25.8	13.6 / 32.1	3.6 / 204.4	0.3 / 16.9
NARTW	2.4 / 6.9	0.7 / 23.8	23.7 / 32.1	0.2 / 138.4	0 / 15.3
OWCSU	0.1 / 1.6	4.3 / 29.4	0.1 / 0.3	0.4 / 178.2	0 / 15.8
OWSWM	0 / 1.5	4.1 / 31.7	0.1 / 0.3	0 / 209.6	0 / 18.8
WELHT	-0.1 / 1.6	-0.8 / 26.1	0 / 29.8	20.4 / 201.2	1.7 / 16.1
WELIN	-0.1 / 5.1	-1.8 / 23.1	0.5 / 36	0.4 / 145.3	0 / 15.8
WQBCB	0 / 2.3	0.9 / 27.5	21.8 / 32.6	4.3 / 269.6	0.3 / 19.4
WQBMP	0.8 / 1.7	3 / 10.6	27.4 / 31.1	70.5 / 125.6	6.5 / 12.3
CBMJB	0 / 1.6	4.6 / 36.7	0 / 0.4	0 / 231.4	0 / 18.4
CBMPR	0 / 3.2	7.6 / 30.5	0 / 0.4	0 / 198.2	0 / 15.7
CBVGI	-0.2 / 1.7	2.3 / 31.6	9.9 / 27.5	23.6 / 195.7	2 / 18.2
CBVTC	-0.3 / 2.1	-0.7 / 35.1	0.1 / 20.3	0 / 239.0	0 / 22.1
DELBL	0 / 2.4	-0.3 / 33.3	0 / 7.7	0 / 195.9	0 / 17.9
DELSL	0 / 2.8	-0.5 / 31.4	0.1 / 36.3	0 / 346.9	0 / 32.1
MULB6	0.7 / 4.5	-1.4 / 28.0	13 / 35.4	7.8 / 243	0.6 / 18.7
MULBA	0.5 / 2.7	-0.2 / 30.1	0 / 15.6	4.9 / 240.7	0.4 / 18.7
ACEBB	-0.1 / 2.8	2.6 / 36	4.3 / 41.7	2.8 / 488.7	0.2 / 32.4
ACESP	-0.1 / 3.7	4.3 / 45.9	6.6 / 46	0.4 / 284	0 / 25.8
NIWOL	0 / 2.8	1.6 / 34.9	0.1 / 38.6	0.1 / 489.1	0 / 35.2
NIWTA	0.1 / 2.3	0.4 / 36	0 / 33.4	0 / 390.7	0 / 30.5
NOCMS	0 / 3.5	-0.4 / 34.6	7.8 / 37.2	2.4 / 264.8	0.2 / 21.5
NOCZI	0 / 3.5	-0.3 / 33.1	1.6 / 35.4	4.3 / 232.9	0.3 / 18.2
SAPFD	1.2 / 2.8	6.7 / 32.8	4.3 / 32.2	1.5 / 204.8	0.1 / 14.1
SAPML	1.3 / 2.3	7.3 / 31.7	1.8 / 37.5	3.3 / 179.5	0.2 / 11.6
APAEB	0.8 / 3.5	5.7 / 33.2	0 / 32.2	2 / 185.4	0 / 23.2
APAES	-0.1 / 3.7	2.9 / 33.6	0 / 30.6	0 / 210.6	0 / 16.7
JOB09	-0.2 / 0.9	20.9 / 35.4	22.7 / 53.8	0 / 221.4	0 / 13.1
JOB10	1.2 / 0.3	24.7 / 33.4	16.7 / 42.8	0 / 498.6	0 / 28.0
RKBBR	1.0 / 2.3	15 / 35.4	1.4 / 36	0.3 / 500	0 / 8.7
RKBUH	0.4 / 1.7	13.3 / 34.1	0.2 / 33.6	0 / 285.3	0 / 21.3
WKBFR	1.1 / 3.5	6.2 / 33.7	0 / 17.6	0 / 248.8	0 / 22.1
WKBWB	0 / 1.9	1.6 / 35.4	0 / 22.0	0 / 193.7	0 / 18.4

Table 8. Number of deployments analyzed in first-stage, harmonic regression analysis.

NERR site	*Depth*	*DO (mg/l)*	*DO (% sat)*	*Temp.*	*Salinity*
ELKAP	34	28	29	36	35
ELKSM	36	26	26	36	36
PDBBY	28	22	25	28	24
PDBJL	44	35	35	49	49
SOSSE	13	16	17	26	24
SOSWI	14	9	9	24	22
TJROS	64	50	51	65	64
TJRTL	21	26	26	28	27
GRBGB	25	33	33	34	34
GRBSQ	19	18	18	19	19
HUDSK	31	26	26	30	25
HUDTS	29	25	25	30	25
NARPC	44	31	32	44	43
NARTW	14	13	13	14	14
OWCSU	38	34	33	38	38
OWCWM	30	24	24	30	30
WELHT	25	19	19	23	21
WELIN	34	34	34	34	34
WQBCB	18	17	17	18	18
WQBMP	2	2	2	2	2
CBMJB	11	9	9	12	12
CBMPR	12	6	6	12	12
CBVGI	16	18	18	18	18
CBVTC	38	32	32	41	40
DELBL	65	62	63	64	63
DELSL	60	53	53	60	60
MULB6	32	27	29	31	30
MULBA	41	33	34	40	40
ACEBB	28	24	24	33	33
ACESP	34	22	23	34	29
NIWOL	61	51	55	63	59
NIWTA	64	55	56	64	63
NOCMS	40	33	34	42	41
NOCZI	46	39	38	46	44
SAPFD	9	35	36	52	50
SAPML	5	48	48	59	59
APAEB	56	29	30	58	58
APAES	41	24	24	37	37
JOB09	26	18	17	28	22
JOB10	24	20	22	24	19
RKBBR	20	10	11	20	20
RKBUH	48	29	29	48	47
WKBFR	70	60	60	70	68
WKBWB	64	53	53	65	65

Table 9. Results of harmonic regression analysis for water quality variables (1996-1998) expressed as percent sums of squares for 12.42 hour cycles (SST), 24 hour cycles (SSD) and interactions between these two cycles (SSTD).

	Water Temperature			**Salinity**			**Depth (m)**		
SITE	% SST	% SSD	% SSTD	% SST	% SSD	% SSTD	% SST	% SSD	% SSTD
ELKAP	2.1	85.8	12.1	18.0	29.3	52.6	18.4	24.8	56.8
ELKSM	48.5	19.0	32.5	37.8	24.5	37.7	54.6	26.4	18.9
PDBBY	32.4	31.8	35.8	19.2	36.4	44.4	33.7	38.7	27.7
PDBJL	8.7	51.7	39.7	12.0	35.1	52.9	8.1	28.8	63.1
SOSSE	10.2	44.2	45.6	60.8	15.0	24.1	57.7	13.4	28.9
SOSWI	27.5	39.1	33.4	55.3	16.4	28.3	67.6	16.7	15.7
TJROS	8.5	19.7	71.8	18.7	30.6	50.7	22.7	21.3	56.0
TJRTL	10.8	29.6	59.5	16.8	24.0	59.2	31.3	23.9	44.8
GRBGB	74.3	11.1	14.5	90.0	4.3	5.7	93.1	3.0	3.9
GRBSQ	29.4	32.5	38.1	82.6	8.8	8.6	93.5	2.8	3.8
HUDSK	0.5	84.7	14.9	5.0	22.0	73.0	5.4	49.7	44.9
HUDTS	24.7	42.1	33.1	35.6	35.3	29.2	90.8	5.5	3.7
NARPC	11.7	43.9	44.4	19.9	29.0	51.1	92.0	6.0	2.0
NARTW	53.8	26.1	20.1	64.9	14.5	20.5	92.5	5.5	2.0
OWCSU	5.2	34.1	60.7	7.7	26.4	65.9	3.6	27.1	69.3
OWCWM	10.5	36.6	53.0	12.2	25.2	62.5	6.9	25.8	67.3
WELHT	16.7	47.9	35.5	42.7	17.0	40.3	67.9	9.5	22.6
WELIN	48.1	19.2	32.7	90.3	3.3	6.4	95.9	2.8	1.4
WQBCB	1.0	68.0	31.0	14.7	26.6	58.7	61.5	10.0	28.6
WQBMP	4.9	69.9	25.2	9.2	25.8	65.0	63.0	14.8	22.3
CBMJB	14.0	51.2	34.8	37.8	33.3	28.9	94.1	2.8	3.1
CBMPR	36.0	43.3	20.7	91.3	2.0	6.7	92.0	3.8	4.1
CBVGI	11.3	33.4	55.2	18.0	33.3	48.7	65.3	13.7	21.0
CBVTC	9.4	61.3	29.3	89.4	3.9	6.7	91.9	5.3	2.8
DELBL	8.4	47.0	44.6	68.6	10.2	21.2	67.7	9.8	22.5
DELSL	19.6	27.5	52.9	54.6	13.4	32.0	71.2	8.2	20.5
MULB6	60.2	23.1	16.7	82.4	10.0	7.6	86.2	7.0	6.7
MULBA	8.8	72.3	18.8	77.1	8.4	14.6	84.7	6.2	9.1
ACEBB	10.5	29.7	59.8	79.9	7.9	12.2	93.5	3.8	2.7
ACESP	9.3	32.3	58.4	85.6	7.0	7.4	94.1	3.9	2.0
NIWOL	13.9	21.3	64.9	52.5	26.1	21.4	76.1	9.4	14.5
NIWTA	11.9	34.7	53.4	51.9	19.4	28.7	82.9	7.1	10.0
NOCMS	15.0	24.8	60.2	73.2	9.4	17.4	87.6	5.8	6.6
NOCZI	6.3	75.7	18.0	59.7	14.5	25.8	89.2	4.5	6.3
SAPFD	13.3	33.5	53.2	46.5	36.1	17.4	68.1	7.1	24.7
SAPML	37.1	35.3	27.6	73.7	12.0	14.3	80.5	10.2	9.3
APAEB	3.2	61.3	35.5	9.1	30.5	60.4	24.4	22.1	53.5
APAES	4.6	55.3	40.1	8.8	22.3	68.9	25.0	21.9	53.1
JOB10	1.3	92.3	6.4	10.7	54.6	34.7	1.4	38.9	59.6
JOB9	1.3	83.6	15.1	6.1	41.9	52.0	1.5	44.4	54.1
RKBBR	9.2	39.9	50.8	38.3	15.2	46.5	45.6	11.0	43.4
RKBUH	11.1	33.2	55.7	18.7	15.9	65.4	40.5	14.6	44.9
WKBFR	4.6	25.1	70.3	5.6	19.2	75.1	1.6	16.3	82.1
WKBWB	4.3	46.4	49.4	4.4	30.4	65.3	1.5	19.7	78.8

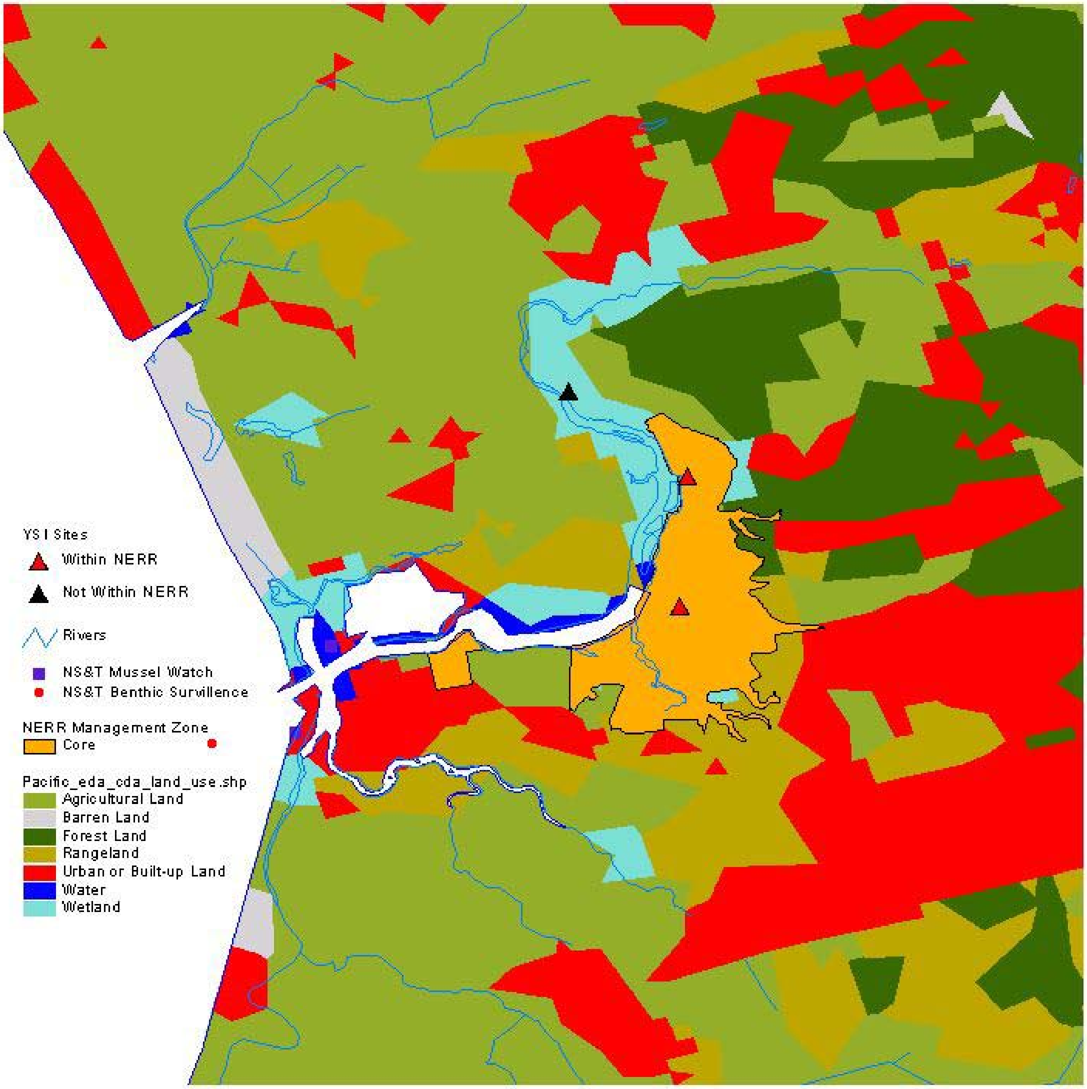
Table 9. Continued.

	DO (% saturation)			**DO (mg/L)**		
SITE	% SST	% SSD	% SSTD	% SST	% SSD	% SSTD
ELKAP	1.8	78.0	20.2	1.8	76.9	21.2
ELKSM	14.3	50.6	35.2	15.9	51.3	32.8
PDBBY	21.6	35.5	42.9	18.4	37.8	43.8
PDBJL	11.1	48.9	40.0	12.3	47.8	39.9
SOSSE	25.7	40.7	33.6	34.8	30.0	35.2
SOSWI	27.3	39.8	32.9	39.2	26.9	33.9
TJROS	10.1	28.8	61.1	10.1	28.3	61.6
TJRTL	7.8	34.9	57.3	8.1	35.2	56.7
GRBGB	15.2	27.8	57.0	20.7	25.5	53.8
GRBSQ	59.0	22.1	19.0	58.4	21.8	19.8
HUDSK	2.3	83.0	14.7	1.9	80.1	17.9
HUDTS	59.0	21.9	19.1	64.5	18.7	16.8
NARPC	10.8	62.0	27.2	10.8	60.1	29.2
NARTW	38.7	25.4	36.0	43.9	25.3	30.9
OWCSU	4.1	23.7	72.1	3.5	21.3	75.2
OWCWM	8.0	31.4	60.7	9.5	30.6	59.9
WELHT	12.5	42.9	44.5	20.1	36.7	43.2
WELIN	68.1	13.5	18.4	77.5	9.6	12.9
WQBCB	42.6	7.0	50.4	1.5	78.8	19.7
WQBMP	4.5	63.4	32.1	4.4	57.7	38.0
CBMJB	27.0	13.7	59.4	29.8	13.2	57.0
CBMPR	40.1	30.3	29.6	40.2	30.9	28.9
CBVGI	3.0	27.7	69.3	3.9	26.9	69.1
CBVTC	40.2	21.2	38.6	41.7	20.8	37.5
DELBL	10.5	40.2	49.3	12.1	39.5	48.4
DELSL	32.3	12.4	55.4	32.8	13.5	53.7
MULB6	33.5	25.1	41.4	47.0	20.3	32.8
MULBA	34.0	37.5	28.5	41.5	28.5	30.1
ACEBB	39.9	20.7	39.4	47.5	18.4	34.1
ACESP	37.6	18.1	44.3	41.2	17.6	41.1
NIWOL	17.0	21.0	62.0	18.8	21.8	59.4
NIWTA	41.8	19.2	39.1	42.7	18.8	38.5
NOCMS	7.7	29.2	63.2	8.1	29.8	62.2
NOCZI	17.8	60.0	22.2	19.5	54.9	25.6
SAPFD	34.8	16.6	48.6	37.1	15.9	47.0
SAPML	52.2	18.8	29.0	57.7	16.9	25.4
APAEB	14.6	41.4	44.0	15.5	37.1	47.4
APAES	10.0	37.5	52.5	10.8	36.6	52.7
JOB10	4.4	45.5	50.1	4.8	42.3	52.9
JOB9	5.1	61.0	34.0	5.3	60.9	33.8
RKBBR	17.2	22.4	60.5	15.8	19.9	64.4
RKBUH	11.5	39.5	49.0	11.1	39.1	49.8
WKBFR	9.4	28.4	62.3	9.3	28.1	62.6
WKBWB	7.4	32.3	60.3	7.1	30.1	62.8

Table 10. Results of metabolism analyses for 27 of 44 NERR sites from 1996-1998 data. Production (Pg), respiration (Rtot) and net ecosystem metabolism (NEM) measured as $gO^2/m^2/d$.

	Depth (m)	Pg	Rtot	NEM	Pg/Rtot
ELKAP	0.7	10.57	11.82	-1.26	0.89
ELKSM	2.0	5.61	8.27	-2.66	0.68
PDBBY	4.0	6.48	7.70	-1.22	0.84
PDBJL	1.0	0.54	5.99	-5.45	0.09
SOSSE					
SOSWI					
TJROS					
TJRTL					
GRBGB	6.5	2.24	2.17	0.07	1.03
GRBSQ	3.5	3.42	8.69	-5.27	0.39
HUDSK	1.0	-0.15	-0.34		
HUDTS	1.5	2.39	4.29	-1.90	0.56
NARPC	3.4	12.30	19.22	-6.92	0.64
NARTW	4.8	2.88	5.54	-2.67	0.52
OWCSU					
OWCWM					
WELHT					
WELIN					
WQBCB	1.0	6.93	5.97	0.96	1.16
WQBMP					
CBMJB	1.0	5.20	10.77	-5.58	0.48
CBMPR	1.0	1.45	3.47	-2.02	0.42
CBVGI	1.0	5.20	4.90	0.30	1.06
CBVTC	2.0	6.92	10.45	-3.53	0.66
DELBL					
DELSL					
MULBA					
MULB6					
ACEBB	3.0	7.68	13.39	-5.72	0.57
ACESP	4.5	11.40	20.96	-9.56	0.54
NIWOL	1.0	3.62	5.44	-1.82	0.67
NIWTA	1.0	1.62	4.49	-2.88	0.36
NOCMS					
NOCZI					
SAPFD					
SAPML					
APAES	2.0	3.31	4.12	-0.81	0.74
APEEB	2.0	3.31	4.12	-0.81	0.91
JOB09	1.0	4.60	8.66	-4.06	0.53
JOB10	1.5	4.81	6.86	-2.05	0.70
RKBUH	2.0	5.70	14.93	-9.23	0.38
RKBBR	2.0	4.17	18.77	-14.60	0.22
WKBFR	2.0	2.71	3.61	-0.90	0.75
WKBWB	1.0	2.85	3.88	-1.03	0.73

Elkhorn Slough



Elkhorn Slough, Azevedo Pond (ELKAP)

Characterization (Latitude = 36°50'50"N; Longitude = 121°45'16" W)

Azevedo pond is 53 m long (mainstream linear dimension), has an average depth of 0.7 m MHW, and an average width of 8 m. At the sampling site, the depth is 1 m MHW and the width is 6 m. This site is a tidal pond connected to the main channel of Elkhorn Slough by a culvert. The bottom sediment is organic rich silt. Extensive mats of macroalgae (*Ulva* sp. and *Enteromorpha* sp.) occur within the pond. The dominant marsh vegetation near the sampling site is pickleweed. The dominant upland vegetation includes strawberry and flower fields and grasslands. Upland land use near the sampling site is agriculture. Azevedo Pond has a very narrow (~ 3 m) fringe of marsh with grassland slopes and farmed terraces. The farm surrounding the pond is part of a project to develop best management practices and new growing techniques.

Descriptive Statistics

Thirty-eight deployments were made at this site between Feb 1996 and Dec 1998, with equal coverage in all seasons (Figure 4). Mean deployment duration was 26.8 days. Only three deployments (Mar, May, Nov 1996) were less than 20 days.

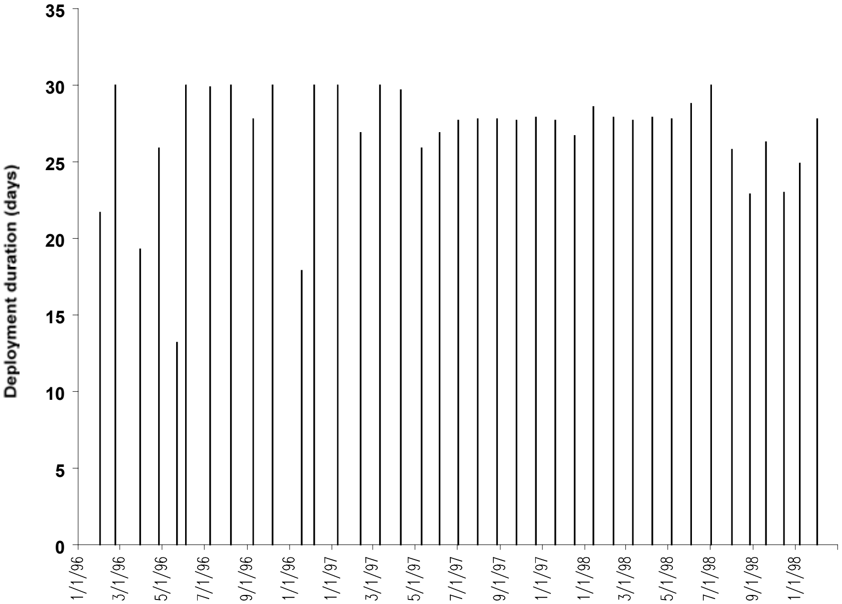


Figure 4. Elkhorn Slough, Azevedo Pond deployments (1996-1998)

Ninety-two percent of annual depth data were included in analyses (90% in 1996, 89% in 1997, and 98% in 1998). Sensors were deployed at a mean depth of 0.3 m below the water surface. Minor fluctuations (< 0.5 m) in water depth were evident from scatter plots for daily and bi-weekly cycles throughout most of 1996-1998, with stronger fluctuations (≥ 1 m) observed between Nov 1997 – Feb 1998 and again in Nov-Dec 1998. Harmonic regression analysis attributed 57% of depth variance to interaction between 12.42 hour and 24 hour cycles. Twenty-five percent of depth variance was attributed to 24-hour cycles and 18% of depth variance was attributed to 12.42 hour cycles.

Ninety-two percent of annual water temperature data were included in analyses (90% in 1996, 89% in 1997, and 98% in 1998). Water temperature followed a seasonal cycle, with mean water temperatures 13-15°C in winter and 20-22°C in summer (Figure 5). Minimum and maximum water temperatures between 1996-1998 were –1.3°C (Dec 1998) and 35.6°C (Aug 1998), respectively. Minimum water temperature below 5°C was only recorded on three occasions (Jan, Dec 1997 and Dec 1998). Maximum water temperature above 30°C was frequently observed in summer. Scatter plots suggest strong fluctuations in daily (1-4°C) and bi-weekly (5-10°C) water temperature in winter, summer, and fall, with even stronger fluctuations (5-15°C) in daily and bi-weekly cycles in spring. Harmonic regression analysis attributed 86% of temperature variance to 24 hour cycles, 12% of temperature variance to interaction between 12.42 hour and 24 hour cycles, and 2% of variance to 12.42 hour cycles.

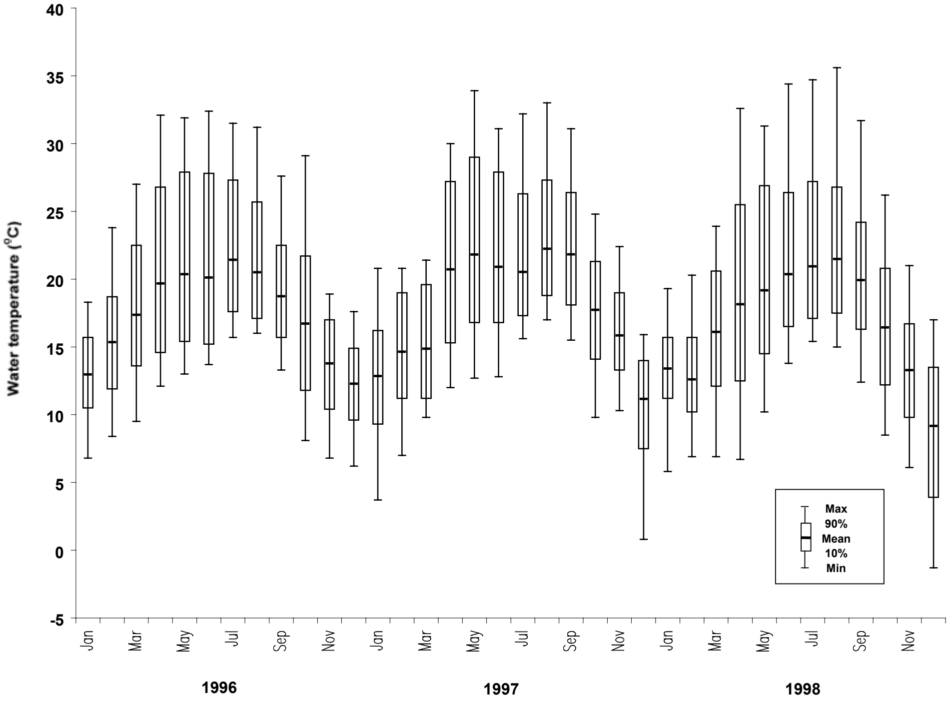


Figure 5. Water temperature statistics for Azevedo Pond, 1996-1998.

Ninety percent of annual salinity data were included in analyses (84% in 1996, 89% in 1997, and 97% in 1998). Mean salinity followed a seasonal cycle; however, large variances were associated with mean salinity values in winter and spring (Figure 6). Mean salinity was 20-22 ppt in winter 1996-1997 and 16-18 ppt in winter/spring 1998 (an El Nino year). Mean salinity in summer 1996-1998 was 33-35 ppt. Minimum and maximum salinity in 1996 was 9.1 ppt and 38.8 ppt, respectively, compared to minimum (0.5 ppt) and maximum (39.2 ppt) salinity between 1997-1998. Scatter plots suggest moderate fluctuations (1-2 ppt) in salinity at daily intervals and even stronger fluctuations (5 ppt) in salinity at bi-weekly intervals. In winter/spring, fluctuations in bi-weekly salinity are comparable to annual fluctuations (15-30 ppt) in salinity. Harmonic regression analysis revealed that 53% of salinity variance was attributed to interaction between 12.42 hour and 24 hour cycles, 29% of salinity variance to 24 hour cycles, and 18% of salinity variance to 12.42 hour cycles.

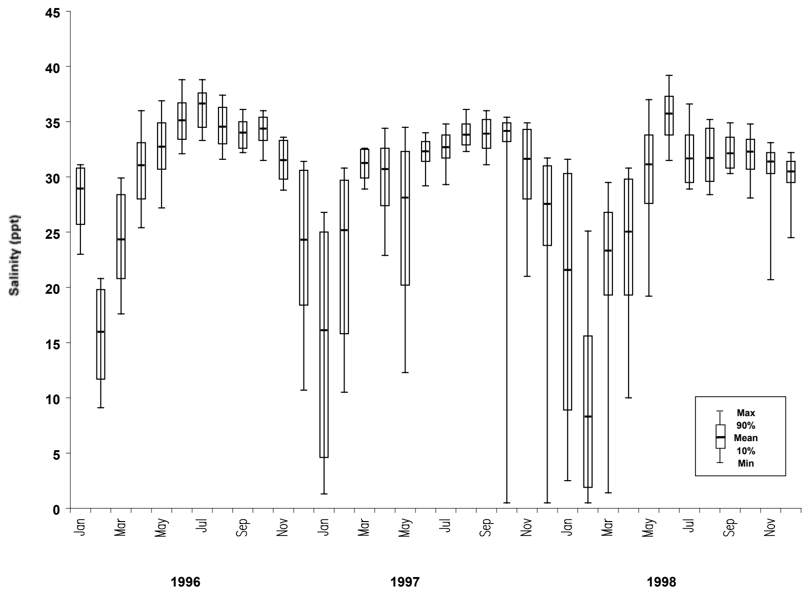


Figure 6. Salinity statistics for Azevedo Pond, 1996-1998.

Eighty-six percent of annual dissolved oxygen data (% saturation) were included in analyses (83% in 1996, 79% in 1997, and 96% in 1998). Mean DO below 50% saturation was never observed and mean DO above 100% saturation was observed on only three occasions (Mar 1996, Apr-May 1997). Minimum DO frequently approached 0% saturation and maximum DO exceeded 350% saturation on three occasions (Aug 1996, Apr-May 1997). Hypoxia was regularly observed in all seasons/years (except winter 1998) and, when present, hypoxia persisted for 18% of the first 48 hours post-deployment on average (Figure 7). Supersaturation was also regularly observed in all seasons/years and, when present, supersaturation persisted for 28% of the first 48 hours post-deployment on average. Scatter plots suggest strong fluctuations (60-100%) in percent saturation throughout 1996-1998, with even stronger fluctuations (>200%) in summer and fall. Harmonic regression analysis attributed 78% of DO variance to 24 hour cycles, 20% of DO variance to interaction between 24 hour and 12.42 hour cycles, and 2% of DO variance to 12.42 hour cycles.

Photosynthesis/Respiration

Almost all (97%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and were used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 11). Instrument drift during the duration of the deployments was not a significant problem at this site. Total respiration exceeded gross production at Azevedo Pond; thus, net ecosystem metabolism and P/R ratio indicated that this is a heterotrophic site (Figure 8). Temperature was significantly ($p<0.05$) correlated with gross production, total respiration and net ecosystem metabolism. Gross production and respiration increased as temperature increased, while net ecosystem metabolism became more autotrophic as temperatures increased. Salinity was significantly ($p<0.05$) correlated with gross production, total respiration, but not net ecosystem metabolism. Gross production and respiration were higher at higher salinity. Metabolic rates strongly followed a seasonal pattern with the highest rates during summer months and the lowest rates during the winter rainy season when temperature and salinity were low.

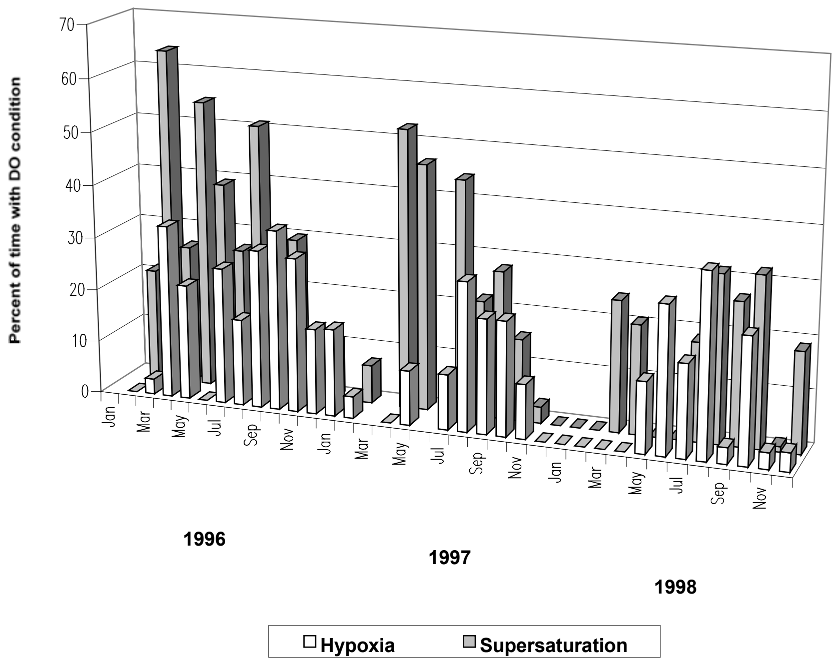


Figure 7. Dissolved oxygen extremes at Azevedo Pond, 1996-1998.

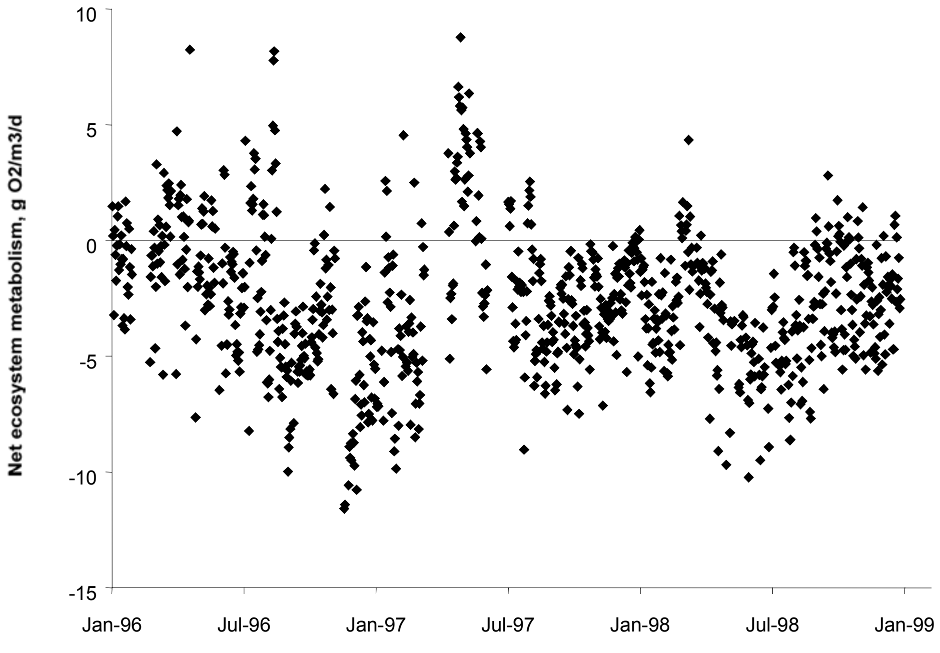


Figure 8. Net metabolism at Azevedo Pond, 1996-1998.

Table 11. Summary of metabolism data and statistics at Azevedo Pond, 1996-1998.

Azevedo Pond	mean	s.e.
Water depth (m)	0.7	
Net production gO_2/m3/d	5.83	0.19
Gross production gO_2/m3/d	15.56	0.32
Total respiration gO_2/m3/d	18.80	0.27
Net ecosystem metabolism g O_2/m3/d	-3.23	0.1
Net ecosystem metabolism g C/m2/y	63	
P/R	0.83	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	97%	
Paired t-test on gross production and total respiration	$p < 0.001$	
Correlation coefficient	Temperature	Salinity
Gross production	0.48	0.39
Total respiration	0.52	0.46
Net ecosystem metabolism	0.09	ns

Elkhorn Slough, South Marsh (ELKSM)

Characterization (Latitude = 36°49’11”N; Longitude = 121°44’13” W)

South Marsh is 1.5 km long (mainstream linear dimension), has an average depth of 2 m MHW, and an average width of 25 m. At the sampling site, the depth is 2 m MHW and the width is 27 m. This site is a tidal creek in a restored marsh that is separated from the main channel of Elkhorn Slough by a railroad line, roughly 800 m from the monitoring site. Tidal flushing occurs between the marsh and the main channel near the Railroad Bridge. Creek bottom habitats are predominantly silt-clay. The adjacent inter-tidal mudflats are often colonized by macroalgae such as *Ulva* sp. and *Enteromorpha* sp. The dominant marsh vegetation near the sampling site is *Salicornia* sp. The dominant upland vegetation includes a variety of non-native grasses and oak woodlands. The major runoff to this site is from grasslands and uplands on the Reserve. South Marsh is relatively un-impacted by anthropogenic influences except for inputs of agricultural runoff from the main channel of the slough or through the Reserve.

Descriptive Statistics

Thirty-six deployments were made at this site between Jan 1996 and Nov 1998, with equal coverage during all seasons (Figure 9). Mean deployment duration was 27.7 days. Only one deployment (Sep 1996) was less than 20 days.

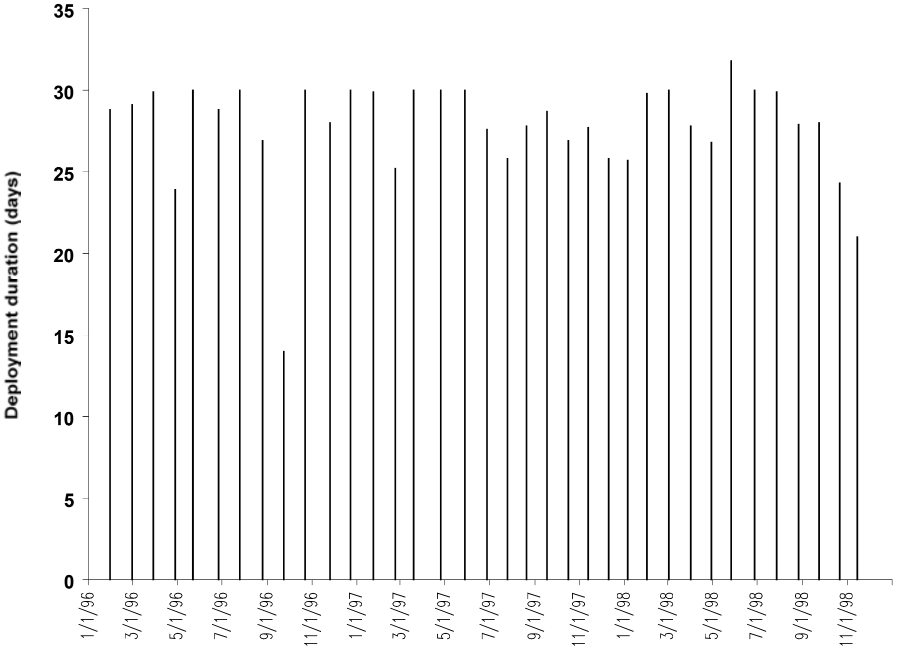


Figure 9. Elkhorn Slough, South Marsh deployments (1996-1998).

Ninety percent of annual depth data were included in analyses (92% in 1996, 86% in 1997, and 91% in 1998). Sensors were deployed at a mean depth of 1.4 m below the water surface. Strong fluctuations (1-2 m) in water depth were evident from scatter plots. Harmonic regression analysis attributed 55% of depth variance to 12.42 hour cycles, 26% of depth variance to 24 hour cycles, and 19% of depth variance to interaction between 12.42 hour and 24 hour cycles.

Ninety percent of annual water temperature data were included in analyses (92% in 1996, 86% in 1997, and 91% in 1998). Water temperature followed a seasonal cycle, with mean water temperatures 12-14°C in winter (except for Dec 1998, mean = 10°C) and 18-20°C in summer (Figure 10). Minimum and maximum water temperatures between 1996-1998 were 5.5°C (Dec 1998) and 24.4°C (Sep 1997), respectively. Water temperature below 10°C was infrequently observed (Jan, Mar 1996; Dec 1997, 1998) and temperatures above 25°C were never observed. Scatter plots suggest moderate fluctuations (1-2°C) in daily temperatures and strong (2-5°C) fluctuations in bi-weekly temperatures throughout most of the year; however, 5-10°C fluctuations in water temperature at daily and bi-weekly intervals were regularly observed in spring. Harmonic regression attributed 49% of temperature variance to 12.42 hour cycles, 32% of temperature variance to interaction between 12.42 hour and 24 hour cycles, and 19% of temperature variance to 24 hour cycles.

Ninety percent of annual salinity data were included in analyses (92% in 1996, 86% in 1997, and 91% in 1998). Mean salinity followed a seasonal cycle; however, large variances were associated with salinity in winter (Figure 3). Mean salinity in winter/spring was between 26-30 ppt and mean salinity in summer/fall was between 30-34 ppt. Minimum and maximum salinity observed between 1996-1998 was 8.3 ppt (Feb 1998) and 39.2 (Jun 1998), respectively. Scatter plots indicated minor fluctuations (1-2 ppt) in daily salinity and moderate fluctuations (2-5 ppt) in bi-weekly salinity throughout the year, except for large variation (≥ 15 ppt) during at least one month each winter.

Harmonic regression analysis attributed 38% of salinity variance to both 12.42 hour cycles and interaction between 12.42 hour and 24 hour cycles, and 24% of salinity variance to 24 hour cycles.

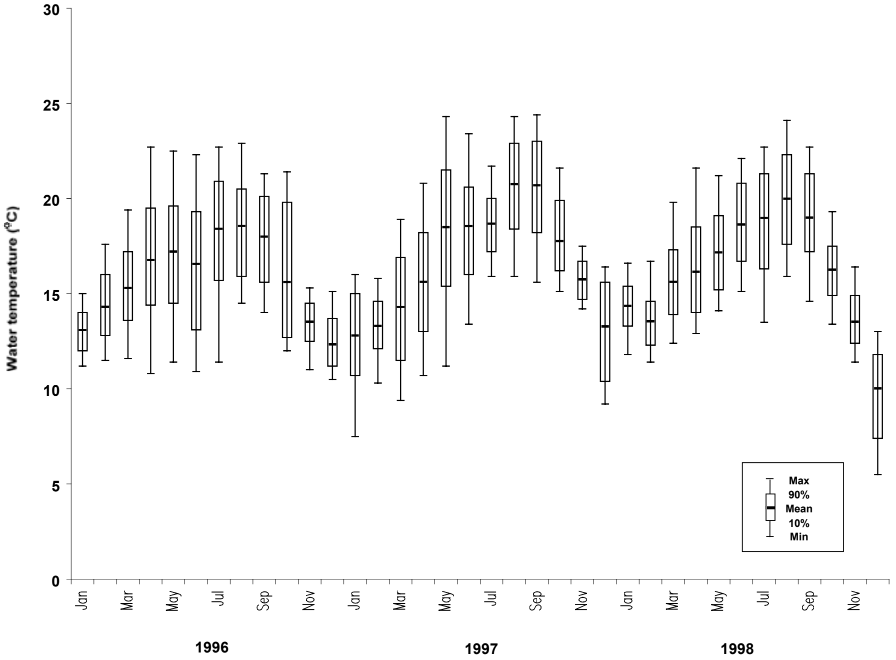


Figure 10. Water temperature statistics for South Marsh, 1996-1998.

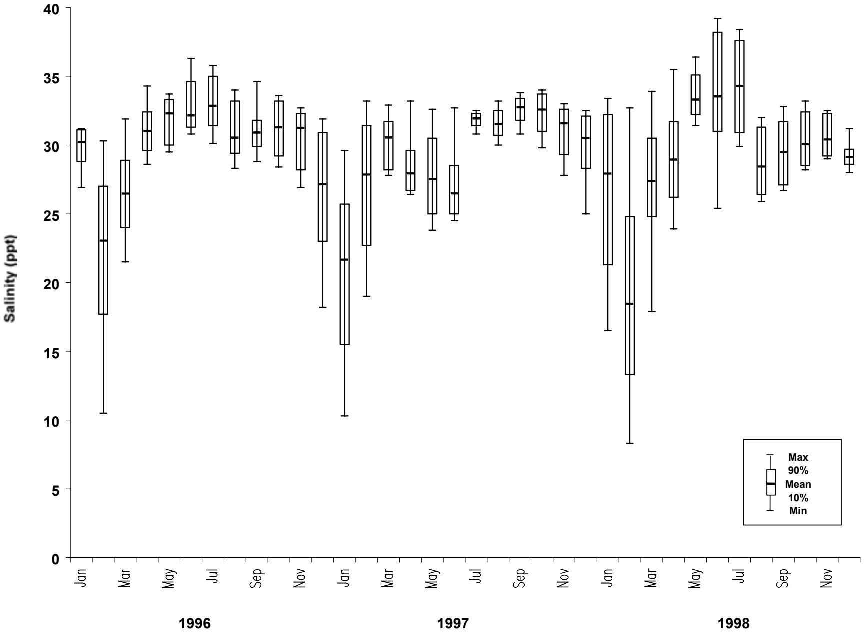


Figure 11. Salinity statistics for South Marsh, 1996-1998.

Sixty-five percent of annual dissolved oxygen (% saturation) data were included in analyses (82% in 1996, 43% in 1997, and 70% in 1998). Mean DO below 50% saturation was only observed on two occasions (Apr 1996, Mar 1997) and mean DO above 100% saturation was also only observed on two occasions (Feb, Mar 1998). Mean DO was typically 60-100% year round. Minimum DO approached 0% saturation on several occasions (Mar-Apr 1996 and Feb-Mar, May, Oct 1997) and maximum DO exceeded 200% saturation on one occasion (Nov 1996). Hypoxia was observed on two occasions (Oct 1996, Feb 1997) and, when present, hypoxia persisted for 11.6% of the first 48 hours post-deployment on average (Figure 12). Supersaturation was observed on several occasions (most notably Mar-Apr 1996 and Feb 1998) and, when present, supersaturation persisted for 16% of the first 48 hours post-deployment on average. Scatter plots suggest that percent saturation regularly fluctuated by 20-60% saturation over daily and bi-weekly intervals in 1996 and 1998 (except spring in both years), with even stronger fluctuations (60-100% sat) recorded for most of 1997. Harmonic regression analysis attributed 51% of DO variance to 24 hour cycles, 35% of DO variance to interaction between 12.42 and 24 hour cycles, and 14% of DO variance to 12.42 hour cycles.

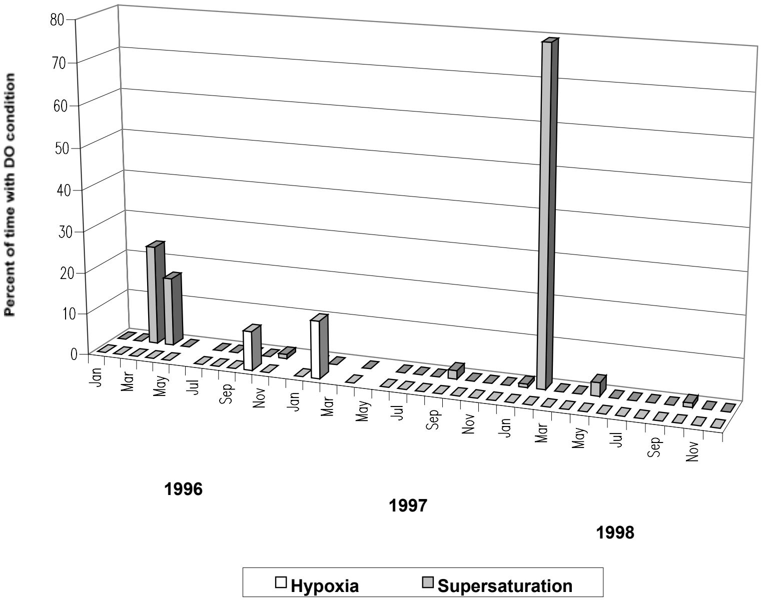


Figure 12. Dissolved oxygen extremes at South Marsh, 1996-1998.

Photosynthesis/Respiration

Over four fifths (88%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and were used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 12). Instrument drift during the duration of the deployments was not a significant problem at this site. Total respiration exceeded gross production at South Marsh; thus, the net ecosystem metabolism and P/R ratio indicated that this is a heterotrophic site (Figure 13). Temperature was significantly ($p<0.05$) correlated with gross production, total respiration and net ecosystem metabolism. Gross production and respiration increased as temperature increased, while net ecosystem metabolism became more heterotrophic as temperatures increased. Salinity was significantly ($p<0.05$) correlated with gross production and total respiration but not net ecosystem metabolism. Gross production and respiration were higher at higher salinity. Thus, the metabolic rates strongly followed a seasonal pattern with the highest rates during summer months and the lowest rates during the winter rainy season when temperature and salinity were low.

Table 12. Summary of metabolism data and statistics at South Marsh, 1996-1998.

South Marsh	mean	s.e.
Water depth (m)	2.0	
Net production gO_2/m3/d	1.00	0.05
Gross production gO_2/m3/d	3.16	0.09
Total respiration gO_2/m3/d	4.05	0.10
Net ecosystem metabolism g O_2/m3/d	-0.89	0.05
Net ecosystem metabolism g C/m2/y	-26	
P/R	0.78	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	88%	
Paired t-test on gross production and total respiration	$p < 0.001$	
Correlation coefficient	Temperature	Salinity
Gross production	0.35	0.23
Total respiration	0.38	0.22
Net ecosystem metabolism	-0.11	ns

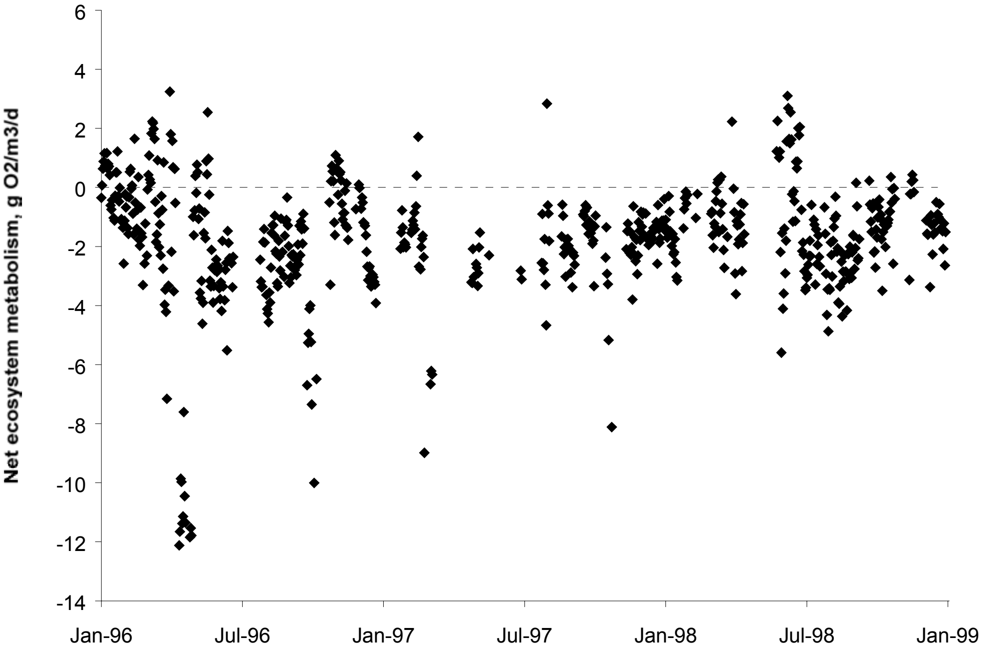
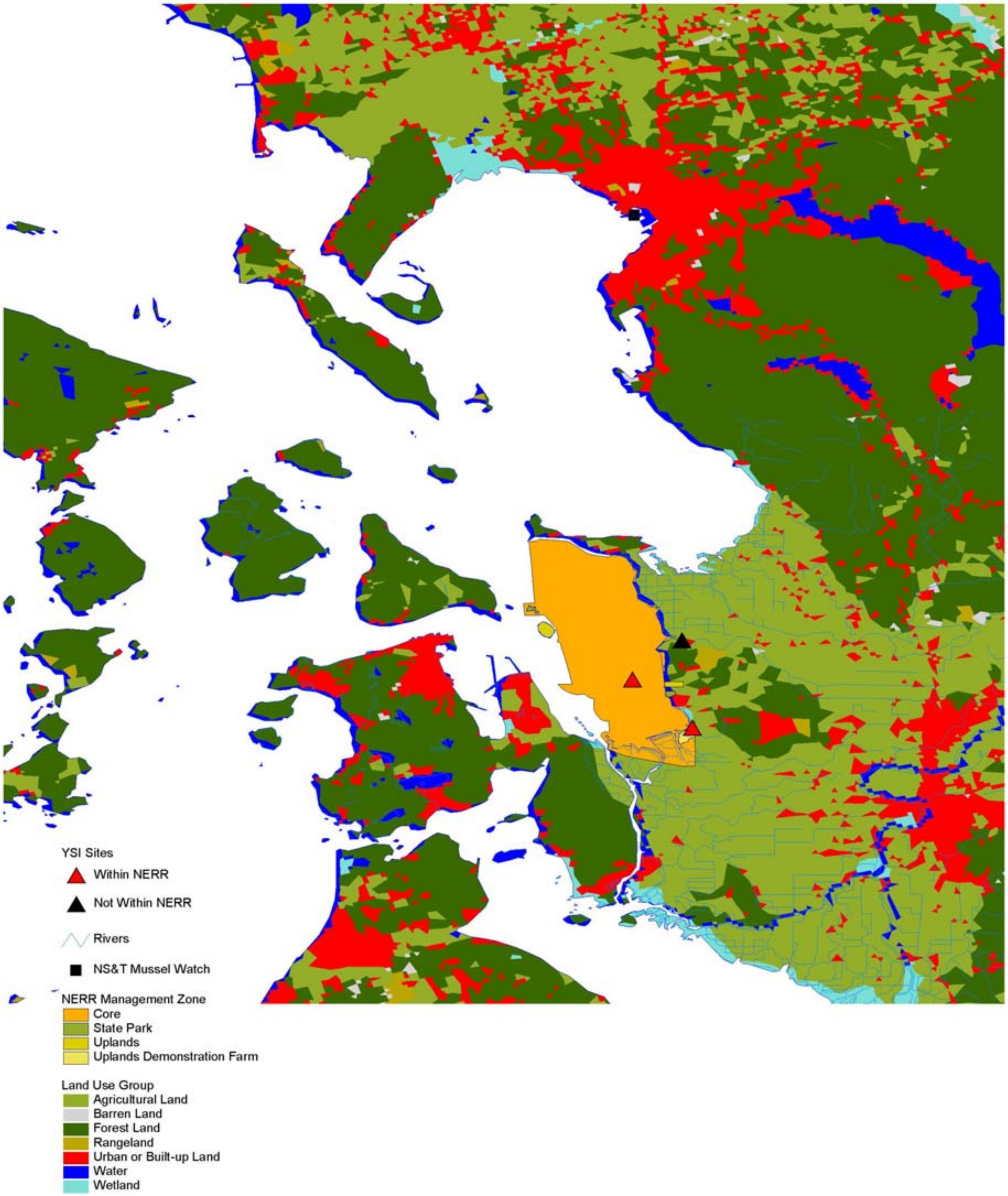


Figure 13. Net metabolism at South Marsh, 1996-1998.

Padilla Bay


YSI Sites
Within NERR
Not Within NERR
Rivers
NS&T Mussel Watch
NERR Management Zone
Core
State Park
Uplands
Uplands Demonstration Farm
Land Use Group
Agricultural Land
Barren Land
Forest Land
Rangeland
Urban or Built-up Land
Water
Wetland

Padilla Bay, Bayview Channel (PDBBY)

Characterization (Latitude = 48° 29' 47" N; Longitude = 122° 30' 07" W)
Tides at Bayview Channel are mixed semidiurnal and tidal range is 1.6 m (2.6 m tide range during spring tides). Padilla Bay is a shallow embayment with inter-tidal channels that drain and distribute tidal waters onto tidal flats. Bayview Channel is one of the major inter-tidal tributary/distributary channels within Padilla Bay, extending about 4.5 km from Swinomish Channel at its "mouth" to the inter-tidal flats. About 2.5 km from the intersection of Bayview Channel with Swinomish Channel, a small (900 m) inter-tidal tributary/distributary channel joins Bayview Channel. The monitoring site is located along the edge of this small channel, about 400 m from its intersection with Bayview Channel. The tributary/distributary channel does not exist as a channel at MHW. At MLW, the tributary/distributary channel is about 2 m deep where it joins Bayview Channel and 0 m deep where it begins draining the inter-tidal flats. Channel width is about 50 m where the monitoring site is located. At the monitoring site, the depth is about 4 m MHW. Creek bottom habitats are fine silt and clay over sand. No bottom vegetation is located at the monitoring site, but eelgrass (*Zostera marina*) is located nearby. The tributary/distributary drains/floods predominately eelgrass (*Zostera marina* and *Z. Japonica*) covered inter-tidal flats. Non-point source pollution has little affect on this site.

Descriptive Statistics
Thirty-four deployments were made at this site between Jan 1996 and Dec 1998, with equal coverage during all seasons except for winter 1997 (Figure 14). Mean deployment duration was 29.2 days. Only one deployment (Jan 1997) was less than 10 days.

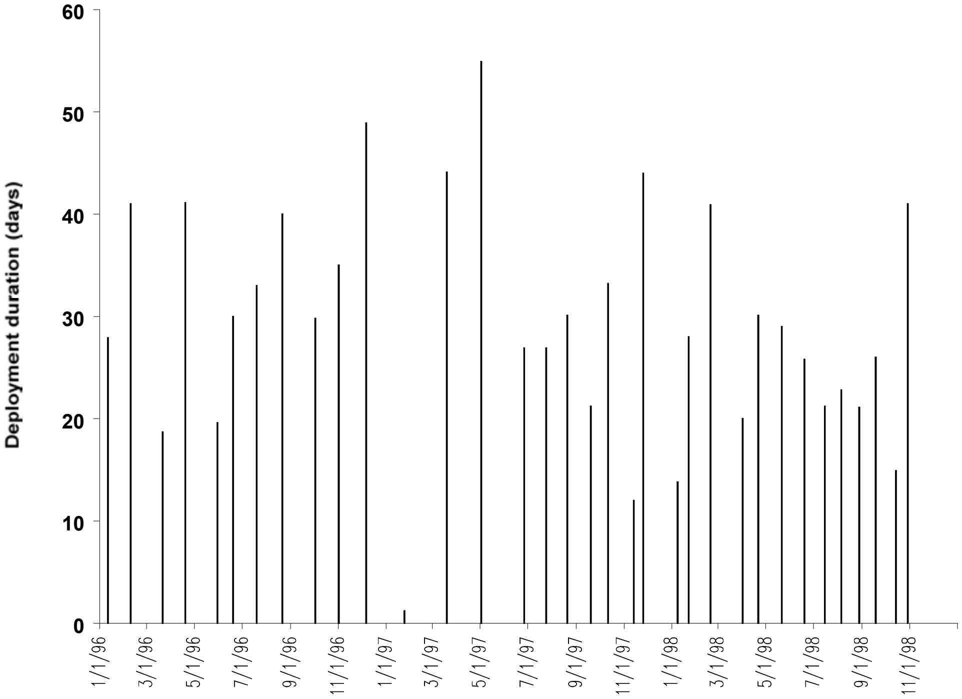


Figure 14. Padilla Bay, Bayview Channel deployments (1996-1998).

Eighty-five percent of annual depth data were included in analyses (85% in 1996, 77% in 1997, and 93% in 1998). Sensors were deployed at a mean depth of 2.3 m below the water surface and 0.8 m above the bottom sediment. Scatter plots suggest strong fluctuations (2-3 m) in daily and bi-weekly depth, with consistent amplitude throughout the data set. Harmonic regression analysis attributed 39% of depth variance to 24 hour cycles, 34% of depth variance to 12.42 hour cycles, and 28% of depth variance to interaction between 12.42 hour and 24 hour cycles.

Eighty-five percent of annual water temperature data were included in analyses (85% in 1996, 77% in 1997, and 93% in 1998). Water temperature followed a seasonal cycle, with mean water temperatures 7-8°C in winter and 13-15°C in summer (Figure 15). Minimum and maximum water temperatures between 1996-1998 were –1.5°C (Dec 1996) and 23.5°C (Jul 1996), respectively. Scatter plots suggest moderate fluctuations (1-2°C) in daily and bi-weekly water temperatures in winter and fall and strong fluctuations (5-10°C) in spring and summer. Harmonic regression analysis attributed 36% of temperature variance to interaction between 12.42 hour and 24 hour cycles, 32% of temperature variance to 12.42 hour cycles, and 32% of temperature variance to 24 hour cycles.

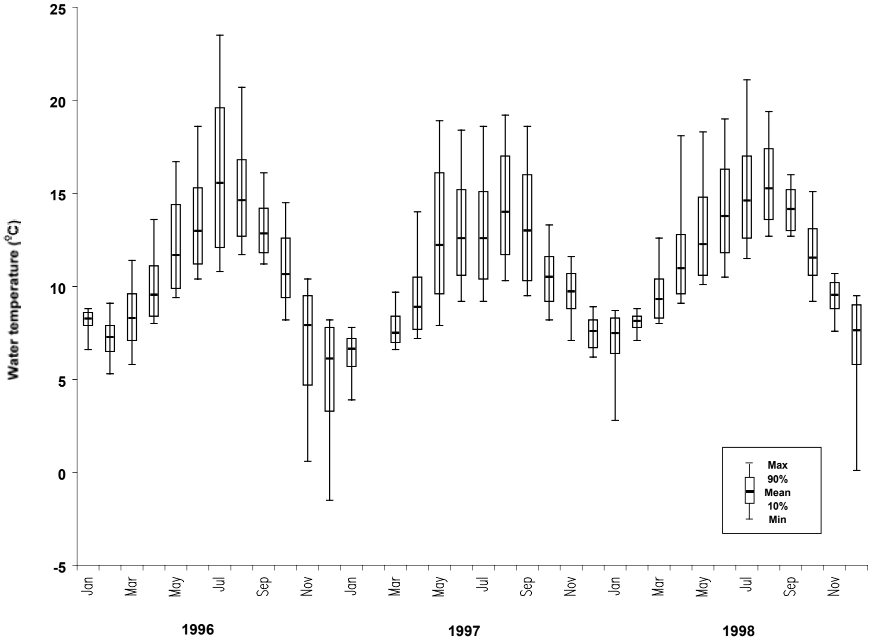


Figure 15. Water temperature statistics at Bayview Channel, 1996-1998.

Sixty-eight percent of annual salinity data were included in analyses (35% in 1996, 77% in 1997, and 91% in 1998). Mean salinity between Jan 1996 and Jun 1997 was 25-31 ppt, but was less variable (28-30 ppt) between Jul 1997 and Dec 1998 (Figure 16). Minimum and maximum salinity between 1996-1998 was 19.9 ppt (Mar 1997) and 32.2 (Mar-Apr 1996), respectively. Scatter plots suggest moderate fluctuations (1-3 ppt) in daily and bi-weekly salinity throughout the data set, with fluctuations equivalent to or in excess of annual variation (6 ppt) in mean salinity during episodic events in all three years. Harmonic regression analysis attributed 44% of salinity variance to interaction between 12.42 hour and 24 hour cycles, 36% of variance to 24 hour cycles, and 20% of variance to 12.42 hour cycles.

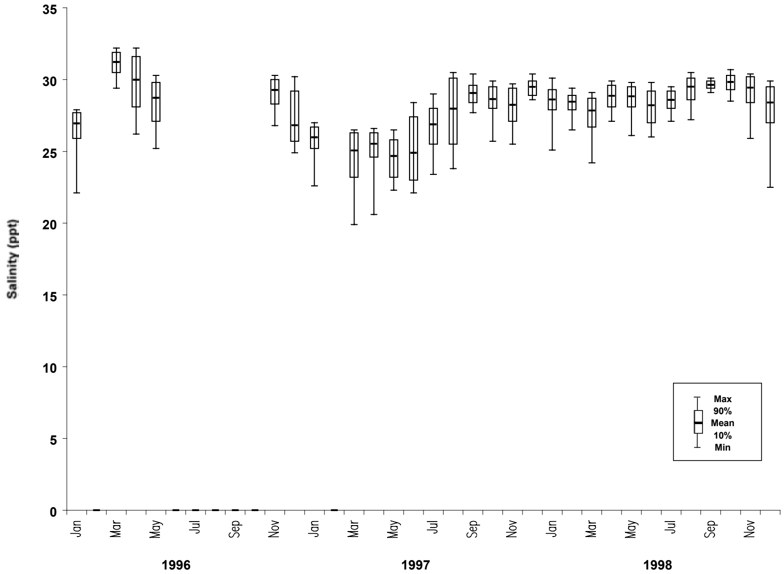


Figure 16. Salinity statistics at Bayview Channel, 1996-1998.

Seventy-eight percent of annual dissolved oxygen (% saturation) data were included in analyses (76% in 1996, 69% in 1997, and 89% in 1998). Mean DO followed a seasonal cycle and was greatest (100-123% sat) in spring and least (76-88% sat) in summer. Minimum and maximum DO between 1996-1998 was 12.6% saturation (Mar 1996) and 225.5% (Jun 1997), respectively. Persistent hypoxia was never observed (Figure 17). Supersaturation was observed regularly in 1996 and 1998, but only in two months in 1997. When present, supersaturation persisted for 28.8% of the first 48 hours post-deployment on average. Scatter plots suggest minor fluctuation (20-40%) in DO over daily and bi-weekly intervals in winter and fall, but strong fluctuations (60-100%) in DO in spring and summer. Harmonic regression analysis attributed 43% of DO variance to interaction between 12.42 hour and 24 hour cycles, 36% of DO variance to 24 hour cycles, and 21% of DO variance to 12.42 hour cycles.

Photosynthesis/Respiration

Over two thirds (71%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and were used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 13). Instrument drift during the duration of the deployments was not a significant problem at this site. Gross production slightly exceeded total respiration at Bayview Channel, although they were not significantly different from each other, the net ecosystem metabolism and P/R ratio indicated that this site is balanced. This was one of the few sites in the Reserve system that was not heterotrophic (Figure 18). Temperature was significantly ($p<0.05$) correlated with gross production and total respiration. Gross production and respiration increased as temperature increased. Salinity was significantly ($p<0.05$) correlated with gross production and net ecosystem metabolism. Gross production decreased as salinity increased, while net ecosystem metabolism became more heterotrophic as salinity increased. Thus, the metabolic rates generally followed a seasonal pattern with the lowest rates during the fall and winter when temperatures were low and the highest rates during spring and summer months, the peak growing period for eelgrass, *Zostera marina*, which covers the inter-tidal flats of Padilla Bay.

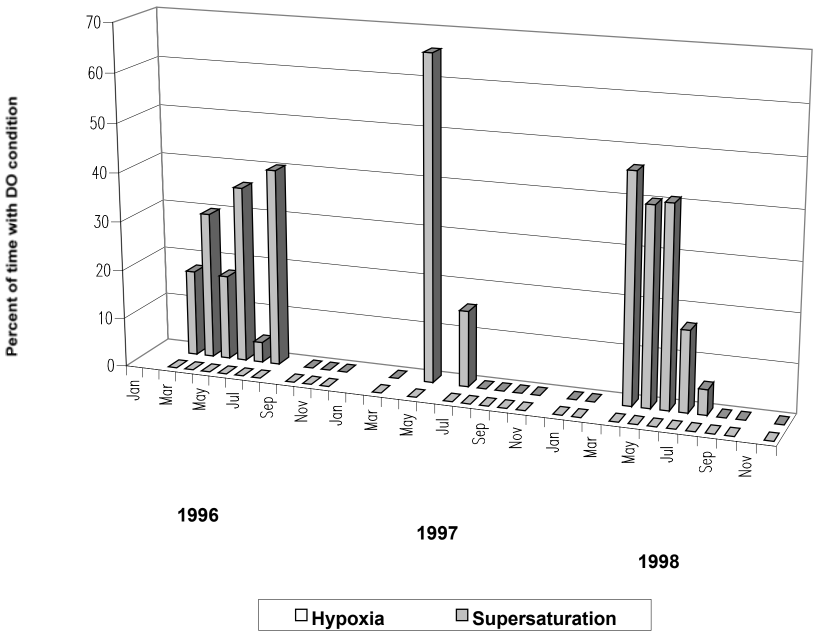


Figure 17. Dissolved oxygen extremes at Bayview Channel, 1996-1998.

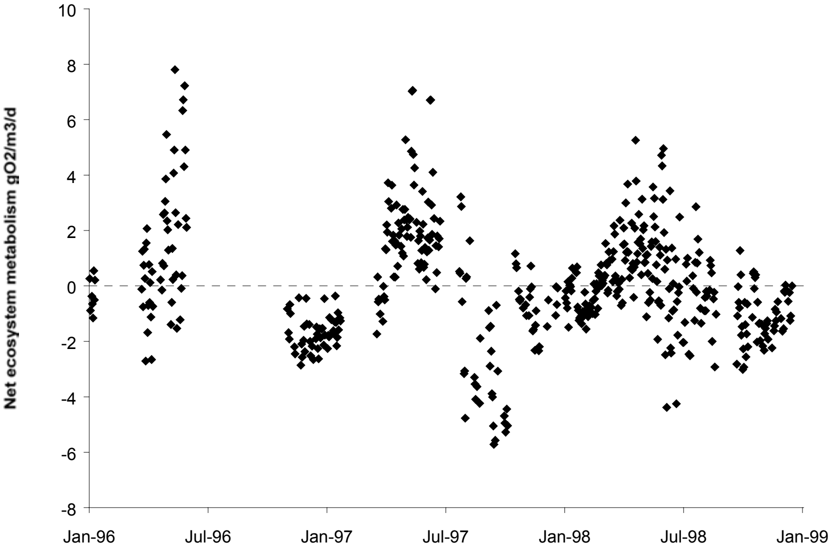


Figure 18. Net metabolism at Bayview Channel, 1996-1998.

Table 13. Summary of metabolism data and statistics at Bayview Channel, 1996-1998.

Bayview Channel	mean	s.e.
Water depth (m)	4.0	
Net production gO_2/m3/d	1.33	0.19
Gross production gO_2/m3/d	3.17	0.39
Total respiration gO_2/m3/d	3.23	0.37
Net ecosystem metabolism g O_2/m3/d	-0.06	0.12
Net ecosystem metabolism g C/m2/y	403	
P/R	0.98	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	71 %	
Paired t-test on gross production and total respiration	ns	
Correlation coefficient	Temperature	Salinity
Gross production	0.30	-0.11
Total respiration	0.30	ns
Net ecosystem metabolism	ns	-0.18

Padilla Bay, Joe Leary Slough (PDBJL)

Characterization (Latitude = 48° 31' 05" N; Longitude = 122° 28' 25" W)
This monitoring site is located near a dam at the mouth of Joe Leary Slough. The dam has twelve, 4' diameter outfall pipes with tide gates that allow freshwater to flow out of the slough, but prevents seawater from entering the slough; however, a small amount of saline water from Padilla Bay seeps through the tide gates during high tide. There are no tides on the "freshwater" side of the dam where the monitoring site is located, although freshwater accumulates behind the tide gates during high water when the tide gates are closed. Joe Leary Slough is 16 km long and drains a 4700 hectare watershed. Water depth varies from about 0.5 to 1.5 m deep and channel width varies from about 1 m to 10 m. At the monitoring site, located in a small holding basin on the freshwater side of the tide gates, water depth varies from 0.5 to 1.5 m during summer and up to 4 m depth during winter floods. Creek bottom habitats near the site are predominantly soft silt and clay without bottom vegetation. There is no marsh vegetation in the basin in which the monitoring site is located and the upland vegetation is agricultural. Land use in Joe Leary Slough includes agriculture (crops, berries, and orchards), pastures, dairy farms, and low-density housing. Activities that potentially impact the site include periodic dredging to provide better drainage from farm lands, low-density development, a closed landfill site, and runoff from farmlands. Joe Leary slough experiences high concentrations of fecal coliform bacteria, nutrients from agriculture, high turbidity, and low dissolved oxygen concentrations.

Descriptive Statistics
Sixty deployments were made at this site between Jan 1996 and Dec 1998, with equal coverage during all seasons (Figure 19). Mean deployment duration was 16.4 days. Two deployments in 1997 and seven deployments in 1998 were less than 10 days.

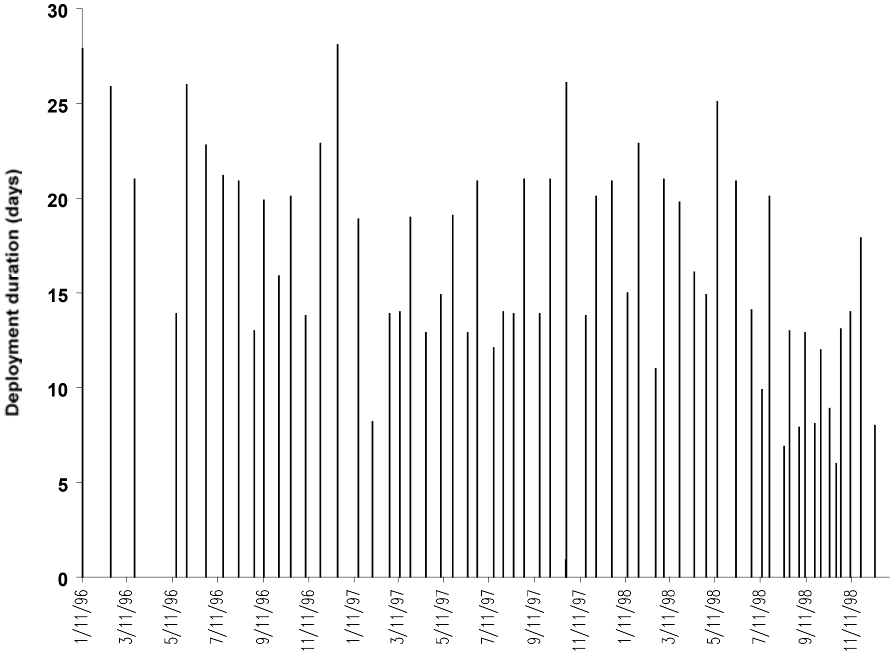


Figure 19. Padilla Bay, Joe Leary Slough deployments (1996-1998).

Eighty-nine percent of annual depth data were included in analyses (76% in 1996, 92% in 1997, and 99% in 1998). Sensors were deployed at mean depth of 0.7 m below the water surface and 0.3 m above the bottom sediment. Scatter plots suggest seasonal variation in daily and bi-weekly depth fluctuations. In summer, depth fluctuations were typically ≤ 1 m; however, between fall and spring depth fluctuations were typically ≥ 1.5 m. Harmonic regression analysis attributed 63% of depth variance to interaction between 12.42 hour and 24 hour cycles, 29% of depth variance to 24 hour cycles, and 8% of depth variance to 12.42 hour cycles.

Eighty-nine percent of annual water temperature data were included in analyses (76% in 1996, 92% in 1997, and 99% in 1998). Water temperature followed a seasonal cycle, with mean water temperatures 5-8°C in winter and 18-21°C in summer (Figure 20). Minimum and maximum water temperatures between 1996-1998 were –0.6°C (Dec 1998) and 28.2°C (Jul 1996), respectively. Scatter plots suggest strong fluctuations (≤ 5°C) in daily water temperature and even stronger fluctuations (≤ 8°C) in bi-weekly water temperatures, with strongest variation occurring in summer. Harmonic regression analysis attributed 52% of temperature variance to 24 hour cycles, 40% of temperature variance to interaction between 12.42 hour and 24 hour cycles, and 8% of temperature variance to 12.42 hour cycles.

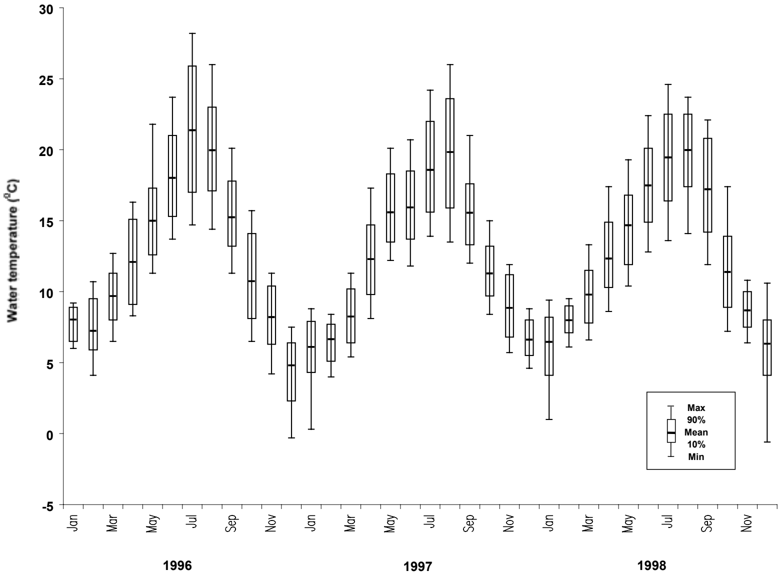


Figure 20. Water temperature statistics at Joe Leary Slough, 1996-1998.

Eighty-nine percent of annual salinity data were included in analyses (76% in 1996, 92% in 1997, and 99% in 1998). Mean salinity followed a pronounced seasonal cycle; however, very large variances (15-25 ppt) were associated with mean salinity readings throughout the data set (Figure 21). Mean salinity was greatest in summer and was 11-13 ppt. Mean salinity in winter 1997 was slightly lower (4-7 ppt) than mean salinity in winter 1996 and 1998 (6-8 ppt). Minimum salinity was always less than 1 ppt throughout the data set. Maximum salinity was almost always greater than 20 ppt between 1996-1998, with a notable exception in summer 1996. Scatter plots suggest daily and bi-weekly fluctuations in salinity were 1-3 times greater than the variation in annual mean salinity (9 ppt). Harmonic regression analysis attributed 53% of salinity variance to interaction between 12.42 hour and 24 hour cycles, 35% of variance to 24 hour cycles, and 12% of variance to 12.42 hour cycles.

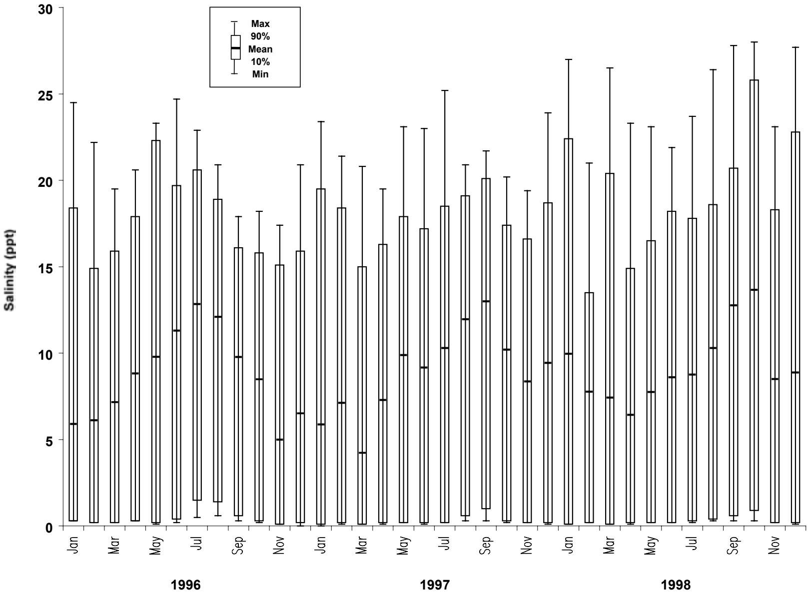


Figure 21. Salinity statistics at Joe Leary Slough, 1996-1998.

Seventy-seven percent of annual dissolved oxygen (% saturation) data were included in analyses (51% in 1996, 80% in 1997, and 99% in 1998). Mean DO followed a seasonal cycle, with lowest percent saturation between Sep-Nov (16-55%) and greatest percent saturation in spring (1996, 1997) or summer (1998). Mean percent saturation in spring 1996 was greater (51% in Apr, 94-107% in May-Jun) than mean percent saturation in spring 1997 (59-61%), which was comparable to mean percent saturation in summer 1998 (54-67%). Hypoxia was regularly observed between 1996-1998 and, when present, hypoxia persisted for 22% of the first 48 hours post-deployment on average (Figure 22). Supersaturation was regularly observed in spring/summer 1996 and sporadically in 1997 and 1998 and, when present, supersaturation persisted for 21% of the first 48 hours post-deployment on average. Scatter plots suggest strong fluctuations (60-100%) in percent saturation throughout the data set, with very strong fluctuations (≥ 120%) in summer. Harmonic regression analysis attributed 49% of DO variance to 24 hour cycles, 40% of DO variance to interaction between 12.42 hour and 24 hour cycles, and 11% of DO variance to 12.42 hour cycles.

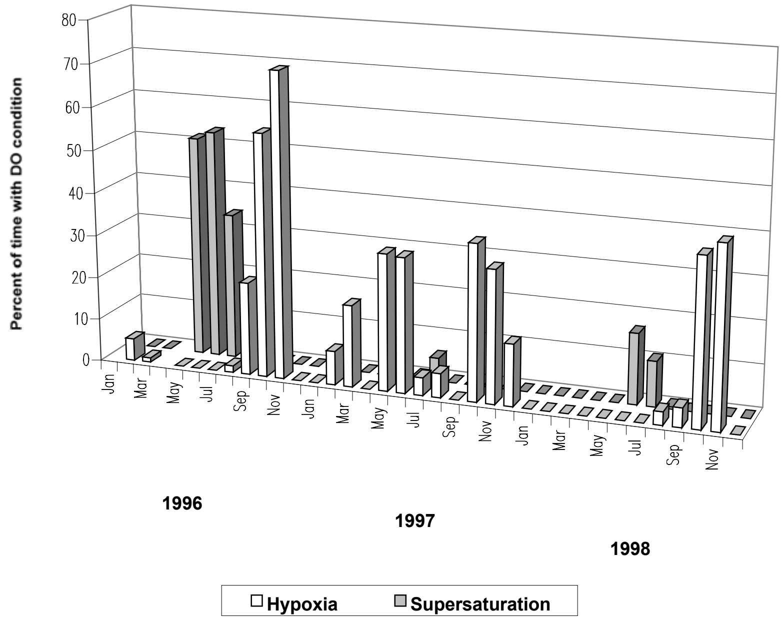


Figure 22. Dissolved oxygen extremes at Joe Leary Slough, 1996-1998.

Photosynthesis/Respiration

Over half (57%) of the data were used to calculate metabolic rates for net production, gross production, total respiration and net ecosystem metabolism (Table 14, Figure 23). Instrument drift during the duration of the deployments was not a significant problem at this site. However, harmonic analyses of the oxygen and salinity data suggested that dissolved oxygen concentrations were controlled by the exchange between Padilla Bay and Joe Leary Slough, not biological processes. It appears likely that some of these rate calculations reflect times when the tidal cycle coincided with the diurnal cycle, for example, a high tide at mid-day bringing in oxygen-rich, high salinity water into the low oxygen, fresh water normally present in the Slough. Thus, the values below should be treated with some skepticism until further analyses can be conducted.

Table 14. Summary of metabolism data and statistics at Joe Leary Slough, 1996-1998.

Joe Leary Slough	mean	s.e.
Water depth (m)	1.0	
Net production $gO_2/m3/d$	-1.24	0.10
Gross production $gO_2/m3/d$	3.31	0.13
Total respiration $gO_2/m3/d$	9.05	0.20
Net ecosystem metabolism $g\ O_2/m3/d$	-5.76	0.16
Net ecosystem metabolism g C/m2/y	-674	
P/R	0.37	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	57 %	
Paired t-test on gross production and total respiration	$p < 0.001$	
Correlation coefficient	Temperature	Salinity
Gross production	-0.18	-0.09
Total respiration	0.30	0.27
Net ecosystem metabolism	0.46	0.33

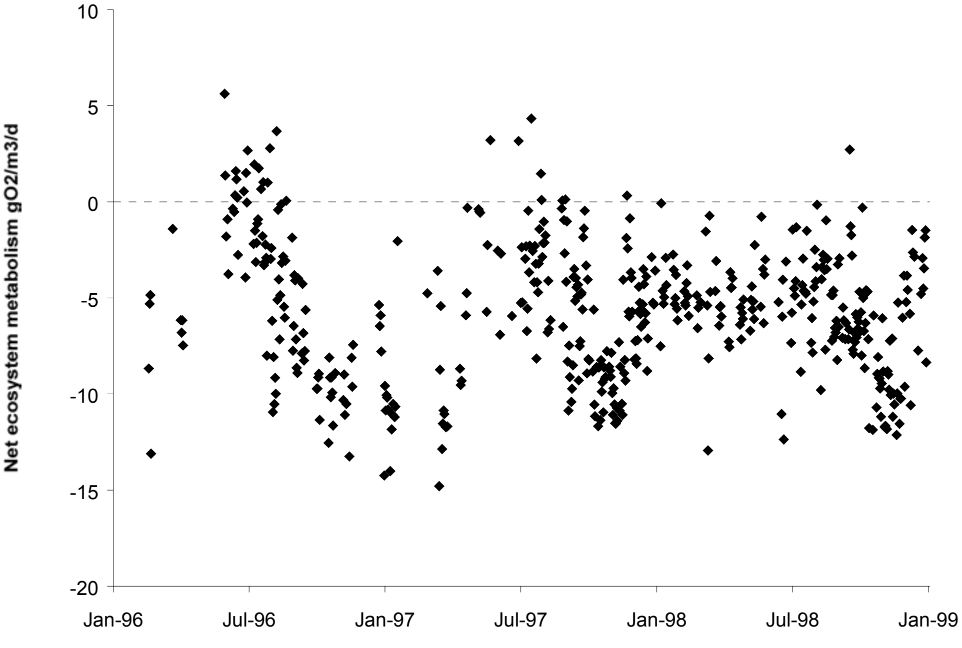
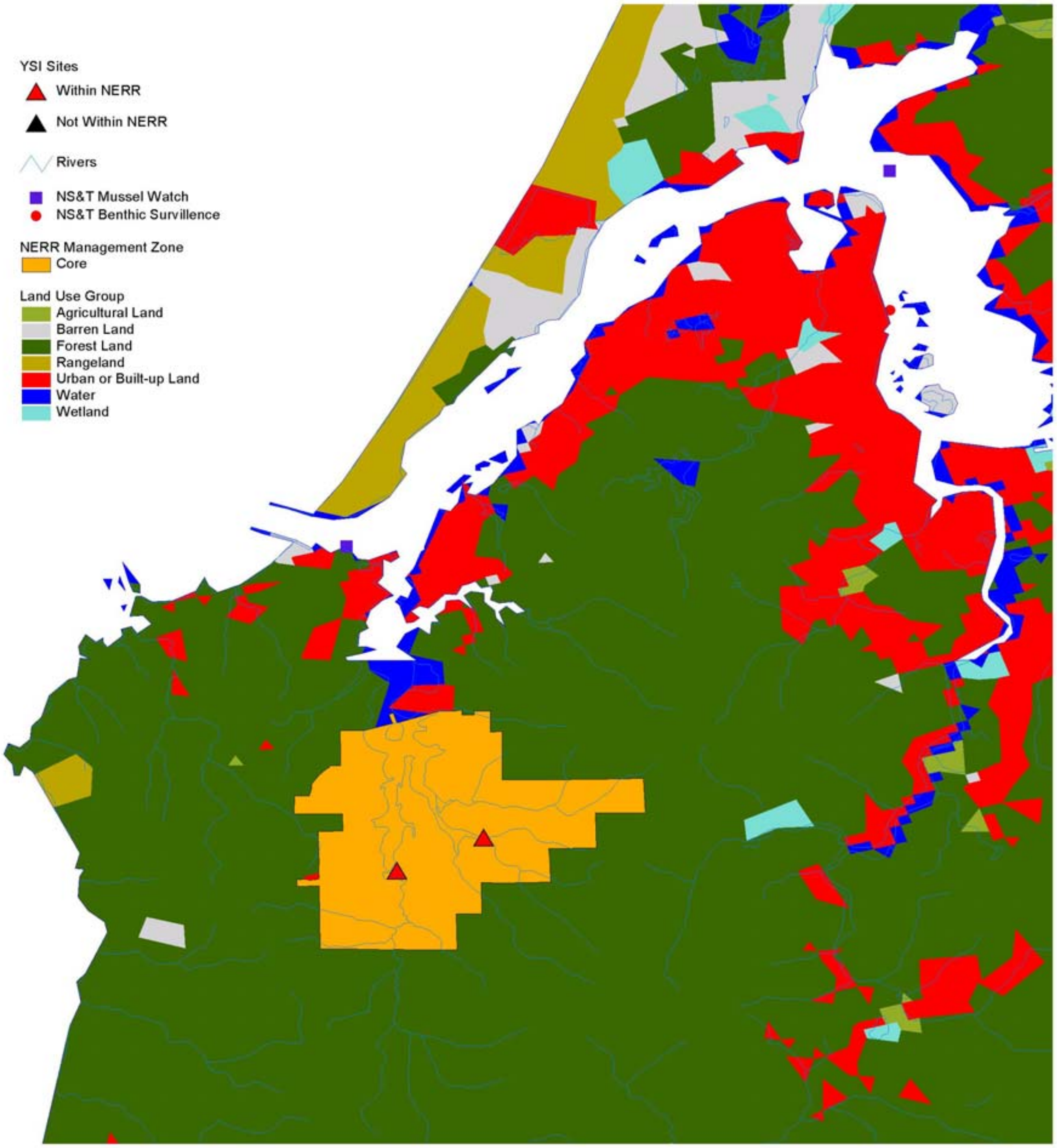


Figure 23. Net metabolism at Joe Leary Slough, 1996-1998.

South Slough



South Slough, Stengstacken Arm (SOSSE)

Characterization

Stengstacken Arm, located approximately 7.7 km east of the mouth of the South Slough estuary in a tidal channel, functions as a reference site for this estuary. The creek/water body is about 2 km long (mainstream linear dimension), has an average depth of 5 m MHW, and an average width of about 150 m. At the sampling site, the depth is 3 m MHW. Natural marsh (4.3 ha) is located adjacent to the sampling site. Tides in South Slough are semidiurnal. Creek bottom habitats are predominantly soft mud colonized by *Zostera marina*. The dominant upland vegetation includes *Carex lyngbyei*, *Triglochin maritima*, *Distichlis spicata* and *Juncus* sp. Upland areas of the Sough Slough watershed are typical of the Coos Bay estuary watershed and include 30-50 year old mixed conifer forests, new and recovering clear-cut lands, and shrub covered slopes. The South Slough contains some stands of small trees over 80 years old and occasional specimens estimated to be well over 100 years old. Sitka spruce (*Picea sitchenis*), Douglas fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and Port Orford cedar (*Chamaecyparis lawsoniana*) are the predominant conifers found in the upland forests. Deciduous upland trees include red alder (*Alnus rubra*) and Pacific wax myrtle (*Myrica californica*), with big leaf maple (*Acer macrophyllum*) and willows (*Salix* spp.) common in riparian areas. Upland land use near the sampling site includes commercial forestry, dairy farming, and residential development. Activities that potentially impact the site include waste from seafood processing plants, septic systems, and shore-based shipyards.

Descriptive Statistics

Twenty-six deployments were made at this site between Jan-Sep 1996, Feb-Jun 1997, Oct 1997-Jan 1998, and Nov 1998 (Figure 24). Mean deployment duration was 17.5 days. Only one deployment (May 1997) was less than 10 days.

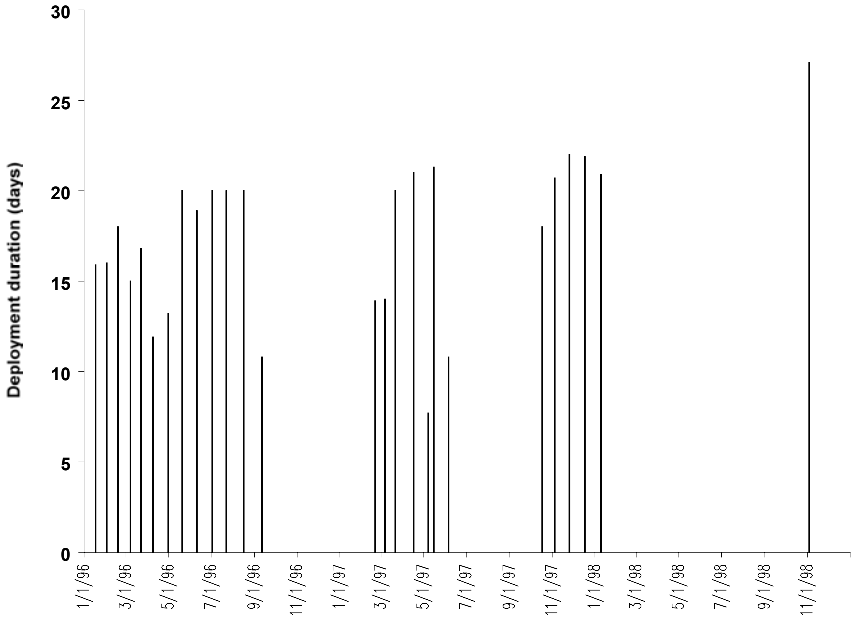


Figure 24. South Slough, Stengstacken Arm deployments (1996-1998).

Forty-six percent of annual depth data were included in analyses (64% in 1996, 50% in 1997, and 22% in 1998). Sensors were deployed at a mean depth of 0.6 m below the water surface. Scatter plots suggest strong fluctuations (> 1.5 m) in depth throughout the data set, except for Feb 1997. Harmonic regression analysis attributed 58% of depth variance to 12.42 hour cycles, 29% of depth variance to interaction between 12.42 hour and 24 hour cycles, and 13% of depth variance to 12.42 hour cycles.

Forty-three percent of annual water temperature data were included in analyses (64% in 1996, 50% in 1997, and 15% in 1998). Water temperature followed a seasonal cycle, with mean water temperatures 8-10°C in winter (1996, 1997) and 17-19°C in summer (Figure 25). Mean winter water temperature was slightly cooler in 1998 (6-8°C) than in 1996 and 1997 (8-10°C). Minimum and maximum water temperatures between 1996-1998 were 0°C (Dec 1998) and 27°C (May 1997), respectively. Scatter plots suggest strong fluctuations (≤ 5°C) in daily water temperatures and stronger fluctuations (≤ 10°C) in bi-weekly water temperatures throughout most of the data set. Harmonic regression analysis attributed 46% of temperature variance to interaction between 12.42 hour and 24 hour cycles, 44% of variance to 24 hour cycles, and 10% of variance to 12.42 hour cycles.

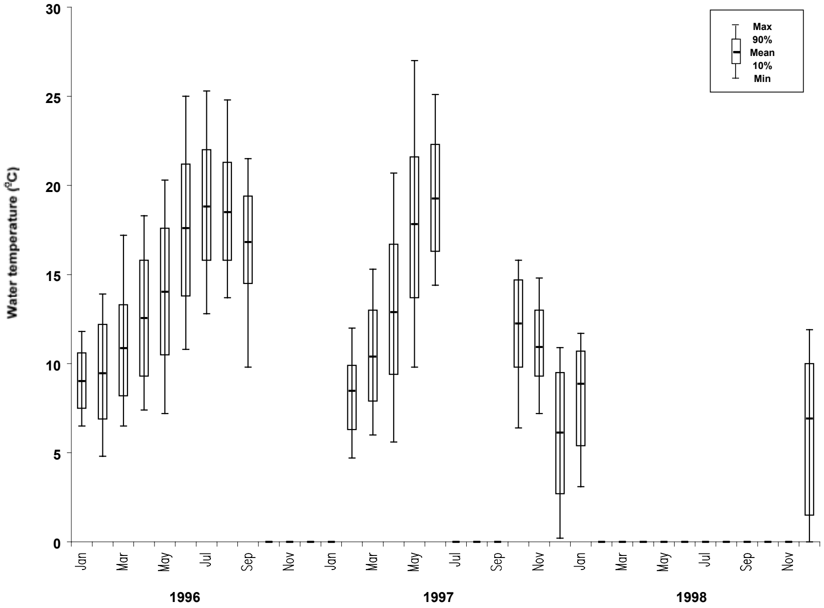


Figure 25. Water temperature statistics at Stengstacken Arm, 1996-1998.

Thirty-nine percent of annual salinity data were included in analyses (85% in 1996, 67% in 1997, and 8% in 1998). Mean salinity followed a seasonal cycle; however, very large variances (≥ 15 ppt) were associated with mean salinity readings throughout the data set (Figure 26). Mean salinity was greatest in summer 1996 (15-19 ppt) and least in winter 1996 and 1997 (≤ 5 ppt). Minimum salinity was always less than 2 ppt and maximum salinity was generally always greater than 20 ppt. Scatter plots suggest strong fluctuations in salinity equivalent to or in excess of annual variation in mean salinity (20 ppt). Harmonic regression analysis attributed 61% of salinity variance to 12.42 hour cycles, 24% of variance to interaction between 12.42 hour and 24 hour cycles, and 15% of variance to 24 hour cycles.

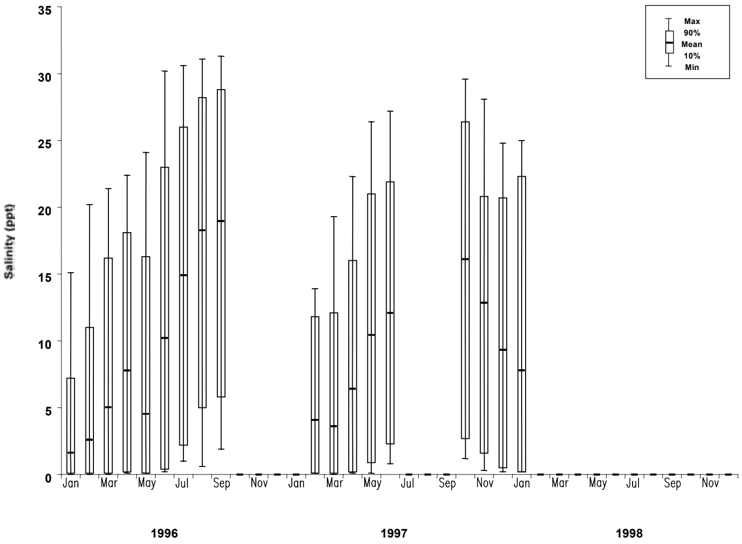


Figure 26. Salinity statistics at Stengstacken Arm, 1996-1998.

Twenty-nine percent of annual dissolved oxygen (% saturation) data were included in analyses (40% in 1996 and 1997, and 7% in 1998). Mean DO ranged from 69-99% saturation. Minimum and maximum DO were 0% saturation (Sep 1996) and 230.2% saturation (May 1997), respectively. Hypoxia was observed in one month (May 1997) and persisted for 2% of the first 48 hours post-deployment (Figure 27). Supersaturation was regularly observed in 1996 and 1997 and, when present, supersaturation persisted for 8.4% of the first 48 hours post-deployment on average. Scatter plots suggest minor fluctuations in percent saturation (20-40%) throughout the data set, with strong fluctuations (60-100%) observed for episodic events in summer 1996 and spring 1997. Harmonic regression analysis attributed 41% of DO variance to 24 hour cycles, 26% of DO variance to 12.42 hour cycles, and 33% of DO variance to interaction between 12.42 hour and 24 hour cycles.

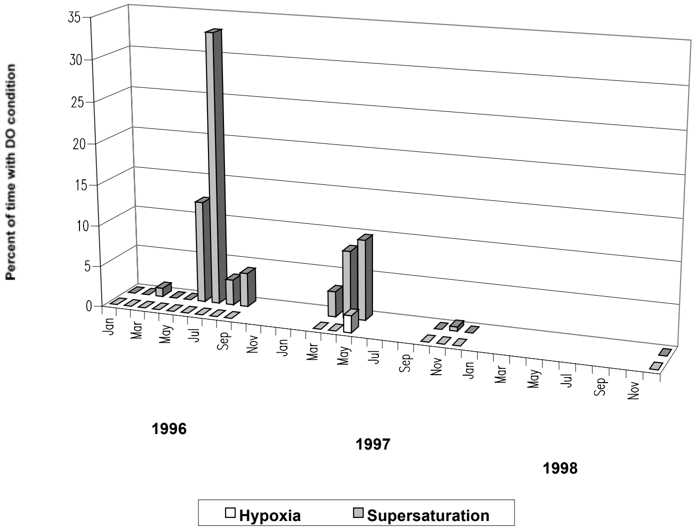


Figure 27. Dissolved oxygen extremes at Stengstacken Arm, 1996-1998.

South Slough, Winchester Arm (SOSWI)

Characterization

Winchester Arm is located in a tidal channel approximately 7.3 km west of the mouth of the South Slough estuary and serves as a management-treatment site. Winchester Arm is adjacent to the Winchester Tidelands Restoration Project, where dikes were removed from a 5.1 ha area in 1996 and 1998. Natural marsh (4.2 Ha) surrounds the project site. Winchester Arm is about 3 km long (mainstream linear dimension) and has an average depth of 6 m MHW. At the sampling site, the length is about 200 m, the width is about 30 m, and the depth is about 3 m MHW. Creek bottom habitats are predominantly soft mud colonized by *Zostera marina*. The dominant marsh vegetation near the sampling site is *Carx lyngbyei*, *Triglochin maritima*, *Distichlis spicata* and *Juncus* sp. Upland areas of the Sough Slough watershed are typical of the Coos Bay estuary watershed and include 30-50 year old mixed conifer forests, new and recovering clear-cut lands, and shrub covered slopes. The South Slough contains some stands of small trees over 80 years old and occasional specimens estimated to be well over 100 years old. Sitka spruce (*Picea sitchenis*), Douglas fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and Port Orford cedar (*Chamaecyparis lawsoniana*) are the predominant conifers found in the upland forests. Upland deciduous trees include red alder (*Alnus rubra*) and Pacific wax myrtle (*Myrica californica*), with big leaf maple (*Acer macrophyllum*) and willows (*Salix* sp.) common in riparian areas. Upland land use near the sampling site includes commercial forestry, dairy farming, and residential development. Activities that potentially impact the site include waste from seafood processing plants, septic systems, and shipyards.

Descriptive Statistics

Twenty-eight deployments were made at this site between Jan-Aug 1996, Mar-Jun 1997, Oct 1997-Jan 1998, and Mar, Jul, Nov 1998 (Figure 28). Mean deployment duration was 16.9 days. Four deployments (Aug 1996; Apr, Jun 1997; Jul 1998) were less than 10 days.

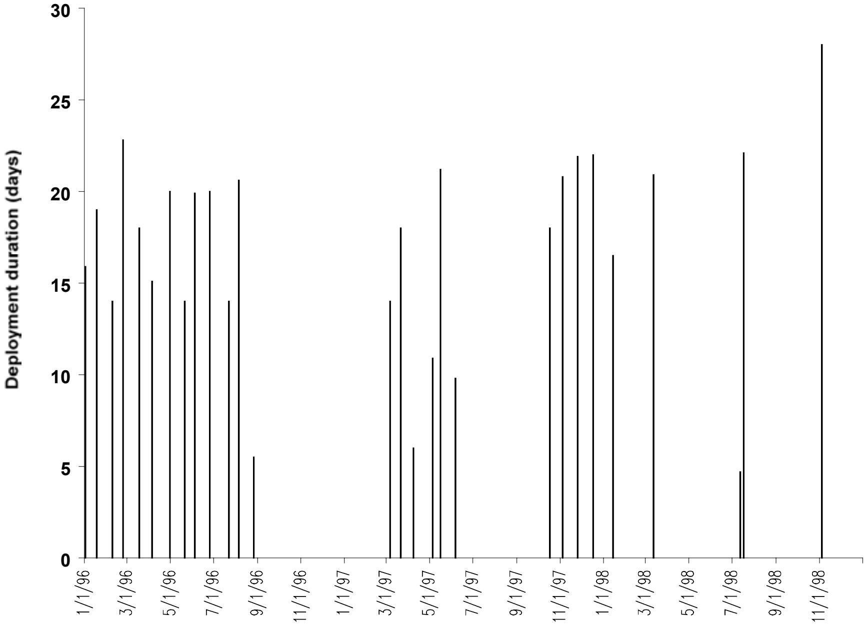


Figure 28. South Slough, Winchester Arm deployments (1996-1998).

Thirty-nine percent of annual depth data were included in analyses (53% in 1996, 39% in 1997, and 25% in 1998). Sensors were deployed at a mean depth of 1 m below the water surface. Scatter plots suggest strong fluctuations (≥ 2 m) in depth throughout the data set. Harmonic regression analysis attributed 67% of depth variance to 12.42 hour cycles, 17% of depth variance to 24 hour cycles, and 16% of depth variance to interaction between 12.42 hour and 24 hour cycles.

Forty-five percent of annual water temperature data were included in analyses (59% in 1996, 40% in 1997, and 35% in 1998). Water temperature followed a seasonal cycle, with mean water temperatures 8-10°C in winter and 17-19°C in summer (Figure 29). Minimum and maximum water temperatures were 1.2°C (Dec 1996) and 25°C (Jul 1998), respectively. Scatter plots suggest strong fluctuations (≤ 3°C) in daily water temperature and stronger fluctuations (≤ 7°C) in bi-weekly water temperature throughout the data set, particularly in spring and summer. Harmonic regression analysis attributed 39% of temperature variance to 24 hour cycles, 28% of temperature variance to 12.42 hour cycles, and 33% of temperature variance to interaction between 12.42 hour and 24 hour cycles.

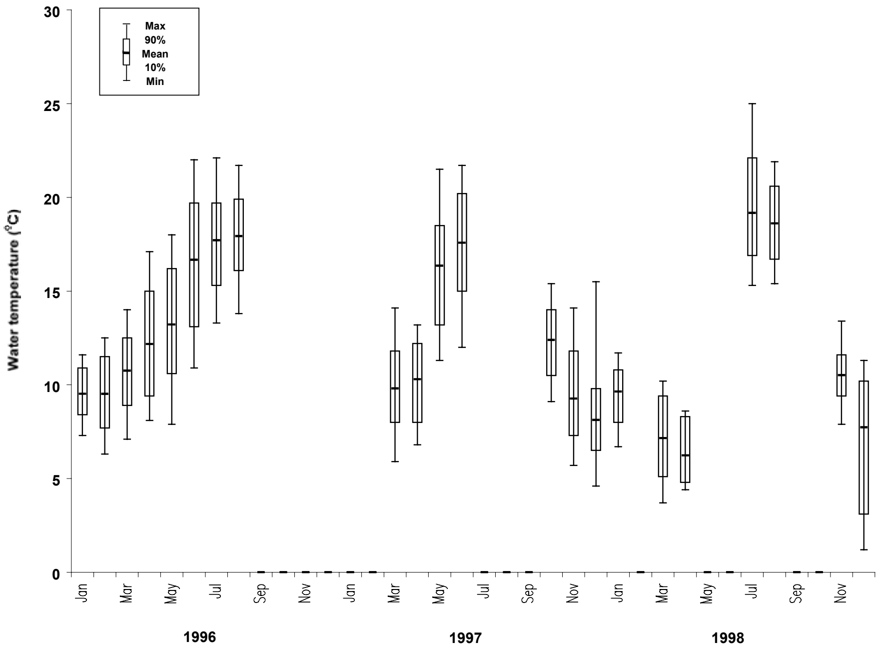


Figure 29. Water temperature statistics at Winchester Arm, 1996-1998.

Forty percent of annual salinity data were included in analyses (59% in 1996, 36% in 1997, and 25% in 1998). Mean salinity followed a seasonal cycle; however, large variances (≥ 20 ppt) were associated with mean salinity readings throughout the data set (Figure 30). Mean salinity was greatest (17-20 ppt) in summer and least in winter (< 5 ppt). Minimum salinity was always less than 2 ppt, except for Aug 1996 (4 ppt). Maximum salinity was always greater than 15 ppt, except for Apr 1998 (14.2 ppt). Scatter plots suggest bi-weekly fluctuations in salinity equivalent to or in excess of annual variation in mean salinity (15 ppt). Harmonic regression analysis attributed 55% of salinity variance to 12.42 hour cycles, 28% of salinity variance to interaction between 12.42 hour and 24 hour cycles, and 17% of salinity variance to 24 hour cycles.

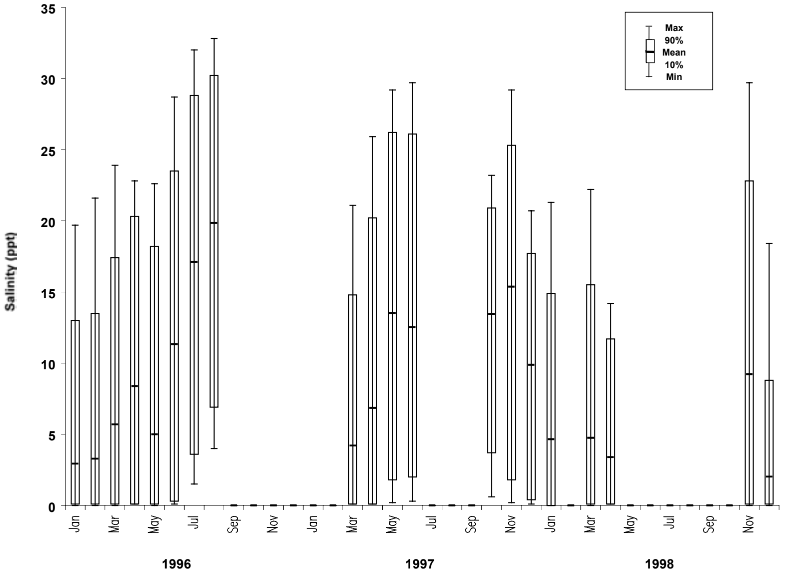


Figure 30. Salinity statistics at Winchester Arm, 1996-1998.

Thirty-one percent of annual dissolved oxygen (% saturation) data in 1996 and 17% of DO data in 1997 were included in analyses. Mean DO ranged from 64-111% saturation. Minimum and maximum DO was 10.9% saturation (Aug 1996) and 149% saturation (May 1997), respectively. Hypoxia was observed in one month (Jul 1996) and lasted 1% of the first 48 hours post-deployment (Figure 31). Supersaturation was observed in four months (May, Jul, Aug 1996 and May 1997) and, when present, supersaturation persisted for 14.2% of the first 48 hours post-deployment on average. Scatter plots suggest 20-40% fluctuation in percent saturation throughout the data set, with ≥100% fluctuation in Aug 1996 and Jun 1997. Harmonic regression analysis attributed 40% of DO variance to 24 hour cycles, 33% of DO variance to interaction between 12.42 hour and 24 hour cycles, and 27% of DO variance to 12.42 hour cycles.

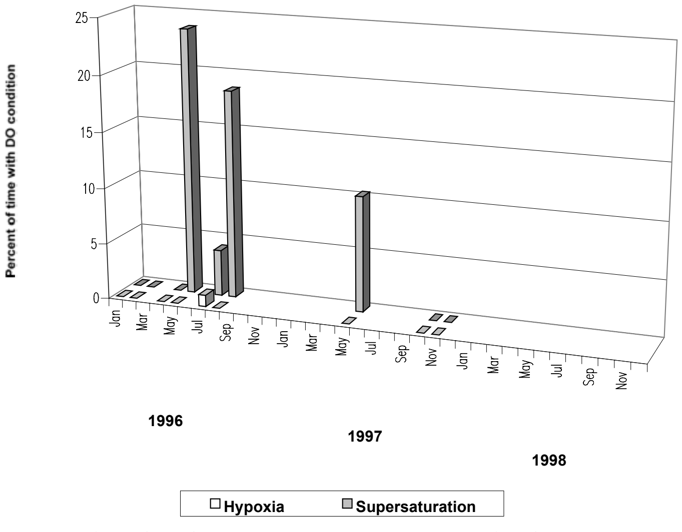
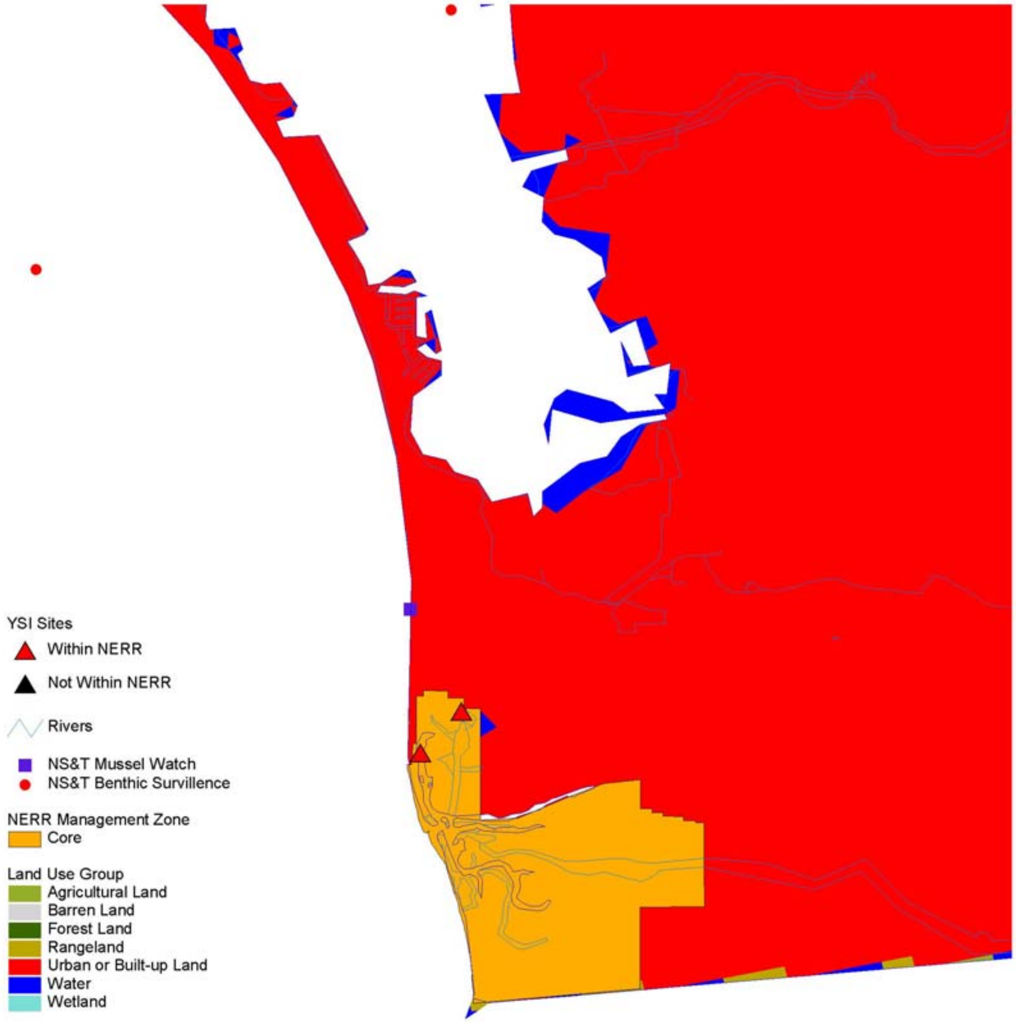


Figure 31. Dissolved oxygen extremes at Winchester Arm, 1996-1998.

Tijuana River



Tijuana River, Oneonta Slough (TJROS)

Characterization (Latitude = 32° 34' N; Longitude = 117° 09'W)
Tides at Oneonta Slough are semidiurnal and range from 2.3 m to –0.5 m. Oneonta Slough is 2 km long (mainstream linear dimension), has an average depth of 2 m MHW, and an average width of 20 m. At the sampling site, the water depth is 2 m MHW and the width is 20 m. Approximately 2/3 of the watershed is in Mexico. Creek bottom habitats are sand, with sparse bottom vegetation. The dominant marsh vegetation near the sampling site includes common pickleweed and Pacific cordgrass. The dominant upland vegetation includes maritime succulent scrub and inland sage scrub. Upland land use near the sampling site includes military airfields to the northeast and residential developments. Activities that potentially impact the site include storm drain runoff from a military airfield and adjacent residential areas, and occasional sewage spills (10-15 MGD) into the Tijuana River from Mexico.

Descriptive Statistics
Sixty-eight deployments were made at this site between Jan 1996 and Dec 1998, with equal coverage during all seasons, except Oct 1997 (Figure 32). Mean deployment duration was 13.3 days. Only three deployments (Jun, Oct 1996 and Nov 1998) were less than 10 days.

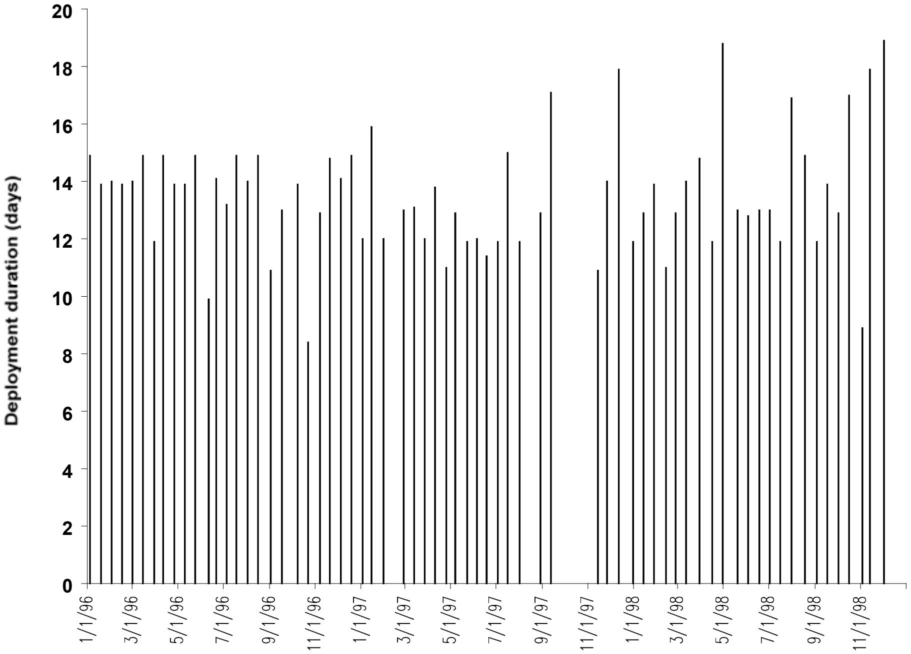


Figure 32. Tijuana River Estuary, Oneonta Slough deployments (1996-1998).

Eighty-three percent of annual depth data were included in analyses (87% in 1996, 71% in 1997, and 90% in 1998). Sensors were deployed at a mean depth of 0.8 m below the water surface and 0.3 m above the bottom sediment. Scatter plots suggest moderate fluctuations (0.75-1.25 m) in depth which gradually increased and decreased with an approximate 6 month periodicity (increase for three months, decrease for three months). Harmonic regression analysis attributed 56% of depth variance to interaction between 12.42 hour and 24 hour cycles, 21% of depth variance to 24 hour cycles, and 23% of depth variance to 12.42 hour cycles.

Eighty-four percent of annual water temperature data were included in analyses (91% in 1996, 71% in 1997, and 90% in 1998). Mean water temperature followed a seasonal cycle; however, large variances were associated with mean values throughout the data set (Figure 33). Mean water temperatures were 14-15°C in winter and 21-23°C in summer. Minimum and maximum water temperatures between 1996-1998 were 7.5°C (Dec 1996, 1998) and 30.3°C (Aug 1996), respectively. Scatter plots suggest strong and abrupt fluctuations (4-10°C, occasionally >10°C) in both daily and bi-weekly temperature, with strongest fluctuations observed in spring and summer. Harmonic regression analysis attributed 72% of temperature variance to interaction between 12.42 hour and 24 hour cycles, 20% of variance to 24 hour cycles, and 8% of variance to 12.42 hour cycles.

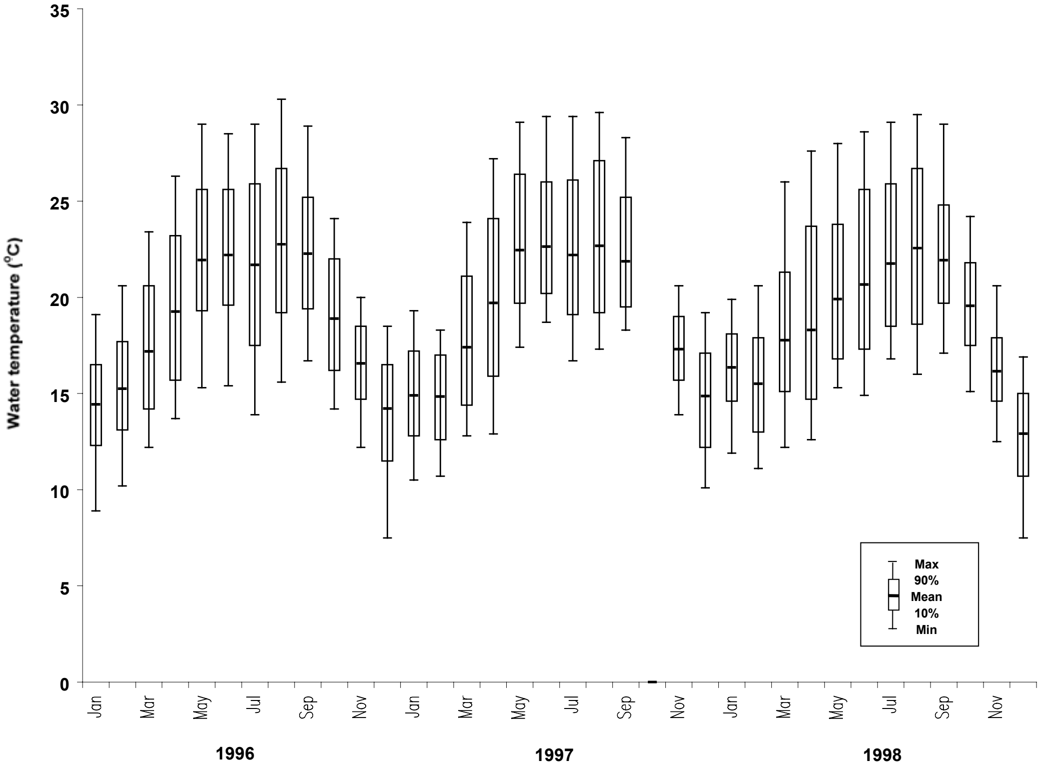


Figure 33. Water temperature statistics at Oneonta Slough, 1996-1998.

Eighty-two percent of annual salinity data were included in analyses (87% in 1996, 71% in 1997, and 90% in 1998). Mean salinity followed a seasonal cycle in 1996 and 1998; however, large variances were associated with mean salinity in winter and spring (Figure 34). Mean salinity was greatest in summer and least in winter. Mean summer salinity was greater in 1996 (35-36 ppt) than in 1997-1998 (30-31 ppt). Mean winter salinity in 1996 and 1997 were similar (28-32 ppt) and substantially less variable than mean winter salinity in 1998 (14-28 ppt). Minimum and maximum salinity between 1996-1998 was 0.3 ppt (Feb 1998) and 40.2 ppt (Sep 1996), respectively. Scatter plots suggest moderate fluctuations (≤ 5 ppt) in daily and bi-weekly salinity, with strong fluctuations (≥ 15 ppt) observed during episodic events in 1996 (Feb, Mar, Nov), 1997 (Jan, Sep, Dec), and 1998 (Jan-May). Harmonic regression analysis attributed 51% of salinity variance to interaction between 12.42 hour and 24 hour cycles, 19% of variance to 12.42 hour cycles, and 30% of variance to 24 hour cycles.

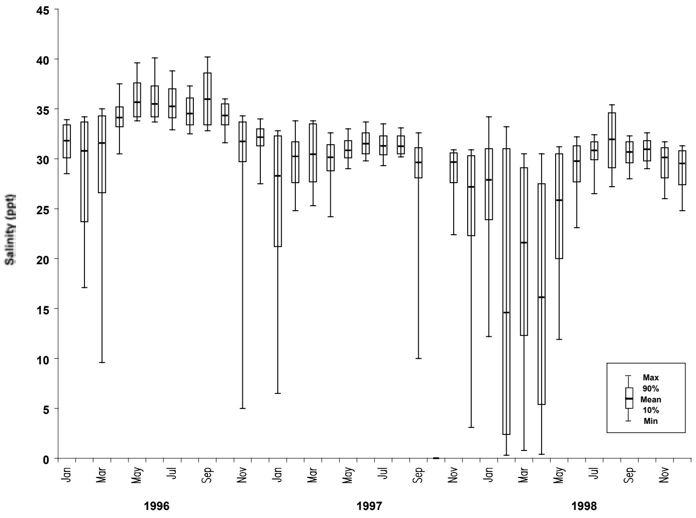


Figure 34. Salinity statistics at Oneonta Slough, 1996-1998.

Seventy-two percent of annual dissolved oxygen (% saturation) data were included in analyses (76% in 1996, 58% in 1997, and 80% in 1998). Mean DO ranged from 34-103% saturation and followed a seasonal cycle, with greatest DO in fall/winter and least in spring/summer. Minimum DO regularly approached 0% saturation in spring and summer 1996-1998 and in fall 1998. Maximum DO was typically < 200% saturation, except for Mar-Jun 1998 when maximum DO ranged from 300-450% saturation. Hypoxia was regularly observed between 1996-1998 and, when present, hypoxia persisted for 18% of the first 48 hours post-deployment on average (Figure 35). Supersaturation was infrequently observed in 1996 and 1997, but regularly observed in 1998. When present, supersaturation persisted 11.5% of the first 48 hours post-deployment on average. Scatter plots suggest strong fluctuations (≥ 80%) in percent saturation throughout the data set, with fluctuations > 400% saturation observed in May-Jun 1998. Harmonic regression analysis attributed 61% of DO variance to interaction between 12.42 hour and 24 hour cycles, 29% of DO variance to 24 hour cycles, and 10% of DO variance to 12.42 hour cycles.

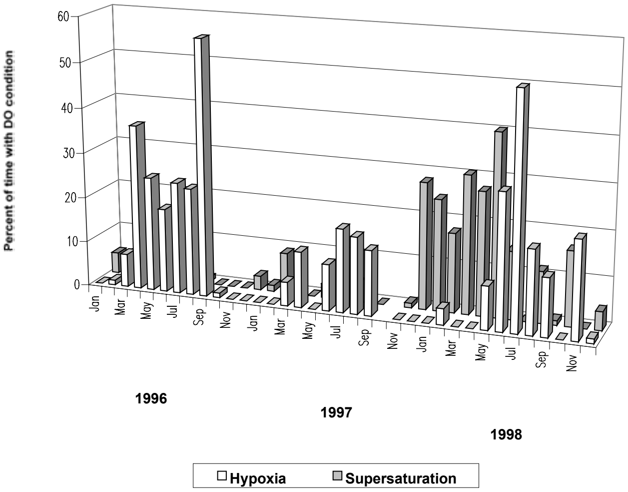


Figure 35. Dissolved oxygen extremes at Oneonta Slough, 1996-1998.

Tijuana River, Tidal Linkage (TJRTL)

Characterization (Latitude = 32°34'N; Longitude =117°09'W)
Tides at the tidal linkage site are semidiurnal and range from 2.3 m to -0.5 m. The Tijuana River is 2 km long (mainstream linear dimension), has an average depth of 2 m at MHW, and an average width of 5 m. The Tidal Linkage site is located in an artificial channel (3 m wide, 400 m long, with average depth 2 m at MHW) that was last dredged out in 1998. At the sampling site the depth is 2 m MHW and the width is 20 m. Creek bottom habitats are predominantly sand and mud with sparse bottom vegetation. The dominant upland vegetation includes maritime succulent scrub and inland sage scrub. Upland land use near the sampling site military airfields, and residential developments.

Descriptive Statistics
Thirty-three deployments were made at this site between May 1997 and Dec 1998, with equal coverage during all months, except Sep 1997 (Figure 36). Mean deployment duration was 13.5 days. Only two deployments (Apr, Nov 1998) were less than 10 days.

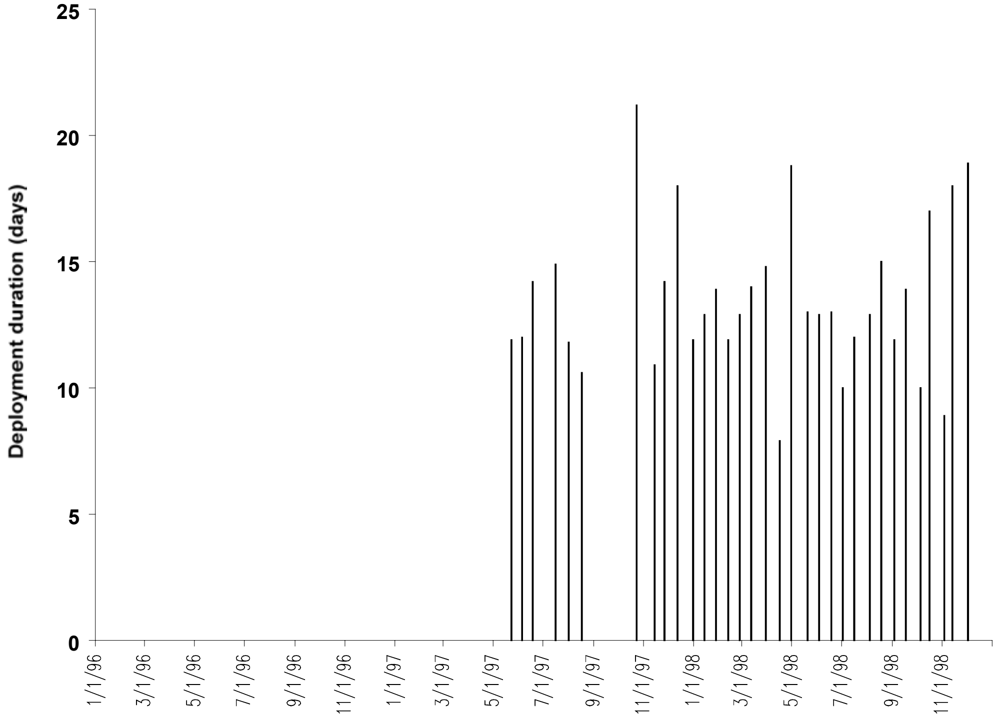


Figure 36. Tijuana River Estuary, Tidal Linkage deployments (1996-1998).

Thirty-five percent of annual depth data in 1997 and 85% of annual depth data in 1998 (85%) were included in analyses. Sensors were deployed at a mean depth of 0.4 m below the water surface and 0.3 m above the bottom sediment. Scatter plots suggest moderate fluctuations (≤ 1 m) in depth throughout the data set, except Nov 1997 – Feb 1998 when depth fluctuations were 1.2 to 1.7 m. Harmonic regression analysis attributed 45% of depth variance to interaction between 12.42 hour and 24 hour cycles, 24% of variance to 24 hour cycles, and 31% of variance to 12.42 hour cycles.

Thirty-eight percent of water temperature data in 1997 and 85% of annual water temperature data in 1998 were included in analyses. Mean water temperature followed a seasonal cycle, with mean water temperatures 13-16°C in fall/winter and 23-25°C in summer (Figure 37). Minimum and maximum water temperatures were 7.5°C (Dec 1998) and 32.1°C (Apr-May 1998), respectively. Scatter plots suggest strong fluctuations (4-10°C, occasionally >10°C) in daily and bi-weekly water temperature throughout the data set, with strongest variation in spring and summer. Harmonic regression analysis attributed 59% of water temperature variance to interaction between 12.42 hour and 24 hour cycles, 30% of temperature variance to 24 hour cycles, and 11% of temperature variance to 12.42 hour cycles.

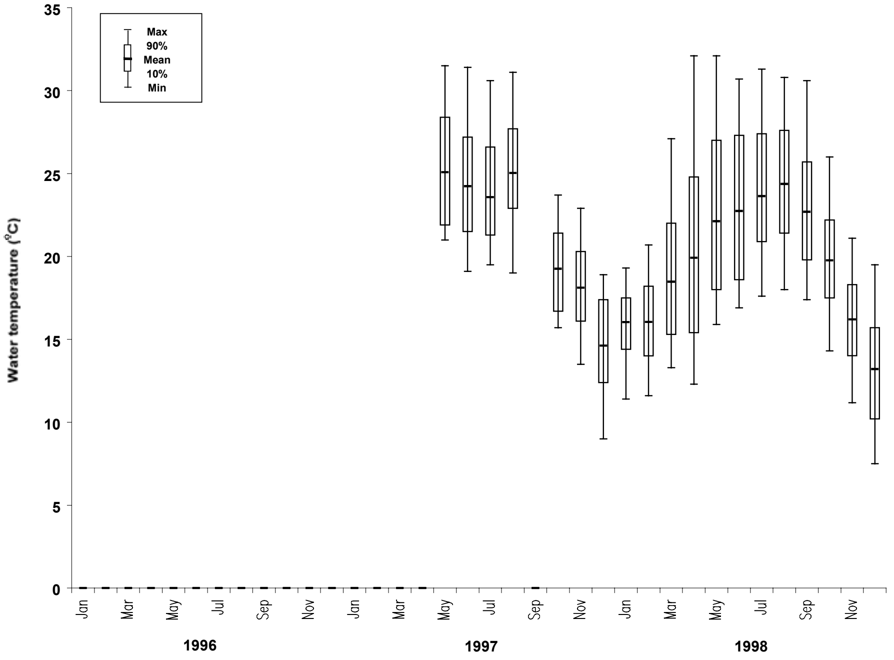


Figure 37. Water temperature statistics at Tidal Linkage, 1996-1998.

Thirty-eight percent of annual salinity data in 1997 and 81% of annual salinity data in 1998 were included in analyses. Mean salinity was 25-31 ppt throughout the data set, except between Feb-May 1998 when mean salinity was 13-22 ppt (Figure 38). Minimum and maximum salinity between May 1997 and Dec 1998 was 0.4 ppt (Feb 1998) and 35.2 ppt (Jun 1998), respectively. Scatter plots suggest moderate fluctuations (≤ 5 ppt) in daily and bi-weekly salinity between May-Nov 1997, strong fluctuations (≤ 10 ppt) between Jun-Dec 1998, and strongest fluctuations (10-25 ppt) during episodic events in Dec 1997 and Feb-May 1998. Harmonic regression analysis attributed 59% of salinity variance to interaction between 12.42 hour and 24 hour cycles, 24% of salinity variance to 24 hour cycles, and 17% of salinity variance to 12.42 hour cycles.

Thirty-eight percent of dissolved oxygen (% saturation) data in 1997 and 80% of DO data in 1998 were included in analyses. Mean DO ranged from 38-96% saturation. Mean DO followed a seasonal cycle; however, very large variances (> 250%) were associated with mean DO in May-Jun 1997 and most of 1998. Mean DO was 84-96% saturation between Oct 1997 – Apr 1998 (except Feb 1998) and 38-77% saturation otherwise. Minimum and maximum DO was 0.2% saturation (Apr 1998) and 462% saturation (Apr 1998), respectively. Hypoxia was observed in May-Aug 1997, Jan 1998, and Apr-Nov 1998 and, when present, hypoxia persisted for 24.8% of the first 48 hours post-deployment on average (Figure 39). Supersaturation was observed during every month with data between May 1997 and Nov 1998 and, when present, supersaturation persisted for 19.2% of the first 48 hours post-deployment on average. Scatter plots suggest strong fluctuations (80-100%) in percent saturation throughout the data set, with strongest fluctuations (> 250%) observed during episodic events in Jun-Aug 1997 and Apr-Oct 1998. Harmonic regression analysis attributed 57% of DO variance to interaction between 12.42 hour and 24 hour cycles, 35% of variance to 24 hour cycles, and 8% of variance to 12.42 hour cycles.

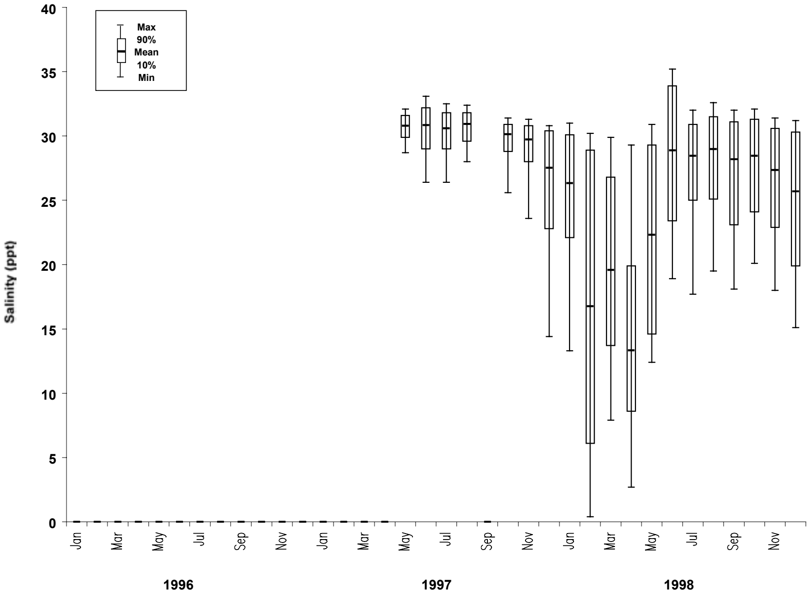


Figure 38. Salinity statistics at Tidal Linkage, 1996-1998.

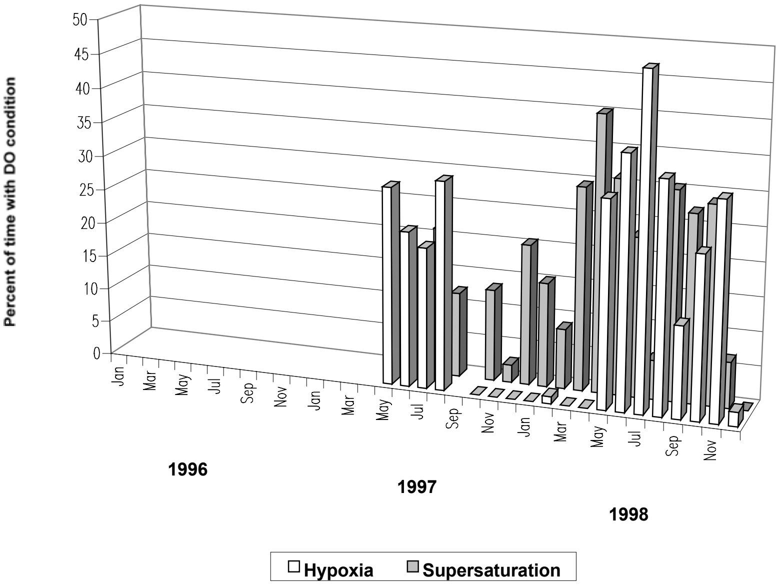
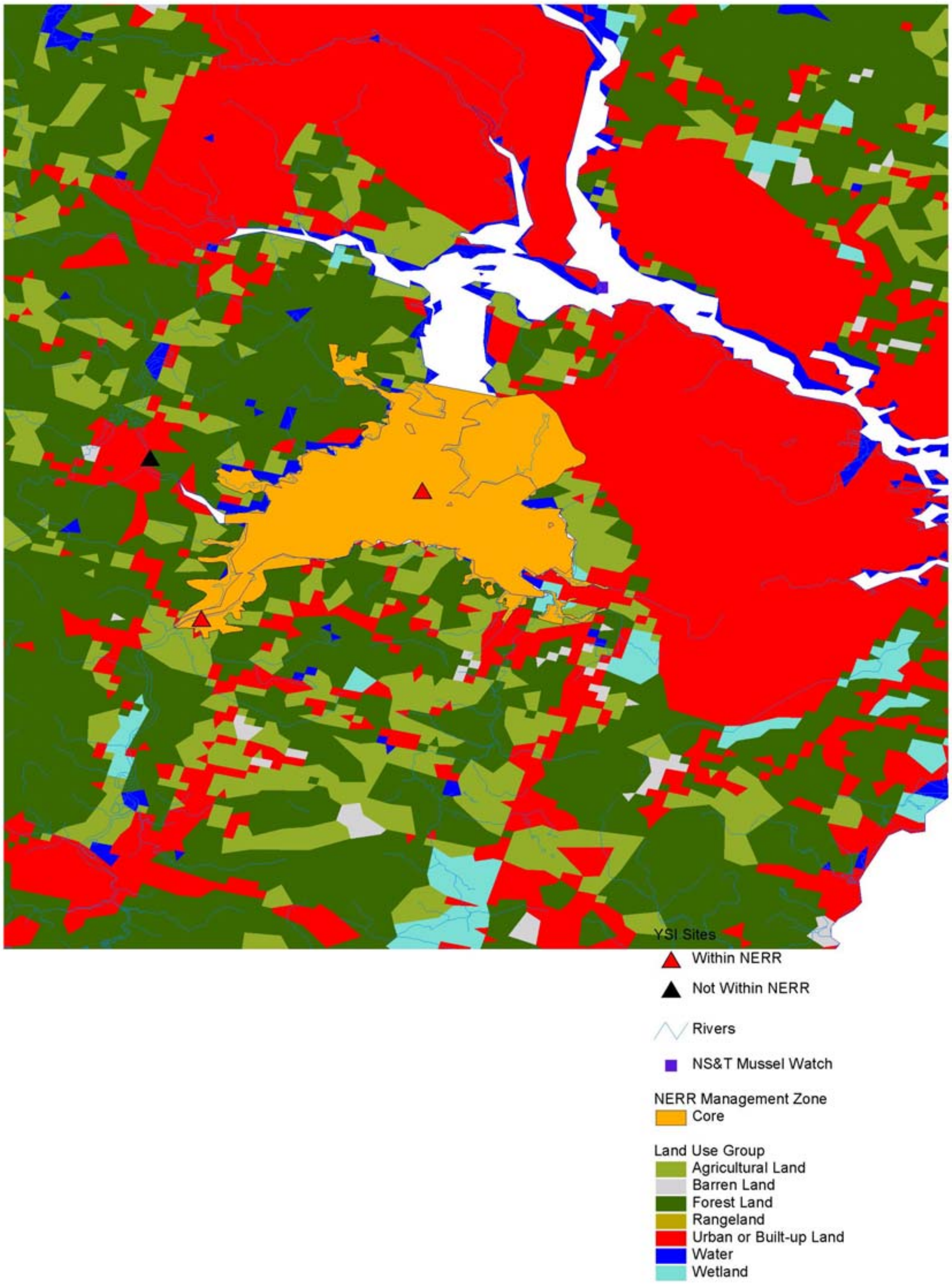


Figure 39. Dissolved oxygen extremes at Tidal Linkage, 1996-1998.

Great Bay


YSI Sites
Within NERR
Not Within NERR
Rivers
NS&T Mussel Watch
NERR Management Zone
Core
Land Use Group
Agricultural Land
Barren Land
Forest Land
Rangeland
Urban or Built-up Land
Water
Wetland

Great Bay Buoy (GRBGB)

Characterization (Latitude = 43°04' 20" N; Longitude = 70°52' 10" W)
Tides in Great Bay are semidiurnal and average 2.1 m in range. The Bay has an average depth of 5 m MHW. At the sampling site, the depth is 9.2 m MHW. Creek bottom habitats are primarily mud and rock, without any bottom vegetation. Salt marsh vegetation in Great Bay is predominantly *Spartina alterniflora* (smooth cordgrass) and *S. patens* (salt meadow hay). A variety of other plant species are found in Great Bay marshes, including eelgrass (*Zostera marina*) which occurs (sometimes extensively) throughout the Great Bay Estuary. Annual and perennial salt marsh asters are found in the Reserve's brackish salt marsh areas. The region is characterized as a transition zone between the deciduous forest to the south and the coniferous forest to the north. Common tree species within the area include white pine, red oak, red pine, hemlock, red maple, quaking aspen, and shagbark hickory. This site is relatively un-impacted by anthropogenic disturbances.

Descriptive Statistics
Thirty-eight deployments were made between Apr-Nov in 1996, 1997, and 1998 (Figure 40). Mean deployment duration was 17.1 days. One deployment (Aug 1997) was less than 10 days.

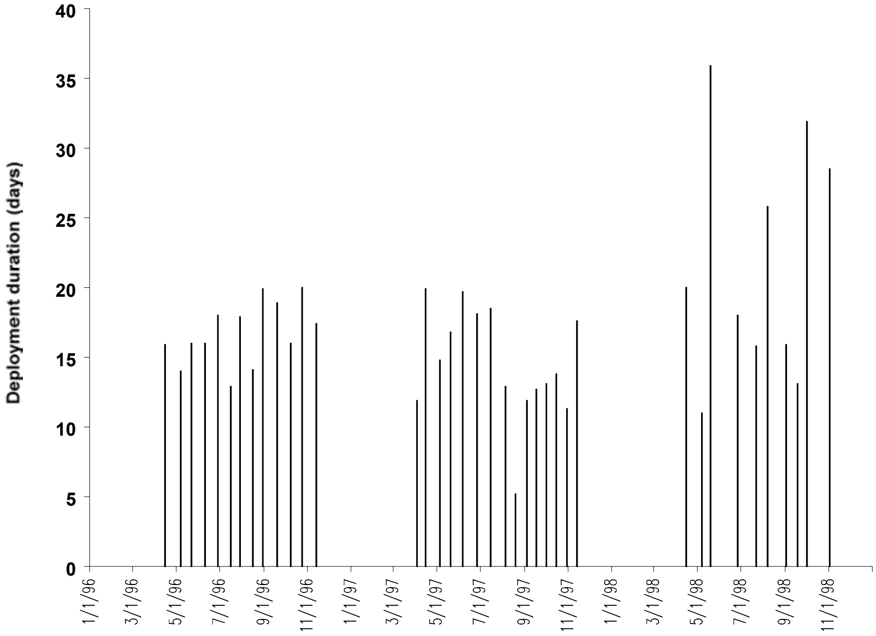


Figure 40. Great Bay Buoy deployments (1996-1998).

Fifty-seven percent of annual depth data in 1996 and 59% of annual depth data in 1997 were included in analyses; no depth data were collected in 1998. The instrument was deployed 1 m below a floating buoy at a mean water depth of 6.5 m MLW so that the depth of the instrument was 5.5-8.2 m above the bottom sediment. Strong fluctuation (2 m) in depth were evident from scatter plots for both daily and bi-weekly intervals; however, amplitude of these fluctuations remained constant across seasons. Harmonic regression analysis attributed 93% of depth variance to 12.42 hour cycles, 3% of variance to 24 hour cycles, and 4% of variance to interaction between 12.42 hour and 24 hour cycles.

Fifty-eight percent of annual water temperature data were included in analyses (58% in 1996 and 1998 and 59% in 1997). Water temperature followed a seasonal cycle; however, annual minimum temperatures were not known because no data were collected between Dec-Mar in all years (Figure 41). Mean water temperature was typically 6-10°C in Apr and Nov and 20-21°C in summer. Minimum and maximum temperatures between Apr-Nov 1996-1998 were 2.2°C (Nov 1997) and 25.3°C (Jul 1997), respectively. Scatter plots suggest moderate fluctuations (1-2°C) in daily water temperature, with stronger fluctuations (3-10°C) in bi-weekly water temperatures, particularly in spring. Harmonic regression analysis attributed 74% of temperature variance to 12.42 hour cycles, 11% of variance to 24 hour cycles, and 15% of variance to interaction between 12.42 hour and 24 hour cycles.

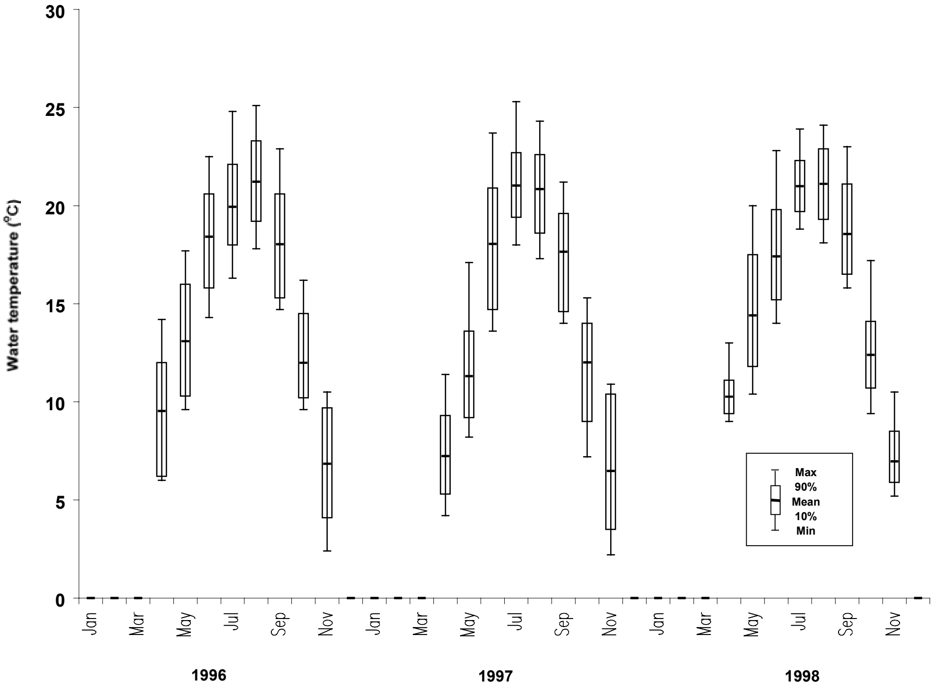


Figure 41. Water temperature statistics for Great Bay Buoy, 1996-1998.

Fifty-eight percent of annual salinity data were included in analyses (58% in 1996 and 1998 and 59% in 1997). Mean salinity followed a seasonal cycle, but large variances were associated with mean salinity in spring and fall (Figure 42). Mean salinity was typically 26-28 ppt in summer and 15-18 ppt in spring and fall. Scatter plots suggest moderate fluctuations (1-3 ppt) in daily and bi-weekly salinity in summer; however, strong salinity fluctuations (≥10 ppt) were observed regularly in spring and fall and during episodic events in summer. Harmonic regression analysis attributed 90% of salinity variance to 12.42 hour cycles, 4% of salinity variance to 24 hour cycles, and 6% of salinity variance to interaction between 12.42 hour and 24 hour cycles.

Fifty-six percent of annual dissolved oxygen (% saturation) data were included in analyses (52% in 1996, 59% in 1997, and 58% in 1998). Mean dissolved oxygen was typically 80-110% saturation; mean DO less than 80% saturation was never observed and mean DO greater than 120% saturation was only observed on one occasion (Jun 1996). Mean DO was slightly less (80-90% sat) in summer than in spring and fall (90-110%); however, large variances were associated with mean DO in the summer. Hypoxia was never observed (Figure 43). Supersaturation was observed in five months and, when present, supersaturation persisted 49% (May 1998), 13-17% (Jul 1996, Sep 1998), and ≤1%

(Apr, Jun 1997) of the first 48 hours post-deployment. Scatter plots suggest daily and bi-weekly fluctuations in percent saturation were typically 20% in spring and fall, but regularly exceeded 40% in summer. Harmonic regression analysis attributed 57% of DO variance to interaction between 12.42 hour and 24 hour cycles, 28% of variance to 24 hour cycles, and 15% of variance to 12.42 hour cycles.

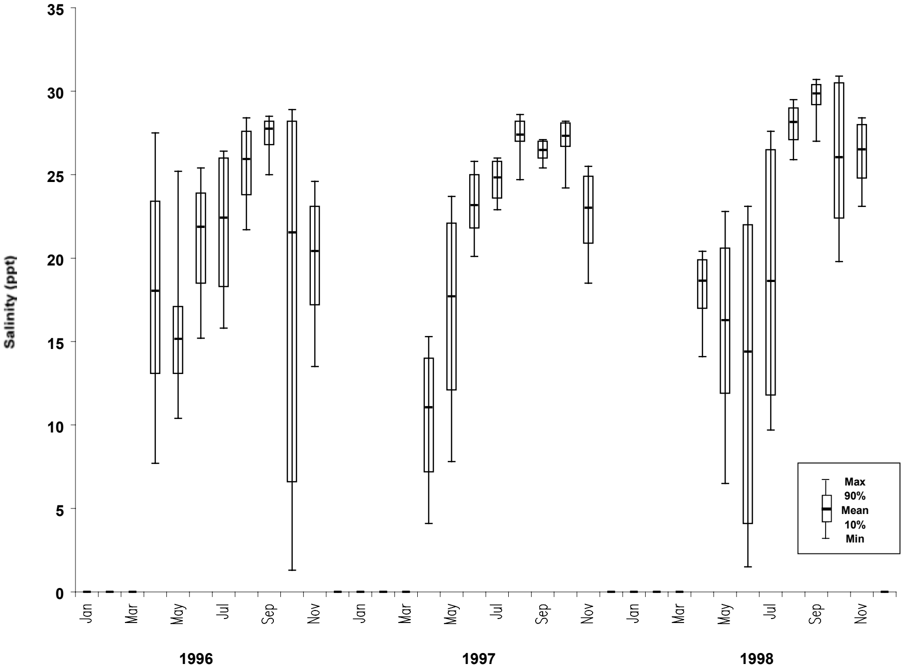


Figure 42. Salinity statistics for Great Bay Buoy, 1996-1998.

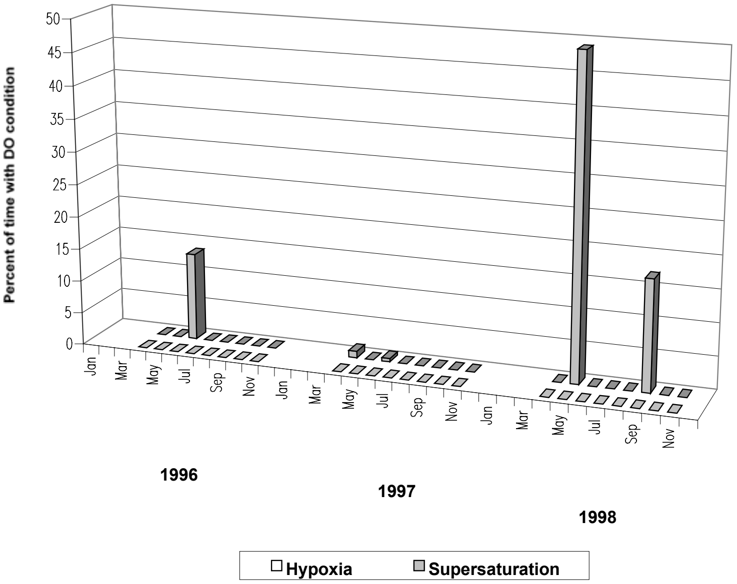


Figure 43. Dissolved oxygen extremes at Great Bay Buoy, 1996-1998.

Photosynthesis/Respiration

Over two thirds (69%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and were used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 15). Instrument drift during the duration of the deployments was not a significant problem at this site. Total respiration only slightly exceeded gross production at the Great Bay Buoy; thus, the net ecosystem metabolism and P/R ratio indicated that this is a site where production and respiration are in balance (Figure 44). Temperature was significantly ($p<0.05$) correlated with gross production, total respiration and net ecosystem metabolism. Gross production and respiration increased as temperature increased, while net ecosystem metabolism became more heterotrophic as temperatures increased. Salinity was significantly ($p<0.05$) correlated with gross production, respiration and net ecosystem metabolism. Gross production and respiration were higher at higher salinity, while net ecosystem metabolism became more autotrophic at higher salinity. Thus, the metabolic rates generally followed a seasonal pattern with the lowest rates during the early spring and late fall when temperature and salinity were low and the highest rates during summer months, although summer rates could be highly variable.

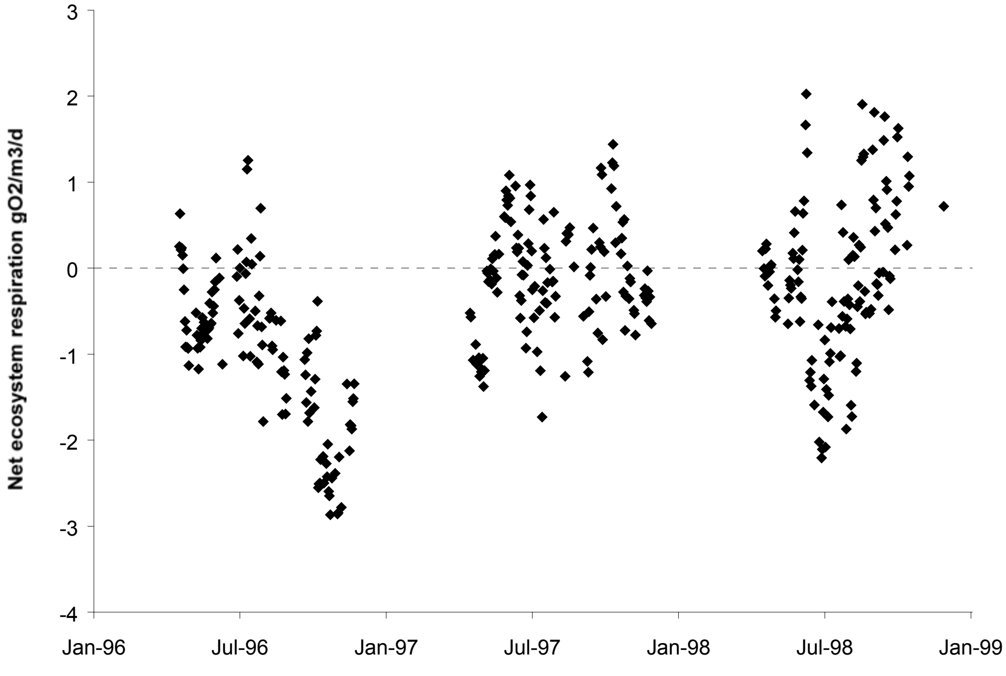


Figure 44. Net metabolism at Great Bay Buoy, 1996-1998.

Table 15. Summary of metabolism data and statistics at Great Bay Buoy, 1996-1998.

Great Bay Buoy	mean	s.e.
Water depth (m)	6.5	
Net production gO_2/m3/d	0.41	0.02
Gross production gO_2/m3/d	1.05	0.05
Total respiration gO_2/m3/d	1.09	0.04
Net ecosystem metabolism g O_2/m3/d	-0.04	0.02
Net ecosystem metabolism g C/m2/y	200	
P/R	0.97	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	69%	
Paired t-test on gross production and total respiration	$p < 0.04$	
Correlation coefficient	Temperature	Salinity
Gross production	0.44	0.29
Total respiration	0.49	0.25
Net ecosystem metabolism	-0.06	0.14

Great Bay, Squamscott River (GRBSQ)

Characterization (Latitude = 43°02'30" N; Longitude = 70°55'20" W)
Tides in Squamscott River are semidiurnal with an average range of 2.1 m. At the sampling site, the depth is 6.2 m at maximum high water. Creek bottom habitats are predominantly mud, with no bottom vegetation. The dominant marsh vegetation near the sampling site is *Spartina alterniflora* and *S. patens*. Upland habitats include salt marsh, farmland, and riparian. Activities that potentially impact the site include urban stormwater runoff, two municipal wastewater treatment plants, agriculture, and residential septic systems.

Descriptive Statistics
Eighteen deployments were made at this site between Jul-Nov 1997 and Apr-Nov 1998 (Figure 45). Mean deployment duration was 18.3 days and no deployments were less than 10 days.

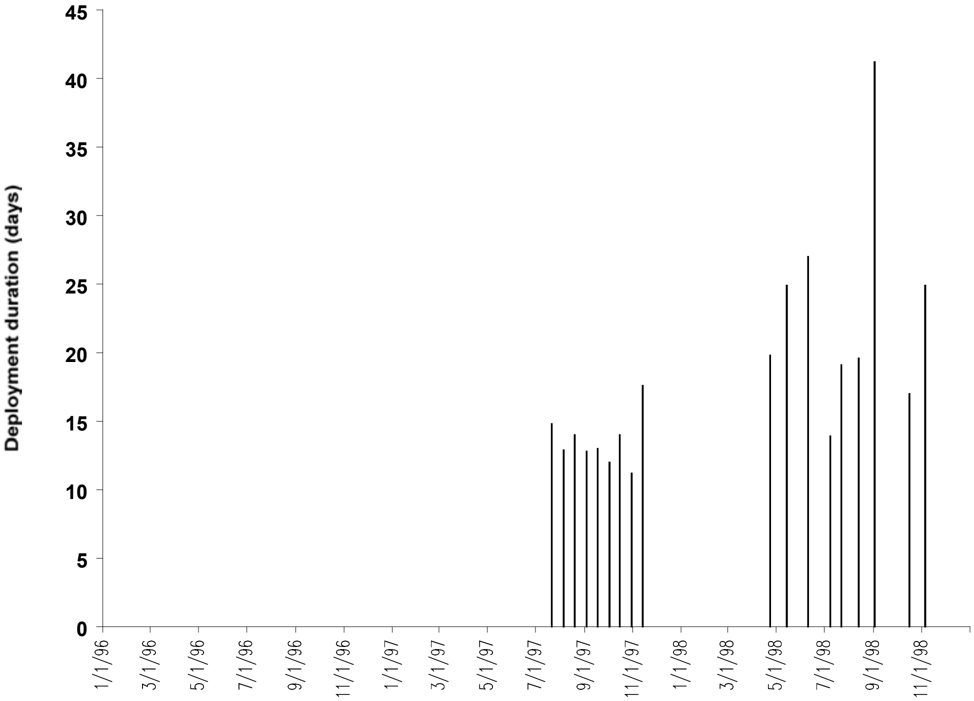


Figure 45. Great Bay, Squamscott River deployments (1996-1998).

Thirty-four percent of annual depth data in 1997 and 48% of annual depth data in 1998 were included in analyses. Sensors were deployed at a mean depth of 3.5 m below the water surface and 0.5 m above the bottom sediment. Strong fluctuations (2-4 m) in depth were evident from scatter plots, with consistent amplitude throughout the data set. Between Jul-Nov 1998, sensors were deployed shallower (0.5-3 m) than during Jul-Nov 1997 and Apr-Jun 1998 (3-6 m). Harmonic regression analysis attributed 93% of depth variance to 12.42 hour cycles, 3% of depth variance to 24 hour cycles, and 4% of depth variance to interaction between 12.42 hour and 24 hour cycles.

Thirty-four percent of annual water temperature data in 1997 and 48% of annual water temperature data in 1998 were included in analyses. Water temperature followed a seasonal cycle; however because no data were collected in winter, true annual minimum temperatures were not known (Figure 46). Mean water temperatures were 22-23°C in summer, 11-12°C in Apr and Oct and 5-6°C in Nov. Minimum and maximum water temperatures were 0.8°C (Nov 1998) and 27°C (Jul 1998), respectively. Scatter plots suggest moderate fluctuations (1-2°C) in daily water temperature, with strong temperature fluctuations (3-10°C) at bi-weekly intervals. Harmonic regression analysis attributed 38% of temperature variance to interaction between 12.42 hour and 24 hour cycles, 29% of temperature variance to 12.42 hour cycles, and 33% of temperature variance to 24 hour cycles.

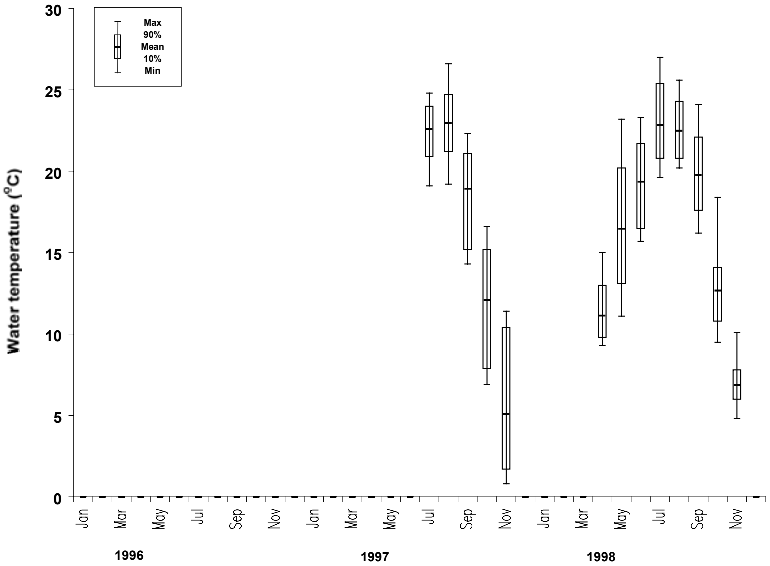


Figure 46. Water temperature statistics for Squamscott River, 1996-1998.

Thirty-four percent of annual salinity data in 1997 and 48% of annual salinity data in 1998 were included in analyses. Salinity followed a seasonal cycle; however, large variances (≥10 ppt) were associated with mean salinity readings throughout most of the data (Figure 3). Mean salinity was greatest (20-26 ppt) in summer/fall and least in spring (4-6 ppt). Mean salinity was higher than usual in fall 1997 and lower than usual in summer 1998. Minimum and maximum salinity observed was 0 ppt (May-Jun 1998) and 29.9 (Aug-Sep 1998), respectively. Scatter plots suggest strong fluctuations (5-10 ppt) in daily and bi-weekly salinity between Jul-Oct 1997 and Aug-Sep 1998. Strongest fluctuations (10-20+ ppt) in daily and bi-weekly salinity occurred in Nov 1997, May-Jul 1998, and Oct-Nov 1998. Harmonic regression analysis attributed 82% of salinity variance to 12.42 hour cycles and 9% of salinity variance each to 24 hour cycles and interaction between 12.42 hour and 24 hour cycles.

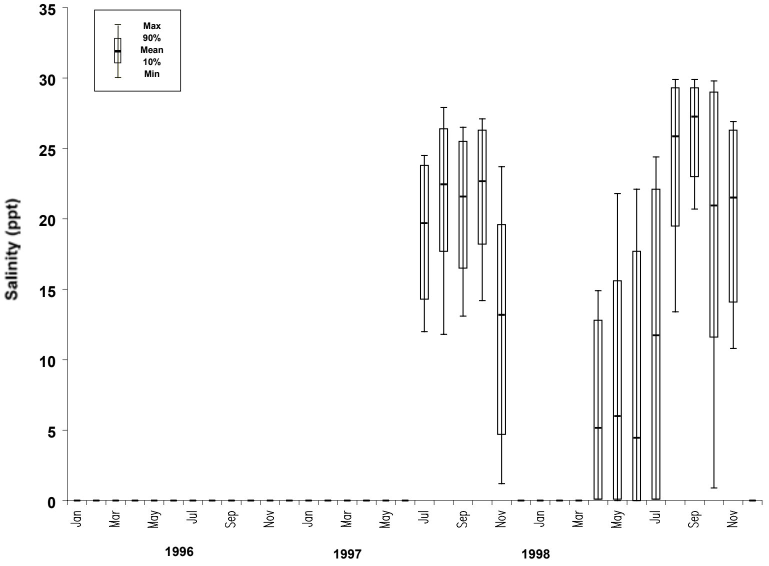


Figure 47. Salinity statistics for Squamscott River, 1996-1998.

Thirty-four percent of annual dissolved oxygen (% saturation) data in 1997 and 41% of annual dissolved oxygen data in 1998 were included in analyses. Mean dissolved oxygen ranged from 88-101% saturation. Minimum and maximum percent saturation was 45.2% (Aug 1997) and 147.3% (Oct 1997), respectively. Hypoxia was never observed (Figure 48). Supersaturation was only observed in two months (Oct 1997, Jun 1998) and, when present, supersaturation persisted for less than 4% of the first 48 hours post-deployment on average. Scatter plots suggest that percent saturation fluctuated by 20-60% over daily and bi-weekly intervals. Harmonic regression analysis attributed 59% of DO variance to 12.42 hour cycles, 22% of DO variance to 24 hour cycles, and 19% of DO variance to interaction between 12.42 hour and 24 hour cycles.

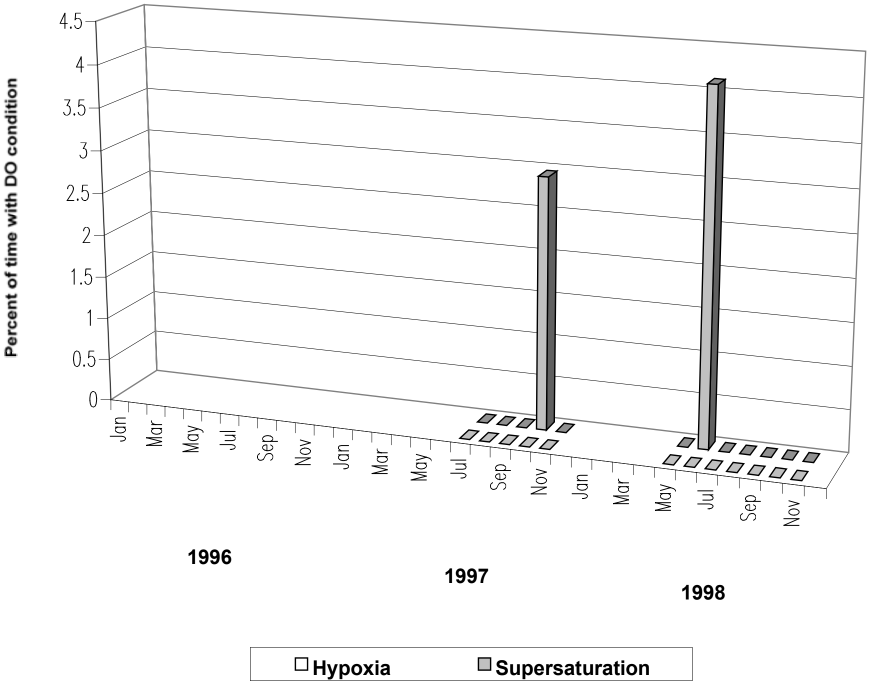


Figure 48. Dissolved oxygen extremes at Squamscott River, 1996-1998.

Photosynthesis/Respiration

Over three quarters (80%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and was used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 16). Instrument drift during the duration of the deployments was not a significant problem at this site. Total respiration exceeded gross production at Squamscott River; thus, the net ecosystem metabolism and P/R ratio indicated that this is a heterotrophic site (Figure 49). Temperature was significantly ($p<0.05$) correlated with gross production and total respiration, but not net ecosystem metabolism. Gross production and respiration increased as temperature increased. Salinity was not significantly ($p<0.05$) correlated with any metabolic measurement.

Table 16. Summary of metabolism data and statistics at Squamscott River, 1996-1998.

Squamscott River	mean	s.e.
Water depth (m)	3.5	
Net production $gO_2/m3/d$	0.48	0.04
Gross production $gO_2/m3/d$	1.46	0.10
Total respiration $gO_2/m3/d$	1.72	0.11
Net ecosystem metabolism $g O_2/m3/d$	-0.27	0.03
Net ecosystem metabolism g C/m2/y	55	
P/R	0.85	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	80	
Paired t-test on gross production and total respiration	$p < 0.001$	
Correlation coefficient	Temperature	Salinity
Gross production	0.39	ns
Total respiration	0.40	ns
Net ecosystem metabolism	ns	ns

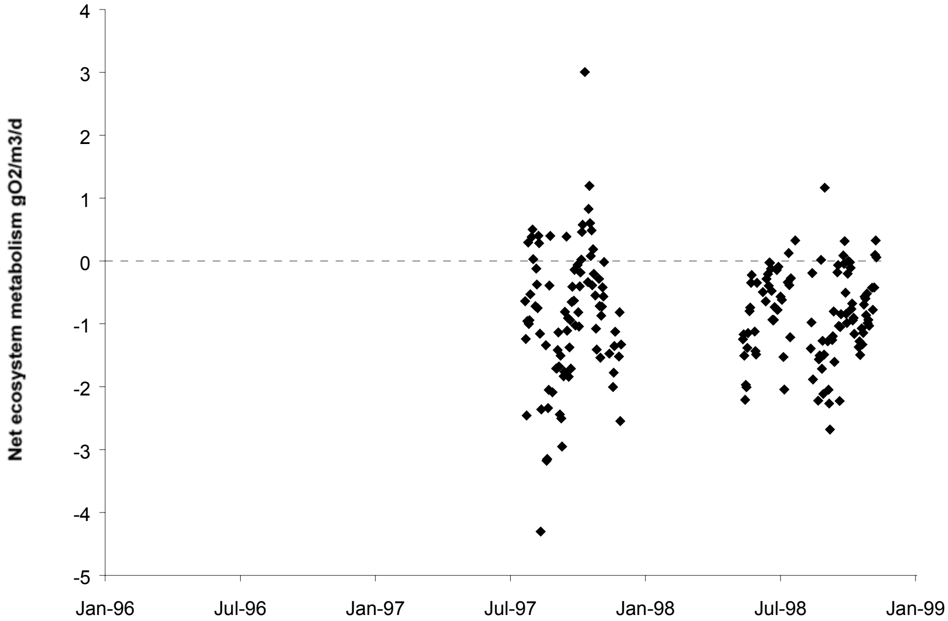
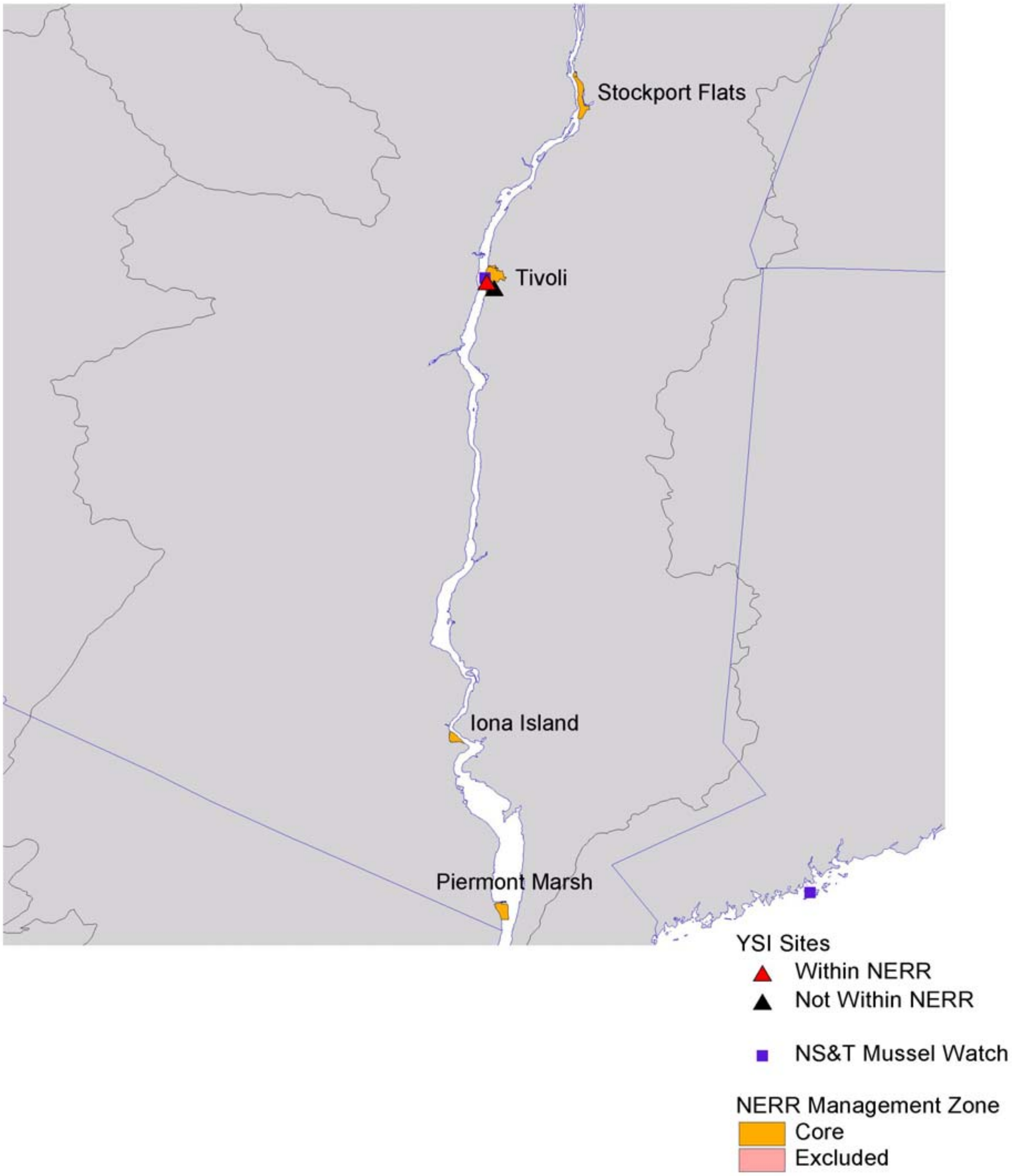


Figure 49. Net metabolism at Squamscott River, 1996-1998.

Hudson River



Hudson River, Sawkill Creek (HUDSK)

Characterization (Latitude = 42°01'54" N; Longitude = 73°53'59" W)
Sawkill Creek drains a watershed of 69 km^2. Water depth ranges between 1.5 and 4.5 m depending on creek water levels and the width is about 7 m. Creek bottom habitats are predominantly sand, gravel, and glacial till without bottom vegetation. Sawkill Creek is a shady creek surrounded by a mixed hardwood forest of maple, oak, hemlock, and pine. Upland land use near the sampling site includes forests, agriculture, and low- to medium-density residential housing. Activities that potentially impact the site include residential runoff from lawn fertilizers and septic tanks.

Descriptive Statistics
Thirty-three deployments were made at this site between Apr-Jul 1996 and Apr-Dec 1997 and 1998 (Figure 50). Mean deployment duration was 17.7 days. Only two deployments (Jul, Nov 1997) were less than 10 days.

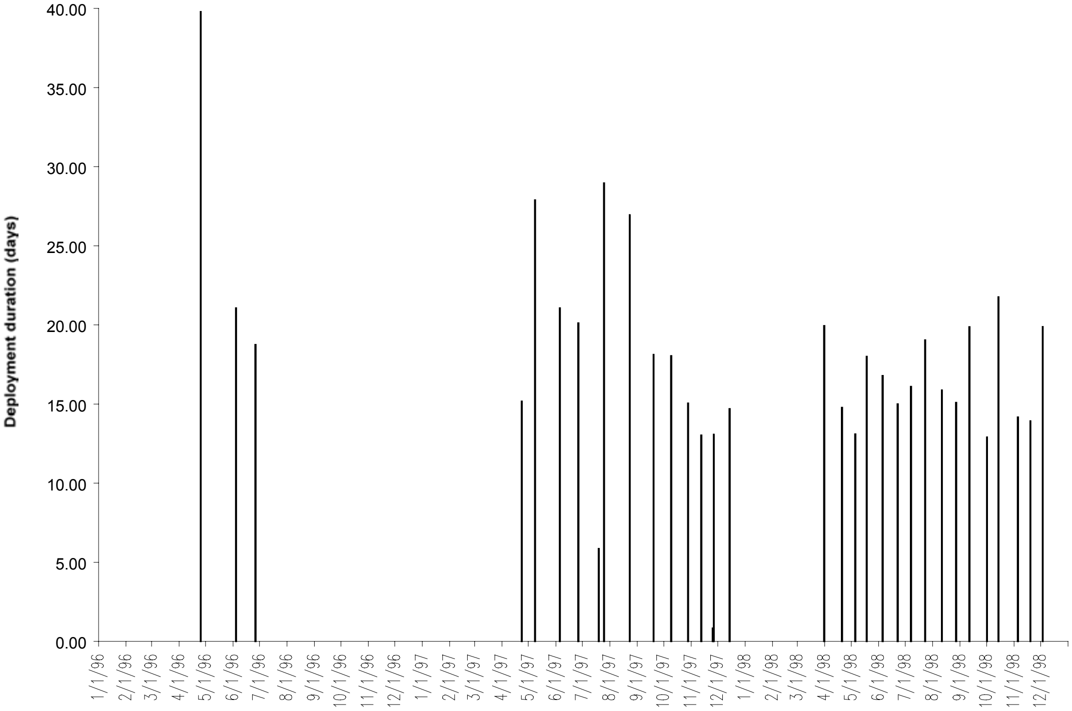


Figure 50. Hudson River, Sawkill Creek deployments (1996-1998).

Fifty-two percent of annual depth data were included in analyses (17% in 1996, 65% in 1997, and 73% in 1998). Sensors, located on the upstream side of a dam spillway, were typically deployed at a depth of 0.7 m below the water surface and 0.5 m above the bottom sediment. Minor fluctuations (≤ 0.4 m) in daily and bi-weekly water depth were evident from scatter plots. Harmonic regression analysis attributed 50% of depth variance to 24 hour cycles, 45% of depth variance to interaction between 12.42 hour and 24 hour cycles, and 5% of depth variance to 12.42 hour cycles.

Forty-nine percent of annual water temperature data were included in analyses (17% in 1996, 58% in 1997, and 73% in 1998). Water temperature followed a seasonal cycle; however, because no data were collected in Jan-Feb, true annual minimum temperature may not be known (Figure 51). Mean water temperature was 12-14°C in Apr-May, 20-21°C in Jul-Aug, and 3-5°C in Nov-Dec. Minimum and maximum water temperatures between 1996-1998 were 0.1°C (Dec 1997) and 24.3°C (Jul 1997), respectively. Scatter plots suggest moderate fluctuations (1-2°C) in daily water temperature and strong fluctuations (≥5°C) in bi-weekly water temperature. Harmonic regression analysis attributed 85% of temperature variance to 24 hour cycles, 14% of temperature variance to interaction between 12.42 hour and 24 hour cycles, and 1% of temperature variance to 12.42 hour cycles.

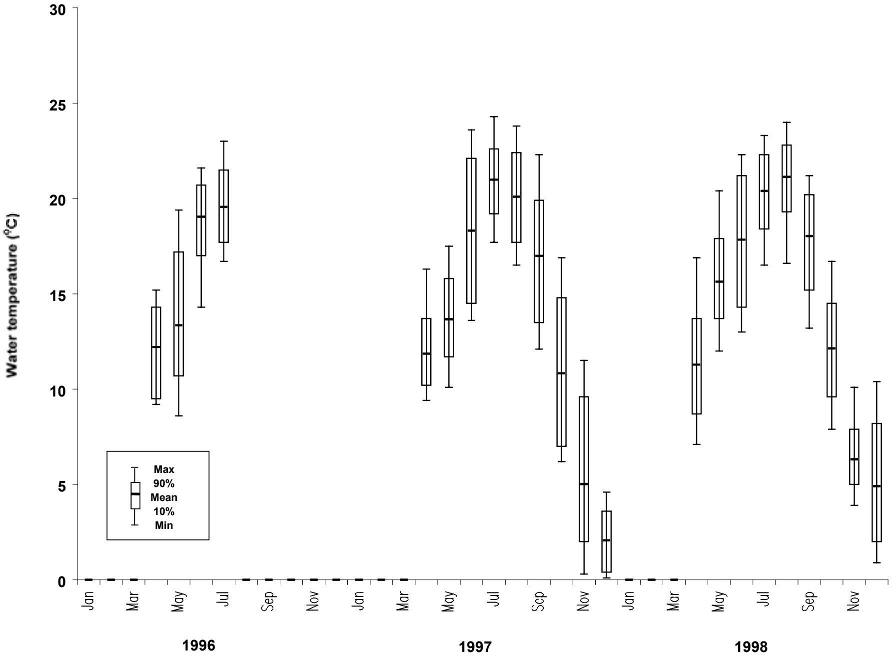


Figure 51. Water temperature statistics for Sawkill Creek, 1996-1998.

Forty-one percent of annual salinity data were included in analyses (17% in 1996, 32% in 1997, and 73% in 1998). All salinity measurements were between 0.1 and 0.2 ppt, with no discernable seasonal pattern. Harmonic regression analysis attributed 73% of salinity variance to interaction between 12.42 hour and 24 hour cycles, 22% of salinity variance to 24 hour cycles, and 5% of salinity variance to 12.42 hour cycles.

Forty-three percent of annual dissolved oxygen (% saturation) data were included in analyses (17% in 1996, 38% in 1997, and 73% in 1998). Mean percent saturation varied from 80-100% throughout the data set. Minimum and maximum DO between 1996-1998 was 18.9% saturation and 122.1% saturation, respectively. Hypoxia and supersaturation were never observed. Scatter plots indicated minor fluctuations (≤20%) in daily and bi-weekly percent saturation throughout the data set, except for Jul 1998 when fluctuations approached 80%. Harmonic regression analysis attributed 83% of DO variance to 24 hour cycles, 15% of DO variance to interaction between 12.42 hour and 24 hour cycles, and 2% of DO variance to 12.42 hour cycles.

Photosynthesis/Respiration

Less than one third (31%) of the data used to calculate metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor). This reduced data set (when flow in the creek was less than 0.4 m3/s) was used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 17). Because the YSI is deployed just upstream of a dam in the creek, physical processes such as advection of different water masses and enhanced exchange across the air-water interface probably control the oxygen dynamics rather than biological processes. Instrument drift during the duration of the deployments was not a significant problem at this site. Total respiration only slightly exceeded gross production at Sawkill Creek; thus, the net ecosystem metabolism and P/R ratio indicated that this is a site where production and respiration are balanced (Figure 52). Temperature was significantly ($p<0.05$) correlated with gross production, total respiration and net ecosystem metabolism. Respiration increased as temperature increased, while gross production decreased as temperature increased. Net ecosystem metabolism became more heterotrophic as temperature increased. In this freshwater system, salinity was always zero ppt.

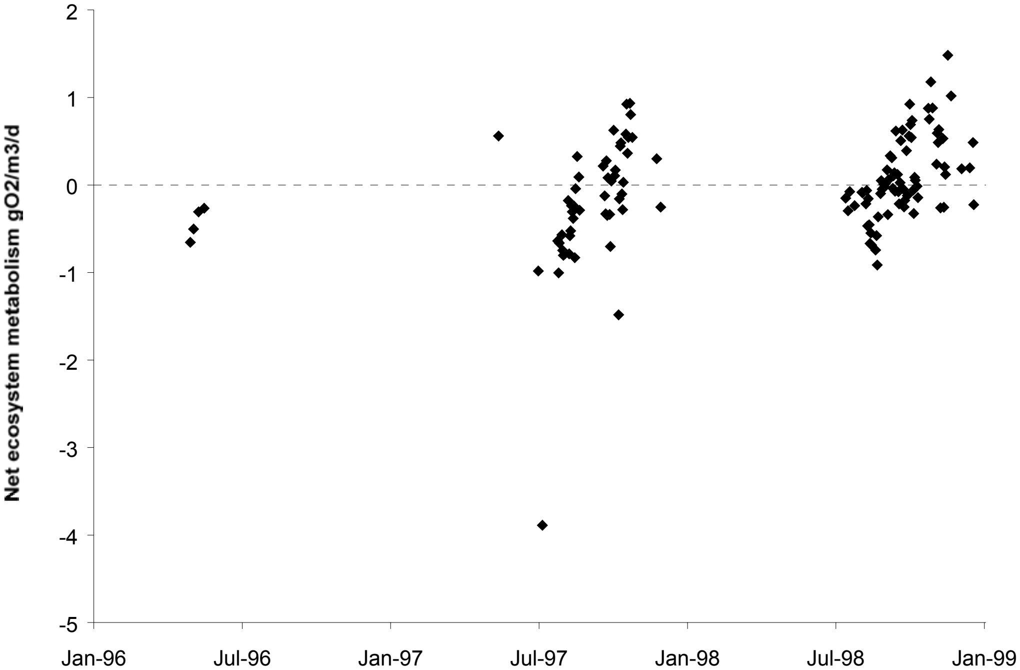


Figure 52. Net metabolism at Sawkill Creek, 1996-1998.

Table 17. Summary of metabolism data and statistics at Sawkill Creek, 1996-1998.

Sawkill Creek	mean	s.e.
Water depth (m)	1.0	
Net production gO_2/m3/d	0.30	0.04
Gross production gO_2/m3/d	0.65	0.04
Total respiration gO_2/m3/d	0.69	0.06
Net ecosystem metabolism g O_2/m3/d	-0.03	0.05
Net ecosystem metabolism g C/m2/y	18	
P/R	0.95	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	31 %	
Paired t-test on gross production and total respiration	ns	
Correlation coefficient	Temperature	Salinity
Gross production	-0.34	ns
Total respiration	0.19	ns
Net ecosystem metabolism	-0.51	ns

Hudson River, Tivoli South Bay (HUDTS)

Characterization (Latitude = 42°02'15"N; Longitude = 73°55'10"W)

Tidal range at Tivoli South Bay is 1.19 m. The bay is 1.3 km long (mainstream linear dimension), has an average depth of 1 m MHW, and an average width of 530 m. A railroad embankment (consisting of three bridges) along the western edge of Tivoli South Bay separates this bay from the Hudson River, although there is a nearly complete tidal exchange between Hudson Bay and Tivoli South Bay. The sampling site is located at one of the railroad bridges where the depth is 1 m MHW. Creek bottom habitats are predominantly silt-sand, with extensive beds of *Trapa natans* (Eurasian water chestnut, exotic) in Tivoli South Bay and extensive beds of *Vallisneria americana* (Water celery, native) in the shallows of the Hudson River adjacent to Tivoli South Bay. At low tide, much of the bay is exposed mudflat with water chestnut. The dominant marsh vegetation near the sampling site is cattail. Upland vegetation is primarily mixed hardwood forest. Upland land use near the sampling site includes forests, agriculture, and low to medium density residential housing. Activities that potentially impact the site include septic tanks and lawn fertilizers.

Descriptive Statistics

Thirty-seven deployments were made at this site between Apr-Dec in 1996 and 1998 and May-Dec in 1997 (Figure 53). Mean deployment duration was 18.8 days. Only three deployments, all in Dec 1997, were less than 10 days.

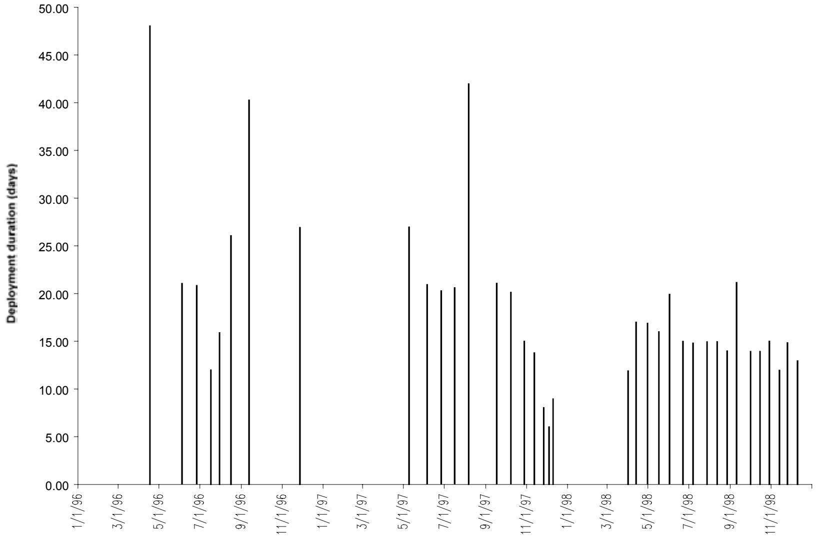


Figure 53. Hudson River, Tivoli South Bay deployments (1996-1998).

Fifty-seven percent of annual depth data were included in analyses (47% in 1996, 54% in 1997, and 70% in 1998). Sensors were typically deployed at a depth of 0.9 m below the water surface and 0.5 m above the bottom sediment. Strong fluctuations (1-2 m) in water depth were evident from scatter plots for daily and bi-weekly intervals, with consistent amplitude throughout the data set. Harmonic regression analysis attributed 91% of depth variance to 12.42 hour cycles, 5% of depth variance to 24 hour cycles, and 4% of depth variance to interaction between 12.42 hour and 24 hour cycles.

Fifty-five percent of annual water temperature data were included in analyses (47% in 1996, 48% in 1997, and 70% in 1998). Water temperature followed a seasonal cycle; however, because data were not collected in Jan-Mar, annual minimum water temperature may not be known (Figure 54). Mean water temperature was typically 10-14°C in Apr-May, 24-25°C in Jul-Aug, and 4-6°C in Nov-Dec. Minimum and maximum water temperatures between 1996-1998 were 0°C (Dec 1996, 1997) and 29.8°C (Jul 1997), respectively. Scatter plots suggest strong fluctuation (2-5°C) in daily water temperature and even stronger fluctuation (5-10°C) in bi-weekly water temperatures. Harmonic regression analysis attributed 42% of temperature variance to 24 hour cycles, 25% of variance to 12.42 hour cycles, and 33% of variance to interaction between 12.42 hour and 24 hour cycles.

Forty-four percent of annual salinity data were included in analyses (27% in 1996, 35% in 1997, and 70% in 1998). All salinity measurements were between 0 and 0.1 ppt, with no discernable seasonal pattern. Harmonic regression analysis attributed 36% of salinity variance to 12.42 hour cycles, 35% of salinity variance to interaction between 12.42 hour and 24 hour cycles, and 29% of salinity variance to 24 hour cycles.

Forty-four percent of annual dissolved oxygen (% saturation) data were included in analyses (47% in 1996, 27% in 1997, and 59% in 1998). Mean DO followed a seasonal cycle, with lowest percent saturation recorded in Jul-Sep (70-85% sat) and greatest percent saturation recorded in spring and fall (85-100%). Minimum and maximum percent saturation between 1996-1998 was 8.3% (Aug 1998) and 154% (Jun 1996), respectively. Hypoxia was observed in two months (Jul-Aug 1998) and, when present, hypoxia persisted for <1.5% of the first 48 hours post-deployment on average (Figure 55). Super-saturation was observed in four months (Apr, Jun 1996; Jul 1997; Jun 1998) and, when present, supersaturation persisted for <7% of the first 48 hours post-deployment on average. Scatter plots suggest moderate fluctuation (20-60%) in percent saturation over daily and bi-weekly cycles, but strong fluctuations (60-100%) were observed in Jun 1996, Jul 1997, and Jun-Sep 1998. Harmonic regression analysis attributed 59% of DO variance to 12.42 hour cycles, 19% of DO variance to interaction between 12.42 hour and 24 hour cycles, and 22% of DO variance to 24 hour cycles.

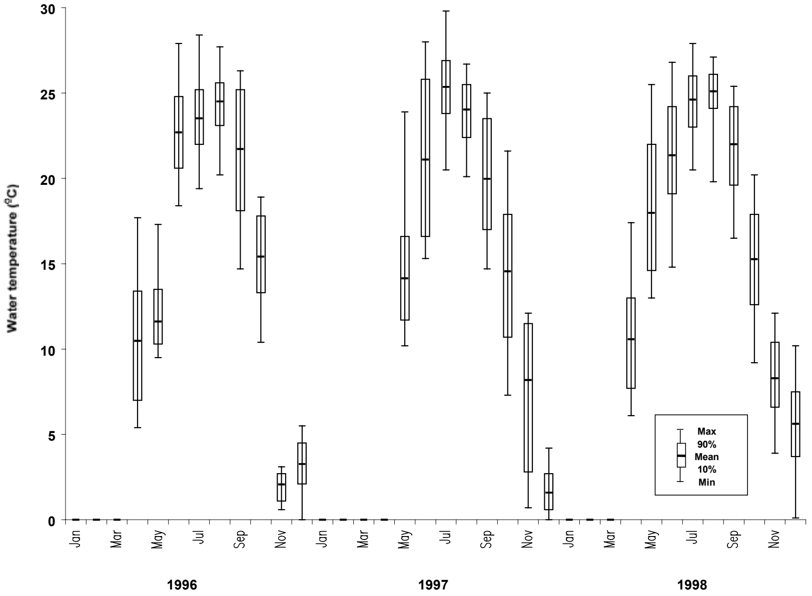


Figure 54. Water temperature statistics for Tivoli South Bay, 1996-1998.

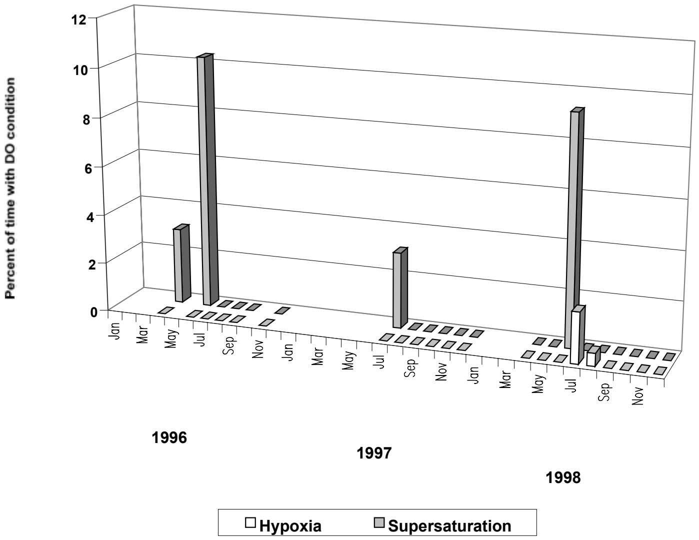


Figure 55. Dissolved oxygen extremes at Tivoli South Bay, 1996-1998.

Photosynthesis/Respiration

Three quarters (76%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and were used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 18). Instrument drift during the duration of the deployments was not a significant problem at this site. Total respiration exceeded gross production at Tivoli South Bay; thus, the net ecosystem metabolism and P/R ratio indicated that this is a heterotrophic site (Figure 56). Temperature was significantly ($p<0.05$) correlated with gross production, total respiration and net ecosystem metabolism. Gross production and respiration increased as temperature increased, while net ecosystem metabolism became more heterotrophic as temperature increased. In this freshwater system, salinity was always zero ppt. Metabolic rates were extremely variable during the growing season of Eurasian water chestnut that covers Tivoli South Bay between June and September.

Table 18. Summary of metabolism data and statistics at Tivoli South Bay, 1996-1998.

Tivoli South	mean	s.e.
Water depth (m)	1.5	
Net production gO_2/m3/d	0.40	0.06
Gross production gO_2/m3/d	2.41	0.13
Total respiration gO_2/m3/d	3.58	0.16
Net ecosystem metabolism g O_2/m3/d	-1.18	0.07
Net ecosystem metabolism g C/m2/y	-118	
P/R	0.67	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	76 %	
Paired t-test on gross production and total respiration	$p < 0.001$	
Correlation coefficient	Temperature	Salinity
Gross production	0.50	ns
Total respiration	0.61	ns
Net ecosystem metabolism	-0.45	ns

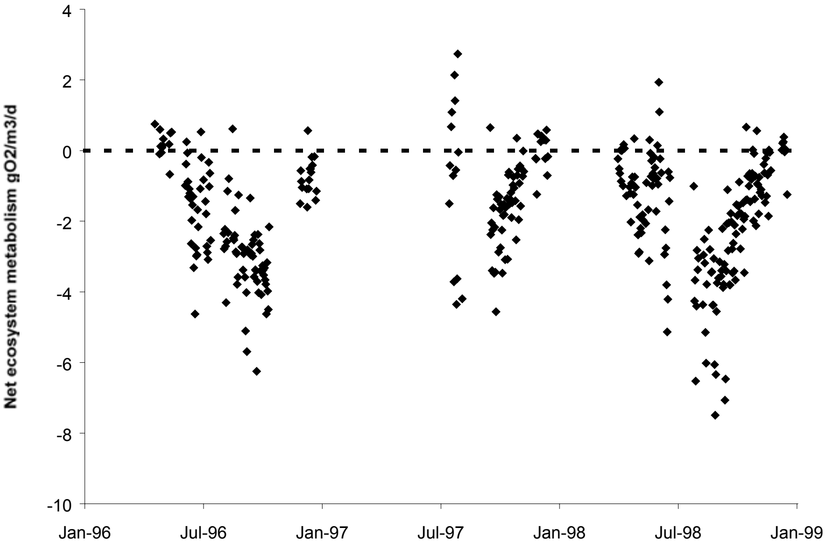
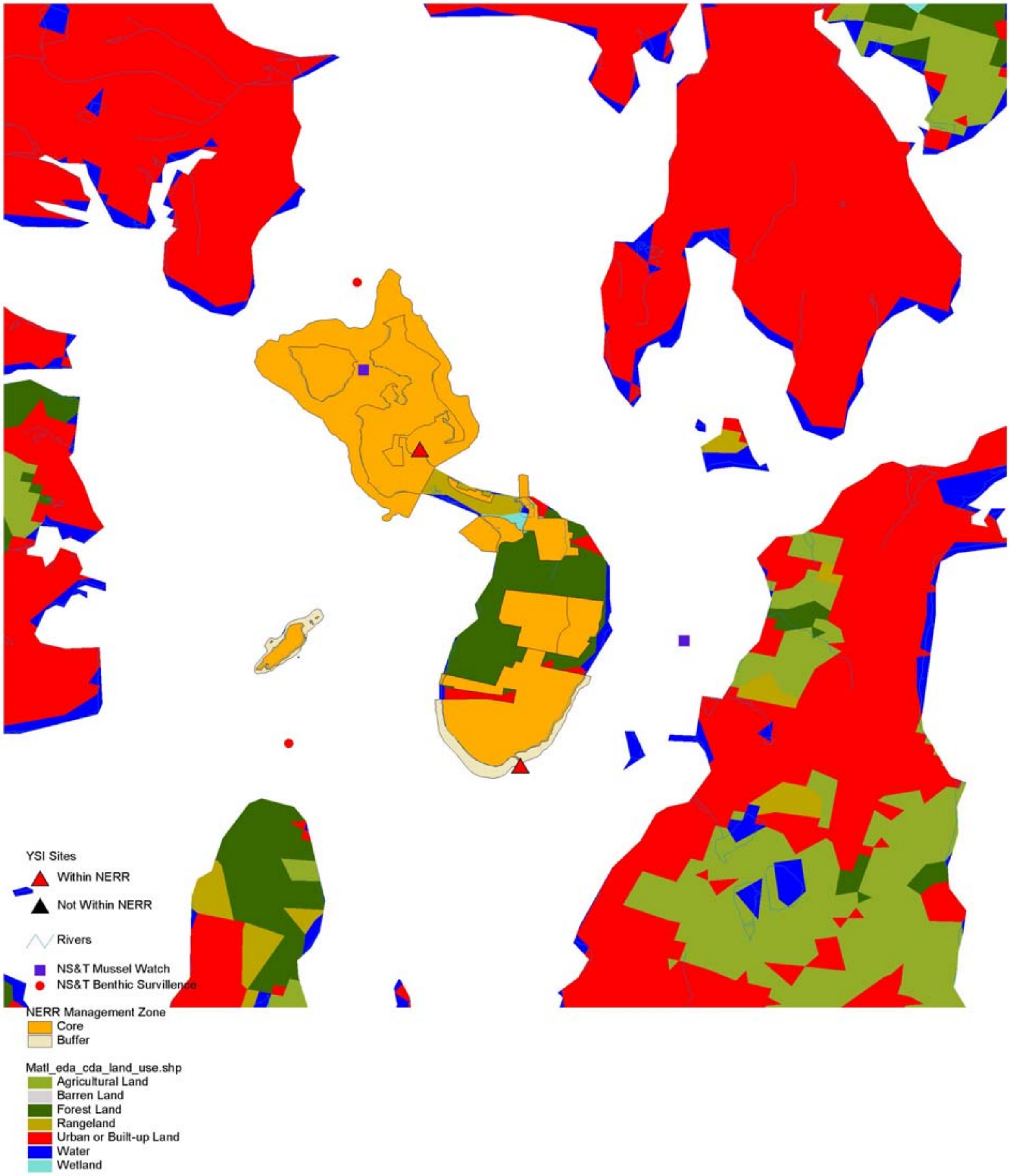


Figure 56. Net metabolism at Tivoli South Bay, 1996-1998.

Narragansett Bay



Narragansett Bay, Potters Cove (NARPC)

Characterization (Latitude = 41°38' 25"N; Longitude = 71°20' 28"W)
Tides at Potters Cove are semidiurnal and range from –0.2 m to 1.7 m (average 1.1 m). The main estuary (Narragansett Bay) is 40 km long (mainstream linear dimension), has an average depth of 8.3 m MHW, and an average width of ~10-12 km. At the sampling site, the depth is ~3.5 - 4 m MHW and the width of the cove is 0.9 km, while the width of the East Passage here to the opposite shore (Bristol) is ~ 2.7 km. This site is located at a point approximately one-third of the way down the estuary. Bottom habitats are predominantly silt and sand, with some organic mud, and support communities of *Ulva* sp. and other macroalgal bottom vegetation. The dominant marsh vegetation near the sampling site is a degraded *Phragmites* sp./ *Spartina alterniflora* marsh. The dominant upland vegetation includes scrub/shrub. Upland land use near the sampling site includes a restricted flow saltmarsh and a small number of very low-density dwellings. Activities that potentially impact the site include illegally discharged boater waste and pollutants from the upper urbanized Bay which is a source of nutrients, bacteria, and very low level toxics. Potters Cove received wastes from boaters until a federal no-discharge zone was declared for all Rhode Island State waters in late spring 1998. Potters Cove is considered impacted from possible continuing boater discharges (now illegal, but relying on voluntary compliance) and upper Bay pollution sources including sewage treatment effluents, urbanized runoff, and Combined Sewer Overflows (CSO's) which combine industrial, commercial, domestic, and storm-water waste into a single, often untreated, discharge.

Descriptive Statistics
Forty-six deployments were made at this site between Jan 1996 and Dec 1998, with equal coverage during all seasons (Figure 57). Mean deployment duration was 30 days and two deployments (Apr 1996 and Aug 1998) were less than 10 days.

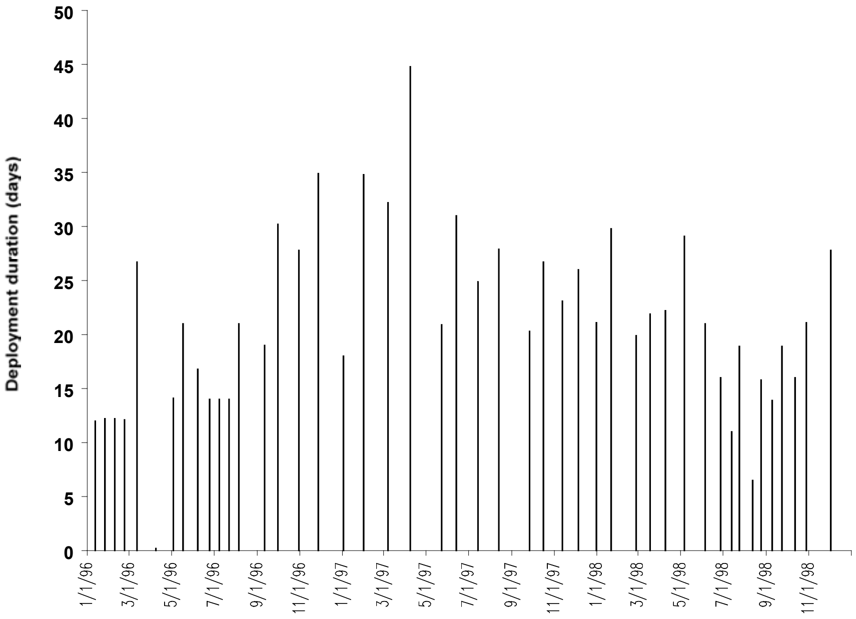


Figure 57. Narragansett Bay, Potters Cove deployments (1996-1998).

Eighty-seven percent of annual depth data were included in analyses (83% in 1996, 88% in 1997, and 89% in 1998). Sensors were typically deployed at a depth of 2.5 m below the water surface (range = 1.7-3.2 m) and 1 m above the bottom sediment. Strong fluctuations (2-3 m) in daily and bi-weekly water depth were evident from scatter plots, with consistent amplitude throughout the data set. Harmonic regression analysis attributed 92% of depth variance to 12.42 hour cycles, 6% of variance to 24 hour cycles, and 2% of variance to interaction between 12.42 hour and 24 hour cycles.

Eighty-seven percent of annual water temperature data were included in analyses (83% in 1996, 88% in 1997, and 89% in 1998). Water temperature followed a seasonal cycle, with mean water temperature 3-5°C in winter (1997, 1998) and 20-22°C in summer (Figure 58). Mean water temperature between Jan-Mar 1996 was slightly lower (1-3°C) than mean water temperature in Jan-Mar 1997 and 1998. Minimum and maximum water temperatures between 1996-1998 were –1.3°C (Feb 1996) and 25.8 (Jul 1997), respectively. Scatter plots suggest strong fluctuations (1-2°C) in daily water temperature and stronger fluctuations (3-8°C) in bi-weekly water temperature in summer, fall, and winter. Harmonic regression analysis attributed 44% of temperature variance to both 24 hour cycles and interaction between 12.42 hour cycles and 24 hour cycles, and 12% of temperature variance to 12.42 hour cycles.

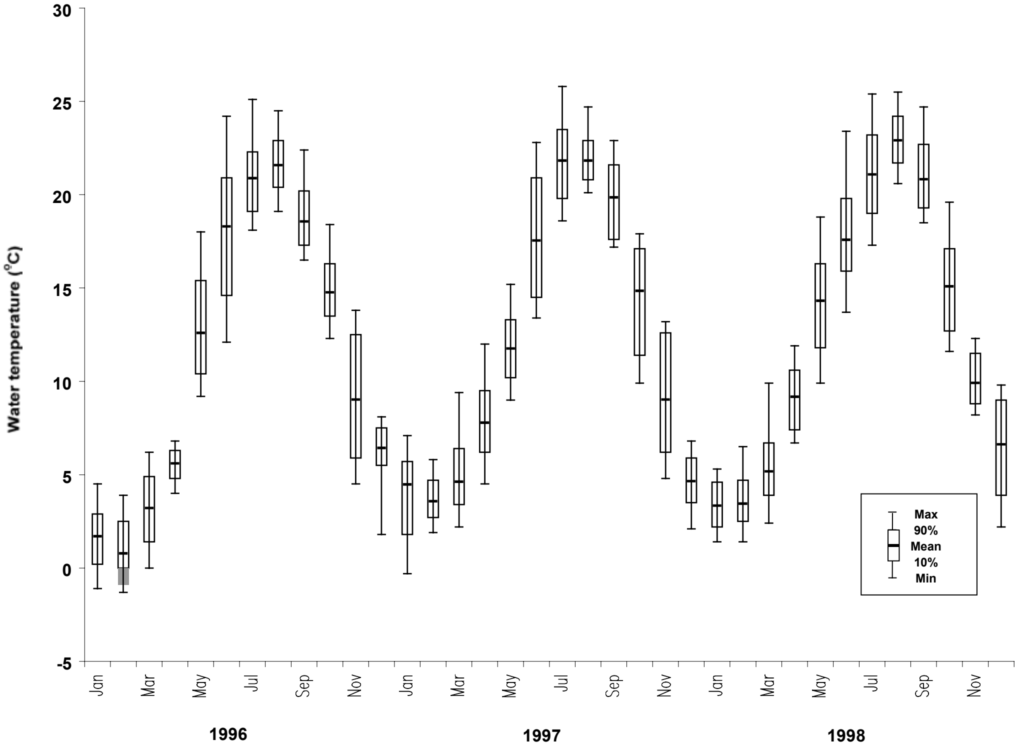


Figure 58. Water temperature statistics for Potters Cove, 1996-1998.

Eighty-six percent of annual salinity data were included in analyses (80% in 1996, 88% in 1997, and 89% in 1998). Mean salinity was typically 25-30 ppt between 1996-1998. Mean salinity was greatest between Jul-Oct and least between Dec-Mar; however, large variances were often associated with mean salinity values (Figure 59). Minimum and maximum salinity between 1996-1998 was 13.6 ppt (Jun 1998) and 32.1 ppt (Sep 1997), respectively. Scatter plots suggest daily and bi-weekly fluctuations in salinity equivalent to annual variation in mean salinity throughout the data set. Fluctuations in salinity >10 ppt were observed during episodic events in Jan 1996 and Jun 1998. Harmonic regression analysis attributed 51% of salinity variance to interaction between 12.42 hour and 24 hour cycles, 29% of variance to 24 hour cycles, and 20% of variance to 12.42 hour cycles.

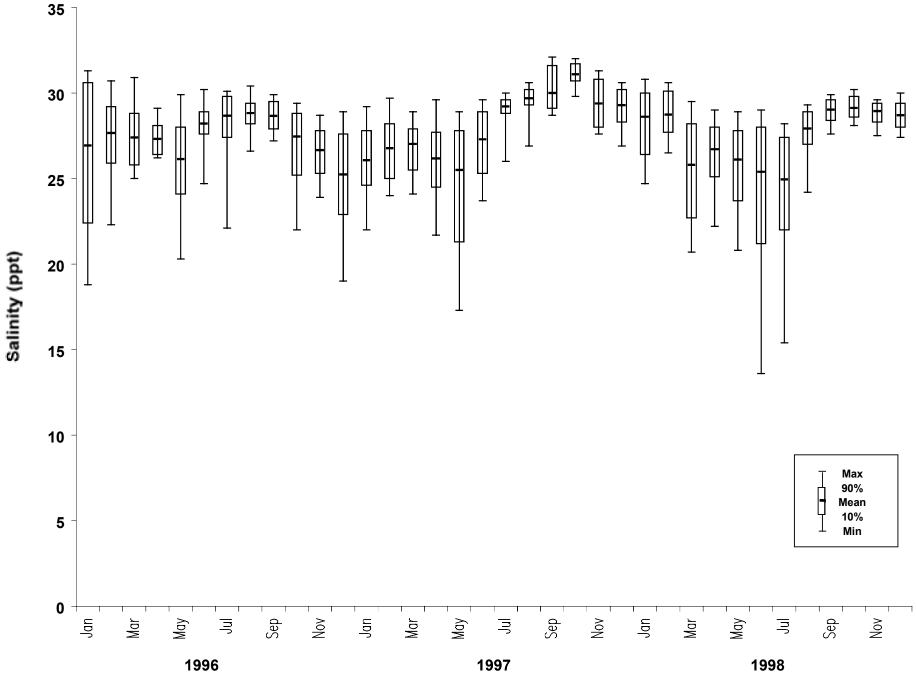


Figure 59. Salinity statistics at Potters Cove, 1996-1998.

Sixty-seven percent of annual dissolved oxygen (% saturation) data were included in analyses (60% in 1996, 71% in 1997 and 1998). Mean DO was typically 50-110% saturation and followed a seasonal cycle, with greatest DO in spring, fall and winter. Mean DO below 50% saturation and mean DO above 120% saturation was never observed. Minimum and maximum DO between 1996-1998 was 3.6% saturation (Aug 1998) and 204.4% saturation (May 1998), respectively. Hypoxia was observed in one month (Jul 1998) and persisted for 4% of the first 48 hours post-deployment (Figure 60). Supersaturation was observed in eight months between 1996-1998 and, when present, supersaturation persisted for 24% of the first 48 hours post-deployment on average. Scatter plots suggest minor fluctuations (20-40%) in percent saturation in winter and fall (1996, 1997). Strong fluctuations (60-100%) in percent saturation were regularly observed in spring and summer. Harmonic regression analysis attributed 62% of DO variance to 24 hour cycles, 27% of DO variance to interaction between 12.42 hour and 24 hour cycles, and 11% of DO variance to 12.42 hour cycles.

Photosynthesis/Respiration

Nearly three quarters (74%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and were used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 19). Instrument drift during the duration of the deployments was not a significant problem at this site. Total respiration exceeded gross production at Potters Cove; thus, the net ecosystem metabolism and P/R ratio indicated that this is a heterotrophic site (Figure 61). Temperature was significantly ($p<0.05$) correlated with gross production, total respiration and net ecosystem metabolism. Gross production and respiration increased as temperature increased, while net ecosystem metabolism became more heterotrophic as temperature increased. Salinity was not significantly ($p<0.05$) correlated with any metabolic measurement.

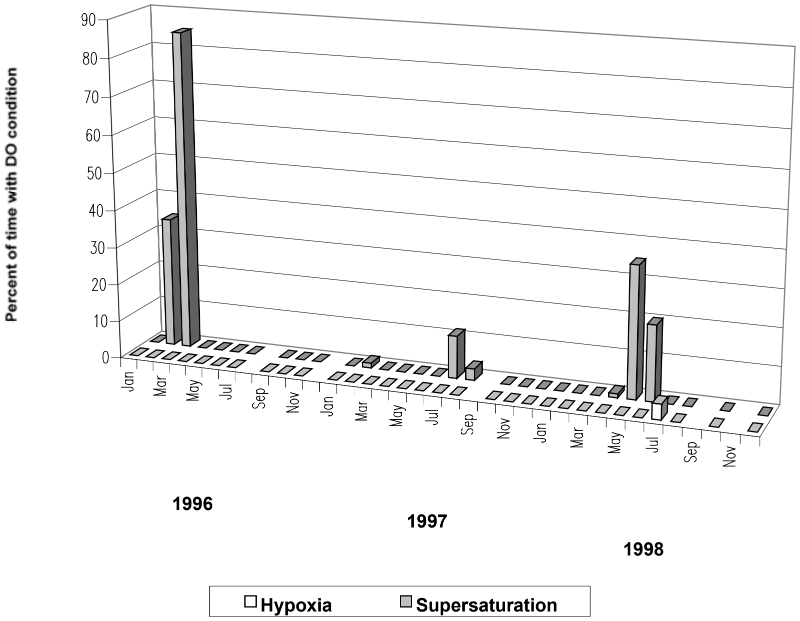


Figure 60. Dissolved oxygen extremes at Potters Cove, 1996-1998.

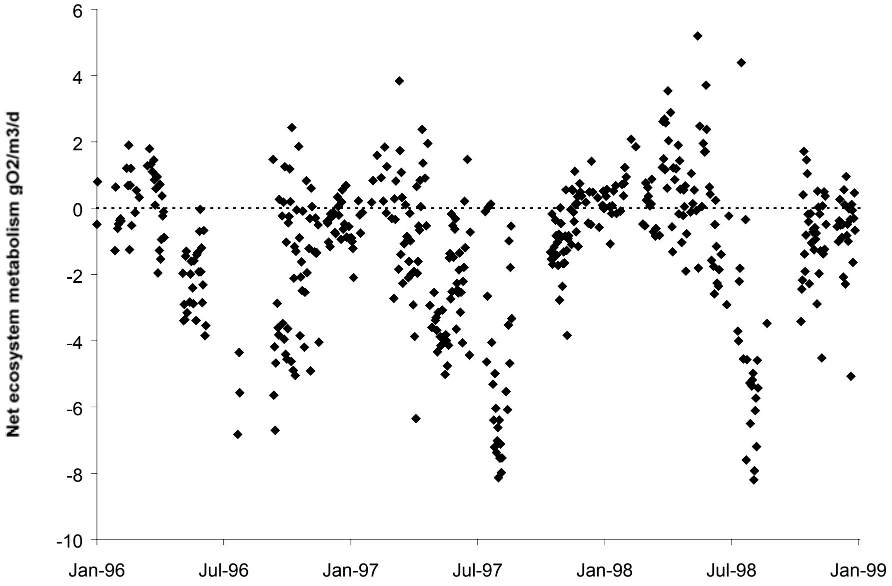


Figure 61. Net metabolism at Potter's Cove, 1996-1998.

Table 19. Summary of metabolism data and statistics at Potter's Cove, 1996-1998.

Potters Cove	mean	s.e.
Water depth (m)	8.3	
Net production gO_2/m3/d	0.90	0.05
Gross production gO_2/m3/d	2.35	0.09
Total respiration gO_2/m3/d	2.67	0.11
Net ecosystem metabolism g O_2/m3/d	-0.32	0.05
Net ecosystem metabolism g C/m2/y	127	
P/R	0.88	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	74%	
Paired t-test on gross production and total respiration	$p < 0.001$	
Correlation coefficient	Temperature	Salinity
Gross production	0.47	ns
Total respiration	0.55	ns
Net ecosystem metabolism	-0.33	ns

Narragansett Bay, T-wharf (NARTW)

Characterization (Latitude = 41° 34'53"N; Longitude = 71° 19'18"W)
Tides at T-wharf are semidiurnal and range from –0.2 m to 1.7 m (average 1.1 m). The Narragansett Bay estuary is 40 km long (mainstream linear dimension), has an average depth of 8.3 m MHW, and an average width of ~10-12 km. At the sampling site, the width from the T Wharf to Carr Point in Portsmouth on the eastern shore of the Bay is 2.44 km, and the mean depth is ~5 m MHW, with depth rapidly dropping off to >10 m within 100 m of this site. The T-wharf is located in fairly open water roughly mid-way between the head and the mouth of the estuary. Bottom habitats are mostly sand and some silt, with low-density macroalgae (*Fucus* sp. and *Codium* sp.) and a small eelgrass bed nearby. The dominant marsh vegetation near the sampling site is *Spartina alterniflora*. The dominant upland vegetation includes scrub/shrub. Activities that potentially impact the site include pollution sources to the Bay, primarily nutrients coming from both upper Bay and offshore deep waters (this area is a possible upwelling/mixing zone for deep waters coming into Narragansett Bay from offshore). The T-wharf site is at the southern tip of an island and is considered a relatively non-impacted site.

Descriptive Statistics
Fifteen deployments were made at this site between Sep 1996 and Dec 1997, with equal coverage during all months (Figure 62). Mean deployment duration was 27 days. Only two deployments (Sep, Dec 1997) were less than 15 days.

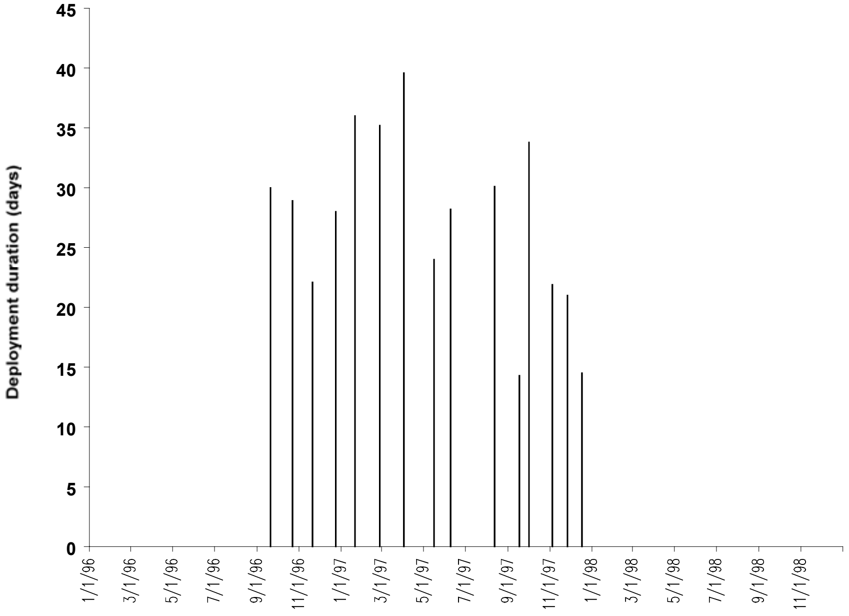


Figure 62. Narragansett Bay, T-wharf deployments (1996-1998).

Twenty-four percent of annual depth data in 1996 and 87% of annual depth data in 1997 were included in analyses. Sensors were deployed at a mean depth of 3.8 m below the water surface (range = 2.7-4 m) and 1 m above bottom sediment. Scatter plots suggest strong fluctuation (2 m) in daily and bi-weekly depth readings, with consistent amplitude throughout the data set (except for Dec 1997 when fluctuations exceeded 3 m). Harmonic regression analysis attributed 93% of depth variance to 12.42 hour cycles, 5% of depth variance to 24 hour cycles, and 2% of depth variance to interaction between 12.42 hour and 24 hour cycles.

Twenty-four percent of annual water temperature data in 1996 and 87% of annual water temperature data in 1997 were included in analyses. Water temperature followed a seasonal cycle from Sep 1996 to Dec 1997, with mean water temperatures 3-5°C in winter and 19-21°C in summer (Figure 63). Minimum and maximum water temperatures were 0.7°C (Jan 1997) and 23.8 (Aug 1997), respectively. Moderate fluctuations (1-3°C) were observed for daily and bi-weekly water temperatures in all seasons except for Oct-Nov, when strong (≥ 5°C) fluctuations were observed for bi-weekly water temperatures. Harmonic regression analysis attributed 54% of temperature variance to 12.42 hour cycles, 26% of temperature variance to 24 hour cycles, and 20% of temperature variance to interaction between 12.42 hour and 24 hour cycles.

Twenty-four percent of annual salinity data in 1996 and 87% of annual salinity data in 1997 were included in analyses. Mean salinity between Sep 1996 and Dec 1997 was 28-31 ppt (Figure 64). Minimum and maximum salinity was 23.7 ppt (Dec 1996) and 32.1 ppt (Nov 1997), respectively. Scatter plots suggest fluctuations in daily and bi-weekly salinity equivalent to or in excess of variance in annual mean salinity. Harmonic regression analysis attributed 65% of salinity variance to 12.42 hour cycles, 21% of salinity variance to interaction between 12.42 hour and 24 hour cycles, and 14% of salinity variance to 24 hour cycles.

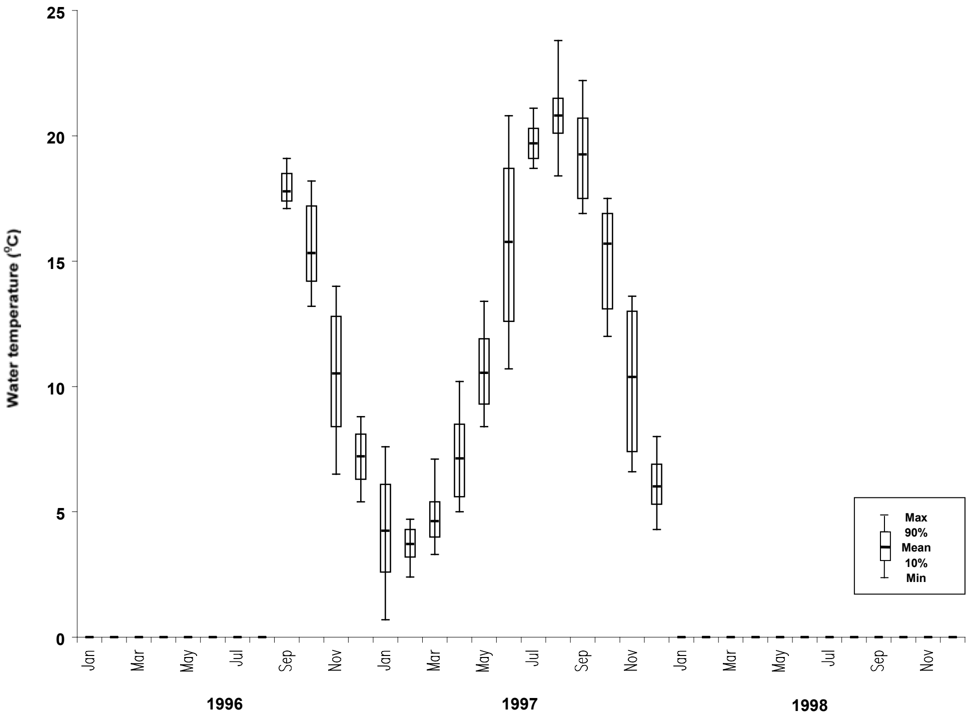


Figure 63. Water temperature statistics for T-wharf, 1996-1998.

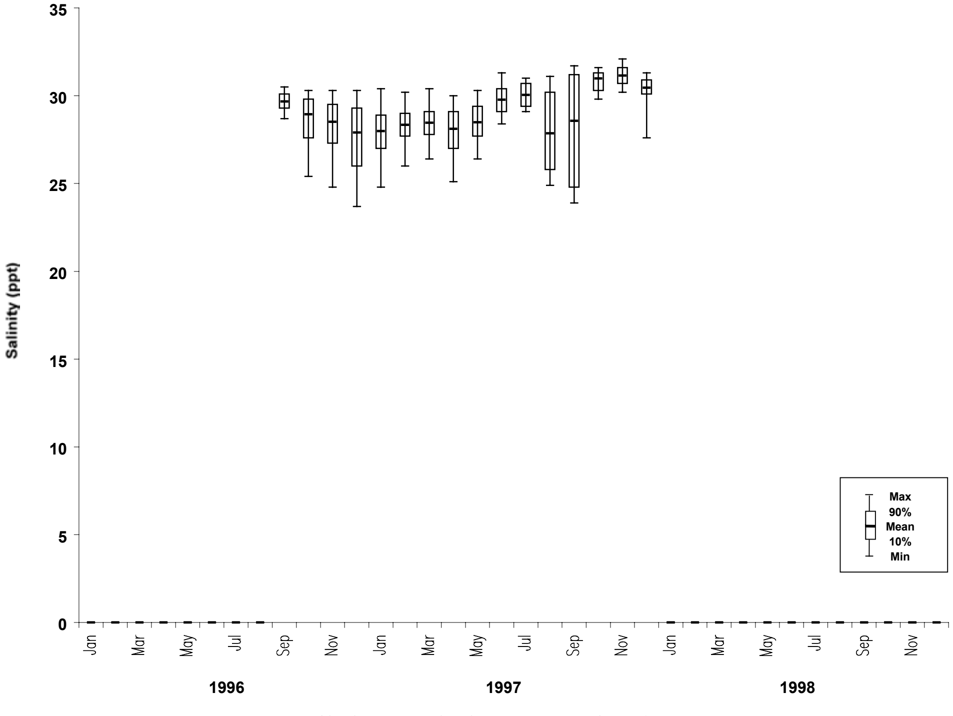


Figure 64. Salinity statistics at T-wharf, 1996-1998.

Twenty-one percent of annual dissolved oxygen (% saturation) data in 1996 and 69% of annual dissolved oxygen (% saturation) data in 1997 were included in analyses. Mean DO was typically 75-110% saturation. Minimum and maximum DO was 0.2% saturation (Aug 1997) and 138.4% saturation (Feb 1997), respectively. Hypoxia was observed in one month (Aug 1997) and persisted for 2% of the first 48 hours post-deployment (Figure 65). Supersaturation was observed in one month (Nov 1997) and persisted for 5.4% of the first 48 hours post-deployment. Scatter plots suggest moderate fluctuation (20-60%) in percent saturation at daily and bi-weekly intervals throughout the data set, except for Mar-Apr and Sep-Oct 1997 when DO fluctuations ≥ 90% were observed. Harmonic regression analysis attributed 39% of DO variance to 12.42 hour cycles, 36% of variance to interaction between 12.42 hour and 24 hour cycles, and 25% of variance to 24 hour cycles.

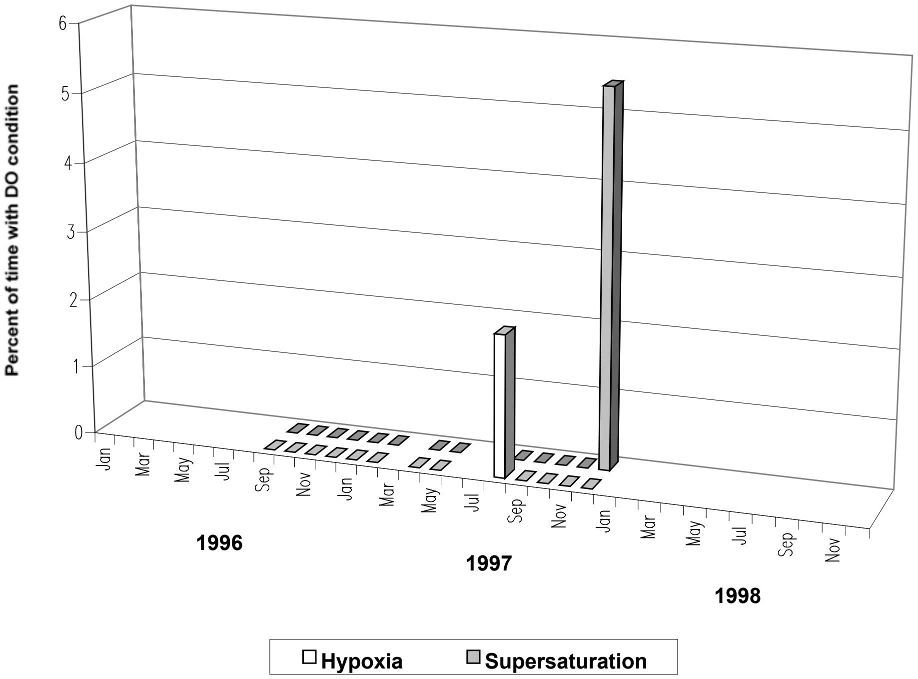


Figure 65. Dissolved oxygen extremes at T-wharf, 1996-1998.

Production/Respiration

Nearly two thirds (62%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and were used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 20). Instrument drift during the duration of the deployments was not a significant problem at this site. Total respiration greatly exceeded gross production at T-wharf; thus, the net ecosystem metabolism and P/R ratio indicated that this is a heterotrophic site (Figure 66). Temperature was significantly ($p<0.05$) correlated with gross production and respiration. Gross production and respiration increased as temperature increased. Salinity was significantly ($p<0.05$) correlated with gross production and total respiration. Gross production and respiration decreased as salinity increased.

Table 20. Summary of metabolism data and statistics at T-wharf, 1996-1998.

T-wharf	mean	s.e.
Water depth (m)	4.83	
Net production $gO_2/m3/d$	0.51	0.06
Gross production $gO_2/m3/d$	1.23	0.12
Total respiration $gO_2/m3/d$	1.45	0.15
Net ecosystem metabolism g $O_2/m3/d$	-0.22	0.07
Net ecosystem metabolism g C/m2/y	61	
P/R	0.85	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	62 %	
Paired t-test on gross production and total respiration	$p < 0.002$	
Correlation coefficient	Temperature	Salinity
Gross production	0.19	-0.18
Total respiration	0.19	-0.21
Net ecosystem metabolism	ns	ns

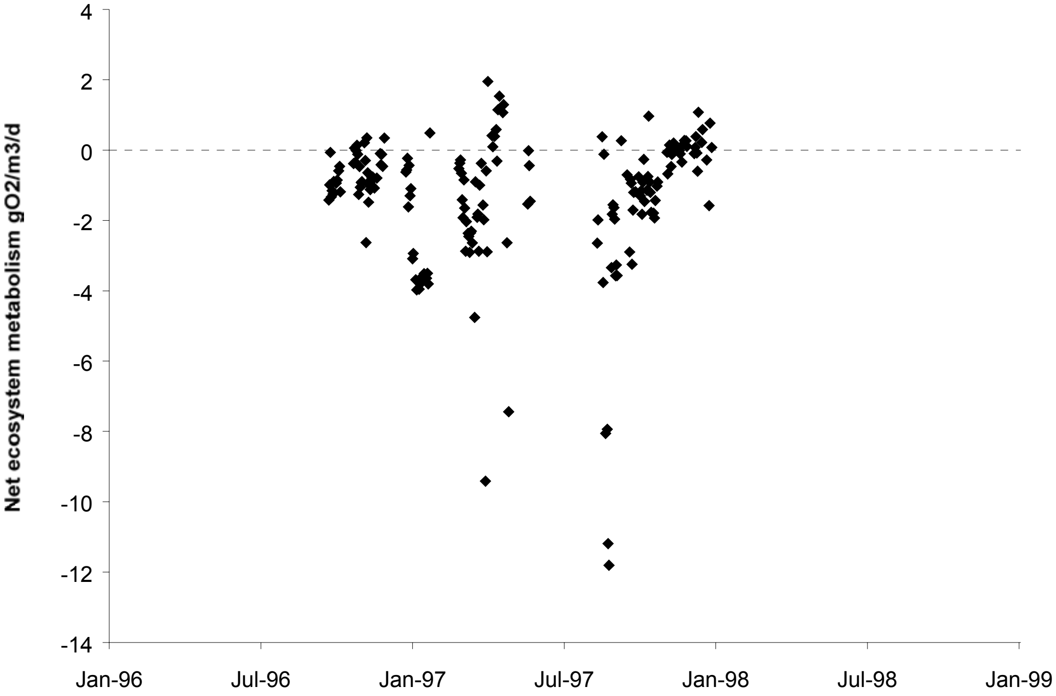
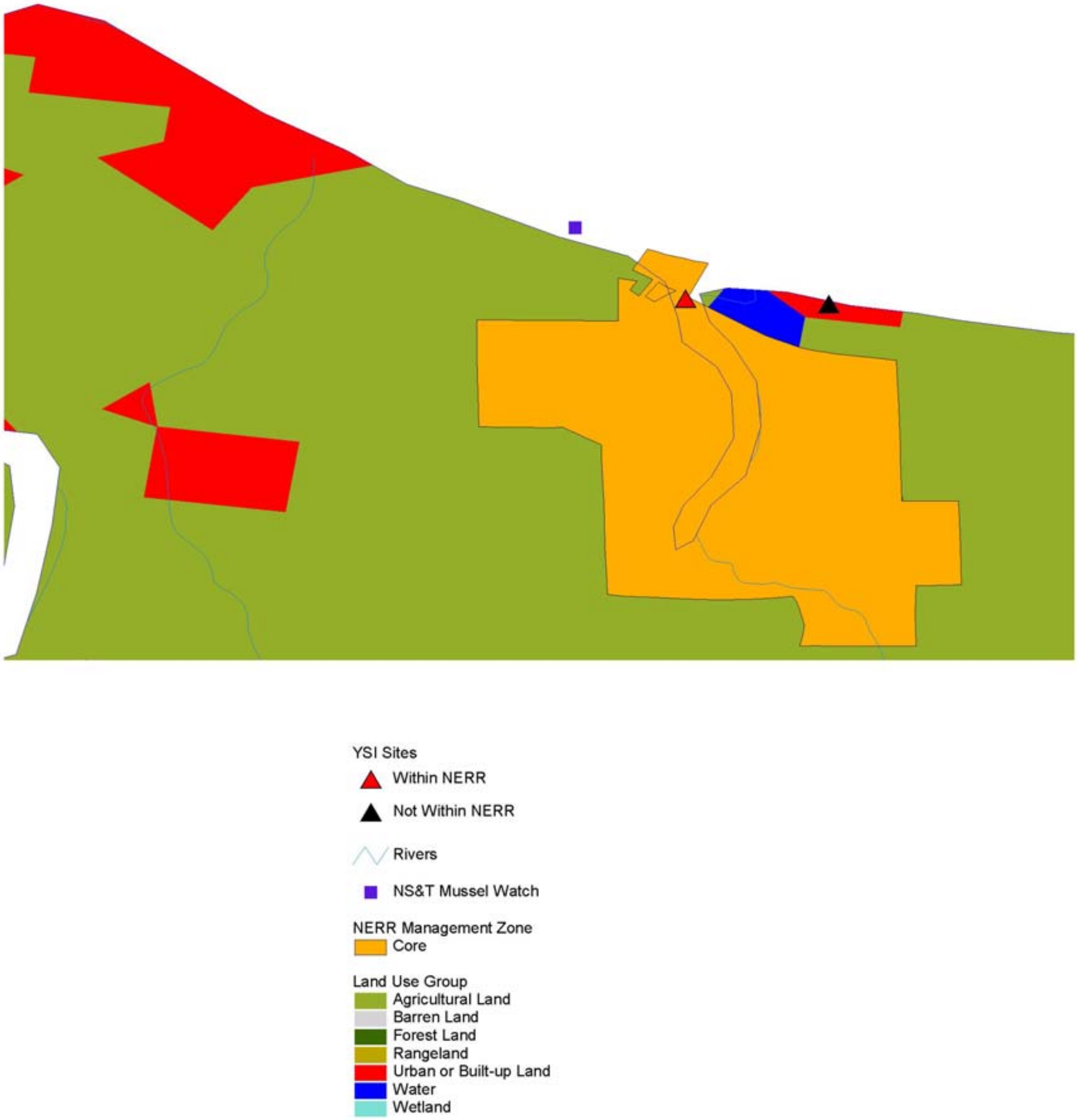


Figure 66. Net metabolism at T-wharf, 1996-1998.

Old Woman Creek



Old Woman Creek, State Route 2 (OWCSU)

Characterization (Latitude = 41°21'45" N; Longitude = 82°30'25"W)
Water level at Old Woman Creek is normally regulated by Lake Erie water levels, except when the barrier beach is closed off, which results in isolation of Old Woman creek from Lake Erie. Water levels are dependent upon wind and wave activity on Lake Erie when the mouth is open. When the mouth is closed, watershed rainfall and evapo-transpiration rates are most important in determining changes in water levels in Old Woman Creek. Water level varies up to 2 m annually and ranges from 173.2 m to 175.6 m above sea level with a long-term average of 174.1 m (International Great Lakes Datum (IGLD) 1985). Old Woman creek is 24 km long (mainstream linear dimension), has an average depth of less than 0.5 m MHW, and an average width of 2-3 m. Creek bottom habitats are predominantly silt and clay, with no aquatic macrophytes within 100 m of the sampling site. At the sampling site the estuary is riverine and relatively deep (1.5 m) and narrow (8 m). The watershed is primarily agricultural, with about 2/3 of the watershed devoted to row-crop agriculture. Orchards, pastures, and forests comprise most of the other land uses. The town of Berlin Heights (pop. 600) is the only urban area in the watershed.

Descriptive Statistics
Forty-five deployments were made at this site between Apr-Oct 1996, 1997, and 1998 (Figure 67). Mean deployment duration was 13 days. Five deployments (May, Jul, Sep 1996; Jun 1997, 1998) were less than 10 days.

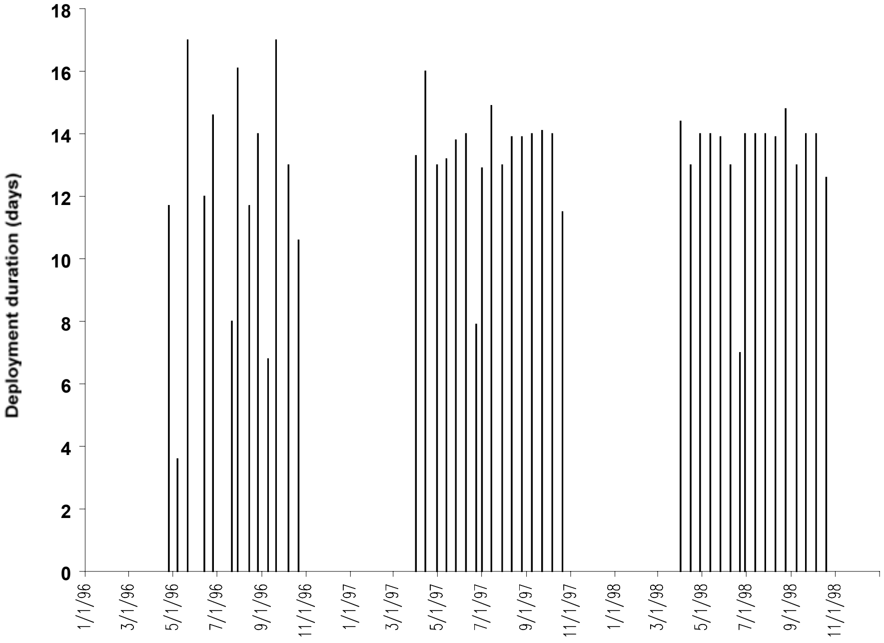


Figure 67. Old Woman Creek, State Route 2 deployments (1996-1998).

Fifty-two percent of seasonal depth data were included in analyses (42% in 1996, 55% in 1997, and 59% in 1998). Sensors were deployed at a mean depth of 0.6 m below the water surface. Scatter plots suggest minor fluctuations (≤ 0.5 m) in daily and bi-weekly water depth throughout most of the data set; however, moderate fluctuations (1 m) were observed during episodic events in Aug-Sep 1997 and

Apr 1998. Harmonic regression analysis attributed 69% of depth variance to interaction between 12.42 hour and 24 hour cycles, 27% of depth variance to 24 hour cycles, and 4% of depth variance to 12.42 hour cycles.

Fifty-one percent of seasonal water temperature data were included in analyses (38% in 1996, 55% in 1997, and 59% in 1998). Water temperature followed a seasonal cycle; however, annual minimum temperature was not known because data were not collected in winter (Figure 68). Mean water temperature was 22-23°C in summer and 10-14°C in spring and fall. Minimum and maximum water temperature between 1996-1998 was 4.3°C (Apr 1997) and 29.4°C (Jun 1996), respectively. Scatter plots suggest moderate fluctuations (≤ 2°C) in daily water temperature and strong fluctuations (≤ 10°C) in bi-weekly water temperature, particularly in spring. Harmonic regression analysis attributed 61% of temperature variance to interaction between 12.42 hour and 24 hour cycles, 34% of temperature variance to 24 hour cycles, and 5% of temperature variance to 12.42 hour cycles.

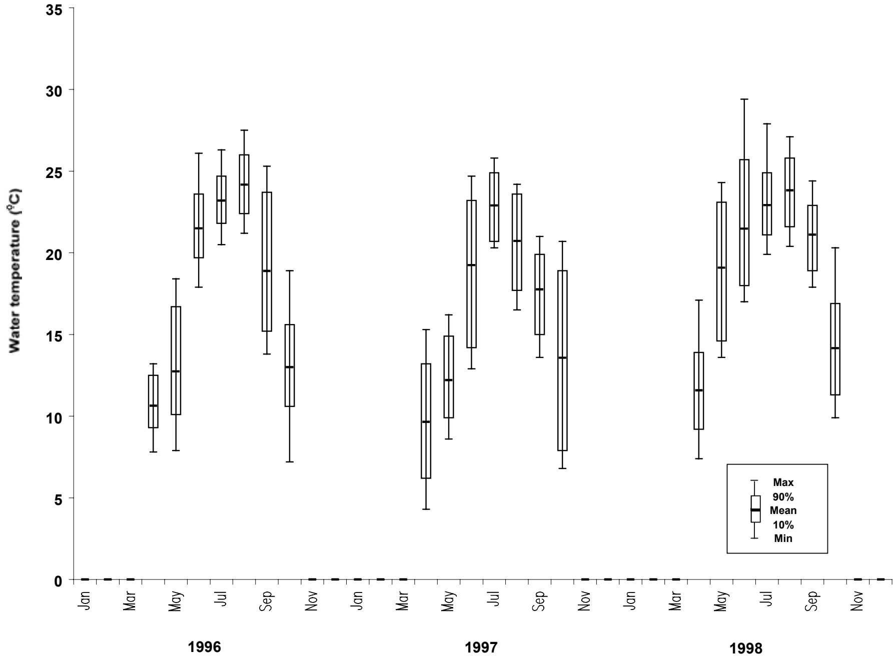


Figure 68. Water temperature statistics at State Route 2, 1996-1998.

Fifty percent of seasonal salinity data were included in analyses (37% in 1996, 55% in 1997, and 59% in 1998). Salinity ranged from 0.1-0.3 ppt, with no discernable seasonal cycle. Harmonic regression analysis attributed 66% of salinity variance to interaction between 12.42 hour and 24 hour cycles, 26% of salinity variance to 24 hour cycles, and 8% of salinity variance to 12.42 hour cycles.

Forty-four percent of seasonal dissolved oxygen (% saturation) data were included in analyses (25% in 1996, 51% in 1997, and 55% in 1998). Mean DO was greatest in spring (70-80% sat) and least in summer or fall (30-60% sat). Minimum and maximum DO between 1996-1998 was 0.4% saturation (Jul 1997) and 178.2% saturation (Aug 1998), respectively. Hypoxia was regularly observed in summer 1997 and infrequently observed in 1996 and 1998 and, when present, hypoxia persisted < 1% to 18% of the first 48 hours post-deployment (Figure 69). Supersaturation was only observed in 1998 and, when present, supersaturation lasted 7% of the first 48 hours post-deployment on average.

Scatter plots suggest minor fluctuations (20-40%) in percent saturation in spring and fall, with moderate fluctuations (40-80%) in summer. Harmonic regression analysis attributed 72% of DO variance to interaction between 12.42 hour and 24 hour cycles, 24% of DO variance to 24 hour cycles, and 4% of DO variance to 12.42 hour cycles.

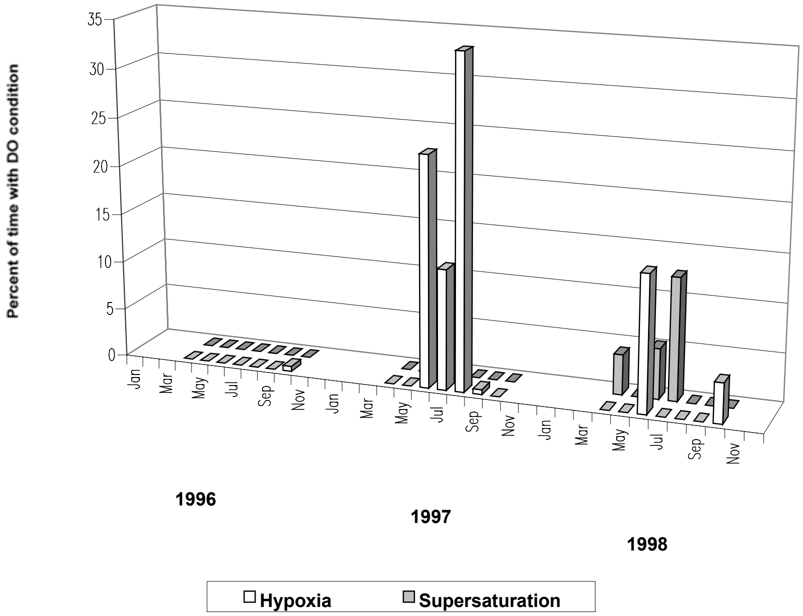


Figure 69. Dissolved oxygen extremes at State Route 2, 1996-1998.

Old Woman Creek, State Route 6 (OWCWM)

Characterization (Latitude = 41°23'15"N; Longitude = 82°30'50"W)
Water level at Old Woman Creek is normally regulated by Lake Erie water levels, except when the barrier beach is closed off, when Old Woman creek is isolated from Lake Erie. Water levels are dependent upon wind and wave activity on Lake Erie when the mouth is open. When the mouth is closed, watershed rainfall and evapo-transpiration rates are most important in determining changes in water levels in Old Woman Creek. Water level varies up to 2 m annually and ranges from 173.2 m to 175.6 m above sea level, with a long-term average of 174.1 m (International Great Lakes Datum (IGLD) 1985). Old Woman creek is 24 km long (mainstream linear dimension), has an average depth of less than 0.5 m MHW, and an average width of 2-3 m. At the sampling site, the depth is 0.5 m and the width is 30 m. At this point the estuary is lacustrine in character and is very broad (just upstream from the sampling point, the estuary is greater than 250 meters wide) and shallow (average depth above the sampling site is less than 0.5 meters). Creek bottom habitats are predominantly silt and clay. No aquatic vegetation occurs at the sampling site; however, extensive beds of *Nelumbo lutea* occur upstream.

Descriptive Statistics
Fifty-two deployments were made at this site between Apr-Oct in 1996, 1997, and 1998 (Figure 70). Mean deployment duration was 11 days. Only one deployment (Jun 1996) was less than five days.

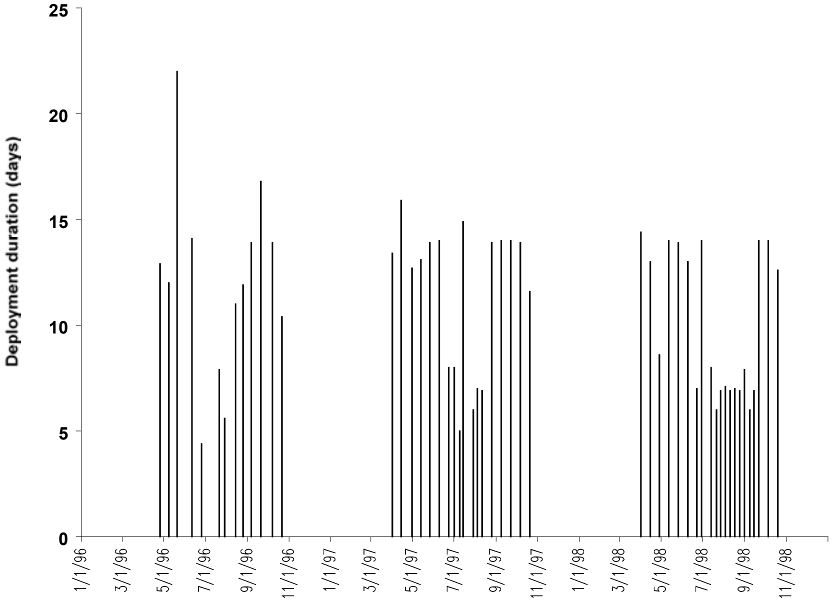


Figure 70. Old Woman Creek, State Route 6 deployments (1996-1998).

Fifty-one percent of seasonal depth data were included in analyses (42% in 1996, 55% in 1997, and 57% in 1998). Sensors were deployed at a mean depth of 0.6 m below the water surface and 0.05-0.32 m above the bottom sediment. Scatter plots suggest minor fluctuations (≤ 0.4 m) in water depth throughout the data set, with 1 m fluctuations observed in Oct 1996, Aug 1997, and Apr 1998. Harmonic regression analysis attributed 67% of depth variance interaction between 12.42 hour and 24 hour cycles, 26% of depth variance to 24 hour cycles, and 7% of depth variance to 12.42 hour cycles.

Fifty-two percent of seasonal water temperature data were included in analyses (43% in 1996, 55% in 1997, and 59% in 1998). Water temperature followed a seasonal cycle; however, annual minimum water temperatures were not known because data were not collected in winter (Figure 71). Mean water temperature was typically 23-25°C in summer and 10-15°C in spring and fall. Minimum and maximum water temperatures observed were 4.1°C (Oct 1996) and 31.7°C (Jun 1998), respectively. Scatter plots suggest moderate fluctuations (1-2°C) in daily water temperature, with strong fluctuations (3-10°C) in bi-weekly water temperature throughout the data set. Harmonic regression analysis attributed 53% of temperature variance to interaction between 12.42 hour and 24 hour cycles, 37% of temperature variance to 24 hour cycles, and 10% of temperature variance to 12.42 hour cycles.

Fifty-two percent of seasonal salinity data were included in analyses (43% in 1996, 55% in 1997, and 59% in 1998). Salinity was 0.1-0.3 ppt throughout the data set, with no discernable seasonal cycle. Harmonic regression analysis attributed 63% of salinity variance to interaction between 12.42 hour and 24 hour cycles, 25% of variance to 24 hour cycles, and 12% of variance to 12.42 hour cycles.

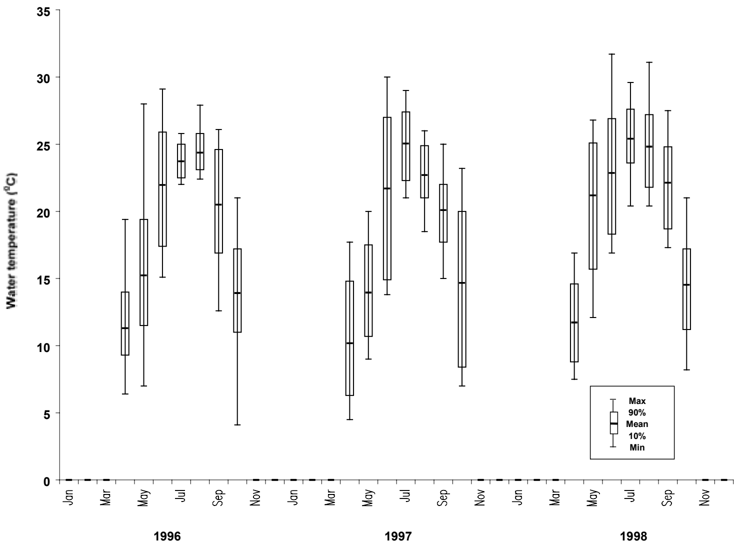


Figure 71. Water temperature statistics at State Route 6, 1996-1998.

Forty-three percent of seasonal dissolved oxygen (% saturation) data were included in analyses (32% in 1996, 47% in 1997, and 50% in 1998). Mean DO followed a seasonal cycle, with lowest DO (38-60% sat) in summer and greatest DO (70-120% sat) in spring and fall. Minimum and maximum DO between 1996-1998 was 0% saturation (Aug 1998) and 209.6% saturation (Jul 1998), respectively. Hypoxia was observed in Jul-Aug during all three years and, when present, hypoxia persisted for <5% of the first 48 hours post-deployment on average (Figure 72). Supersaturation was regularly observed in 1997-1998 and, when present, supersaturation persisted for 6.4% of the first 48 hours post-deployment on average. Scatter plots suggest strong DO fluctuations (≥ 80%) in summer 1996-1998. Harmonic regression analysis attributed 61% of DO variance to interaction between 12.42 hour and 24 hour cycles, 31% of DO variance to 24 hour cycles, and 31% of DO variance to 12.42 hour cycles.

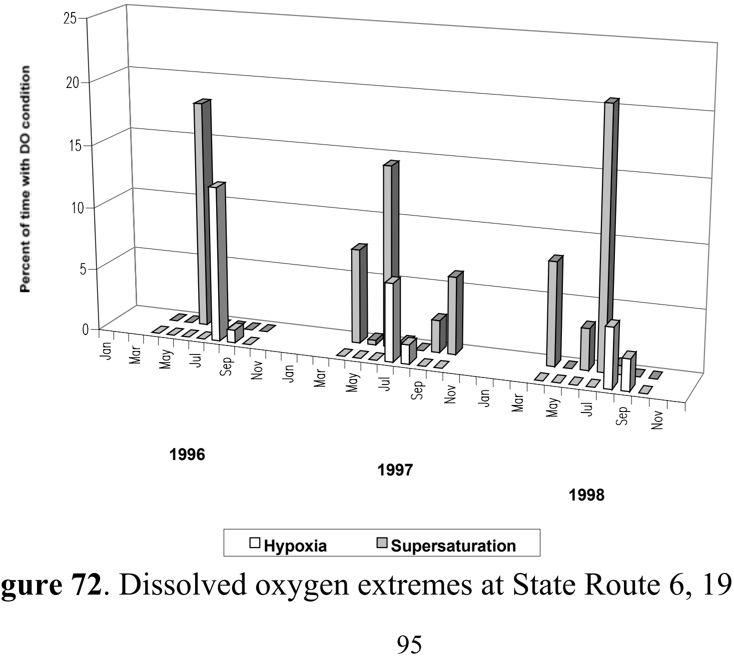
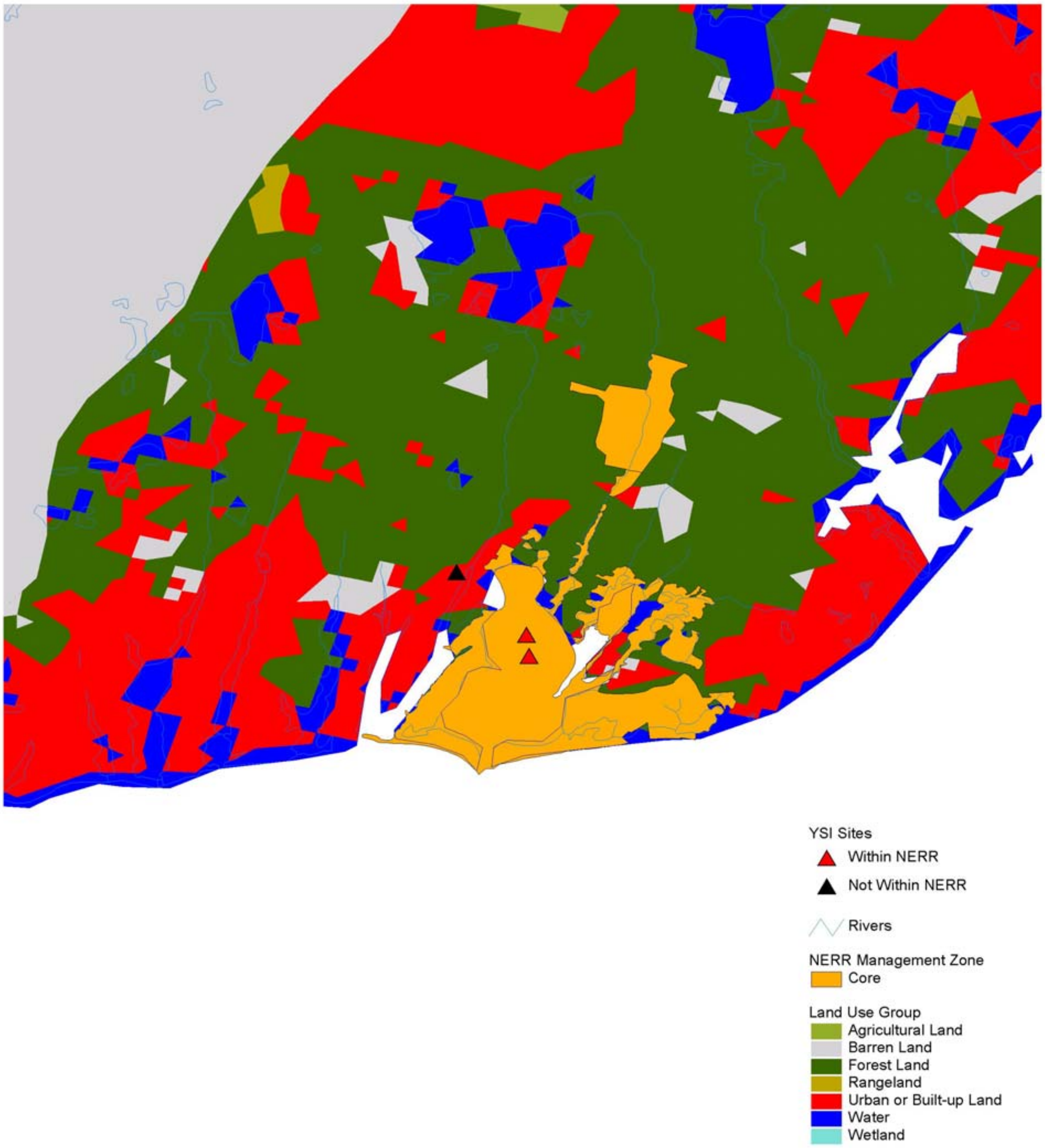


Figure 72. Dissolved oxygen extremes at State Route 6, 1996-1998.

Waquoit Bay


YSI Sites
Within NERR
Not Within NERR
Rivers
NERR Management Zone
Core
Land Use Group
Agricultural Land
Barren Land
Forest Land
Rangeland
Urban or Built-up Land
Water
Wetland

Waquoit Bay, Central Basin (WQBCB)

Characterization (Latitude = 41° 33'56" N; Longitude = 70° 31'16" W)

Tides in Waquoit Bay are semidiurnal with an average range of about 0.4 m. Largely because of the shallow conditions, restricted tidal inlet, and low amplitude tidal signal, tides in the bay are also strongly influenced by wind forcing. The Bay, itself, is about 3 km long, 1.5 km wide, and has a surface area of about 380 ha. Average depth in the bay is 1.3 m (MHW). The site is rather typical of southern New England shallow coastal bays. At the sampling site, the depth is about 2 m (MHW) and monitoring probes are positioned about 0.75 m above the bottom. Bottom sediments are organic rich silts and medium sands. Thick (up to 0.3 m) macroalgae (seaweed) mats overlie much of the bottom of the bay, and largely consist of species *Cladophora vagabunda*, *Gracilaria tikvahiayae*, and *Enteromorpha* sp. The dominant marsh vegetaion near the sampling site are *Spartina alterniflora* and *Spartina patens*. Dominant upland vegetation includes mixed forests of red oak, white oak, and pitch pine, and other shrubs and plants common to coastal New England. Land-use in the bay's watershed is about 60% natural vegetation, but the remaining land is largely residential, with some commercial (retail malls), and minor amounts of agriculture (~3%, cranberry bogs). Activities most likely to impact the site include enhanced nitrogen loads derived from individual residential septic systems and intensive recreational boating during the summer months.

Descriptive statistics

Twenty-five deployments were made at this site between May-Jul 1996, May-Dec 1997, and Aug-Dec 1998 (Figure 73). Mean deployment duration was 13.6 days. Seven deployments (Jun-Aug 1997, Nov 1997, and Aug 1998) were less than 10 days.

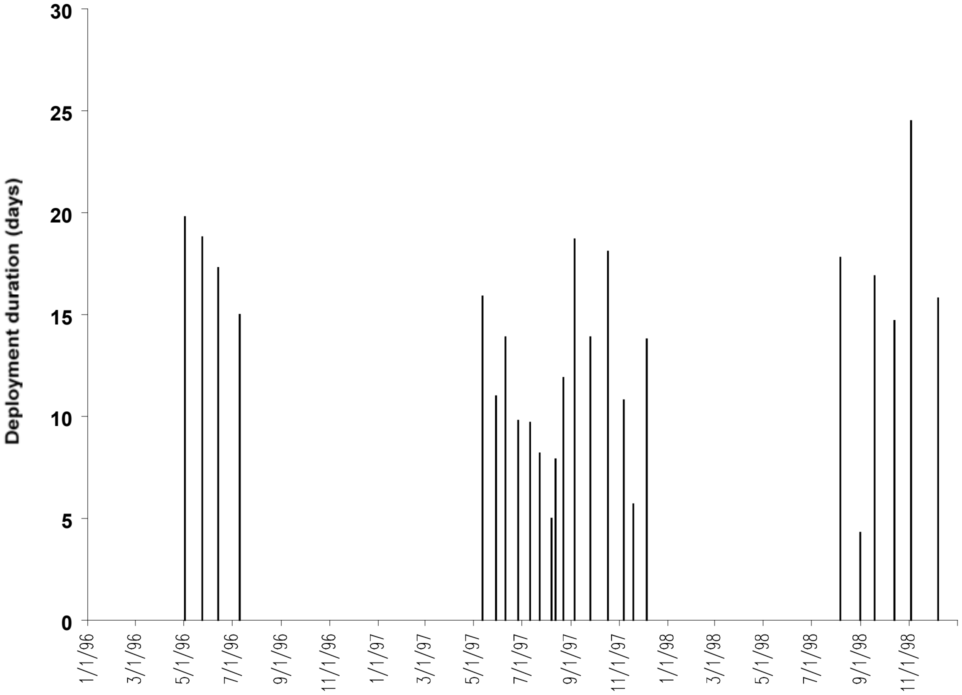


Figure 73. Waquoit Bay, Central Basin deployments (1996-1998).

Thirty-one percent of annual depth data were included in analyses (19% in 1996, 48% in 1997, and

26% in 1998). Sensors were deployed at a mean depth of 1.4 m below the water surface and 0.8 m above the bottom sediment. Scatter plots suggest moderate fluctuations (0.5-1.0 m) in depth throughout the data set. Harmonic regression analysis attributed 61% of depth variance to 12.42 hour cycles, 10% of depth variance to 24 hour cycles, and 29% of depth variance to interaction between 12.42 hour and 24 hour cycles.

Thirty-one percent of annual water temperature data were included in analyses (19% in 1996, 48% in 1997, and 26% in 1998). Water temperature followed a seasonal cycle; however true annual minimum temperatures are unknown because water temperature data were not collected in winter (Figure 74). Mean water temperatures were 15-20°C in spring, 20-25°C in summer and 5-10°C in fall. Minimum and maximum water temperature between 1996-1998 was 0.9°C (Dec 1997) and 27.5°C (Jul 1997, Aug 1998), respectively. Scatter plots suggest moderate fluctuations (1-4°C) in daily water temperature and strong fluctuations (3-7°C) in bi-weekly water temperature throughout the data set, particularly in summer. Harmonic regression analysis attributed 68% of temperature variance to 24 hour cycles, 31% of temperature variance to interaction between 12.42 hour and 24 hour cycles, and 1% of temperature variance to 12.42 hour cycles.

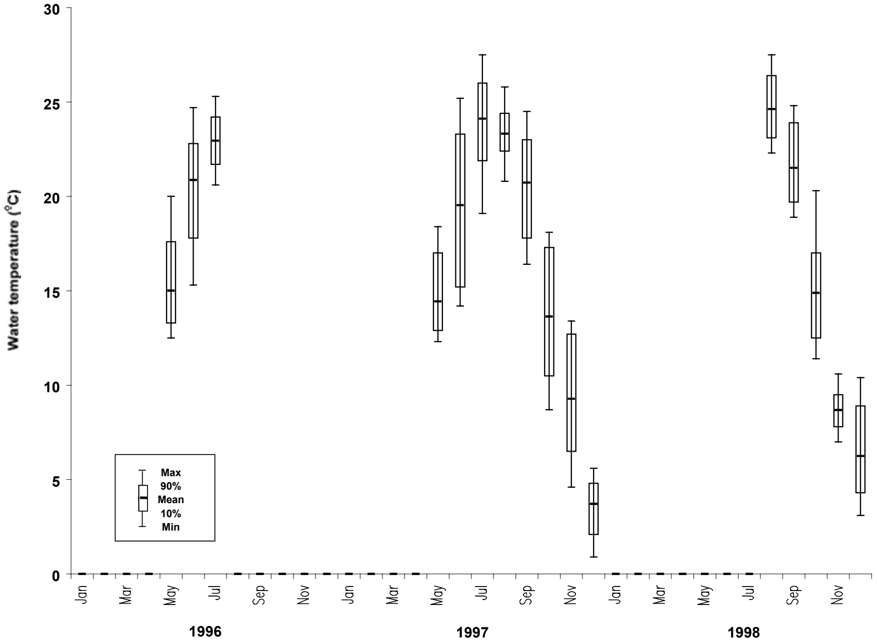


Figure 74. Water temperature statistics at Central Basin, 1996-1998.

Thirty-one percent of annual salinity data were included in analyses (19% in 1996, 48% in 1997, and 26% in 1998). Mean salinity was 28-32 ppt throughout the data set, with no discernable seasonal cycle (Figure 75). Minimum and maximum salinity was 21.8 ppt (May 1996) and 32.6 (Dec 1997), respectively. Scatter plots suggest daily and bi-weekly fluctuations in salinity equivalent to or in excess of annual variation in mean salinity (4 ppt). Harmonic regression analysis attributed 59% of salinity variance to interaction between 12.42 hour and 24 hour cycles, 26% of salinity variance to 24 hour cycles, and 15% of salinity variance to 12.42 hour cycles.

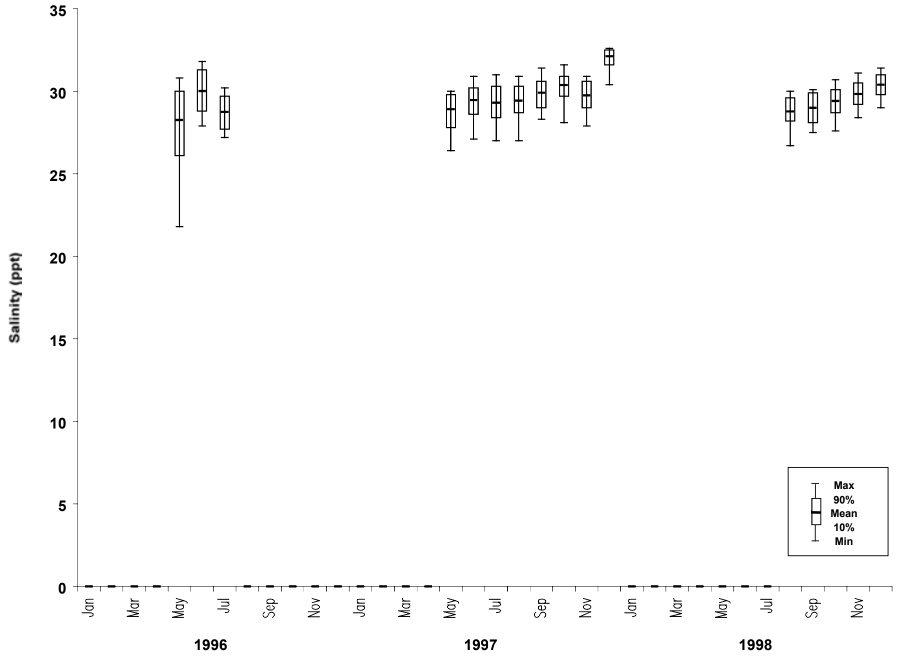


Figure 75. Salinity statistics for Central Basin, 1996-1998.

Twenty-nine percent of annual dissolved oxygen (% saturation) data were included in analyses (15% in 1996, 47% in 1997, and 24% in 1998). Mean DO was 92-140% saturation throughout the data set. Minimum and maximum DO was 4.3% saturation (Jun 1996) and 269.6% saturation (Jun 1997), respectively. Hypoxia was observed in one month (Jun 1996) and persisted for 1% of the first 48 hours post-deployment (Figure 76). Supersaturation was observed during every month of data collection, except for Dec 1997, and persisted for 29.7% of the first 48 hours post-deployment on average. Scatter plots suggest strong fluctuation (80-200%) in percent saturation throughout the data set, with greatest fluctuation occurring in summer. Harmonic regression analysis attributed 43% of DO variance to 12.42 hour cycles, 50% DO variance to interaction between 12.42 hour and 24 hour cycles, and 7% of DO variance to 24 hour cycles.

Photosynthesis/Respiration

Almost all (92%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and was used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 21). Instrument drift was not a problem at this site. Gross production slightly exceeded total respiration at Central Basin, and the net ecosystem metabolism and P/R ratio indicated that this site is slightly autotrophic, one of two sites in the Reserve system that was autotrophic (Figure 77). Temperature was significantly ($p<0.05$) correlated with gross production and total respiration. Gross production and respiration increased as temperature increased. Salinity was not significantly ($p<0.05$) correlated with any metabolic measurement.

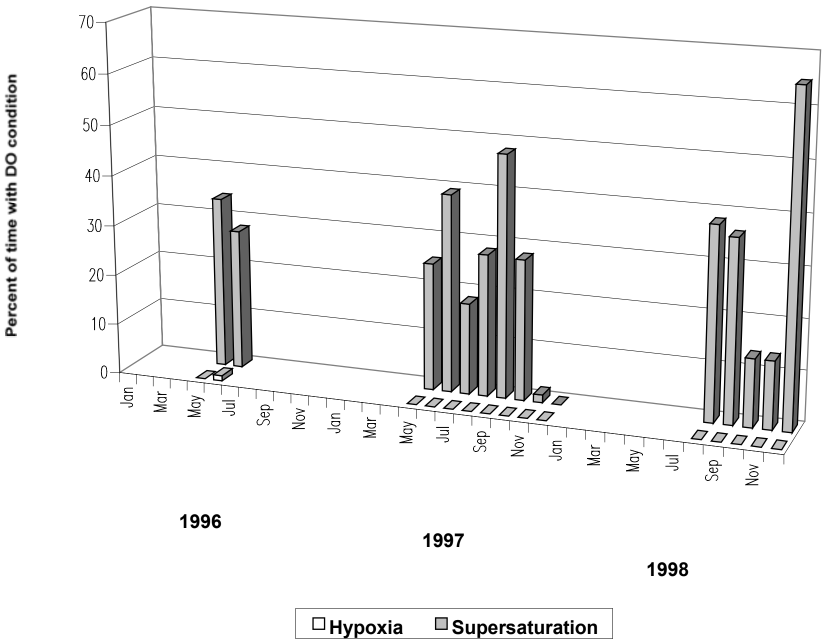


Figure 76. Dissolved oxygen extremes at Central Basin, 1996-1998.

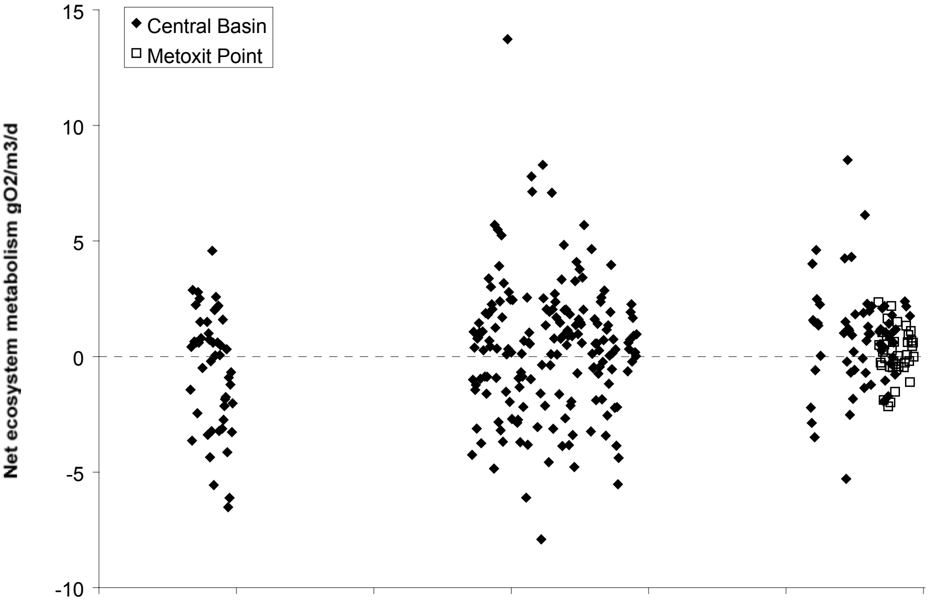


Figure 77. Net metabolism at Central Basin, 1996-1998.

Table 21. Summary of metabolism data and statistics at Central Basin, 1996-1998.

Central Basin	mean	s.e.
Water depth (m)	1.14	
Net production $gO_2/m3/d$	3.39	0.16
Gross production $gO_2/m3/d$	7.54	0.32
Total respiration $gO_2/m3/d$	7.29	0.33
Net ecosystem metabolism g $O_2/m3/d$	0.26	0.15
Net ecosystem metabolism g C/m2/y	334	
P/R	1.04	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	92 %	
Paired t-test on gross production and total respiration	$p = 0.05$	
Correlation coefficient	Temperature	Salinity
Gross production	0.47	ns
Total respiration	0.46	ns
Net ecosystem metabolism	ns	ns

Waquoit Bay, Metoxit Point (WQBMP)

Characterization (Latitude = 41° 34’08” N; Longitude = 70° 31'18” W)

The Metoxit Point site is only a few hundred meters from the Central Basin site and became the replacement site for Central Basin in 1998. For this reason, its general characteristics are essentially identical to those outlined for the Central Basin site; however, there are some minor but important differences with respect to the amount of hydrographic variability at this site.

Descriptive Statistics

Two deployments were made at this site in Nov 1998 (28.6 day) and Dec 1998 (15.8 days).

Sensors were deployed at a mean depth of 1.1 m below the water surface and 0.8 m above the bottom sediment. Scatter plots suggest moderate fluctuations (0.5-0.8 m) in depth in Nov and Dec 1998. Harmonic regression analysis attributed 63% of depth variance to 12.42 hour cycles, 22% of variance to interaction between 12.42 hour and 24 hour cycles, and 15% of variance to 24 hour cycles.

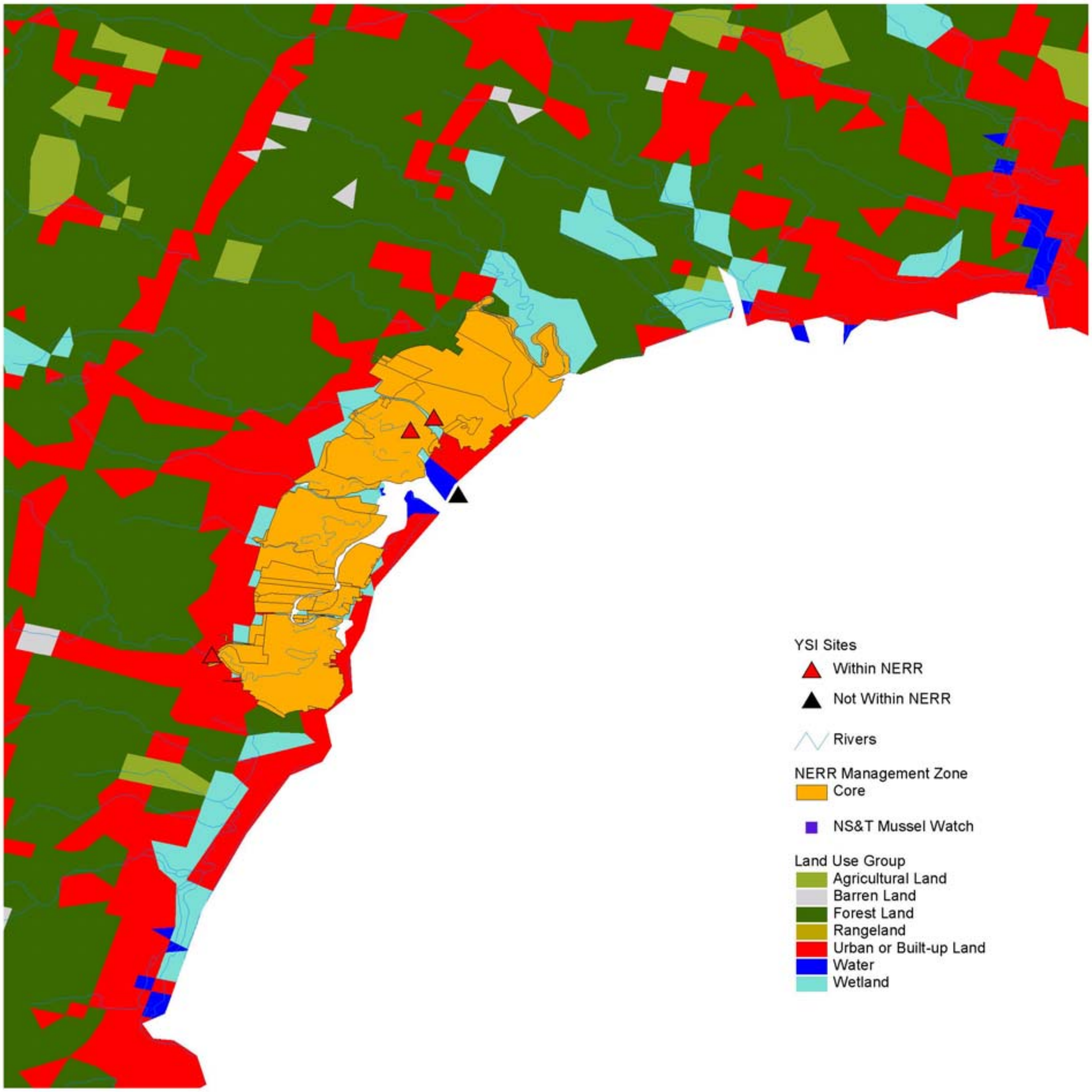
Mean water temperature in Nov and Dec 1998 was 8.6°C and 6.4°C, respectively. Minimum and maximum temperature was 3°C and 10.6°C, respectively. Scatter plots suggest moderate fluctuation (≤ 3°C) in daily water temperature and strong fluctuations (2-6°C) in bi-weekly water temperature, with greater fluctuation in Dec than in Nov. Harmonic regression analysis attributed 70% of temperature variance to 24 hour cycles, 25% of temperature variance to interaction between 12.42 hour and 24 hour cycles, and 5% of temperature variance to 12.42 hour cycles.

Mean salinity in Nov-Dec 1998 was 29.6-29.9 ppt. Minimum and maximum salinity was 27.4 ppt and 31.1 ppt, respectively. Scatter plots suggest moderate (< 5 ppt) fluctuations in daily and bi-weekly salinity in Nov and Dec, with slightly greater fluctuation in Nov. Harmonic regression analysis attributed 65% of salinity variance to interaction between 12.42 hour and 24 hour cycles, 26% of salinity variance to 24 hour cycles, and 9% of salinity variance to 12.42 hour cycles.

Mean dissolved oxygen (% saturation) in Nov-Dec 1998 was 100-102% saturation. Minimum and maximum DO was 70.5% saturation and 125.6% saturation, respectively. Hypoxia was never observed. Supersaturation was observed in Nov and persisted for 2% of the first 48 hours post-deployment. Scatter plots suggest moderate fluctuation (< 50%) in percent saturation at daily and bi-weekly intervals, with slightly greater fluctuation in Nov than in Dec. Harmonic regression analysis attributed 63% of DO variance to 24 hour cycles, 32% of DO variance to interaction between 12.42 hour and 24 hour cycles, and 5% of DO variance to 12.42 hour cycles.

Average metabolic rates and other statistics were not calculated for Metoxit Point because only 47 days of data were available, between November 3, 1998 and December 23, 1998. Rates at this site were very similar to those measured in the Central Basin.

Wells


YSI Sites
Within NERR
Not Within NERR
Rivers
NERR Management Zone
Core
NS&T Mussel Watch
Land Use Group
Agricultural Land
Barren Land
Forest Land
Rangeland
Urban or Built-up Land
Water
Wetland

Wells, Head of Tide (WELHT)

Characterization (Latitude = 43°17'54"N; Longitude = 70°35'14"W)
Tides at Head of Tide are semidiurnal and range from 2.6 m to 2.9 m (average 2.6 m). This site is located 4 miles south of the Wells Reserve, just downstream of the Webhannet Falls (freshwater) and 10 feet east of Route One. The creek/waterbody is 2,443 m long (mainstream linear dimension), has an average depth of 1.3 m MHW, and an average width of 224 m. At the sampling site, the depth is 0.36 m MHW and the width is 8.5 m. Creek bottom habitats are predominantly soft mud, sand, and rocky substrate with no bottom vegetation. The dominant marsh (brackish marsh) vegetation near the sampling site includes *Spartina pectinata, Typha angustifolia, and Potentilla angerina*. The dominant upland vegetation includes *Acer rubrum, Betula lenta, Pyrus malus, Syringa vulgaris, Prunus* sp., and *Lonicera* sp. Upland land use near the sampling site includes the Route One Bridge directly over the site, a seasonal farm stand, and a small parking area overlooking the Webhannet River waterfall. Activities that potentially impact the site include runoff from Route One (heavily used from the late spring through early fall), a gas station south of the site and a large plaza/grocery area just north of the site. On occasion, elver nets are placed adjacent to the sampling site. The headwaters of Webhannet are relatively undeveloped.

Descriptive statistics
Twenty-two deployments were made at this site between Apr-Dec 1996, Mar-Dec 1997, and Apr-Nov 1998 (Figure 78). Mean deployment duration was 31.2 days. Only one deployment (Aug 1996) was less than 20 days.

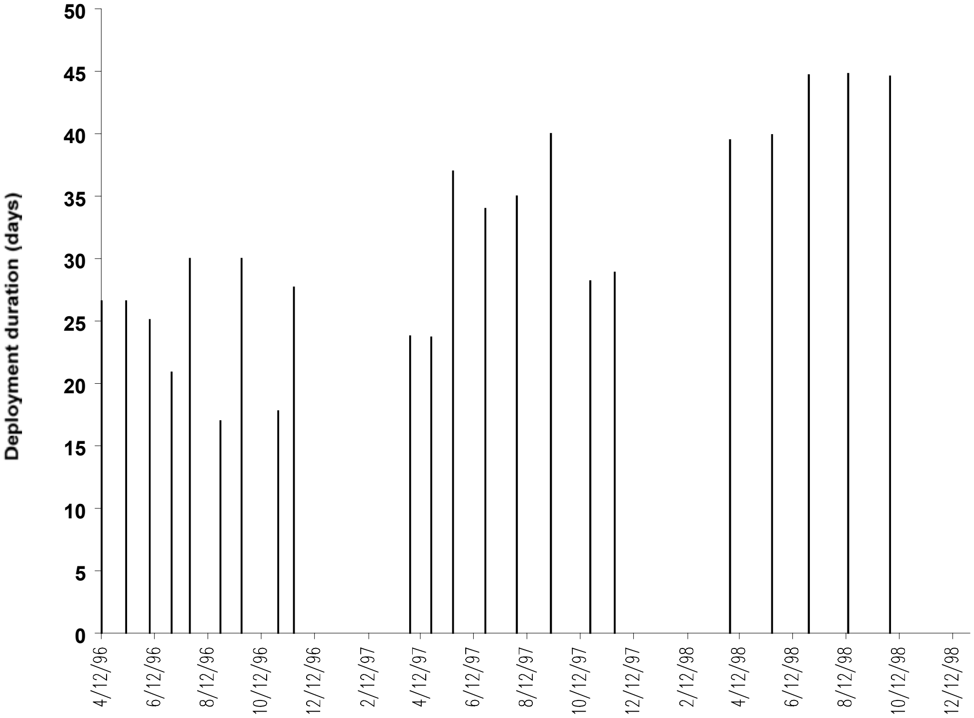


Figure 78. Wells, Head of Tide deployments (1996-1998).

Sixty-five percent of annual depth data were included in analyses (61% in 1996, 69% in 1997, and 66% in 1998). Sensors were deployed at a mean depth of 0.4 m below the water surface and 0.3 m above the bottom sediment. Scatter plots suggest strong fluctuations (≥ 0.8 m) in water depth throughout the data set, except for Mar 1997 (0.2 m). Harmonic regression analysis attributed 68% of depth variance to 12.42 hour cycles, 23% of depth variance to interaction between 12.42 hour and 24 hour cycles, and 9% of depth variance to 24 hour cycles.

Sixty-five percent of annual water temperature data were included in analyses (61% in 1996, 69% in 1997, and 66% in 1998). Water temperature followed a seasonal cycle; however, annual minimum water temperatures were not known because no data were collected in winter (Figure 79). Mean water temperature was 4-13°C in Apr-May, 15-18°C in Jun-Sep, and 1-10°C in Nov-Dec. Minimum and maximum observed water temperature between 1996-1998 was –0.8°C (Dec 1998) and 26.1°C (Jul 1998), respectively. Scatter plots suggest strong fluctuation (5-10°C) in daily and bi-weekly water temperatures throughout the data set, except for Dec 1996 and 1997 and May 1997 when fluctuations were < 5°C and 15°C, respectively. Harmonic regression analysis attributed 48% of temperature variance to 24 hour cycles, 35% of temperature variance to interaction between 12.42 hour and 24 hour cycles, and 17% of temperature variance to 12.42 hour cycles.

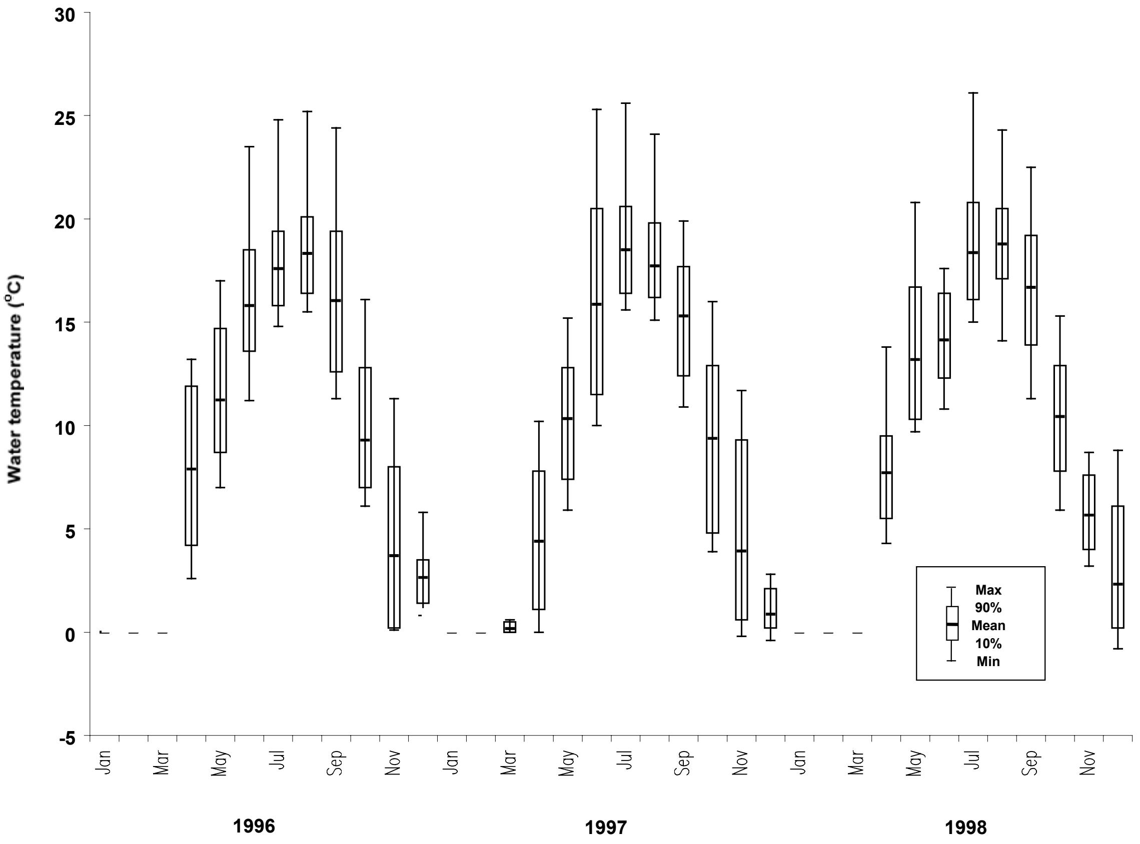


Figure 79. Water temperature statistics at Head of Tide, 1996-1998.

Sixty-five percent of annual salinity data were included in analyses (61% in 1996, 69% in 1997, and 66% in 1998). Large variances (7-30 ppt) were associated with mean salinity throughout the data set (Figure 80). Mean salinity was 0-5 ppt, except in Aug-Sep 1996 (7-14 ppt), Jul-Sep 1997 (6-7 ppt), and Sep 1998 (10 ppt). Minimum salinity regularly approached 0 ppt. Maximum salinity observed between 1996-1998 was 29.8 ppt (Aug 1996). Scatter plots suggest daily and bi-weekly fluctuations in salinity equivalent to, or in excess of, annual variation in mean salinity. Harmonic regression analysis attributed 43% of salinity variance to 12.42 hour cycles, 17% of salinity variance to 24 hour cycles, and 40% of salinity variance to interaction between 12.42 hour and 24 hour cycles.

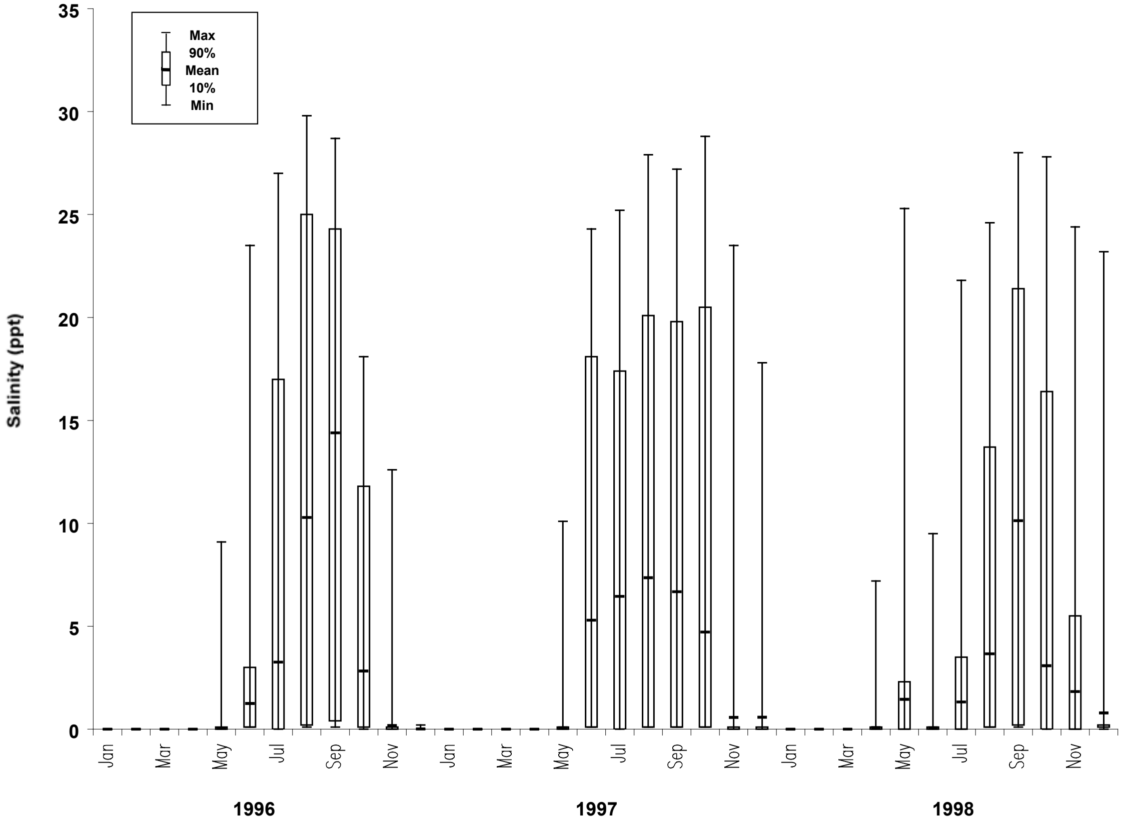


Figure 80. Salinity statistics at Head of Tide, 1996-1998.

Fifty-four percent of annual dissolved oxygen data (% saturation) were included in analyses (54% in 1996, 51% in 1997, and 58% in 1998). Mean DO was 65-112% saturation throughout the data set, with no apparent seasonal cycle. Minimum and maximum DO between 1996-1998 was 20.4% saturation (Jul 1997) and 201.2% saturation (Aug 1998), respectively. Hypoxia was observed in one month (Oct 1997) and persisted for 1% of the first 48 hours post-deployment (Figure 81). Supersaturation was observed in four months (Aug 1996, Jun-Jul 1997, and Aug 1998) and, when present, supersaturation persisted for 2.8% of the first 48 hours post-deployment on average. Scatter plots suggest moderate fluctuations (≤ 60%) in percent saturation throughout the data set, except during episodic events in summer 1996-1998 when fluctuations ≥ 100% were observed. Harmonic regression analysis attributed 45% of DO variance to interaction between 12.42 hour and 24 hour cycles, 43% of DO variance to 24 hour cycles, and 12% of DO variance to 12.42 hour cycles.

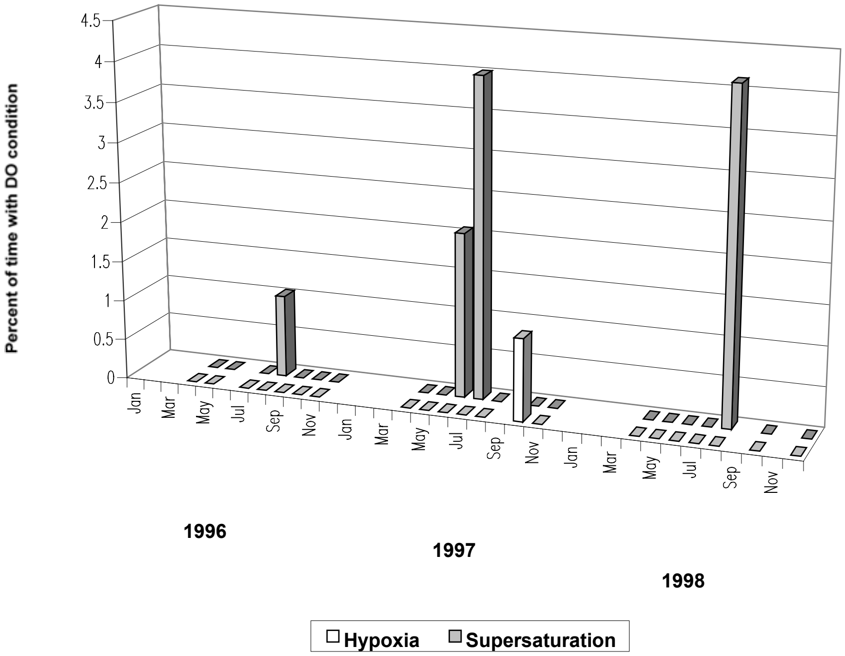


Figure 81. Dissolved oxygen extremes at Head of Tide, 1996-1998.

Wells, Inlet Site (WELIN)

Characterization (Latitude = 43°19'12"N; Longitude = 70°33'48"W)
Tides at the Inlet site are semidiurnal and range from 2.6 m to 2.9 m (average 2.6 m). This site is located 1.5 miles south of the Wells Reserve, at the Wells Harbor pier. The water body is 2,443 m long (mainstream linear dimension), has an average depth of 1.3 m MHW, and an average width of 224 m. At the sampling site, the depth is about 2.54 m MHW and the width is 500 m. Creek bottom habitats are predominantly sand with no bottom vegetation (some *Mytilus edulis* reefs). The dominant marsh vegetation near the sampling site is *Spartina alterniflora* and *Spartina patens*. There is a mixture of *Pinus strobus* and *Populus tremuloides* colonizing a large dredge area near the site. Upland land use near the sampling site includes Wells Harbor, which was most recently dredged in 1971, has moorings for approximately 200 commercial fishing and recreational boats, a boat repair facility, and a restaurant directly adjacent to the site. Close proximity to extensive development surrounding the mouth of the Webhannet salt-marsh estuary is the activity most likely to negatively impact this site. The shoreline surrounding this site is highly developed with motels, restaurants, private homes and seasonal rentals, and heavily used public beaches.

Descriptive statistics
Thirty-three deployments were made at this site between Jan 1996 and Nov 1998, with equal coverage during all months (Figure 82). Mean deployment duration was 29.4 days. Only three deployments (Apr 1996, Jun 1996, and Jan 1997) were less than 20 days.

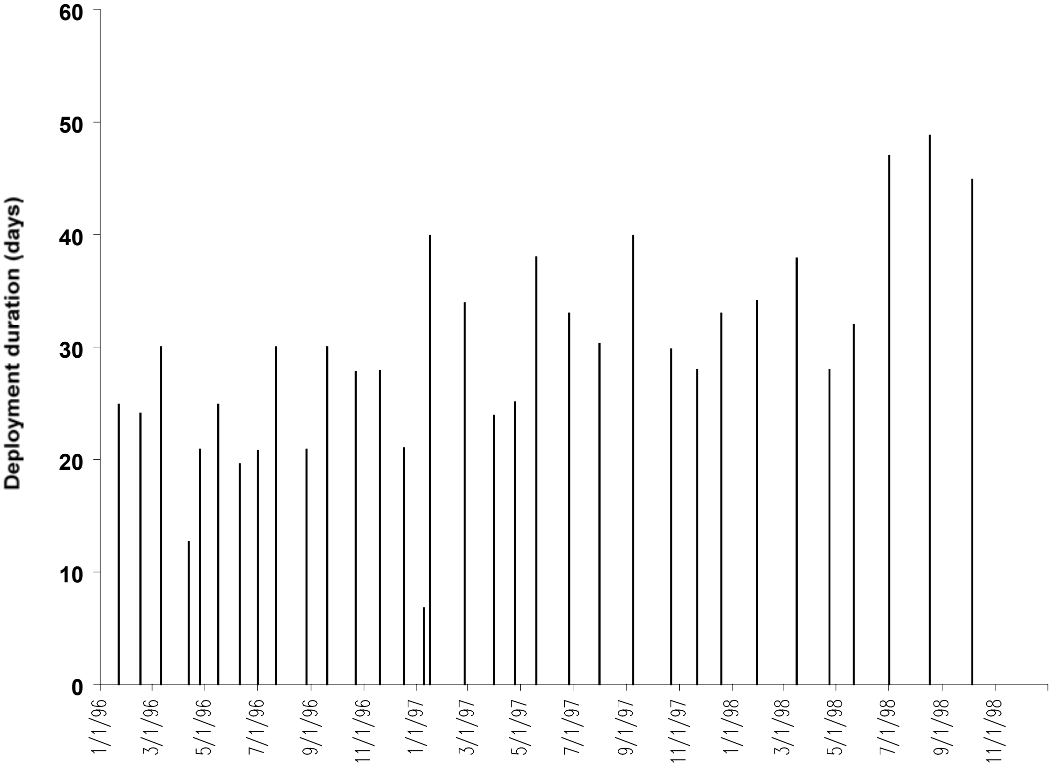


Figure 82. Wells, Inlet Site deployments (1996-1998).

Eighty-nine percent of annual depth data were included in analyses (93% in 1996, 95% in 1997, and 78% in 1998). Sensors were deployed at a mean depth of 2.6 m below the water surface and 1.0 m above the bottom sediment. Scatter plots suggest strong fluctuations in depth (≥ 3 m) throughout the data set, except for Jan 1996 (~ 2 m). Harmonic regression analysis attributed 96% of depth variance to 12.42 hour cycles, 3% of depth variance to 24 hour cycles, and 1% of depth variance to interaction between 12.42 hour and 24 hour cycles.

Eighty-eight percent of annual water temperature data were included in analyses (93% in 1996 and 1997, 78% in 1998). Water temperature followed a seasonal cycle, with mean water temperatures 1-3°C in winter and 15-17°C in summer (Figure 83). Minimum and maximum water temperature between 1996-1998 was –1.8°C (Jan 1996) and 23.1°C (Jul 1997), respectively. Scatter plots suggest strong fluctuations in daily (≤ 5°C) and bi-weekly (5-10°C) water temperatures, with strongest fluctuations occurring in spring and summer. Harmonic regression analysis attributed 48% of temperature variance to 12.42 hour cycles, 33% of temperature variance to interaction between 12.42 hour and 24 hour cycles, and 19% of temperature variance to 24 hour cycles.

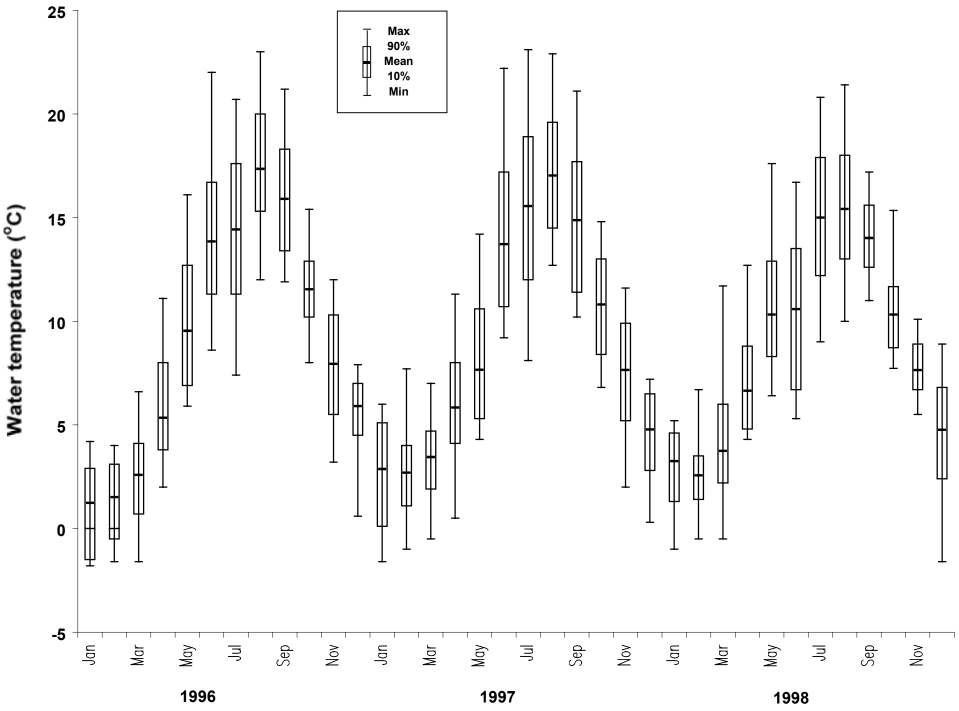


Figure 83. Water temperature statistics at Inlet Site, 1996-1998.

Eighty-eight percent of annual salinity data were included in analyses (93% in 1996 and 1997, 78% in 1998). Mean salinity was 28-34 ppt; however, large variances were associated with mean salinity values throughout the data set (Figure 84). Minimum and maximum salinity between 1996-1998 was 0.5 ppt (Oct 1998) and 36 ppt (Feb 1997), respectively. Scatter plots suggest fluctuations in daily and bi-weekly salinity equivalent to, or in excess of, annual variation in mean salinity (except for Jul-Aug 1996, May, Aug, and Sep 1997, and Aug 1998). Harmonic regression analysis attributed 91% of salinity variance to 12.42 hour cycles, 6% of salinity variance to interaction between 12.42 hour and 24 hour cycles, and 3% of salinity variance to 24 hour cycles.

Eighty-five percent of annual dissolved oxygen (% saturation) data were included in analyses (93% in 1996, 85% in 1997, and 78% in 1998). Mean DO was 60-113% saturation throughout the data set. Minimum and maximum DO between 1996-1998 was 0.4% saturation (Nov 1998) and 145.3% saturation (Oct 1997), respectively. Hypoxia was observed in six months in 1998 and, when present, hypoxia persisted for 14.2% of the first 48 hours post-deployment on average (Figure 85). Super-saturation was observed once in 1996, once in 1998, and in five months in 1997. Except for Jul 1997, when supersaturation persisted for 58% of the first 48 hours post-deployment, super-saturation persisted for 3.9% of the first 48 hours post-deployment on average when present. Scatter plots suggest moderate fluctuations in percent saturation (20-80%) in 1996-1997 and winter 1998, but strong fluctuations in percent saturation (80-120%) in spring, summer, and fall 1998. Harmonic regression analysis attributed 68% of DO variance to 12.42 hour cycles, 14% of DO variance to 24 hour cycles, and 18% of DO variance to interaction between 12.42 hour and 24 hour cycles.

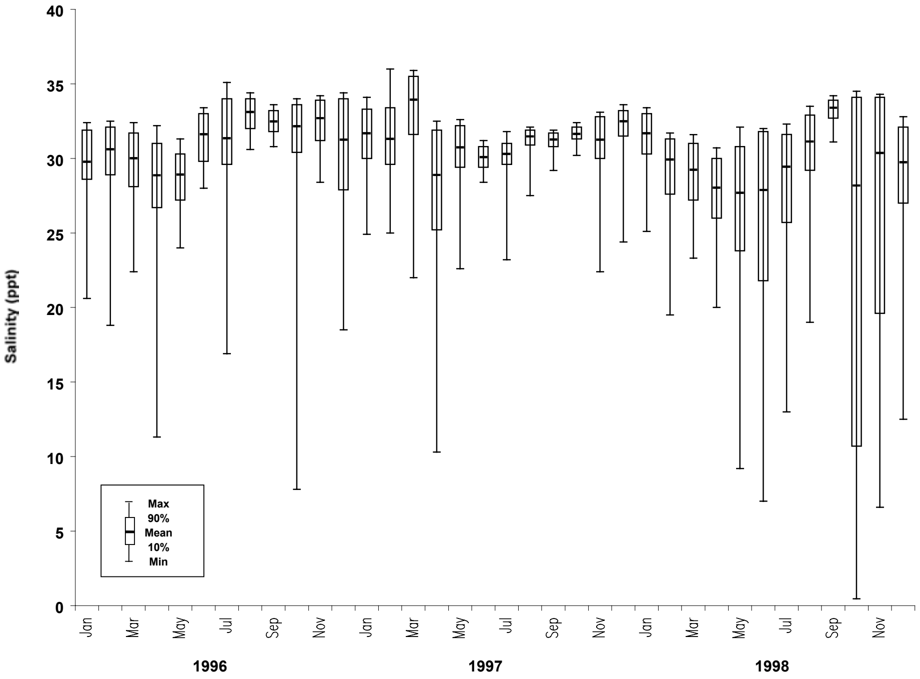


Figure 84. Salinity statistics at Inlet site, 1996-1998.

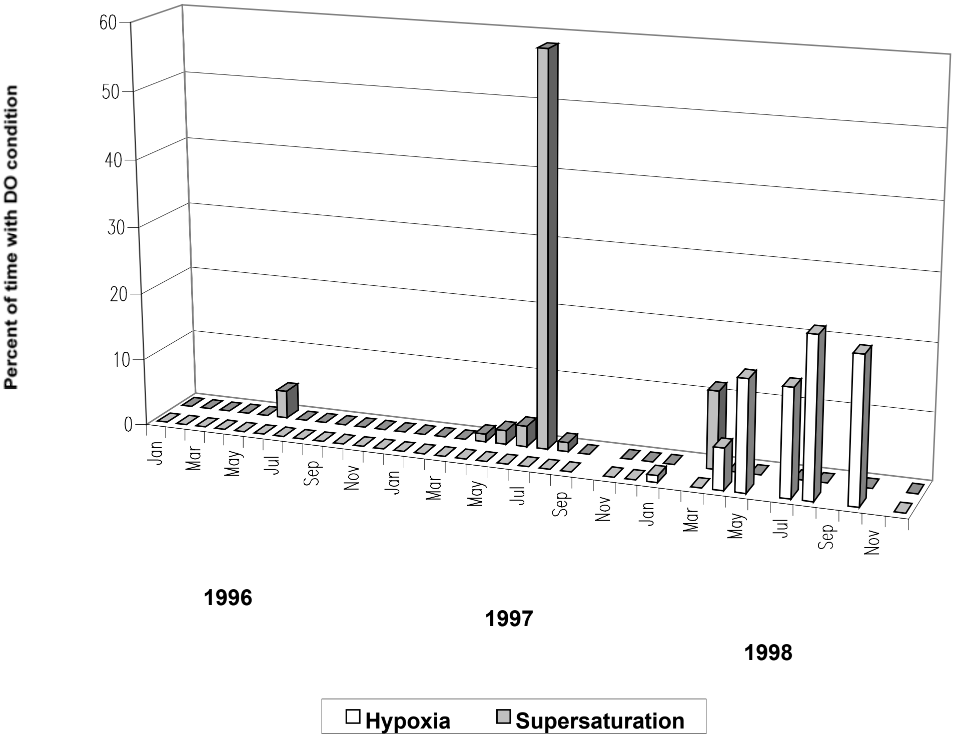
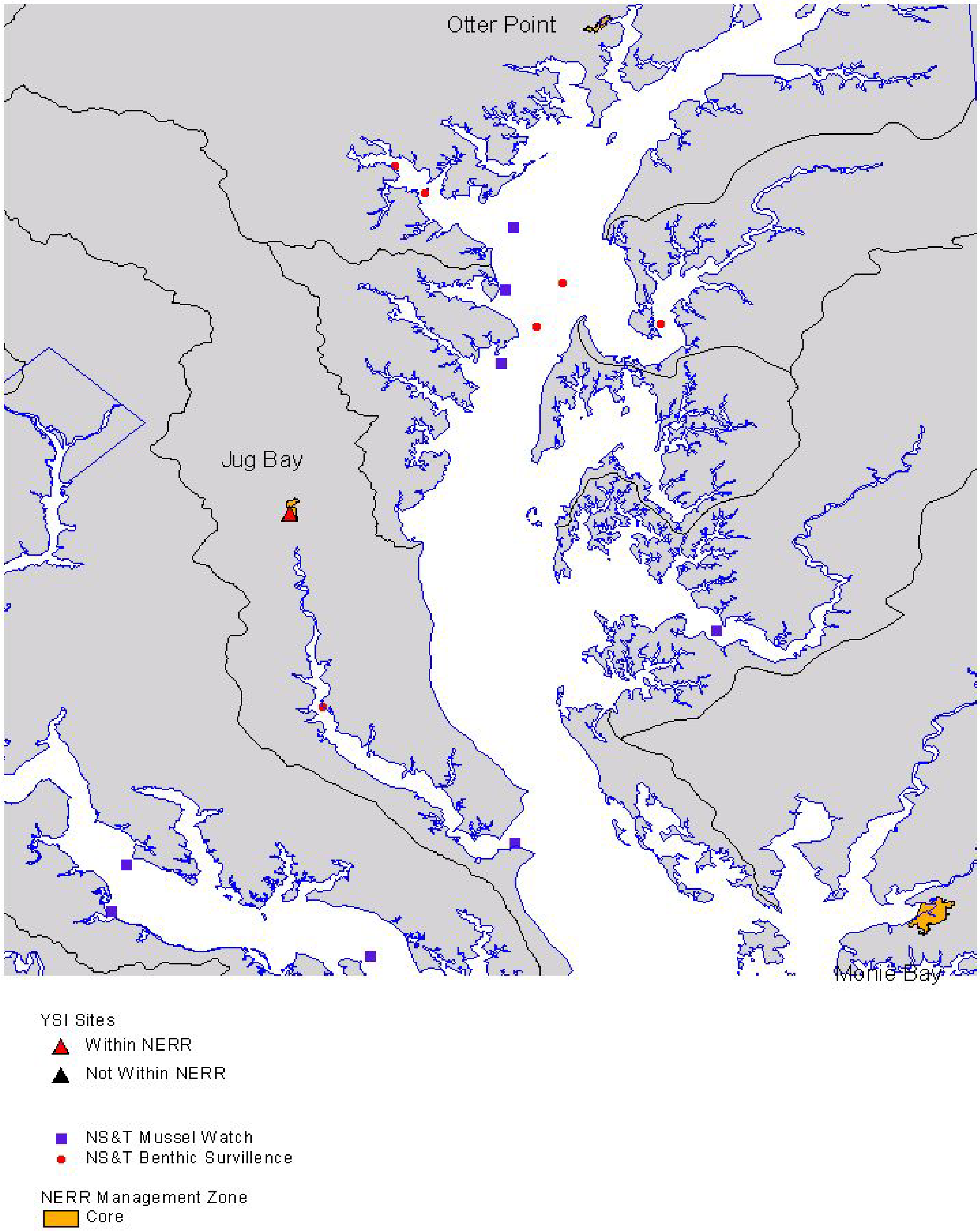


Figure 85. Dissolved oxygen extremes at Inlet site, 1996-1998.

Chesapeake Bay, MD



Chesapeake Bay Maryland, Jug Bay (CBMJB)

Characterization (Latitude = 38° 46' 00" N; Longitude = 76° 42' 30" W)

This site is in a shallow tidal marsh creek in the upper reaches of the Patuxent River. Tides at Jug Bay are semidiurnal and average 0.75 m in range. The creek has an average width of 5 m. Creek bottom habitats are silt-clay with no bottom vegetation. Marsh vegetation near the sampling site includes wild rice, cattails, arrow arum, arrowhead, cattails, pickerelweed, spatterdock, rose mallow, and *Phragmites* sp. One of the most important plants in the tidal wetlands is wild rice. The dominant upland vegetation includes mixed hardwood forest of oaks, hickory, sweet gum, American beech, poplars, red maple, sassafras, and Virginia pine. The sub-canopy contains American holly, sweet bay, musclewood, flowering and silky dogwood, witch hazel, smooth alder, red maple, and black gum. Upland land use near the sampling site includes a park, residential development, and agriculture. Activities that potentially impact the site include nutrient inputs from sewage treatment plants and non-point source runoff.

Descriptive Statistics

Twenty-three deployments were made at this site between Apr-Sep 1996, Jul-Nov 1997, and Jun-Sep 1998 (Figure 86). Mean deployment duration was 11.9 days. Only two deployments (Jun, Jul 1996) were less than five days.

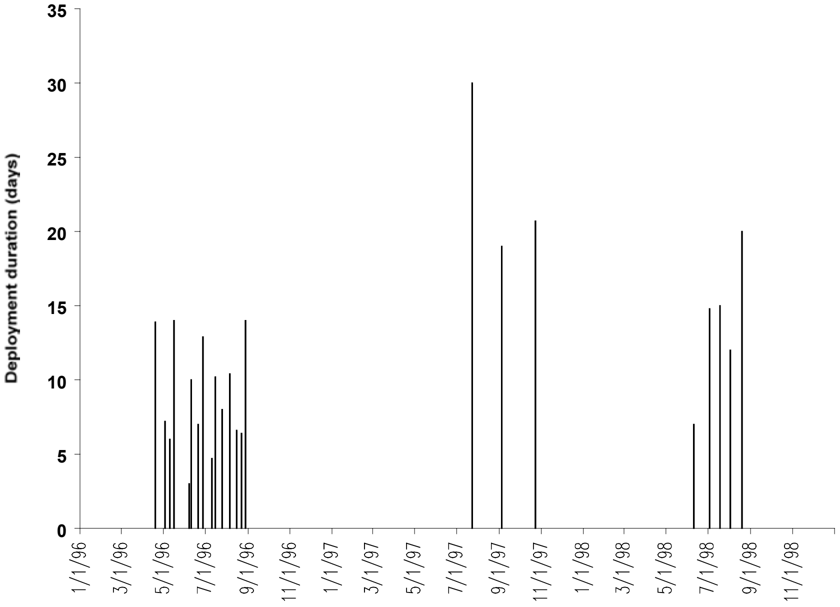


Figure 86. Chesapeake Bay MD, Jug Bay deployments, 1996-1998.

Twenty-four percent of annual depth data were included in analyses (37% in 1996, 18% in 1997, and 19% in 1998). Sensors were deployed at a mean depth of 0.6 m below the water surface and 0.1 m above the bottom sediment. Moderate fluctuation (0.75-1 m) in water depth was evident for daily and bi-weekly cycles from scatter plots. Harmonic regression analysis attributed 94% of depth variance to 12.42 hour cycles, and 3% of depth variance to both 24 hour cycles and interaction between 12.42 hour and 24 hour cycles.

Twenty-four percent of annual water temperature data were included in analyses (37% in 1996, 18% in 1997, and 19% in 1998). Water temperature likely followed a seasonal cycle; however, winter water temperatures were unknown (Figure 87). Mean water temperature in Jul-Sep 1996-1998 was 25-27°C. Minimum and maximum temperatures recorded between 1996-1998 were 4.6°C (Oct-Nov 1997) and 36.7C (Jun 1996), respectively. Scatter plots suggest strong fluctuation (2-10°C) in water temperature at both daily and bi-weekly intervals. Harmonic regression analysis attributed 51% of water temperature variance to 24 hour cycles, 35% of temperature variance to interaction between 12.42 hour and 24 hour cycles, and 14% of variance to 12.42 hour cycles.

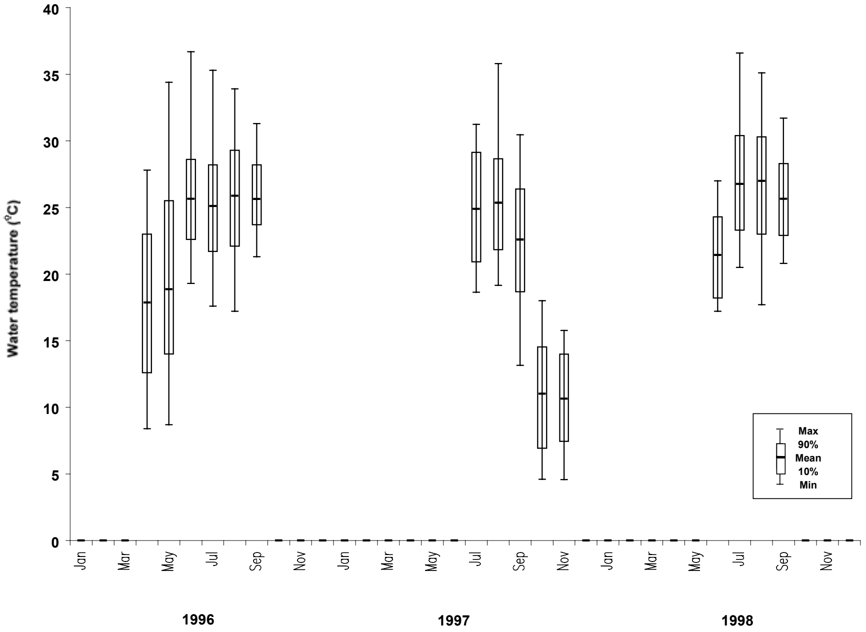


Figure 87. Water temperature statistics at Jug Bay, 1996-1998.

Twenty-four percent of annual salinity data were included in analyses (37% in 1996, 18% in 1997, and 19% in 1998). Absolute values for salinity were between 0-0.4 ppt. Salinity followed no apparent seasonal cycle. Harmonic regression analysis attributed 38%, 33%, and 29% of salinity variance to 12.42 hour cycles, 24 hour cycles, and interaction between these two cycles, respectively.

Thirty-one percent of annual dissolved oxygen (% saturation) data from 1996 and 15% of dissolved oxygen (% saturation) data from 1998 were included in analyses; no dissolved oxygen data were collected in 1997. During Apr-Sep 1996, mean dissolved oxygen varied between 42% saturation (Jul) and 66% saturation (Sep). In Jul-Aug 1998, mean dissolved oxygen readings varied between 33-40% saturation. Minimum and maximum DO recorded in 1996 was 0% saturation and 231% saturation, respectively. Hypoxia was observed during every month (except Apr 1996) and persisted for 22.1% of the first 48 hours post-deployment on average (Figure 88). Supersaturation was also observed every month (except Jul 1996) and persisted for 8.3% of the first 48 hours post-deployment on average. Scatter plots suggest strong (80-200%) fluctuation in DO readings at daily and bi-weekly intervals. Harmonic regression analysis attributed 59% of DO variance to interaction between 12.42 hour and 24 hour cycles, 27% of DO variance to 12.42 hour cycles, and 14% of DO variance to 24 hour cycles.

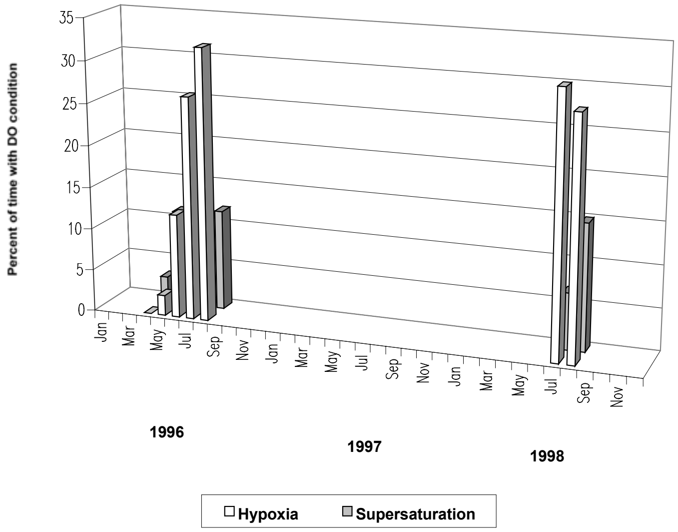


Figure 88. Dissolved oxygen extremes at Jug Bay, 1996-1998.

Photosynthesis/Respiration

Over three quarters (76%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and were used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 22). Instrument drift during the duration of the deployments was not a significant problem at this site. Respiration rates exceeded production rates at Jug Bay; thus, the net ecosystem metabolism and P/R ratio indicated that this is a very heterotrophic site (Figure 89). Temperature was significantly ($p<0.05$) correlated with total respiration and net ecosystem metabolism. Respiration increased as temperature increased, while net ecosystem metabolism became more heterotrophic as temperatures increased. Salinity was significantly ($p<0.05$) correlated with net ecosystem metabolism, but not gross production or total respiration. Net ecosystem metabolism became more heterotrophic at higher salinity.

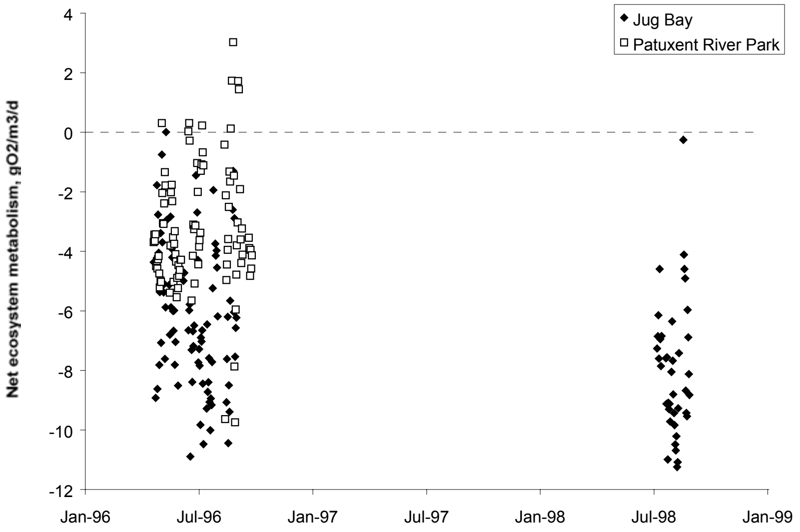


Figure 89. Net metabolism at Jug Bay and Patuxent River Park, 1996-1998.

Table 22. Summary of metabolism data and statistics for Jug Bay, 1996-1998.

Jug Bay	mean	s.e.
Water depth (m)	0.73	
Net production gO_2/m3/d	-1.08	0.36
Gross production gO_2/m3/d	10.22	0.70
Total respiration gO_2/m3/d	19.29	0.71
Net ecosystem metabolism g O_2/m3/d	-9.07	0.28
Net ecosystem metabolism g C/m2/y	-651	
P/R	0.53	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	76	
Paired t-test on gross production and total respiration	p<0.001	
Correlation coefficient	Temperature	Salinity
Gross production	ns	ns
Total respiration	0.23	ns
Net ecosystem metabolism	-0.38	-0.34

Chesapeake Bay Maryland, Patuxent River Park (CBMPR)

Characterization (Latitude / Longitude: 38° 46’ 00” N, 76° 42’ 30” W)
This site is located in the upper reaches of the Patuxent River near Jackson Landing on the west flank of the river. Tides in the river are semidiurnal and average 0.75 m in range. The Patuxent River is 175 km long (mainstream linear dimension), has an average depth of 5 m MHW, and an average width of 750 m. At the sampling site, the width is 50 m. This site is in the main channel of the river. The bottom sediment is silt-clay with no bottom vegetation. The dominant marsh vegetation near the sampling site includes cattails and wild rice. The dominant upland vegetation is mixed hardwood forest. Upland land use near the sampling site includes residential development and farming. Activities that potentially impact the site include nutrient inputs from sewage treatment plants and non-point source runoff.

Descriptive Statistics
Twenty-six deployments were made at this site between Apr-Sep 1996, Jul-Nov 1997, and Jun-Aug 1998 (Figure 90). Mean deployment duration was 11.3 days. Only three deployments (May, Jun, Jul 1996) were less than 5 days.

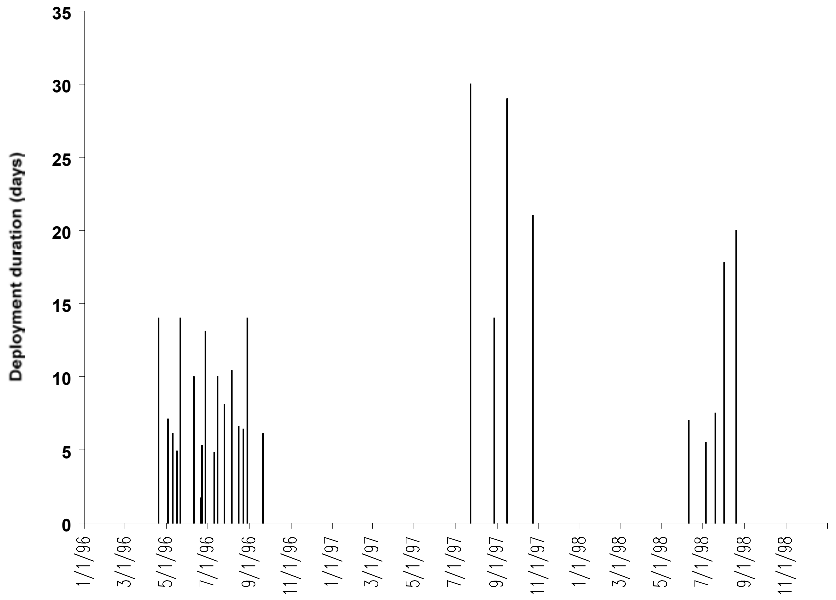


Figure 90. Chesapeake Bay MD, Patuxent River Park deployments (1996-1998).

Twenty-seven percent of annual depth data were included in analyses (39% in 1996, 26% in 1997, and 16% in 1998). Sensors were deployed at a mean depth of 2.3 m below the water surface and 0.1 m above the bottom sediment. Moderate fluctuations (0.5-1 m) in daily and bi-weekly water temperature were evident from scatter plots. Harmonic regression analysis attributed 92% of depth variance to 12.42 hour cycles and 4% of depth variance to both 24 hour cycles and interaction between 12.42 hour and 24 hour cycles.

Twenty-six percent of annual water temperature data were included in analyses (39% in 1996, 26% in 1997, and 14% in 1998). Water temperature likely followed a seasonal cycle; however because water temperature data were only collected between Apr-Nov, true amplitude of such a seasonal cycle could not be determined (Figure 91). Mean water temperature in Jul-Sep 1996-1997 was 24-26°C, slightly lower than mean water temperature in Jul-Sep 1998 (26-28°C). Minimum and maximum temperatures recorded between 1996-1998 were 7.6°C (Nov 1997) and 30.5°C (Jul 1998), respectively. Scatter plots suggest moderate fluctuation (<2°C) in daily water temperature cycles and strong fluctuation (≥5°C) in bi-weekly temperature cycles. Harmonic regression analysis attributed 43% of temperature variance to 24 hour cycles, 36% of temperature variance to 12.42 hour cycles and 21% of temperature variance to interaction between 12.42 hour and 24 hour cycles.

Twenty-six percent of annual salinity data were included in analyses (39% in 1996, 26% in 1997, and 14% in 1998). Absolute values for salinity were between 0-1 ppt. Mean salinity was greatest in 1997 (>0.2 ppt). Salinity readings were fairly constant at daily and bi-weekly intervals. Harmonic regression analysis revealed that variance in salinity, although very minor, was primarily (91%) attributed to 12.42 hour cycles. Twenty-four hour cycles only accounted for 2% of salinity variance and interaction between 12.42 hour and 24 hour cycles accounted for 7% of salinity variance.

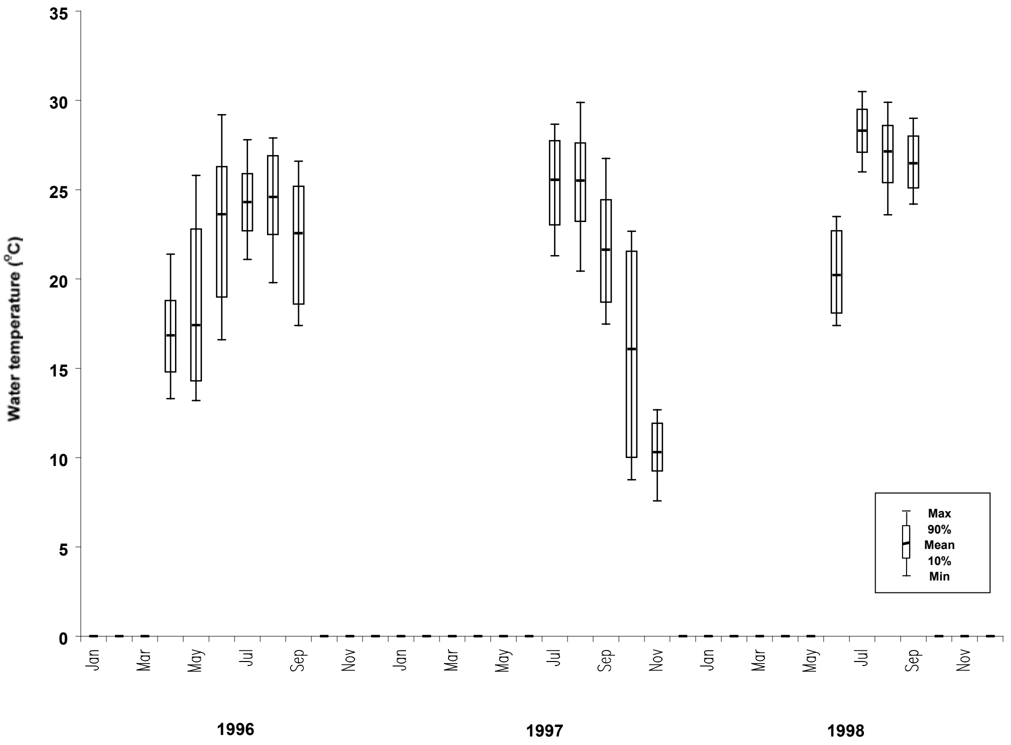


Figure 91. Water temperature statistics for Patuxent River Park, 1996-1998.

Thirty-one percent of dissolved oxygen (% saturation) data in 1996 were included in analysis; no dissolved oxygen data were collected in 1997-1998. Mean DO between Apr-Sep 1996 ranged from a low of 67% saturation (Apr) to a high of 102% saturation (Aug). Minimum (0% sat) and maximum (198.2% sat) DO were both recorded in Aug 1996. Hypoxia was observed in one month (Jul 1996) and persisted for 10.6% of the first 48 hours post-deployment (Figure 92). Supersaturation was observed in two months and persisted for 3.1% (May 1996) and 36.9% (Jul 1996) of the first 48 hours post-deployment. Scatter plots suggest strong fluctuations (20% sat) in daily DO cycles and even stronger fluctuations (50-200% sat) in bi-weekly DO cycles. Harmonic regression analysis attributed 40% of DO variance to 12.42 hour cycles and 30% of DO variance to both 24 hour cycles interaction between 12.42 hour and 24 hour cycles.

Photosynthesis/Respiration

Over three quarters (76%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and were used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 23). Instrument drift during the duration of the deployments was not a significant problem at this site. Respiration rates exceeded production rates at Patuxent River Park; thus, the net ecosystem metabolism and P/R ratio indicated that this is a heterotrophic site (Figure 89). Temperature was significantly ($p<0.05$) correlated with gross production, total respiration and net ecosystem metabolism. Gross production and respiration increased as temperature increased, while net ecosystem metabolism became more autotrophic as temperatures increased. Salinity was not significantly ($p<0.05$) correlated with any metabolic measurement.

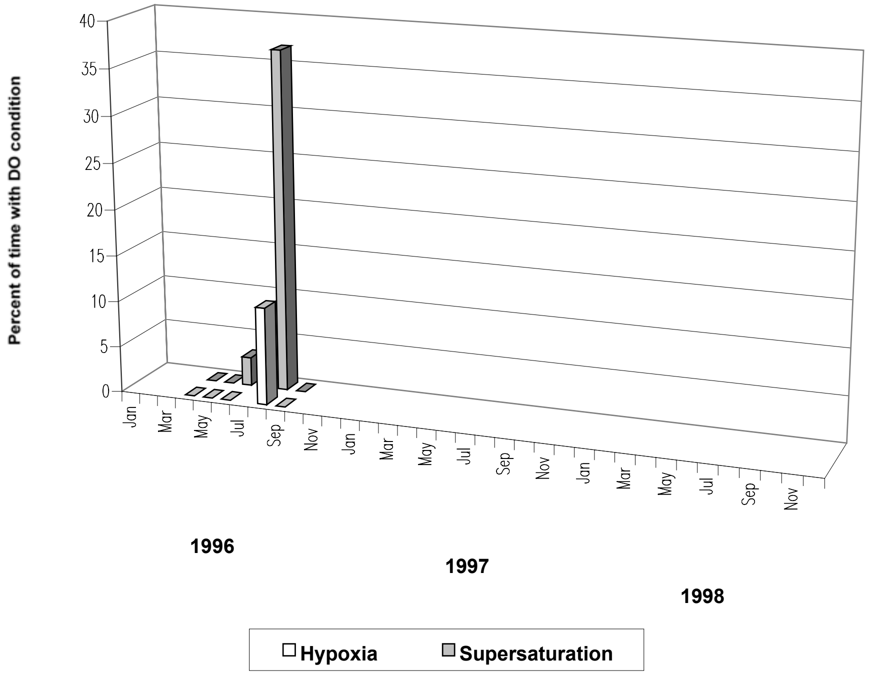
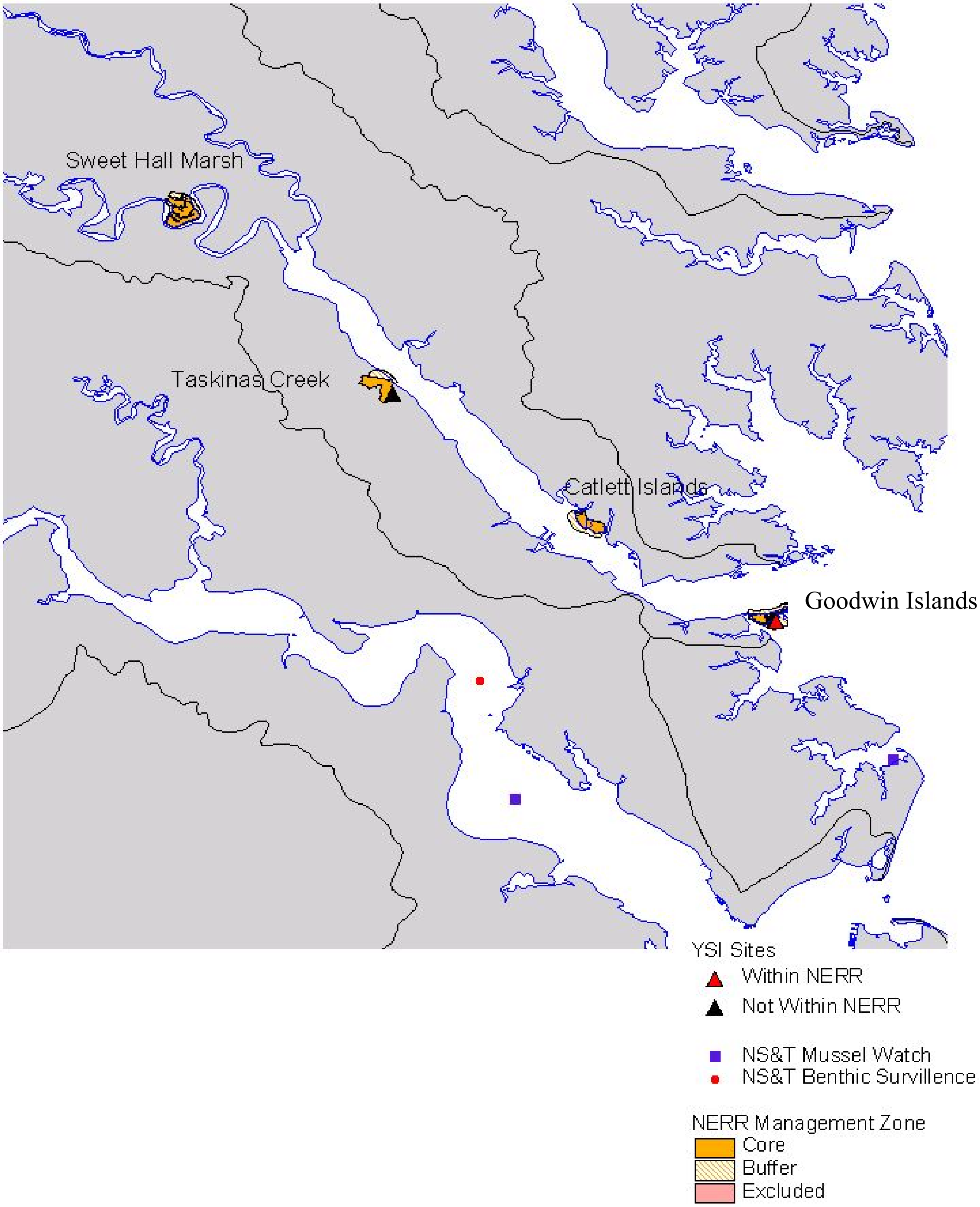


Figure 92. Dissolved oxygen extremes at Patuxent River Park, 1996-1998.

Table 23. Summary of metabolism data and statistics at Patuxent River Park, 1996-1998.

Patuxent River Park	mean	s.e.
Water depth (m)	2.41	
Net production $gO_2/m3/d$	0.46	0.14
Gross production $gO_2/m3/d$	3.04	0.25
Total respiration $gO_2/m3/d$	4.36	0.26
Net ecosystem metabolism g $O_2/m3/d$	-1.32	0.15
Net ecosystem metabolism g C/m2/y	-184	
P/R	0.70	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	76%	
Paired t-test on gross production and total respiration	p<0.001	
Correlation coefficient	Temperature	Salinity
Gross production	0.58	ns
Total respiration	0.43	ns
Net ecosystem metabolism	0.21	ns

Chesapeake Bay, VA



Chesapeake Bay Virginia, Goodwin Islands (CBVGI)

Characterization (Latitude = 37°13' 00"N; Longitude = 76°23' 37"W)

The Goodwin Islands component of the CBNERR-VA is on the mouth of the York River at the northeastern tip of York County. Circulation patterns at the Goodwin Islands are influenced by York River discharge and the wind patterns of the Chesapeake Bay. The Goodwin Islands represent relatively pristine marsh islands surrounded by inter-tidal flats, submerged aquatic vegetation (SAV) beds, a single constructed oyster reef, and shallow open estuarine waters. Dominant marsh species include Saltmarsh Cordgrass (*Spartina alterniflora*), Salt Grass (*Distichlis spicata*), and Saltmeadow Hay (*Spartina patens*). Forested wetland ridges are dominated by estuarine scrub/shrub vegetation with upland ridges dominated by mixed oak and pine communities. The sampling station is located in a shallow embayment on the southeastern side of the main island. The station is located approximately 400 m from shore, average water depth on the order of 1 m, amongst submerged aquatic vegetation beds dominated by eelgrass (*Zostera marina*) and Widgeon grass (*Ruppia maritima*). Tides are semi-diurnal and range from 0.4-1.1 m (average 0.67m). Sub-tidal substrate is dominated by sand. Potential activities that could impact the site include light recreational and commercial boating and recreational and commercial fishing.

Descriptive Statistics

Thirty-seven deployments were made at this site between October 1997 and December 1998, with equal coverage in all seasons (Figure 93). Mean deployment duration was 11.6 days. Only one deployment (Sep 1998) was slightly (4.9 days) less than 5 days.

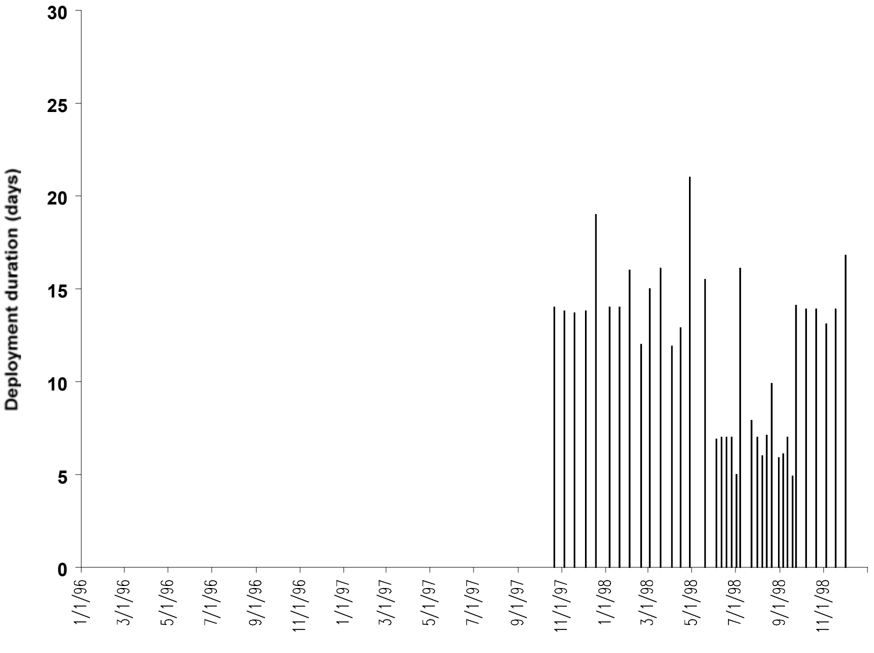


Figure 93. Chesapeake Bay VA, Goodwin Islands deployments (1996-1998).

Ninety-seven percent of annual depth data in 1997 and 19% of annual depth data in 1998 were included in analyses; no data were collected in 1996. Sensors were deployed at a mean depth of 0.6 m below the water surface and 0.5 m above the bottom sediment. Moderate fluctuation (0.5-1 m) in water depth was evident for daily and bi-weekly cycles from scatter plots. Harmonic regression analysis attributed 65% of depth variance to 12.42 hour cycles, 14% of depth variance to 24 hour cycles, and 21% of depth variance to interaction between 12.42 hour and 24 hour cycles.

Ninety-seven percent of annual water temperature data in 1997 and 19% of annual temperature data in 1998 were included in analyses; no data were collected in 1996. Water temperature followed a seasonal cycle between Oct 1997 and Dec 1998, with mean water temperature 7°C in winter and 27°C in summer (Figure 94). Minimum and maximum water temperatures recorded between Oct 1997 and Dec 1998 were 2.3°C (Jan 1998) and 31.6°C (Jul 1998), respectively. Scatter plots suggest strong fluctuation (1-3°C) in water temperature over daily cycles and even stronger fluctuation (≥5°C) in water temperature at bi-weekly intervals. Water temperature gradually warmed throughout the day. Harmonic regression analysis attributed 55% of temperature variance to interaction between 12.42 hour and 24 hour cycles, 34% of temperature variance to 24 hour cycles, and 11% of temperature variance to 12.42 hour cycles.

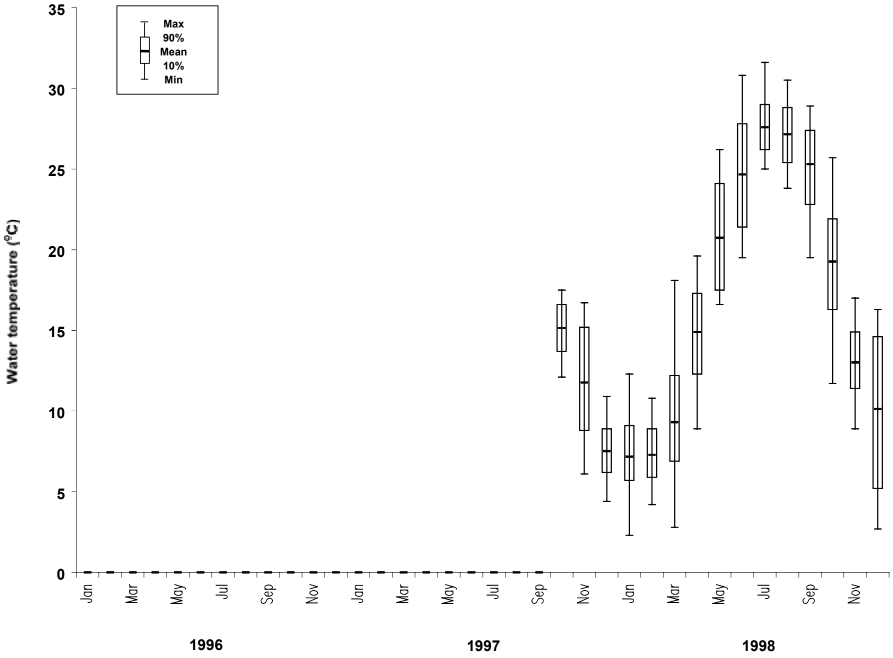


Figure 94. Water temperature statistics at Goodwin Island, 1996-1998.

Ninety-seven percent of annual salinity data in 1997 and 19% of annual salinity data in 1998 were included in analyses; no data were collected in 1996. Salinity followed a well-defined seasonal cycle between Oct 1997 and Dec 1998. Mean salinity was greatest (23-25 ppt) in summer and fall and least (13-15 ppt) in winter and spring (Figure 95). Salinity range between Oct 1997 and Dec 1998 was moderate, with minimum salinity of only 9.9 ppt (Jan 1998) and maximum salinity of 27.5 ppt (Nov 1998). Fluctuations in salinity at daily and bi-weekly cycles were minor (1-3 ppt) in comparison with seasonal fluctuations in salinity. Harmonic regression analysis attributed 49% of salinity variance to interaction between 12.42 hour and 24 hour cycles, 33% of salinity variance to 24 hour cycles, and 18% of salinity variance to 12.42 hour cycles.

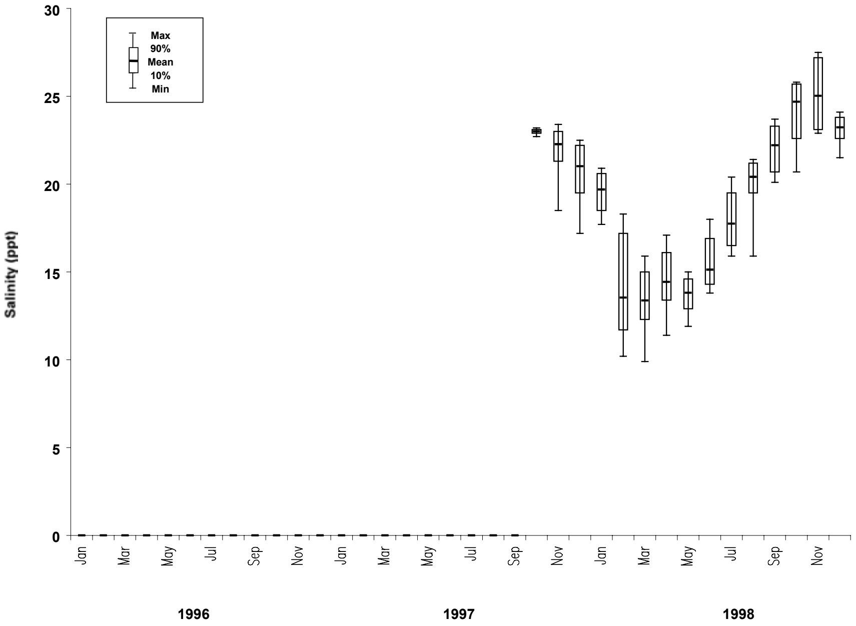


Figure 95. Salinity statistics at Goodwin Islands, 1996-1998.

Ninety-one percent of annual dissolved oxygen (% saturation) data were included in analyses (74% in 1997 and 95% in 1998). Mean dissolved oxygen readings were ≥100% saturation between Oct 1997 and Dec 1998, except for Jul-Aug 1998. Minimum and maximum DO readings were 23.6% (Oct 1998) and 195.7% (May 1998), respectively. Hypoxia was only observed in Oct 1998 and persisted for 1% of the first 48 hours post-deployment (Figure 96). Supersaturation was regularly observed and, when present, supersaturation persisted for 19.5% of the first 48 hours post-deployment on average. Scatter plots revealed DO fluctuations of 40-100% at daily and bi-weekly intervals, except for Jan-Feb 1998 when DO fluctuated by 20-40%. Harmonic regression analysis attributed 69% of DO variance to interaction between 12.42 hour and 24 hour cycles, 28% of DO variance to 24 hour cycles, and 3% of DO variance to 12.42 hour cycles.

Photosynthesis/Respiration

Nearly all (95%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and were used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 24). Instrument drift during the duration of the deployments was not a significant problem at this site. Gross production exceeded total respiration at Goodwin Islands; thus, the net ecosystem metabolism and P/R ratio indicated that this is an autotrophic site, one of the few in the Reserve system (Figure 97). Temperature was significantly ($p<0.05$) correlated with gross production, total respiration and net ecosystem metabolism. Gross production and respiration increased as temperature increased, while net ecosystem metabolism became more heterotrophic as temperatures increased. Salinity was significantly ($p<0.05$) negatively correlated with gross production and total respiration but not net ecosystem metabolism. Gross production and respiration were higher at lower salinity. Thus, the metabolic rates strongly followed a seasonal pattern with the highest rates during summer months and the lowest rates during winter when temperature and salinity were low and river flow was high.

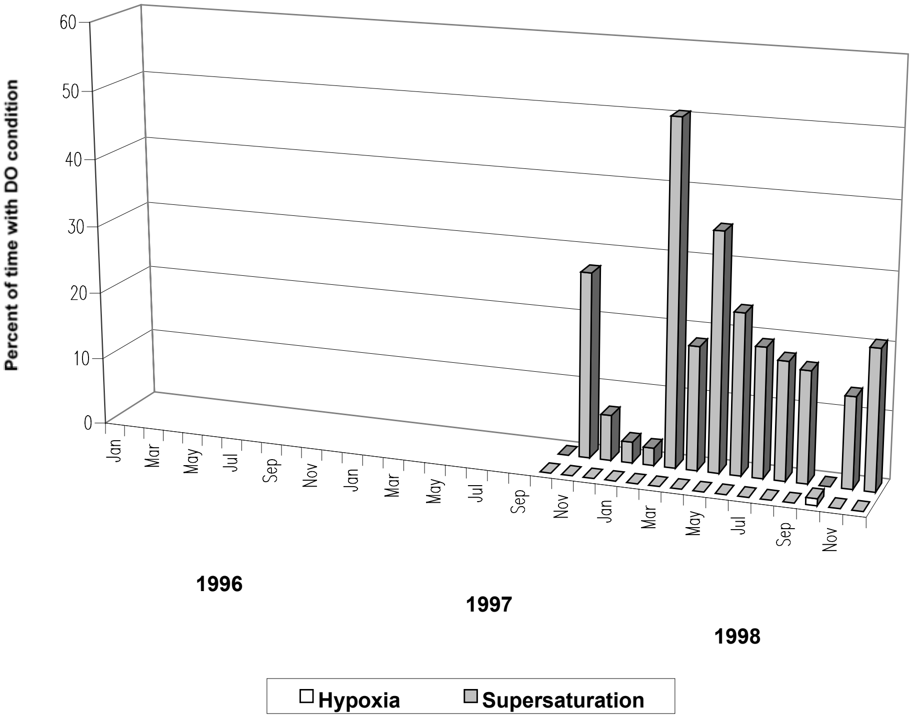


Figure 96. Dissolved oxygen extremes at Goodwin Islands, 1996-1998.

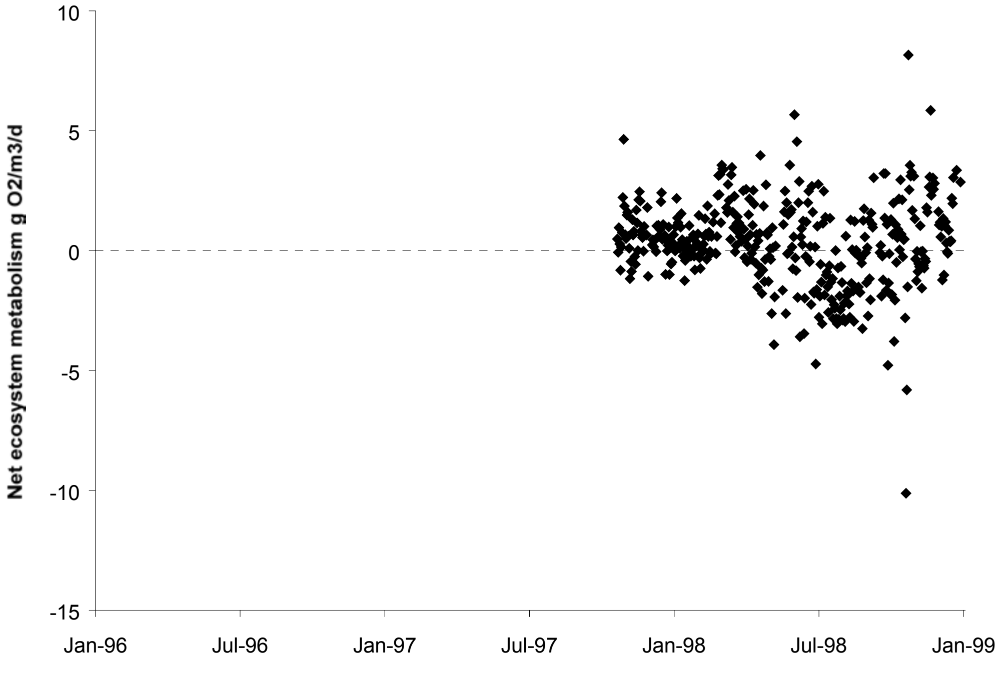


Figure 97. Net metabolism at Goodwin Islands, 1996-1998.

Table 24. Summary of metabolism data and statistics at Goodwin Islands, 1996-1998.

Goodwin Island	mean	s.e.
Water depth (m)	1.0	
Net production $gO_2/m3/d$	2.33	0.09
Gross production $gO_2/m3/d$	4.68	0.16
Total respiration $gO_2/m3/d$	4.37	0.18
Net ecosystem metabolism g $O_2/m3/d$	0.31	0.09
Net ecosystem metabolism g C/m2/y	203	
P/R	1.07	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	95%	
Paired t-test on gross production and total respiration	p<.0001	
Correlation coefficient	Temperature	Salinity
Gross production	0.64	-0.16
Total respiration	0.67	-0.19
Net ecosystem metabolism	-0.68	ns

Chesapeake Bay Virginia, Taskinas Creek (CBVTC)

Characterization (Latitude = 37° 24' 24"N; Longitude = 76° 42' 52")

The Taskinas Creek watershed is representative of an inner coastal plain rural watershed within the southern Chesapeake Bay system. Taskinas Creek is approximately 3 km in length and flows in a northeasterly direction eventually emptying into the York River. This watershed is dominated by forested and agricultural land uses with an increasing urban land use component. The non-tidal portion of Taskinas Creek contains feeder streams, which drain oak-hickory forests, maple-gum-oak-ash swamps and freshwater marshes. Dominant low tidal creek marsh species include Saltmarsh cordgrass (*Spartina alterniflora*), Salt Grass (*Distichlis spicata*), and Saltmeadow Hay (*Spartina patens*) at the creek mouth. Three-square (*Scirpus americanus* and *S. olneyi*) and Big Cordgrass (*Spartina cynosauroides*) characterize the middle marsh reaches and freshwater mixed (no single species covers more than 50%) wetlands in the upstream reaches. The data logger station is located near the mouth of Taskinas Creek in the lower tidal creek bank region. Water depth and width are roughly 2 m and 20 m, respectively. Tides are semi-diurnal and range from 0.4-1.2 m (average 0.85 m). Sub-tidal substrate is primarily fine sediments (42% fine sand, 30% clay, and 28% silt). Potential activities that impact the site include residential development, selective hardwood logging, and light recreational boating activity. Wildlife populations are known to influence microbiological water quality within the watershed.

Descriptive Statistics

Seventy-one deployments were made at this site between Jan 1996 and Dec 1998 (Figure 98). Equal coverage was provided in all seasons; however, deployment duration was greater (≥ 20 days) between Nov 1996 and Aug 1998 (with two exceptions) than the rest of the study. Mean deployment duration was 13.8 days. Only two deployments (Apr 1997, Aug 1998) were less than five days.

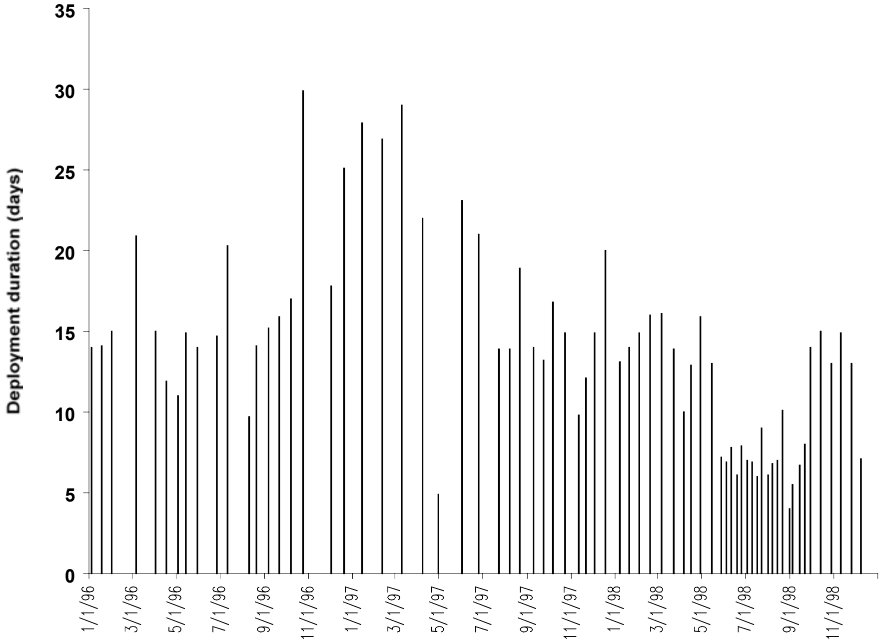


Figure 98. Chesapeake Bay VA, Taskinas Creek deployments (1996-1998).

Eighty-seven percent of annual depth data were included in analyses (72% in 1996, 91% in 1997, and 98% in 1998). Sensors were deployed at a mean depth of 0.9 m below the water surface and 0.5 m above the bottom sediment. Moderate fluctuation (0.5-1 m) in water depth was evident at daily and bi-weekly intervals from scatter plots, with consistent amplitude throughout the data. Harmonic regression analysis attributed 92% of depth variance to 12.42 hour cycles and 4% of depth variance to both 24 hour cycles and interaction between 12.42 hour and 24 hour cycles.

Ninety percent of annual water temperature data were included in analyses (80% in 1996, 96% in 1997, and 95% in 1998). Water temperature followed a seasonal cycle, with mean water temperature 26-28°C in summer in all three years (Figure 99). Mean winter water temperature in 1997 and 1998 was 5-7°C, compared to a mean winter water temperature of 2°C in 1996. Minimum and maximum water temperatures recorded between 1996 and 1998 were -0.7°C (Jan 1996) and 35.1°C (Jul 1998), respectively. Scatter plots suggest strong fluctuations (2-4°C) in daily water temperature and even stronger fluctuations (5-10°C) in bi-weekly water temperature. Water temperature was lowest at night and increased, sometimes abruptly, throughout the day. Amplitude of bi-weekly fluctuations remained fairly constant on a seasonal basis. Harmonic regression analysis attributed 61% of temperature variance to 24 hour cycles, 29% of temperature variance to interaction between 12.42 hour and 24 hour cycles, and 10% of temperature variance to 12.42 hour cycles.

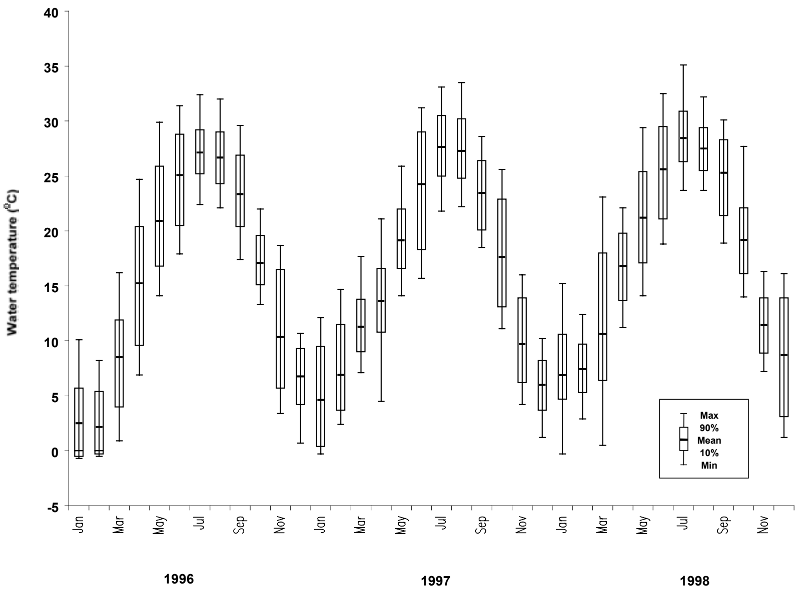


Figure 99. Water temperature statistics for Taskinas Creek, 1996-1998.

Eighty-six percent of annual salinity data were included in analyses (76% in 1996, 88% in 1997, and 95% in 1998). Salinity followed a seasonal cycle in 1997 and 1998, but seasonal variation in salinity was not evident in 1996 (Figure 100). Mean salinity in summer 1997 and 1998 was 14-16 ppt and mean salinity in winter 1997 and 1998 was 3-5 ppt. In 1996, mean salinity only varied between 6-10 ppt. Minimum and maximum salinity recorded between 1996-1998 was 0.1 ppt (Mar 1996) and 20.3 ppt (Nov 1998), respectively. Scatter plots suggest strong fluctuation (5-10 ppt) in salinity at both daily and bi-weekly intervals that were almost equivalent to seasonal variation in salinity. Harmonic regression analysis attributed 89% of salinity variance to 12.42 hour cycles, 7% of salinity variance to interaction between 12.42 hour and 24 hour cycles, and 4% of salinity variance to 24 hour cycles.

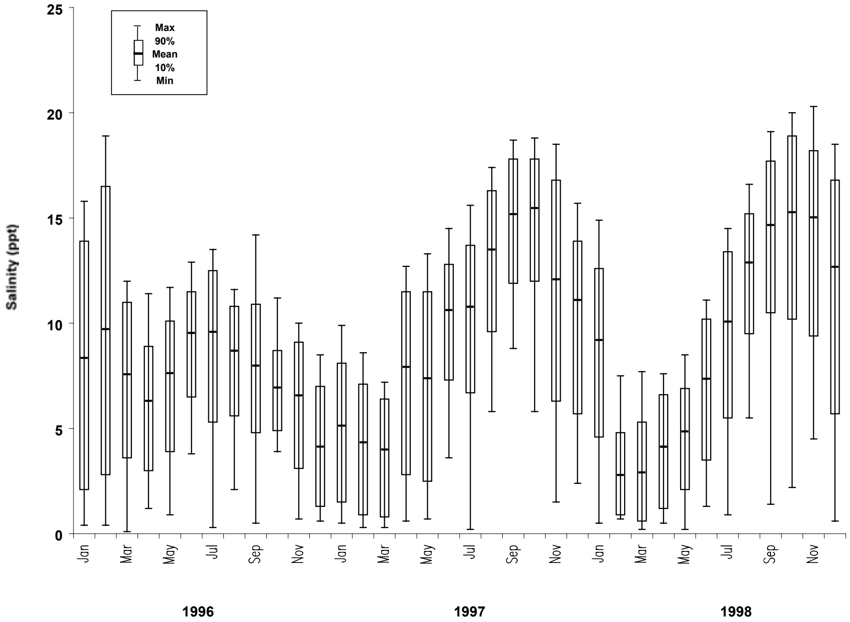


Figure 100. Salinity statistics for Taskinas Creek, 1996-1998.

Seventy-six percent of annual dissolved oxygen (% saturation) data were included in analyses (71% in 1996, 70% in 1997, and 88% in 1998). Mean DO below 50% saturation was only observed in two months (Jul 1996, Jun 1997) and mean DO above 100% saturation was also only observed in two months (Feb, Mar 1996). Mean DO was lowest in the summer and greatest in winter. Minimum and maximum DO observed between 1996-1998 was 0% saturation (Jun 1997) and 239% saturation (May 1996), respectively. Hypoxia was rarely observed and when present, lasted less than 2% of the first 48 hours post-deployment on average (Figure 101). Supersaturation was frequently observed, and when present lasted an average of 14% of the first 48 hours post-deployment. Scatter plots indicated fluctuations in percent saturation was greatest in spring and summer (60-120%) and least in fall and winter (20-60%) at both daily and bi-weekly intervals. Harmonic regression attributed 40% of DO variance to 12.42 hour cycles, 39% of DO variance to interaction between 12.42 hour and 24 hour cycles, and 21% of DO variance to 24 hour cycles.

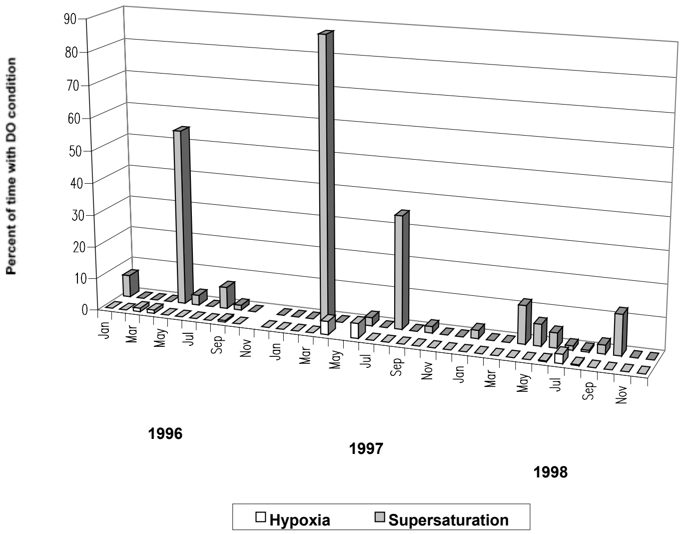


Figure 101. Dissolved oxygen extremes at Taskinas Creek, 1996-1998.

Photosynthesis/Respiration

Over four fifths (83%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and were used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 25). Instrument drift during the duration of the deployments was not a significant problem at this site. Total respiration exceeded gross production at Taskinas Creek; thus, the net ecosystem metabolism and P/R ratio indicated that this is a heterotrophic site (Figure 102). Temperature was significantly ($p<0.05$) correlated with gross production, total respiration and net ecosystem metabolism. Gross production and respiration increased as temperature increased, while net ecosystem metabolism became more heterotrophic as temperatures increased. Salinity was significantly ($p<0.05$) correlated with gross production, total respiration and net ecosystem metabolism. Gross production and respiration were higher at higher salinity and net ecosystem metabolism became more heterotrophic at higher salinity. Metabolic rates strongly followed a seasonal pattern, with highest rates during summer months and lowest rates during winter when temperature and salinity were low and river flow was high.

Table 25. Summary of metabolism data and statistics at Taskinas Creek, 1996-1998.

Taskinas Creek	mean	s.e.
Water depth (m)	2.0	
Net production gO_2/m3/d	1.06	0.07
Gross production gO_2/m3/d	3.67	0.12
Total respiration gO_2/m3/d	4.78	0.14
Net ecosystem metabolism g O_2/m3/d	-1.11	0.07
Net ecosystem metabolism g C/m2/y	-54	
P/R	0.77	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	83%	
Paired t-test on gross production and total respiration	$p<0.001$	
Correlation coefficient	Temperature	Salinity
Gross production	0.52	0.13
Total respiration	0.65	0.16
Net ecosystem metabolism	-0.38	-0.10

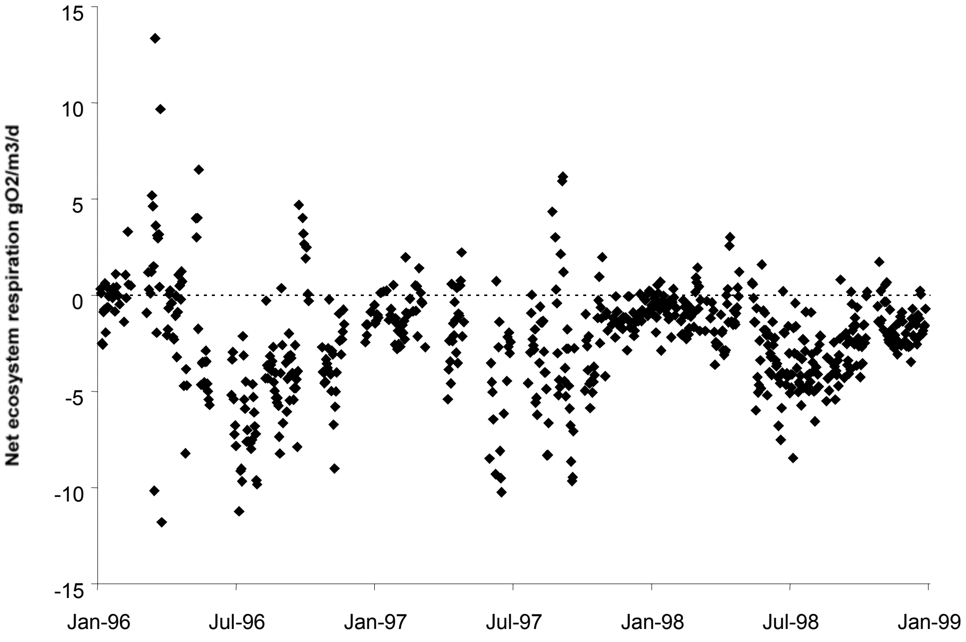
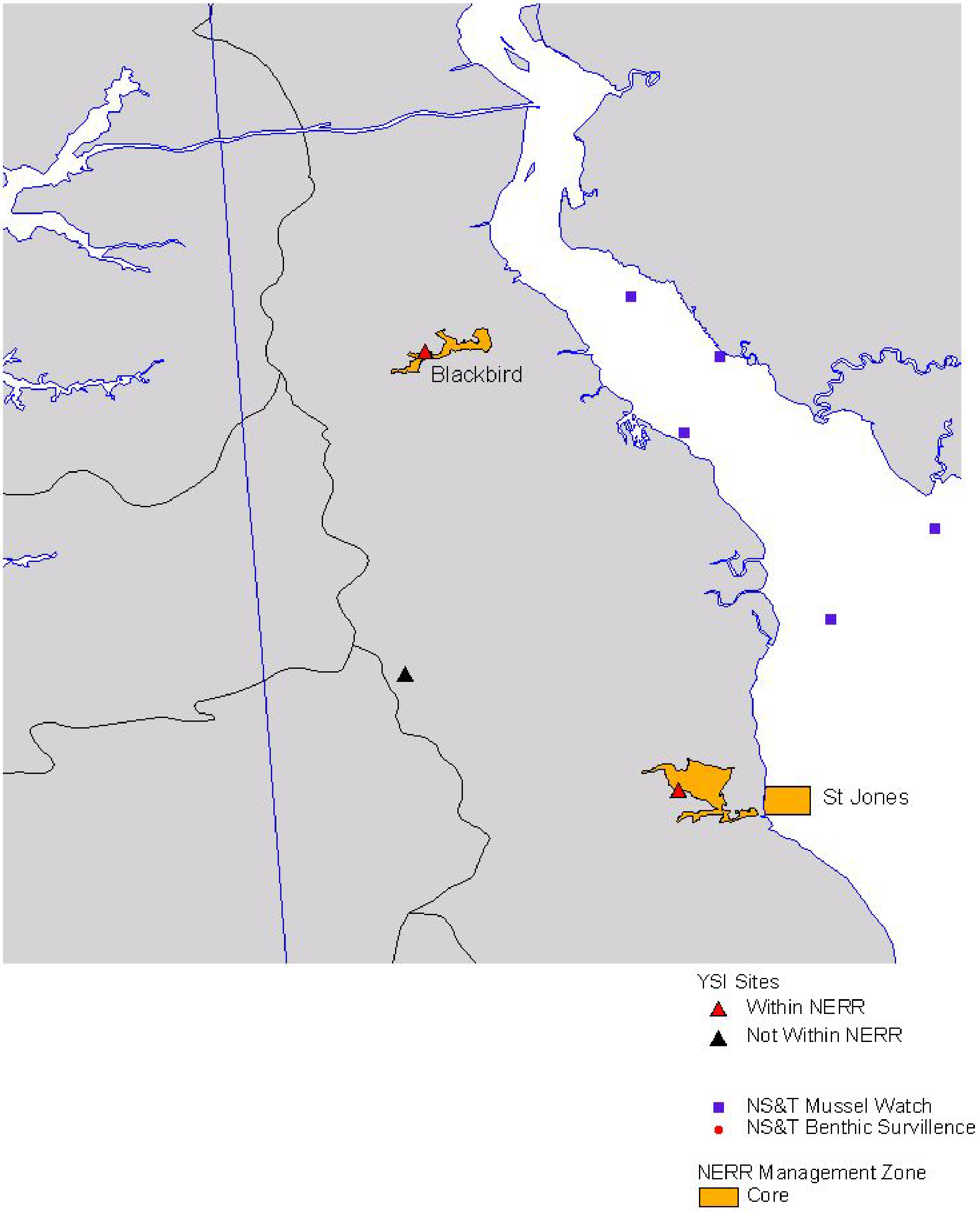


Figure 102. Net metabolism at Taskinas Creek, 1996-1998.

Delaware


Blackbird
St Jones
YSI Sites
▲ Within NERR
▲ Not Within NERR
■ NS&T Mussel Watch
● NS&T Benthic Survillence
NERR Management Zone
Core

Delaware Bay, Blackbird Landing (DELBL)

Characterization (Latitude = 39 23'20"N; Longitude = 75 38'10"W)
The Blackbird Landing site is located in the upper Blackbird Creek at Blackbird Landing Road. The creek is 25.8 km long (mainstream linear dimension), has an average depth of 3 m MHW, and an average width of about 90 m. At the sampling site, the depth is 1.8 m MHW and the width is about 110 m. Creek bottom habitats are predominantly silt and clay, with no bottom vegetation. The dominant marsh vegetation near the sampling site is *Spartina alterniflora*. The dominant upland vegetation is tidal swamp and upland forest. Upland land use near the sampling site includes forests and agriculture. Activities that potentially impact the site include sporadic refuse dumping. Water quality at this site is influenced by freshwater runoff from un-impacted forested areas intermixed with agricultural land uses and a small amount of low-density development.

Descriptive Statistics
Sixty-nine deployments were made at this site between Feb 1996 and Dec 1998, with equal coverage in all seasons (Figure 103). Mean deployment duration was 13.8 days. Only two deployments (May 1996, Sep 1997) were less than 10 days.

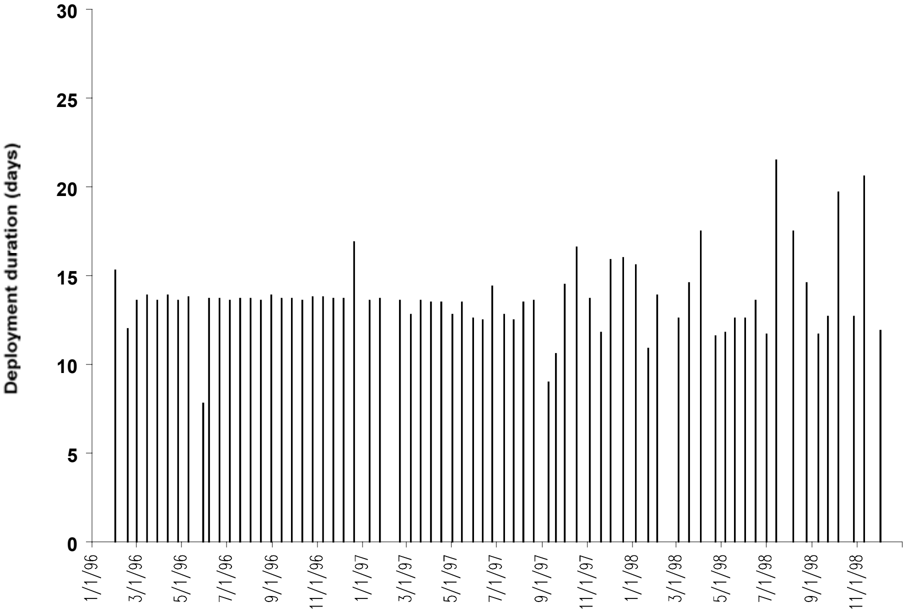


Figure 103. Delaware Bay, Blackbird Landing deployments (1996-1998).

Eighty-six percent of annual depth data were included in analyses (84% in 1996, 87% in 1997, 1998). Sensors were deployed at a mean depth of 1.5 m below the water surface and 0.3 m above the bottom sediment. Strong fluctuation (1.5-2 m) in water depth was evident for daily and bi-weekly intervals from scatter plots, with consistent amplitude throughout the data set. Harmonic regression analysis attributed 68% of depth variance to 12.42 hour cycles, 22% of depth variance to interaction between 12.42 hour and 24 hour cycles, and 10% of depth variance to 24 hour cycles.

Eighty-five percent of annual water temperature data were included in analyses (84% in 1996, 87% in 1997, and 84% in 1998). Water temperature followed a seasonal cycle, with mean water temperature 2-5°C in winter and 25-28°C in summer (Figure 104). Minimum and maximum temperatures between 1996-1998 were -0.3°C (Dec 1998) and 33.3°C (Jul 1997), respectively. Scatter plots suggest strong fluctuation (1-4°C) in water temperature over daily cycles and even stronger fluctuation (≥5°C) at bi-weekly intervals. Harmonic regression analysis attributed 47% of temperature variance to 24 hour cycles, 45% of temperature variance to interaction between 12.42 hour and 24 hour cycles, and 8% of temperature variance to 12.42 hour cycles.

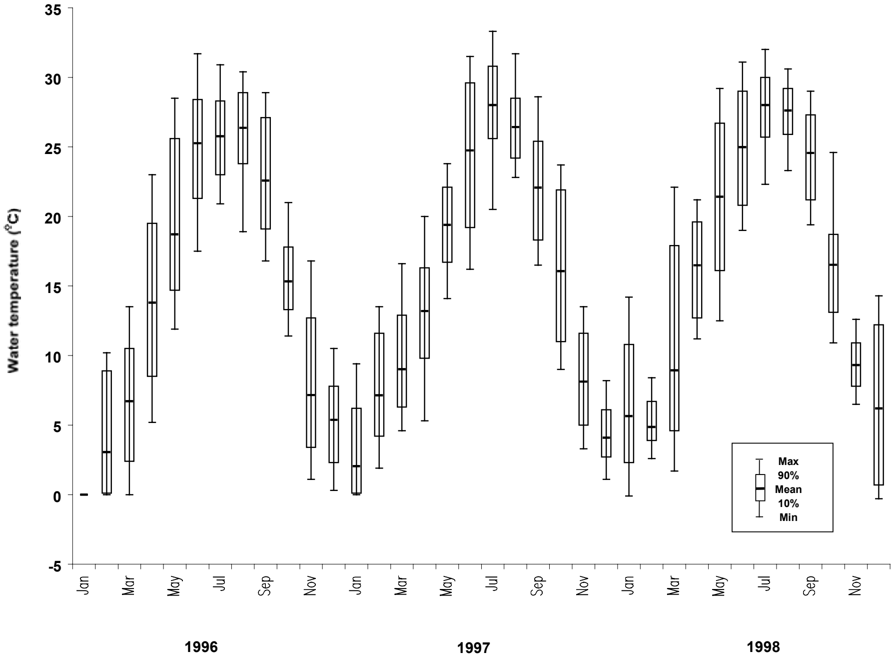


Figure 104. Water temperature statistics for Blackbird Landing, 1996-1998.

Eighty-four percent of annual salinity data were included in analyses (84% in 1996, 1997, and 1998). Salinity followed an expected seasonal cycle in 1997 and 1998 and to a lesser extent in 1996 (Figure 105). Mean salinity in 1997-1998 was 6-7 ppt in summer and <1 ppt in winter. Mean salinity in 1996 was 1-2 ppt in summer and <1 ppt in winter. Zero salinity was regularly observed in winter. Maximum observed salinity never exceeded 8 ppt. Harmonic regression analysis attributed 69% of salinity variance to 12.42 hour cycles, 21% of salinity variance to interaction between 12.42 hour and 24 hour cycles, and 10% of salinity variance to 24 hour cycles.

Eighty-four percent of annual dissolved oxygen (% saturation) data were included in analyses (84% in 1996 and 1998, 83% in 1997). Mean percent saturation remained between 60-100% for most of the year. Mean dissolved oxygen was only less than 50% saturation on two occasions (Jul-Aug 1997). Mean dissolved oxygen only exceeded 100% saturation on two occasions (Nov-Dec 1998). Minimum and maximum DO recorded between 1996-1998 was 0% saturation (Jun-Sep 1997) and 195.9% saturation (Aug 1996), respectively. Hypoxia was restricted to Jun-Sep and, when present, hypoxia persisted for 26.3% of the first 48 hours post-deployment (Figure 106). Supersaturation was observed on several occasions in spring/summer (and Dec 1998) and, when present, supersaturation persisted for 16.8% of the first 48 hours post-deployment on average. Scatter plots document strong fluctuations (60-100%) in percent saturation of DO in spring and summer and minor fluctuations (20-40%) in percent saturation in fall and winter. Harmonic regression analysis attributed 49% of DO variance to interaction between 12.42 hour and 24 hour cycles, 40% of DO variance to 12.42 hour cycles, and 11% of DO variance to 24 hour cycles.

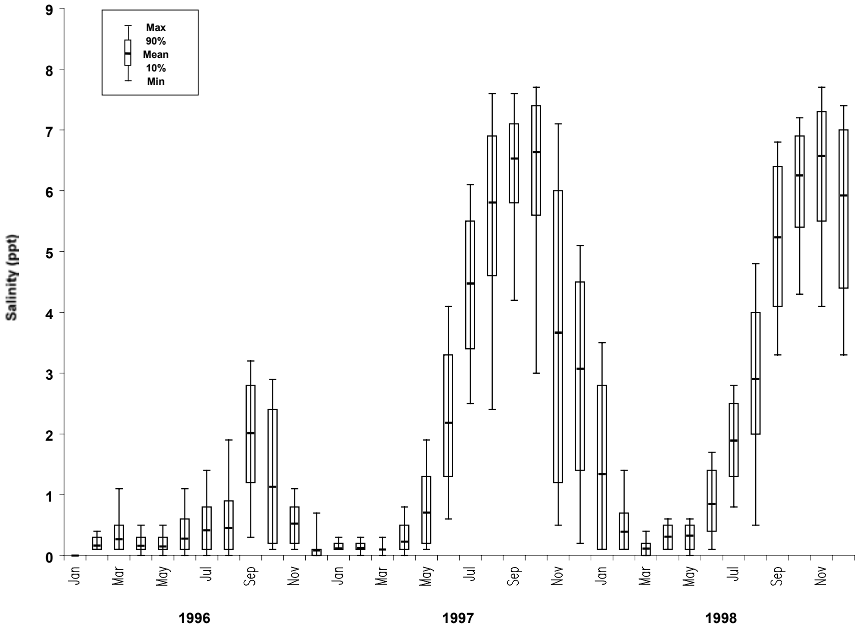


Figure 105. Salinity statistics for Blackbird Landing, 1996-1998.

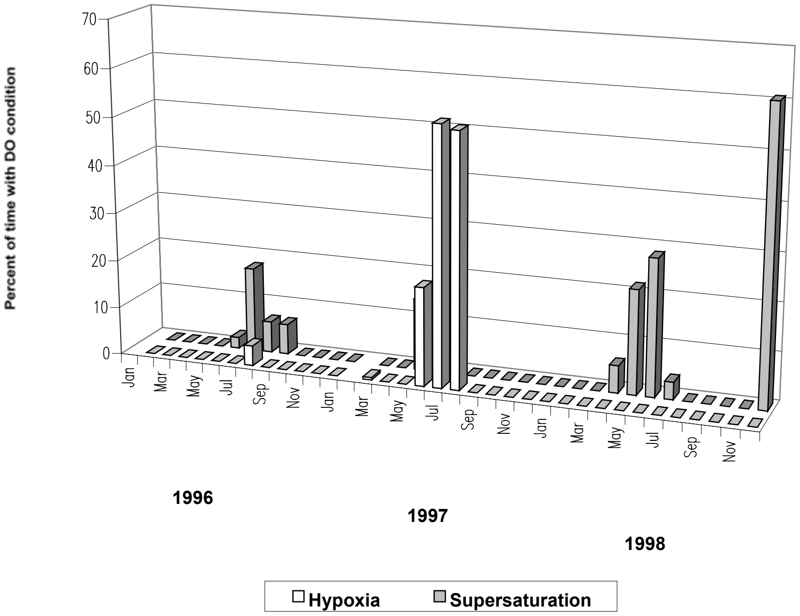


Figure 106. Dissolved oxygen extremes at Blackbird Landing, 1996-1998.

Delaware Bay, Scotton Landing (DELSL)

Characterization (Latitude = 39°05'06" N; Longitude = 75°27'38" W)
The Scotton Landing site is located in the lower St. Jones River at the Scotton Landing Public Fishing Pier, just upstream of Delaware Route 113. The river is 22.3 km long (mainstream linear dimension), has an average depth of 4 m MHW, and an average width of 50 m. At the sampling site, the depth is 3.2 m MHW and the width is 40 m. Creek bottom habitats are predominantly clay and silt, with no bottom vegetation. The dominant marsh vegetation near the sampling site is *Spartina alterniflora* and the dominant upland vegetation includes riparian forest and agricultural crops. Upland land use near the sampling site is primarily agriculture and residential uses. Activities that potentially impact the site include a public boat ramp and freshwater runoff from the relatively urbanized area upstream.

Descriptive Statistics
Sixty-nine deployments were made at this site between Jan 1996 and Dec 1998, with equal coverage in all seasons (Figure 107). Mean deployment duration was 13.8 days. Only four deployments (May 1996, Apr-May 1998, Aug 1998) were less than 10 days.

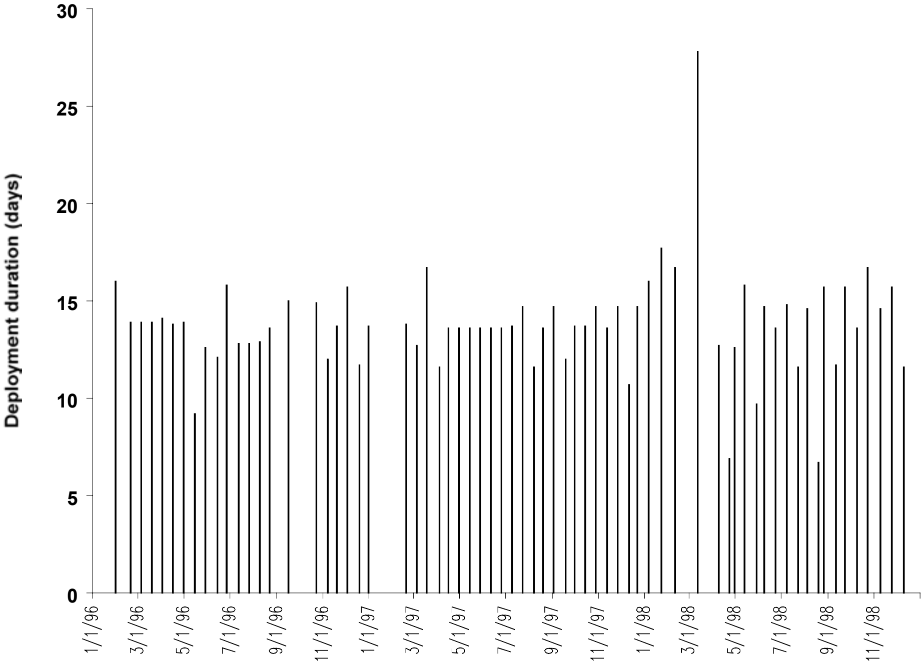


Figure 107. Delaware Bay, Scotton Landing deployments (1996-1998).

Eighty-four percent of annual depth data were included in analyses (75% in 1996, 88% in 1997, 1998). Sensors were deployed at a mean depth of 1.5 m below the water surface and 0.3 m above the bottom sediment. Strong fluctuation (1-1.5 m) in water depth was evident from scatter plots for both daily and bi-weekly intervals, and the amplitude of these fluctuations appeared to remain constant throughout all seasons. Harmonic regression analysis attributed 71% of depth variance to 12.42 hour cycles, 21% of depth variance to interaction between 12.42 hour and 24 hour cycles, and 8% of depth variance to 24 hour cycles.

Eighty-four percent of annual water temperature data were included in analyses (75% in 1996, 88% in

1997, 1998). Water temperature data followed a seasonal cycle, with mean water temperature 4-6°C in winter (1997-1998) and 24-26°C in summer (Figure 108). Mean water temperature in winter 1996 was slightly cooler (3-5°C) than winter 1997-1998 (5-8°C). Minimum and maximum water temperatures between 1996-1998 were -0.5°C (Feb 1996, Jan 1997) and 31.4°C (Jul 1997), respectively. Scatter plots suggest strong fluctuation (1-3°C) in daily water temperature and even stronger fluctuation (5-10°C) in bi-weekly water temperature. Harmonic regression analysis attributed 53% of temperature variance to interaction between 12.42 hour and 24 hour cycles, 27% of temperature variance to 24 hour cycles, and 20% of temperature variance to 12.42 hour cycles.

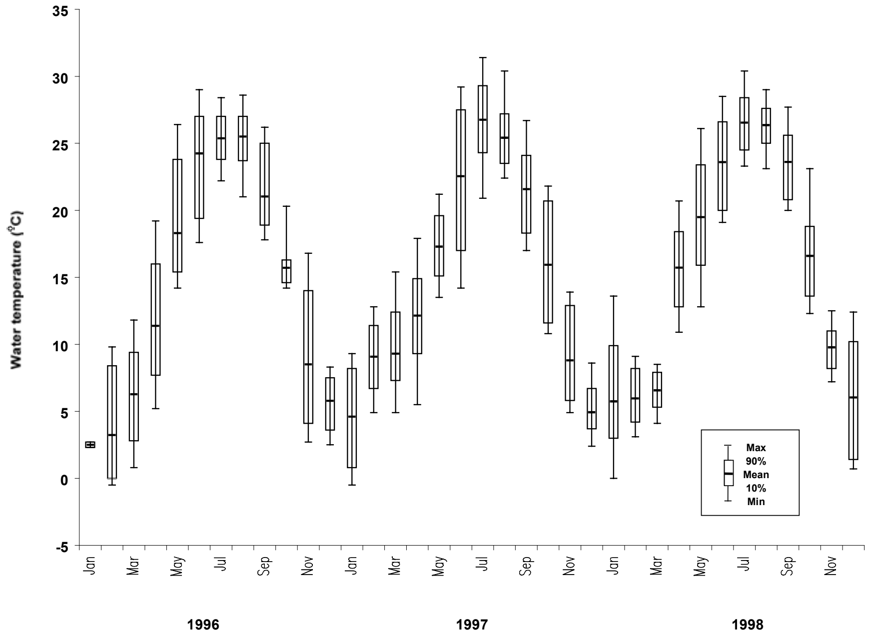


Figure 108. Water temperature statistics for Scotton Landing, 1996-1998.

Eighty-four percent of annual salinity data were included in analyses (75% in 1996, 88% in 1997, 1998). Mean salinity followed a seasonal cycle; however, large variances about mean salinity were observed throughout the data (Figure 109). Mean salinity was 3-5 ppt in winter 1996-1998 and 13-16 ppt in summer/fall 1996-1998. Minimum salinity regularly approached 0 ppt and maximum salinity regularly approached 23 ppt. Scatter plots suggest strong fluctuations (5-15 ppt) in daily and bi-weekly salinity equivalent to or in excess of annual variation in salinity. Harmonic regression analysis attributed 55% of salinity variance to 12.42 hour cycles, 32% of salinity variance to interaction between 12.42 hour and 24 hour cycles, and 13% of salinity variance to 24 hour cycles.

Seventy-five percent of annual dissolved oxygen (% saturation) data were included in analyses (66% in 1996, 82% in 1997, and 78% in 1998). Mean DO followed a seasonal cycle; however, large variances were associated with mean values in summer. Mean dissolved oxygen in summer was 45-50% saturation and 75-100% saturation in fall/winter. Minimum and maximum dissolved oxygen recorded between 1996-1998 was 0% saturation (Jul 1996) and 346.9% saturation (May 1997), respectively. Hypoxia was observed in summer 1996-1998, but was most pronounced in summer 1996. When present, hypoxia typically lasted 6% of the first 48 hours post-deployment, but never persisted more than 15% of first 48 hours post-deployment (Figure 110). Supersaturation was primarily observed between Mar-Aug 1996, with two additional noteworthy occurrences in Jan and Aug 1998. When present, supersaturation typically persisted less than 4% of the first 48 hours post-deployment and never exceeded 15% of the first 48 hours post-deployment. Scatter plots suggest moderate fluctuation (20-60%) in percent saturation throughout 1996-1998, but substantially stronger (≥100%) fluctuations in percent saturation in summer 1996 and 1998. Harmonic regression analysis attributed 55% of DO variance to interaction between 12.42 hour and 24 hour cycles, 32% of DO variance to 12.42 hour cycles, and 13% of DO variance to 24 hour cycles.

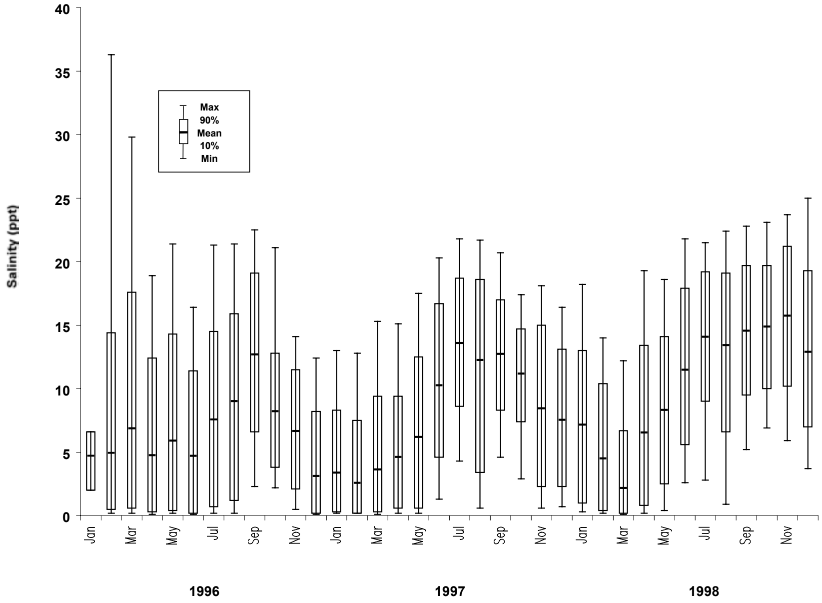


Figure 109. Salinity statistics for Scotton Landing, 1996-1998.

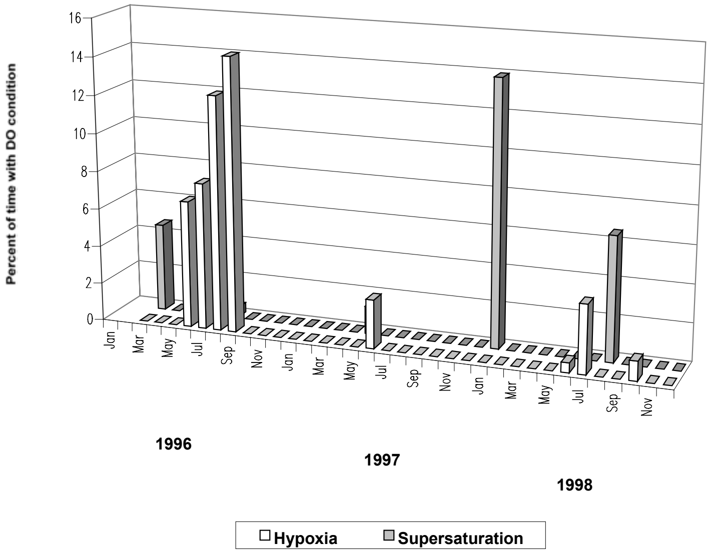
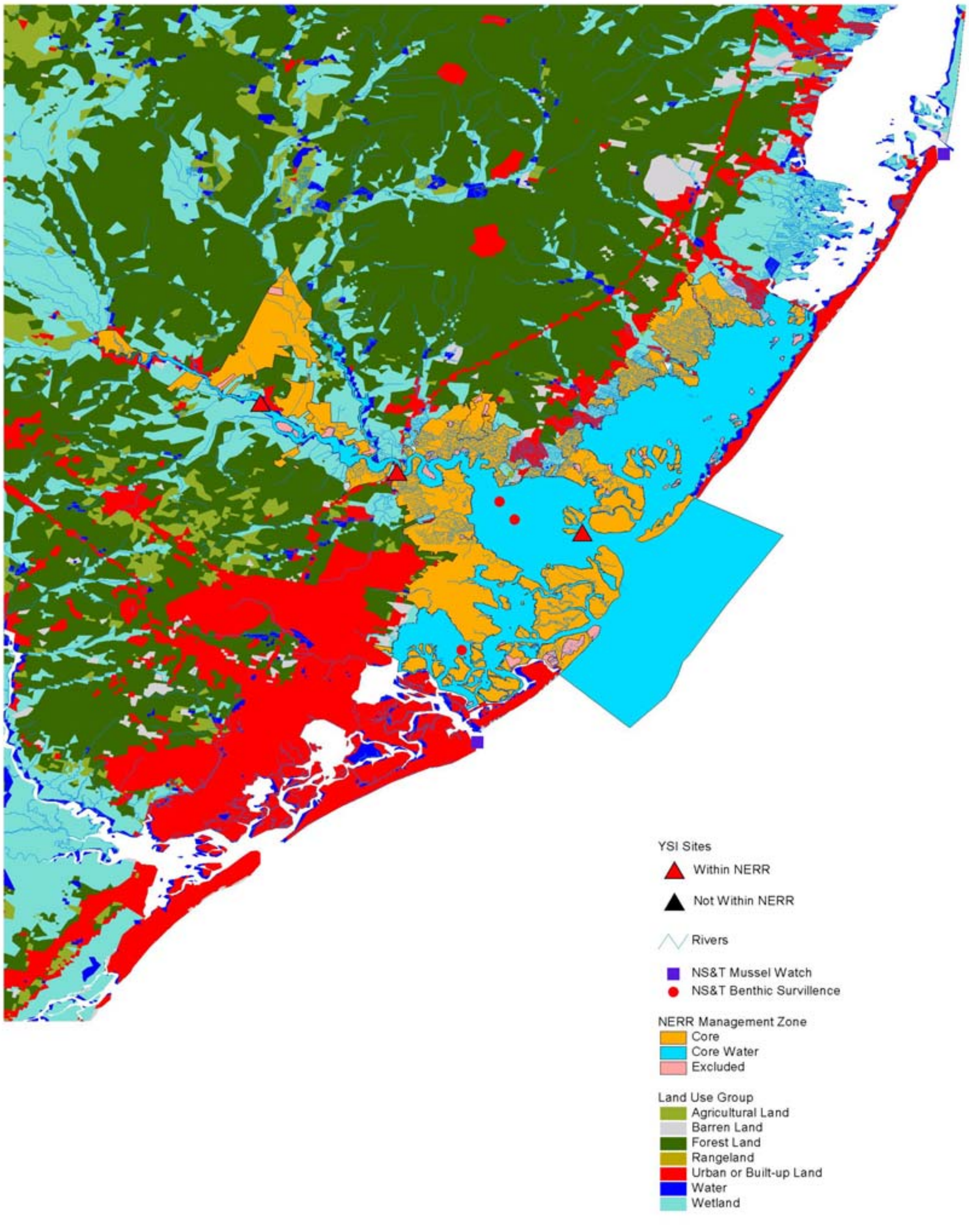


Figure 110. Dissolved oxygen extremes for Scotton Landing, 1996-1998.

Jacques Cousteau at Mullica River



Mullica River, Buoy 126 in Great Bay (MULB6)

Characterization (Latitude = 39°30'29"N; Longitude = 74°20'18"W)
Great Bay is 7 km long (mainstream linear dimension), has an average depth of 3 m MHW, and an average width of 6.75 km. Tides at Buoy 126 are semidiurnal and range from 0.68 m to 1.55 m (average 1.07 m). The site is located on the eastern side of Great Bay and is approximately 100 m from the nearest land, a natural marsh island. At the sampling site, the depth is 4.23 m MHW and the width is 3.5 km. Creek bottom habitats are fine to coarse sand with no bottom vegetation but extensive blue mussel (*Mytilus edulis*) beds surrounding the site. All upland areas in the vicinity of this sampling site are natural marsh islands that are either state or federally owned and protected areas. The activities that potentially impact the site include recreational boating and fishing, and clamming.

Descriptive Statistics
Forty-eight deployments were made at this site between Aug 1996 and Nov 1998, with equal coverage during all seasons (Figure 111). Mean deployment duration was 15.4 days. Only five deployments (Oct 1996; Aug, Oct 1997; Jan, Nov 1998) were less than 10 days.

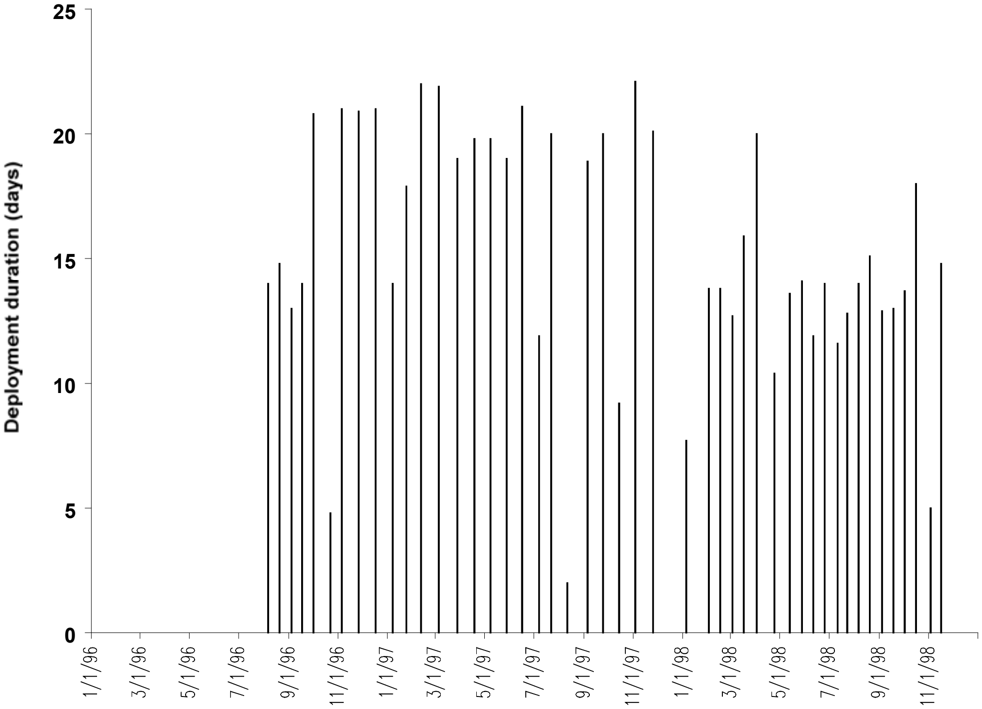


Figure 137. Mullica River, Buoy 126 deployments (1996-1998).

Sixty-six percent of annual depth data were included in analyses (38% in 1996, 81% in 1997, and 78% in 1998). Sensors were deployed at a mean depth of 2.8 m below the water surface and 0.3 m above the bottom sediment. Strong fluctuations (1.5-2 m) were evident from scatter plots, with consistent amplitude throughout the data set. Harmonic regression analysis attributed 86% of depth variance to 12.42 hour cycles and 7% of depth variance to both 24 hour cycles and interaction between 12.42 hour and 24 hour cycles.

Sixty-four percent of annual water temperature data were available for analyses (38% in 1996, 76% in 1997, and 78% in 1998). Water temperature followed a seasonal cycle, with mean water temperatures 4-6°C in winter and 22-24°C in summer (Figure 112). Minimum and maximum water temperatures between 1996-1998 were –1.4°C (Jan 1997) and 28°C (Aug 1998), respectively. Strong fluctuations (1-2°C) in daily water temperature and stronger fluctuations (3-10°C) in bi-weekly water temperature were evident from scatter plots throughout the data set. Fluctuations in water temperature were greatest in Jun-Jul and Oct-Nov in 1997-1998. Harmonic regression analysis attributed 60% of temperature variance to 12.42 hour cycles, 23% of temperature variance to 24 hour cycles, and 17% of temperature variance to interaction between 12.42 hour and 24 hour cycles.

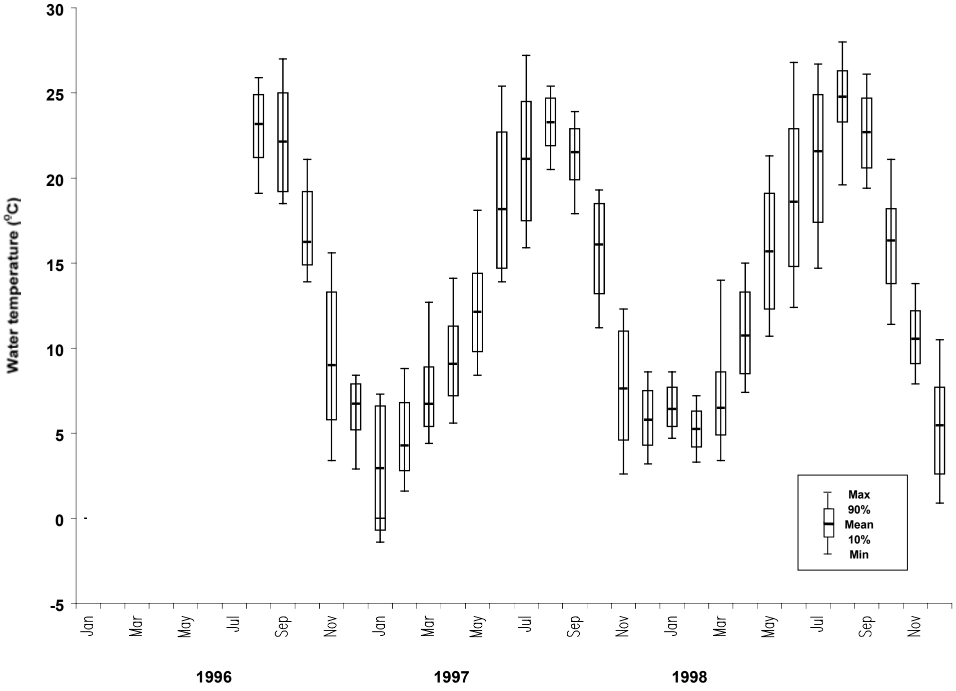


Figure 112. Water temperature statistics at Buoy 126, 1996-1998.

Sixty-three percent of annual salinity data were included in analyses (38% in 1996, 75% in 1997-1998). Mean salinity was 25-31 ppt throughout the data set; however, large variances were associated with mean salinity values (Figure 113). Minimum and maximum salinity between 1996-1998 was 13 ppt (May 1998) and 35.4 (Apr 1997), respectively. Strong fluctuations in daily and bi-weekly salinity equivalent to annual variation in mean salinity were evident from scatter plots. During episodic events in Aug & Dec 1996, Mar & May 1997, and Mar-May 1998, salinity fluctuations exceeded 10 ppt. Harmonic regression analysis attributed 82% of salinity variance to 12.42 hour cycles, 10% of variance to 24 hour cycles, and 8% of variance to interaction between 12.42 hour and 24 hour cycles.

Fifty-six percent of annual dissolved oxygen (% saturation) data were included in analyses (37% in 1996, 68% in 1997, and 64% in 1998). Mean DO was typically between 85-120% saturation throughout the data set. Mean DO below 50% saturation was never observed and mean DO above 100% saturation was regularly observed. Minimum and maximum DO between 1996-1998 was 7.8% saturation (Aug 1996) and 243% saturation (Jun 1998), respectively. Persistent hypoxia was never observed (Figure 114). Supersaturation was observed in summer and fall 1996-1998 and, when present, supersaturation persisted for 20% of the first 48 hours post-deployment on average. Scatter plots suggest moderate fluctuations (20-40%) in percent saturation were observed for daily and biweekly cycles throughout most of the data set, with exceptionally strong (≥ 100%) fluctuations in percent saturation during episodic events in Aug 1996 and Oct 1997. Harmonic regression analysis attributed 41% of DO variance to interaction between 12.42 hour and 24 hour cycles, 34% of DO variance to 12.42 hour cycles, and 25% of DO variance to 24 hour cycles.

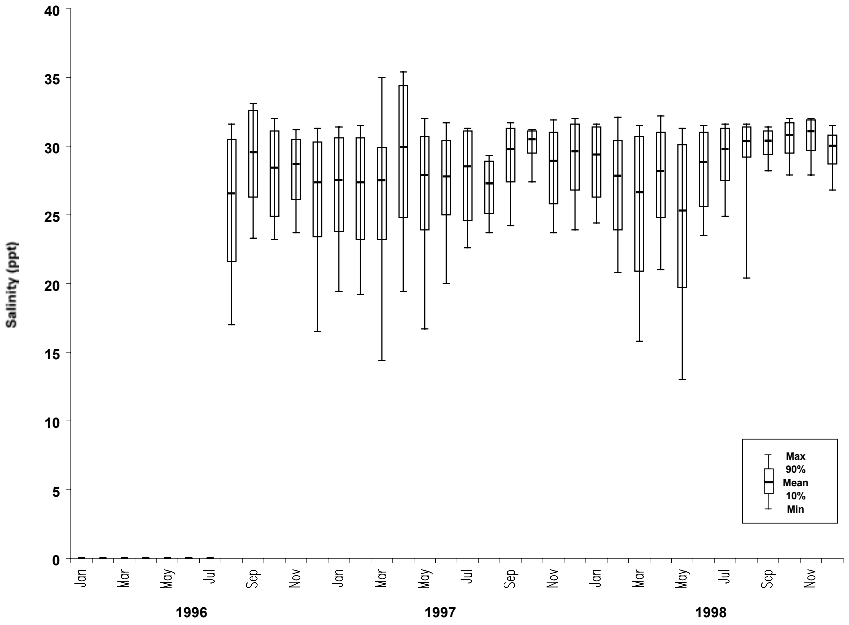


Figure 113. Salinity statistics for Buoy 126, 1996-1998.

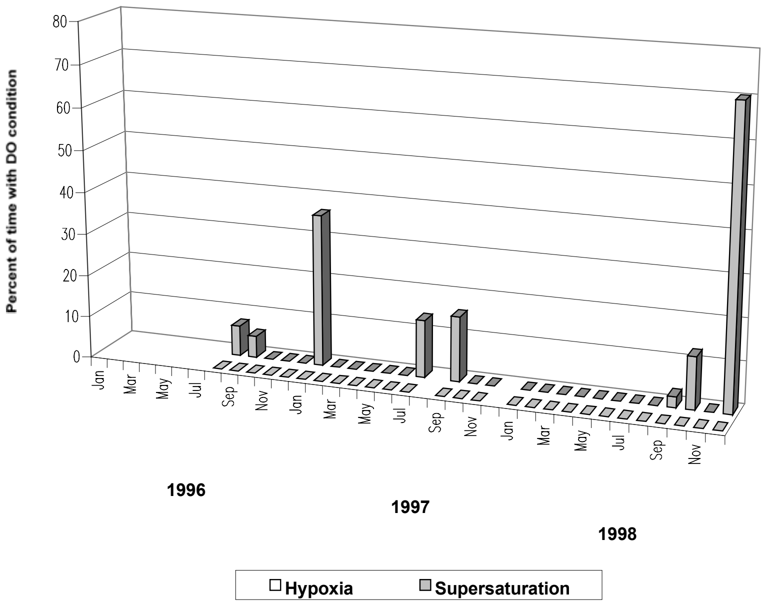


Figure 114. Dissolved oxygen extremes at Buoy 126, 1996-1998.

Mullica River, Lower Bank (MULBA)

Characterization (Latitude = 39°35’37”N; Longitude = 74°33’06”W)
The Mullica River is 34 km long (mainstream linear dimension), has an average depth of 12.8 m MHW, and an average width of 590 m. Tides at Lower Bank are semidiurnal and range from 0.46 m to 1.55 m (average 1.01 m). At the sampling site, the depth is 4.66 m MHW and the width is 290 m. Creek bottom habitats are predominantly fine sand, with no bottom vegetation. The dominant marsh vegetation near the sampling site is *Phragmites* sp. The dominant upland vegetation includes Pineland species such as Pitch pine and White oak. Upland land use near the sampling site includes a bridge and sparsely developed single family homes. Activities that potentially impact the site include recreational boating and agriculture of blueberries and cranberries.

Descriptive Statistics
Forty-one deployments were made at this site between Oct 1996 and Dec 1998, with equal coverage in all seasons (Figure 115). Mean deployment duration was 17.3 days. Only one deployment (Jul 1998) was less than 10 days.

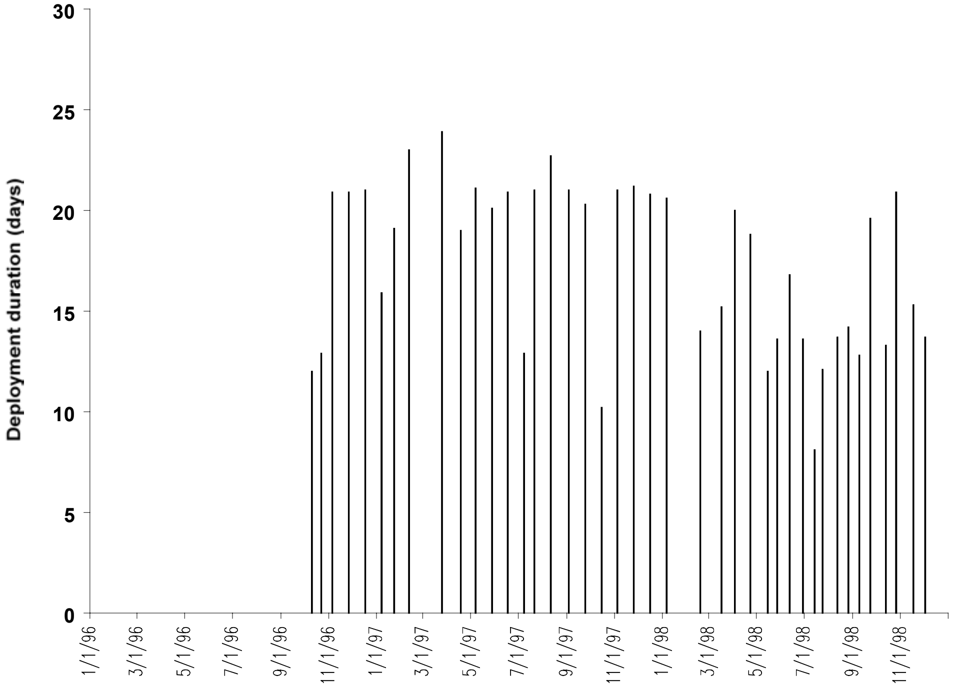


Figure 115. Mullica River, Lower Bank deployments (1996-1998).

Sixty-six percent of annual depth data were included in analyses (22% in 1996, 92% in 1997, and 85% in 1998). Sensors were deployed at a mean depth of 1.7 m below the water surface and 0.3 m above the bottom sediment. Strong fluctuations (1-1.5 m) in depth were evident from scatter plots, with consistent amplitude throughout the data set. Harmonic regression analysis attributed 85% of depth variance to 12.42 hour cycles, 6% of depth variance to 24 hour cycles, and 9% of depth variance to interaction between 12.42 hour and 24 hour cycles.

Sixty-five percent of annual water temperature data were included in analyses (22% in 1996, 89% in 1997, and 85% in 1998). Water temperature followed a seasonal cycle, with mean water temperature

2-5°C in winter and 24-26°C in summer (Figure 116). Minimum and maximum water temperatures between 1996-1998 were -0.2°C (Jan 1997) and 30.1°C (Jul 1997), respectively. Scatter plots suggest moderate fluctuations (1-2°C) in daily water temperature and strong fluctuation (3-10°C) in bi-weekly water temperatures throughout the year, particularly in winter and fall. Harmonic regression analysis attributed 60% of temperature variance to 12.42 hour cycles, 23% of temperature variance to 24 hour cycles, and 17% of temperature variance to interaction between 12.42 hour and 24 hour cycles.

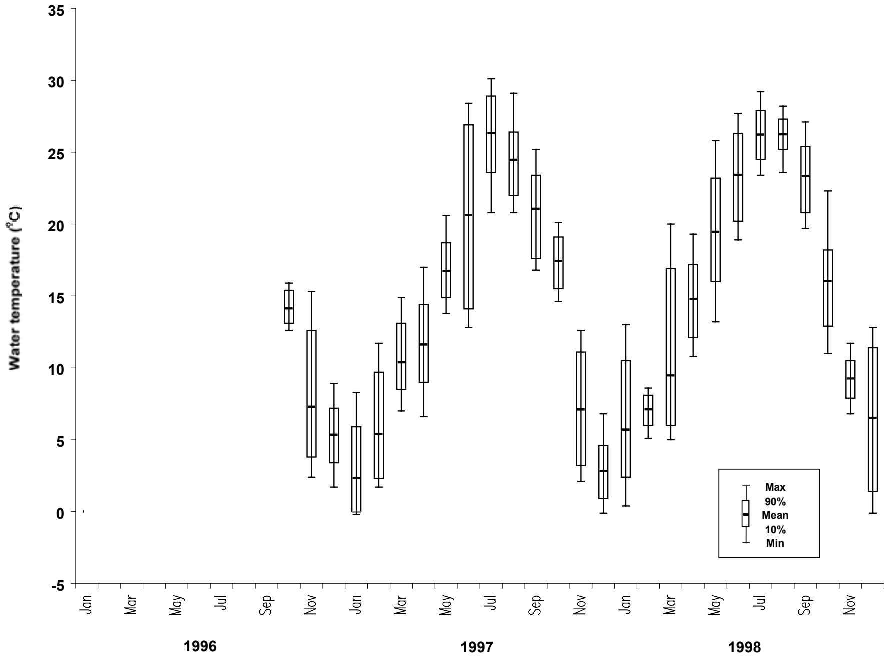


Figure 116. Water temperature statistics for Lower Bank, 1996-1998.

Sixty-five percent of annual salinity data were included in analyses (22% in 1996, 89% in 1997, and 85% in 1998). Mean salinity followed a seasonal cycle; however, large variances were associated with mean salinity values throughout the data set (Figure 117). Mean salinity was 2-8 ppt in summer and fall and 0-2 ppt in winter and spring 1997-1998. Minimum salinity between 1996-1998 was 0 ppt and was observed during almost every month when data were collected. Maximum salinity between 1996-1998 was 15.6 ppt (Nov 1998). Scatter plots suggest strong variation in salinity over daily and bi-weekly intervals equivalent to seasonal variation in mean salinity. Harmonic regression analysis attributed 77% of salinity variance to 12.42 hour cycles, 15% of salinity variance to interaction between 12.42 hour and 24 hour cycles, and 8% of salinity variance to 24 hour cycles.

Fifty-three percent of annual dissolved oxygen (% saturation) data were included in analyses (16% in 1996, 73% in 1997, and 70% in 1998). Mean DO followed a seasonal cycle; however, DO was typically 85-105% saturation throughout the year. Mean DO was greatest (105% saturation in 1997, 120-125% saturation in 1997) in winter and least (80-100% saturation) in summer. Minimum and maximum DO between Oct 1996-Dec 1998 was 4.9% saturation (Jul 1998) and 240.7% saturation (Sep 1998), respectively. Persistent hypoxia was never observed and supersaturation was only observed on four occasions in 1998 (Jan, Mar, Apr, Jul). When present, supersaturation lasted 29% of the first 48 hours post-deployment on average (Figure 118). Scatter plots suggest moderate fluctuations (20-40%) in percent saturation over daily and bi-weekly cycles throughout most of the year, with occasional episodic fluctuations of 60-100% in Sep-Oct. Harmonic regression analysis attributed 38%, 34%, and 28% of variance to 24 hour cycles, 12.42 hour cycles, and interaction between these two cycles, respectively.

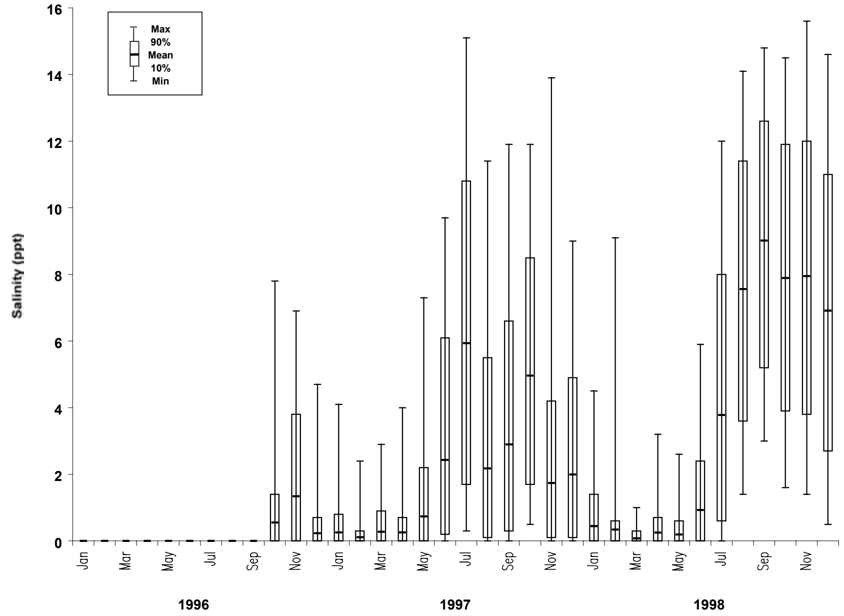


Figure 117. Salinity statistics for Lower Bank, 1996-1998.

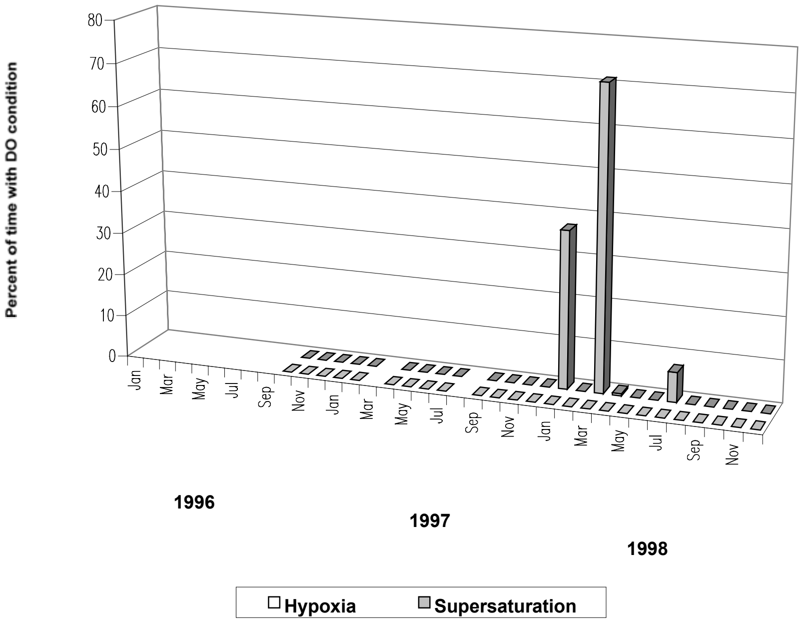
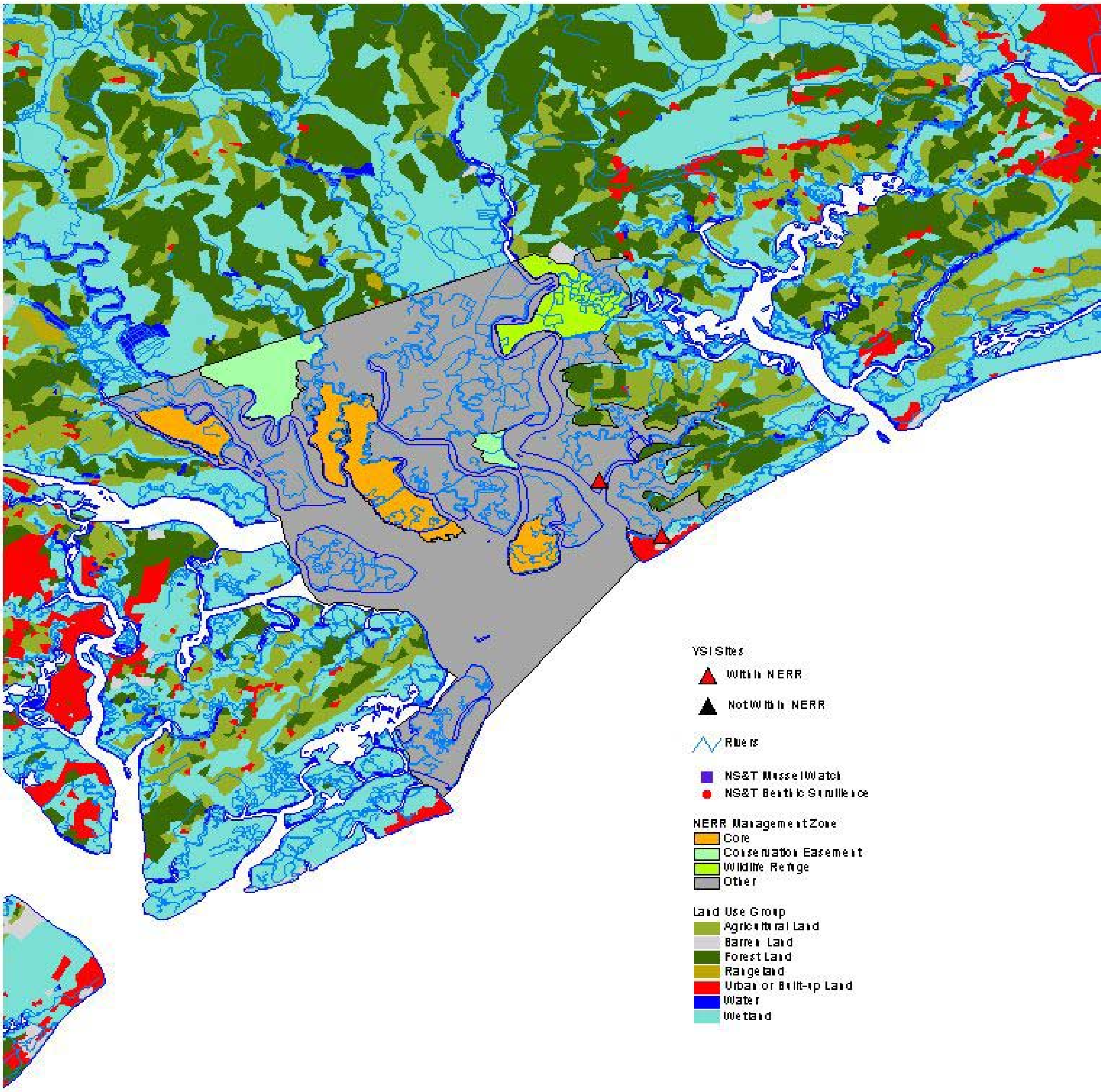


Figure 118. Dissolved oxygen extremes at Lower Bank, 1996-1998.

ACE Basin


YSI Sites
Within NERR
Not Within NERR
Rivers
NS&T Mussel Watch
NS&T Benthic Surveillance
NERR Management Zone
Core
Conservation Easement
Wildlife Refuge
Other
Land Use Group
Agricultural Land
Barren Land
Forest Land
Rangeland
Urban or Built-up Land
Water
Wetland

ACE Basin, Big Bay (ACEBB)

Characterization (Latitude = 32°09'37"N; Longitude = 80°19'26"W)

The Big Bay monitoring station is located in a small creek (2.5-3.7 m wide; 3 m deep at MHW) approximately 68 m from the mouth of Scott Creek, which is approximately 0.9-1.5 m deep at MLW and about 45 m wide. Scott Creek flows into Big Bay Creek about 18 m downstream from the mouth of the monitoring creek. Big Bay Creek is a tributary of the South Edisto River, which empties into St. Helena Sound. Creek bottom habitats are predominantly sand with lots of shell, but no submerged aquatic vegetation due to high turbidity. *Spartina alterniflora* and *Juncus roemerianus* are the dominant salt marsh vegetation. The dominant upland vegetation includes cabbage palmetto, live oak, and red cedar. The uplands contain homes (many with little or no setback or vegetation buffers), a 75-slip marina, several commercial fishing docks with 8-10 commercial shrimp vessels, and three restaurants. In addition, Big Bay Creek has 3 boat ramps and approximately 40 docks constructed of creosote, concrete, Wolmanized pilings, and CCA treated bulkheads. Recreational boat use in the creek near the monitoring site is heavy. Inter-tidal oyster beds are found along the undeveloped bank of Big Bay Creek; however, the creek is closed to shellfish harvesting because of fecal coliform contamination.

Descriptive Statistics

Forty-three deployments were made at this site between January 1996 and December 1998, with equal coverage during all seasons (Figure 119). Mean deployment duration was 19.5 days. Only two deployments (Sep 1996, 1998) were less than five days.

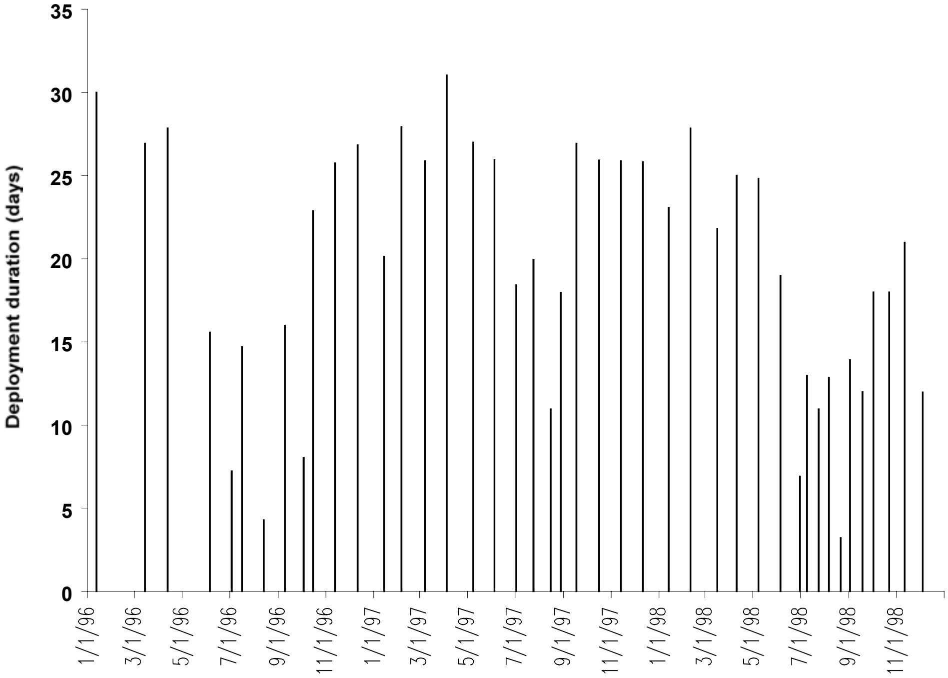


Figure 119. ACE Basin, Big Bay Creek deployments (1996-1998).

Fifty-six percent of annual depth data were included in analyses (37% in 1996, 66% in 1997, and 64% in 1998). Sensors were deployed at a mean depth of 1.25 m below the water surface. Strong fluctuations in water depth (≥ 1m) were associated with daily and spring-neap tidal cycles. Harmonic regression analysis attributed 93% of water depth variation to 12.42 hour cycles, 4% of depth variance to 24 hour cycles, and 3% of depth variance to interaction between 12.42 hour and 24 hour cycles.

Seventy-five percent of annual water temperature data were included in analyses (61% in 1996, 89% in 1997, and 75% in 1998). Water temperature followed a seasonal cycle, with typical water temperatures 10-12°C in the winter and 27-29°C in the summer (Figure 120). Minimum and maximum water temperatures recorded between 1996-1998 were 2.6°C (Jan 1996) and 36°C (Jun 1997), respectively. Scatter plots suggest strong (2°C) fluctuations in daily water temperature and even stronger (≥ 5°C) fluctuations in bi-weekly water temperature during all seasons. Harmonic regression analysis attributed 60% of variance to interaction between 12.42 hour and 24 hour cycles, 10% of temperature variance to 12.42 hour cycles, and 30% of temperature variance to 24 hour cycles.

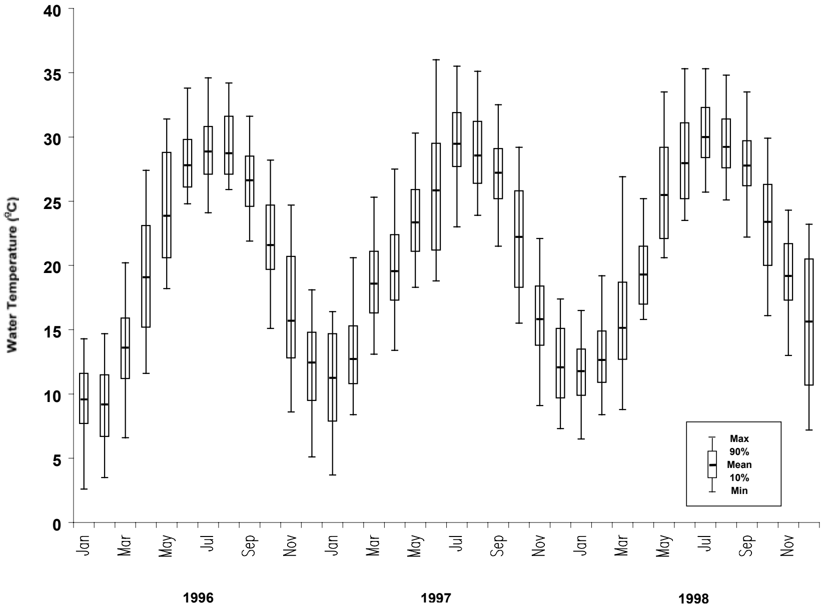


Figure 120. Water temperature statistics for Big Bay Creek, 1996-1998.

Seventy-five percent of annual salinity data were included in analyses (61% in 1996, 89% in 1997, and 75% in 1998). Salinity followed a less pronounced seasonal cycle than water temperature (Figure 121). Mean salinity was lowest in winter and spring and greatest in summer. Mean salinity in winter/spring was typically 25-27 ppt (1996-1997) compared to a mean salinity of ≥ 30 ppt in summer. Winter/spring salinity in 1998 (an El Niño year) was noticeably lower than winter/spring 1996-1997, with typical salinity around 20 ppt. Minimum and maximum salinity observed between 1996-1998 was 4.3 ppt and 41.7 ppt, respectively. Scatter plots suggest strong variation (≥ 5ppt) in daily salinity and stronger variation (≥ 20 ppt) during several episodic events in 1996-1998. Harmonic regression analysis attributed 80% of salinity variance to 12.42 hour cycles, 8% of salinity variance to 24 hour cycles, and 12% of salinity variance to interaction between 12.42 hour and 24 hour cycles.

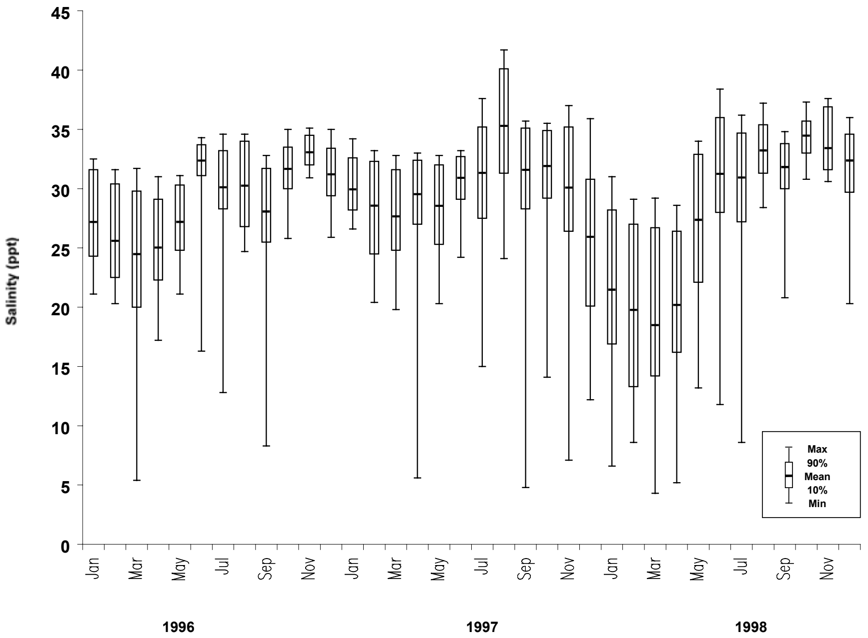


Figure 121. Salinity statistics for Big Bay Creek, 1996-1998.

Fifty-six percent of annual dissolved oxygen (% saturation) data were included in analyses (37% in 1996, 66% in 1997, and 64% in 1998). Dissolved oxygen readings were generally lowest in the summer months. Typical DO in the summer was 65-70% saturation. In Oct 1998, DO was registered at almost 500% saturation and on several occasions DO was registered at approximately 0% saturation. Hypoxia and supersaturation were infrequently observed in all seasons (Figure 122). Hypoxia rarely persisted more than 5% of the first 48 hours post-deployment and only occurred between Jul-Sep (with the exception of Jan 1998). Supersaturation usually lasted about 10% of the first 48 hours post-deployment and occurred in all seasons except spring. Scatter plots indicate that DO often fluctuated drastically (≥ 20% saturation) on daily cycles and even more drastically (≥ 40% saturation) on bi-weekly cycles. Harmonic regression analysis attributed 40% of DO variance to 12.42 hour cycles, 21% of DO variance to 24 hour cycles, and 39% of DO variance to interaction between 12.42 hour and 24 hour cycles.

Photosynthesis/Respiration

Over three quarters (79%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and were used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 26). Instrument drift during the duration of the deployments was not a significant problem at this site. Respiration rates exceeded production rates at Big Bay and the net ecosystem metabolism and P/R ratio indicated that this is a very heterotrophic site (Figure 123). Temperature was significantly ($p<0.05$) correlated with gross production, total respiration and net ecosystem metabolism. Gross production and respiration increased as temperature increased, while net ecosystem metabolism became more heterotrophic as temperatures increased. Salinity was significantly ($p<0.05$) correlated with gross production and net ecosystem metabolism, but not total respiration. Production was higher at higher salinity, while net ecosystem metabolism was more autotrophic at higher salinity.

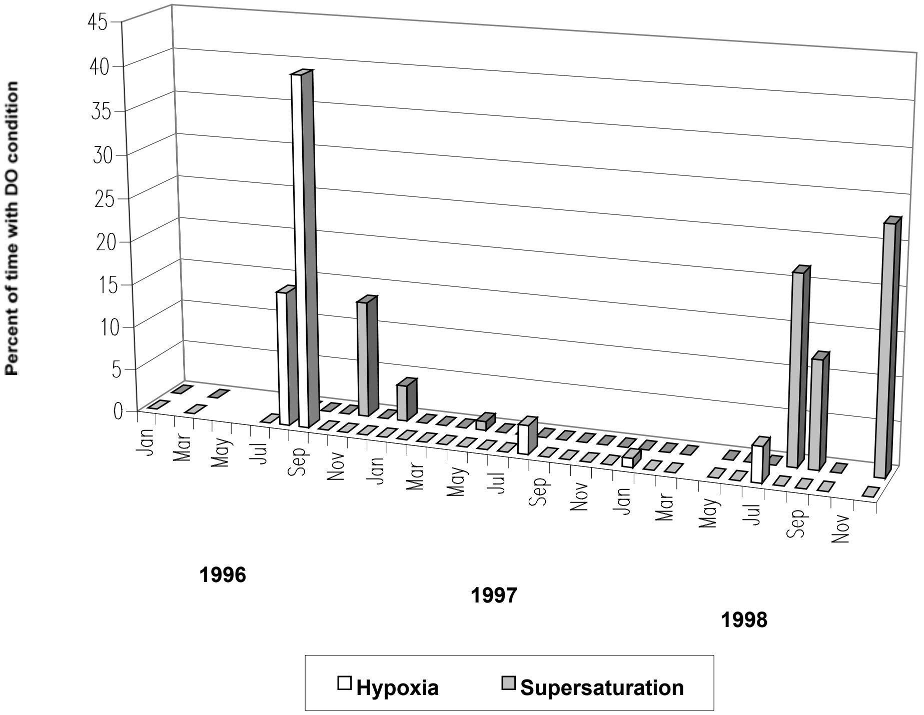


Figure 122. Dissolved oxygen extremes, Big Bay Creek (1996-1998).

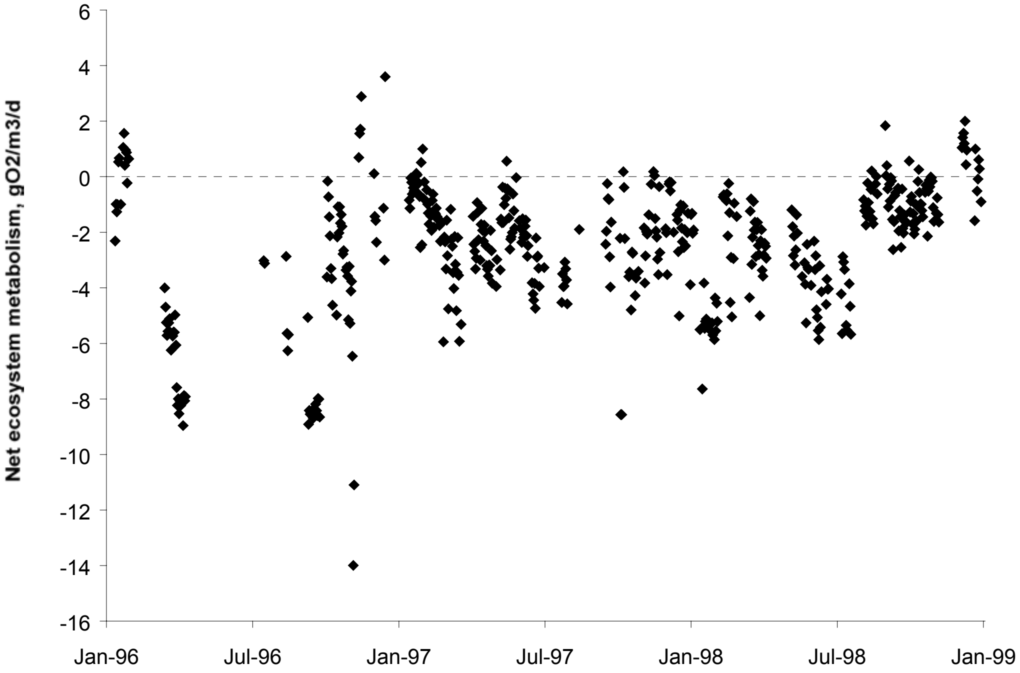


Figure 123. Net metabolism at Big Bay, 1996-1998.

Table 26. Summary of metabolism data and statistics for Big Bay, 1996-1998.

Big Bay	mean	s.e.
Water depth (m)	3.0	
Net production gO_2/m3/d	0.33	0.08
Gross production gO_2/m3/d	2.86	0.10
Total respiration gO_2/m3/d	4.90	0.13
Net ecosystem metabolism g O_2/m3/d	-2.04	0.09
Net ecosystem metabolism g C/m2/y	-541	
P/R	0.58	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	79%	
Paired t-test on gross production and total respiration	$p<0.001$	
Correlation coefficient	Temperature	Salinity
Gross production	0.33	0.13
Total respiration	0.35	ns
Net ecosystem metabolism	-0.16	0.23

ACE Basin, St. Pierre Creek (ACESP)

Characterization (Latitude = 32^{o}01’43”N; Longitude = 80^{o}2’34”W)

The St. Pierre monitoring station is located in a creek that is approximately 18 m wide and about 4.5 m deep at MHW (2 m deep at MLW). Creek bottom habitats are muddy and devoid of vegetation. The monitoring site is approximately 137 m from the mouth of the creek that empties into St. Pierre Creek, a tributary of the South Edisto River that flows into St. Helena Sound. There are no submerged aquatic plant communities in this creek. *Spartina alterniflora* is the dominant vegetation in the salt marshes surrounding the area. Extensive mud flats and oyster reefs fringe the banks. The dominant upland vegetation is wax myrtle, live oak, and palmettos. Development in the immediate area is sparse. The creek near the monitoring site is subject to light boat traffic.

Descriptive Statistics

Forty-three deployments were made at this site between January 1996 and December 1998, with equal coverage during all seasons (Figure 124). Mean deployment duration was 18.6 days. Only four deployments (Nov 1996, Jul-Aug 1997, and Aug 1998) were less than five days.

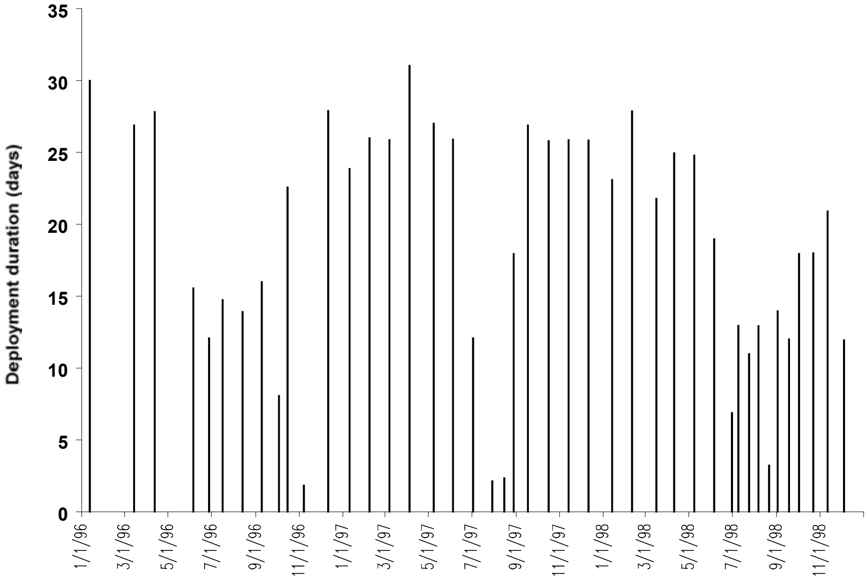


Figure 124. ACE Basin, St. Pierre Creek deployments (1996-1998).

Sixty-nine percent of annual depth data were included in analyses (59% in 1996, 82% in 1997, and 65% in 1998). Instruments were typically deployed at a depth of 1.74 m below the water surface. Strong (≥ 1 m) fluctuations in water depth were evident for daily and bi-weekly cycles from scatter plots. Maximum fluctuation in water depth appeared to occur at regular, bi-weekly intervals, presumably associated with spring-neap tidal cycles. Harmonic regression analysis attributed 94% of these fluctuations to 12.42 hour cycles, 4% of depth variance to 24 hour cycles, and 2% of depth variance to interaction between 12.42 hour and 24 hour cycles.

Seventy percent of annual water temperature data were included in analyses (59% in 1996, 79% in 1997, and 72% in 1998). Water temperature followed a seasonal cycle, with mean water temperatures 10-12°C in winter and 27-29°C in summer (Figure 125). Winter 1996 was slightly cooler than winter 1997 and 1998, whereas summer 1997 was slightly cooler than summer 1996 and 1998. Minimum and maximum water temperatures recorded between 1996-1998 were 4.3°C (Jan 1997) and 45.9°C (Aug 1997), respectively. Scatter plots suggest strong fluctuations (2°C) in daily water temperature and even stronger fluctuations (≥5°C) in bi-weekly water temperature during all seasons. Harmonic regression analysis attributed 59% of temperature variance to interaction between 12.42 hour and 24 hour cycles, 32% of variance to 24 hour cycles, and 9% of variance to 12.42 hour cycles.

Fifty-nine percent of annual salinity data were included in analyses (59% in 1996, 54% in 1997, and 64% in 1998). Salinity followed a less pronounced seasonal cycle than water temperature, but a seasonal cycle was still evident (Figure 126). In general, mean salinity was lowest in the cool, wet winter and spring months and greatest during the warm, dry summer months. Mean salinity in the winter/spring was typically 22-24 ppt (1996-1997) compared with typical salinity of 28-30 ppt in the summer. Winter/spring salinity in 1998 (an El Niño year) was lower than winter/spring 1996-1997, with typical salinity around 16-18 ppt. Minimum and maximum salinity observed between 1996-1998 was 6.6 and 46.0 ppt, respectively, and both occurred in April 1998. Scatter plots suggest strong variation in salinity (≥ 5 ppt) each day with even stronger fluctuations (≥ 20 ppt) observed during several episodic events in 1996-1998. Harmonic regression analysis attributed 86% of salinity variance to 12.42 hour cycles and 7% of salinity variance to both 24 hour cycles and interaction between 12.42 hour and 24 hour cycles.

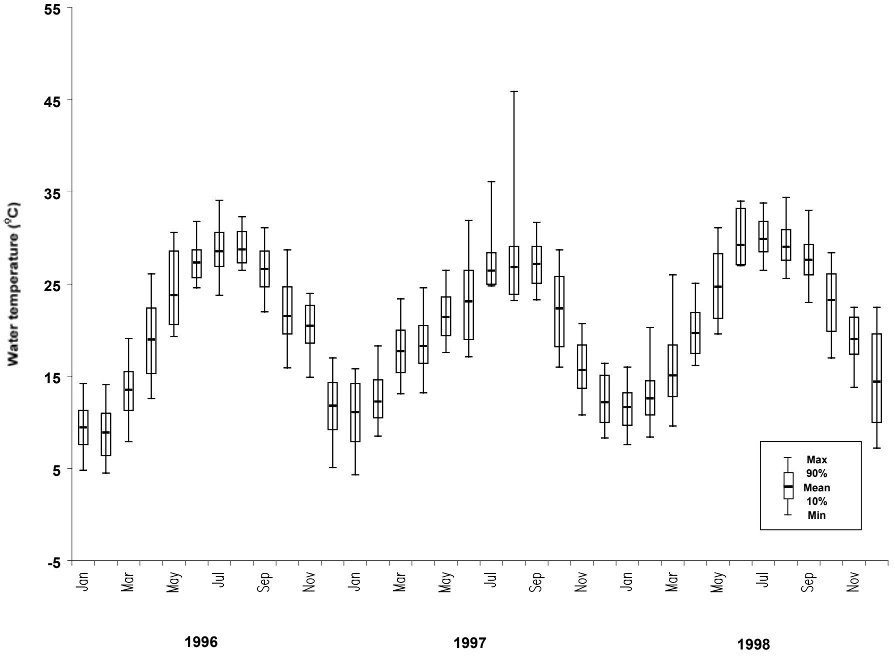


Figure 125. Water temperature statistics for St. Pierre Creek, 1996-1998.

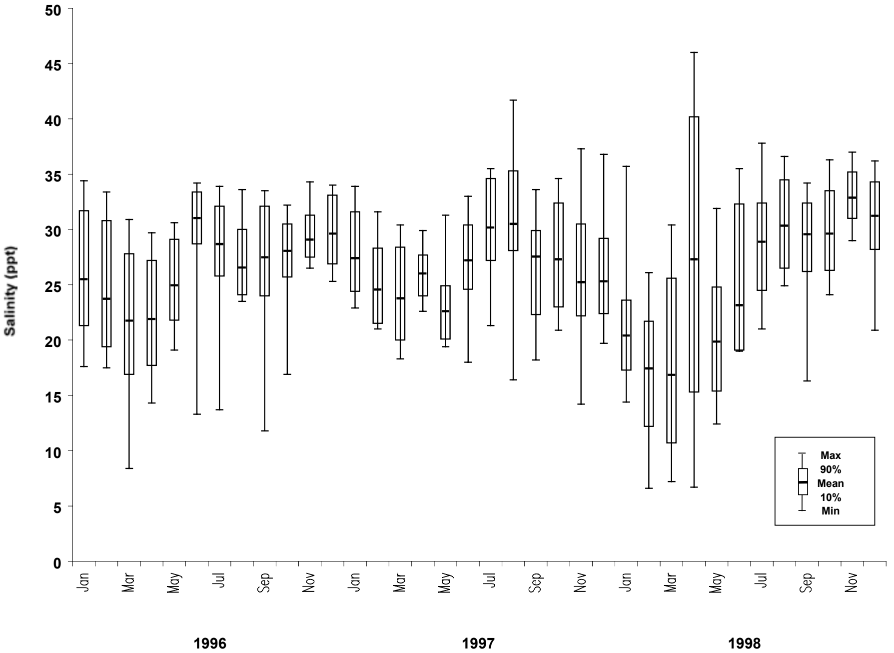


Figure 126. Salinity statistics for St. Pierre Creek, 1996-1998.

Forty-four percent of annual dissolved oxygen (% saturation) data were included in analyses (41% in 1996, 1997 and 52% in 1998). Mean DO was typically 65-90% saturation. Mean percent saturation was usually greatest in winter (88-100%); however, the greatest mean percent saturation (106%) was recorded in June 1998. Mean percent saturation was lowest in July-August, particularly in 1996 (17-36%). On one occasion, DO exceeded 280% (Dec 1996) and on several occasions DO approached 0% saturation. Hypoxia and supersaturation events were rarely observed in all seasons (Figure 127). With the exception of July-August 1996, when hypoxia persisted for almost 50% of the first 48 hours post-deployment, hypoxia usually lasted ≤ 5% of the first 48 hours post-deployment when present. When present (Jan 1996; Jul, Dec 1998), supersaturation typically persisted < 0.25% of the first 48 hours post-deployment. Scatter plots indicated that dissolved oxygen varied drastically (≥ 20%) on daily cycles and even more drastically (≥ 40%) on bi-weekly cycles. Harmonic regression analysis attributed 38% of DO variance to 12.42 hour cycles, 18% of DO variance to 24 hour cycles, and 44% of DO variance to interaction between 12.42 hour and 24 hour cycles.

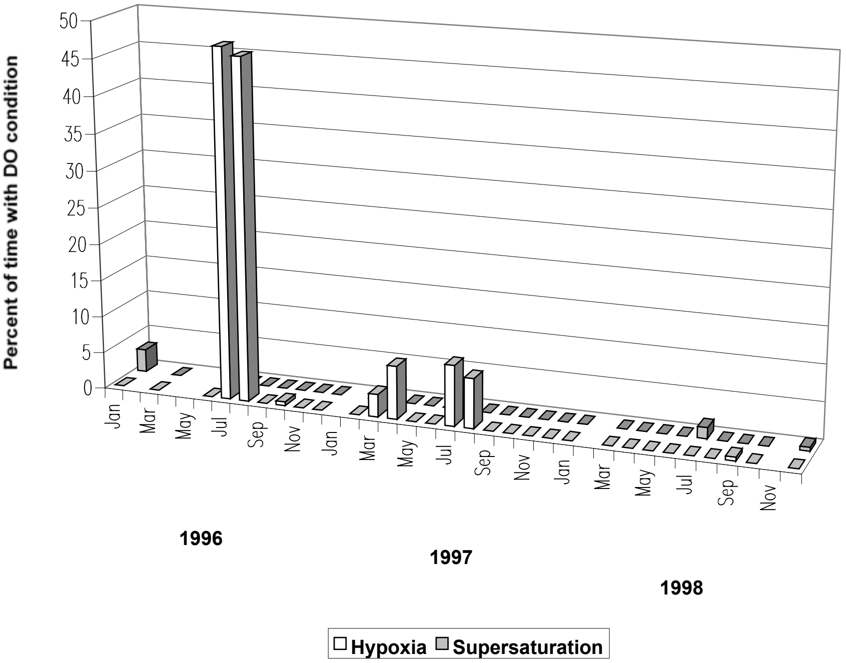


Figure 127. Dissolved oxygen extremes, St. Pierre Creek (1996-1998).

Photosynthesis/Respiration

Over 90% (92%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and was used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 27). Instrument drift during the duration of the deployments was not a significant problem at this site. Respiration rates exceeded production rates at St. Pierre; thus, the net ecosystem metabolism and P/R ratio indicated that this is a heterotrophic site (Figure 128). Temperature was significantly ($p<0.05$) correlated with gross production, total respiration and net ecosystem metabolism. Gross production and respiration increased as temperature increased, while net ecosystem metabolism became more heterotrophic as temperatures increased. Thus, the metabolic rates generally followed a seasonal pattern with the highest rates during summer months and the lowest rates during winter. Salinity was not significantly ($p<0.05$) correlated with any of the metabolic measurements.

Table 27. Summary of metabolism data and statistics for St. Pierre Creek, 1996-1998.

St. Pierre	mean	s.e.
Water depth (m)	4.5	
Net production gO_2/m3/d	0.65	0.06
Gross production gO_2/m3/d	3.52	0.14
Total respiration gO_2/m3/d	4.16	0.13
Net ecosystem metabolism g O_2/m3/d	-0.64	0.09
Net ecosystem metabolism g C/m2/y	153	
P/R	0.85	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	92%	
Paired t-test on gross production and total respiration	$p<0.001$	
Correlation coefficient	Temperature	Salinity
Gross production	0.34	ns
Total respiration	0.48	ns
Net ecosystem metabolism	-0.18	ns

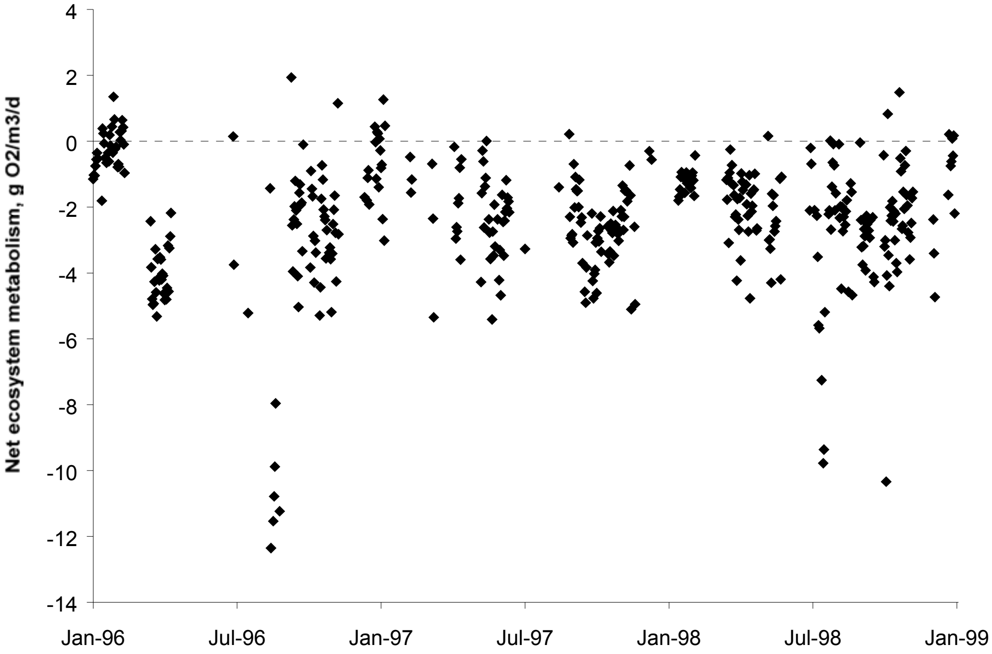
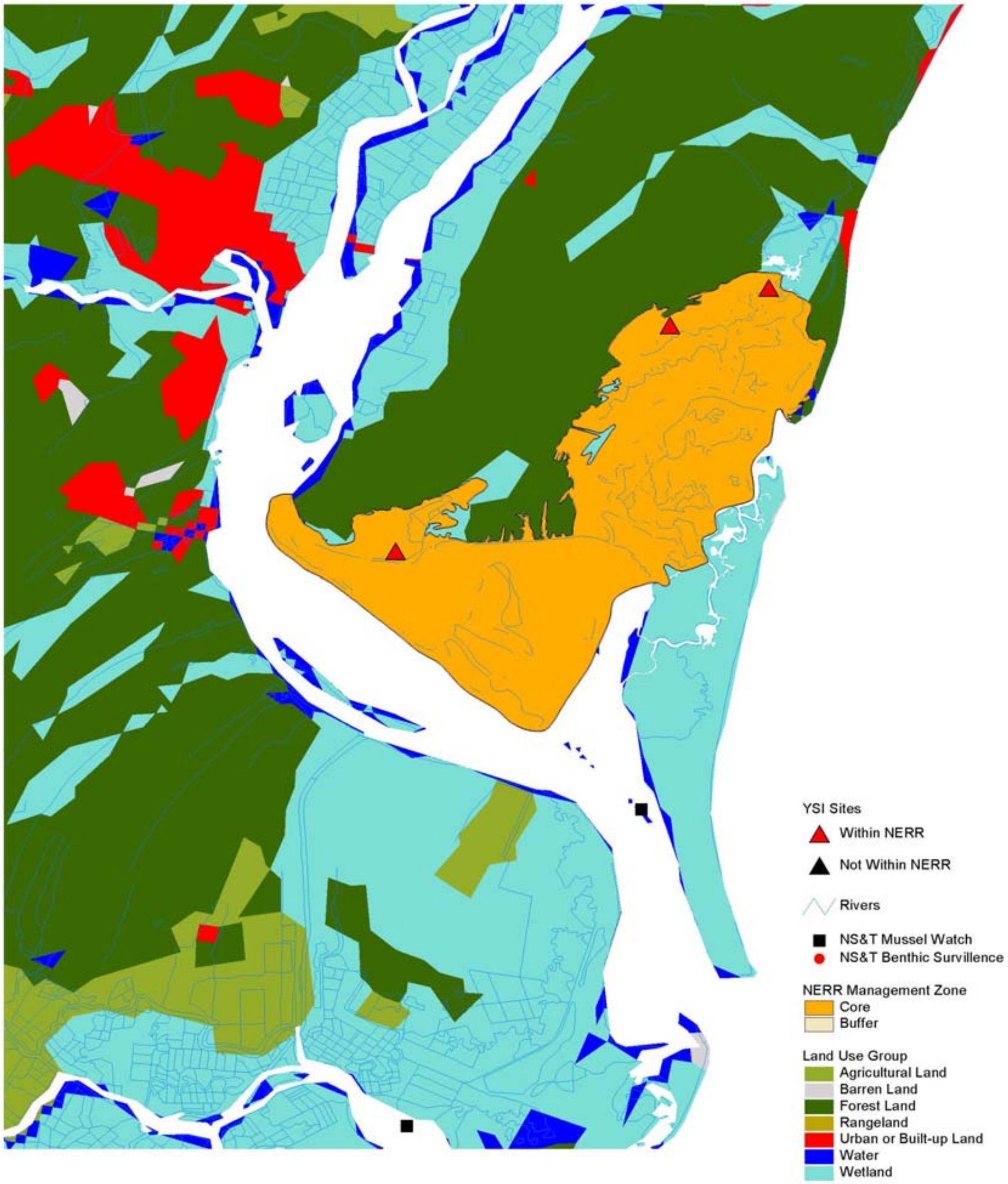


Figure 128. Net metabolism at St. Pierre Creek, 1996-1998.

North Inlet – Winyah Bay



North Inlet-Winyah Bay, Oyster Landing (NIWOL)

Characterization (Latitude = 33° 21'03"N; Longitude = 79°11'50" W)

The Oyster Landing site is located at the confluence of Crabhaul Creek and Oyster Landing. Tides are semidiurnal. The length of the water body is ~5.0 km from the headwaters of Crabhaul Creek to the headwaters of Old Man Creek (mainstream linear dimension). The creek has an average depth of ~2 m MHW and an average width of ~150 m. The sampling site is located ~2.8 km from the headwaters of Crabhaul Creek. At the site, creek depth is ~2.1 m (average at MHW) and the width is ~90 m (at MHW). Creek bottom habitats are predominantly oyster shell hash with some fine sediment and detritus, but no bottom vegetation. The dominant marsh vegetation is *Spartina alterniflora*. Crabhaul Creek drains pine forest uplands and wetlands. The Oyster Landing site is part of the North Inlet estuary that is composed of numerous winding tidal creeks and is considered a pristine inlet estuary due to minimal anthropogenic impacts.

Descriptive Statistics

Sixty-seven deployments were made at this site between Jan 1996 and Dec 1998, with equal coverage during all seasons (Figure 129). Mean deployment duration was 13.8 days. Only three deployments (Jul, Oct 1997 and Jan 1998) were less than 10 days.

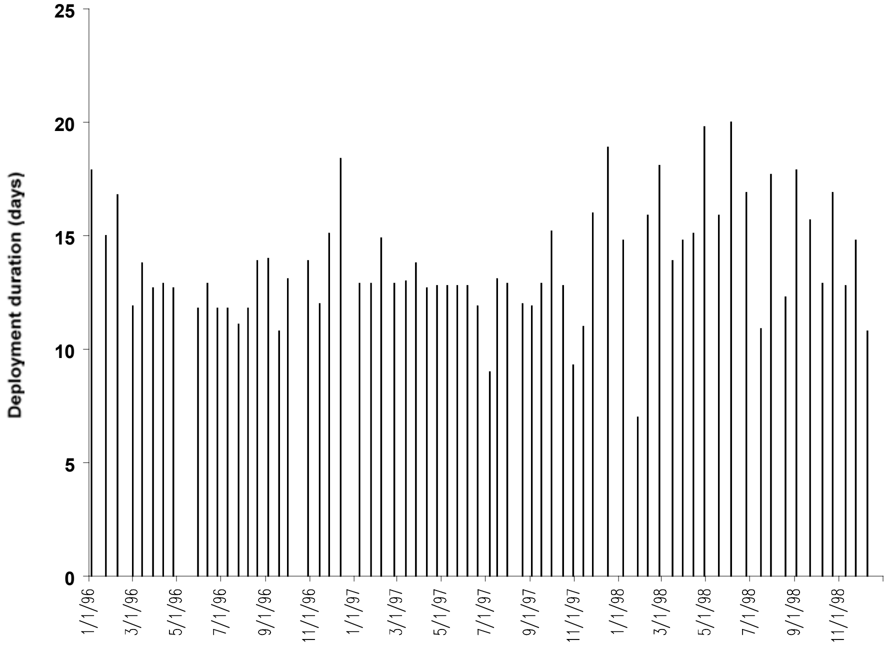


Figure 129. North Inlet-Winyah Bay, Oyster Landing deployments (1996-1998).

Eighty-four percent of annual depth data were included in analyses (79% in 1996, 84% in 1997, and 90% in 1998). Sensors were typically deployed at a depth of 1.5 m below sea level and 0.3 m above the bottom sediment. Strong fluctuations (≥2 m) in depth over daily and bi-weekly cycles were evident from scatter plots, with consistent amplitude throughout the data set. Harmonic regression analysis attributed 76% of depth variance to 12.42 hour cycles, 15% of depth variance to interaction between 12.42 hour and 24 hour cycles, and 9% of depth variance to 24 hour cycles.

Eighty-five percent of annual water temperature data were included in analyses (82% in 1996, 84% in 1997, and 90% in 1998). Water temperature followed a seasonal cycle, with mean water temperatures 9-12°C in winter and 27-29°C in summer (Figure 130). Minimum and maximum water temperatures between 1996-1998 were 1.6°C (Jan 1996) and 34.9°C (Jul 1998), respectively. Scatter plots suggest strong fluctuations (≤ 5°C) in daily water temperature and even stronger fluctuations (5-10°C) in bi-weekly water temperature. Harmonic regression analysis attributed 65% of temperature variance to interaction between 12.42 hour and 24 hour cycles, 21% of temperature variance to 24 hour cycles, and 14% of temperature variance to 12.42 hour cycles.

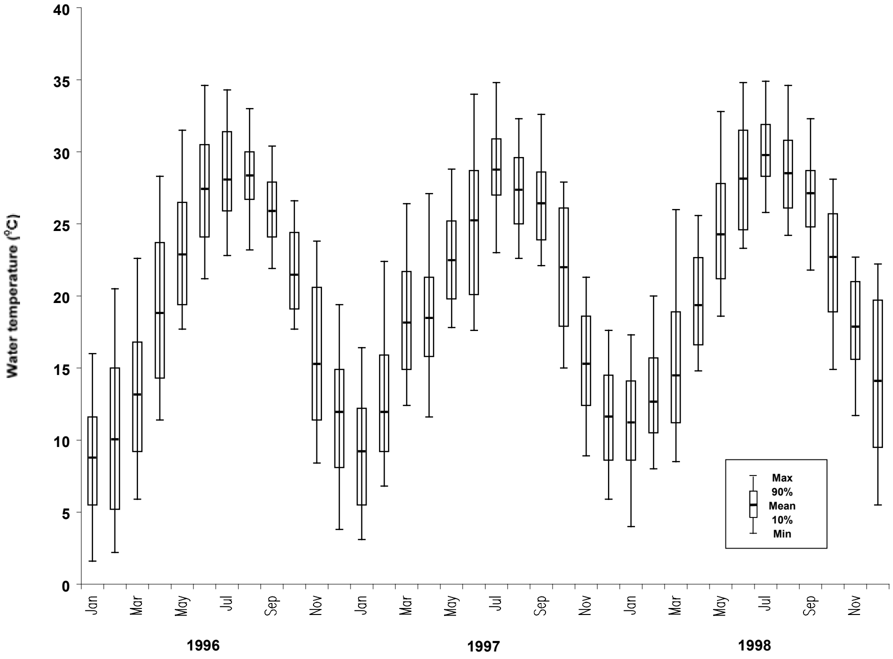


Figure 130. Water temperature statistics at Oyster Landing, 1996-1998.

Eighty percent of annual salinity data were included in analyses (82% in 1996, 84% in 1997, and 75% in 1998). Mean, maximum, and 90th percentile salinity values were typically within 5 ppt of each other (Figure 131). In contrast, mean, minimum, and 10th percentile salinity readings were typically 15-30 ppt different. Maximum salinity regularly exceeded 35 ppt in 1998. Minimum salinity approached 0 ppt in Jul and Sep 1996 and Jan-Mar 1997. Scatter plots suggest strong fluctuation (5-35 ppt) in bi-weekly salinity in all seasons. Harmonic regression analysis attributed 53% of salinity variance to 12.42 hour cycles, 26% of salinity variance to 24 hour cycles, and 21% of salinity variance to interaction between 12.42 hour and 24 hour cycles.

Seventy-nine percent of annual dissolved oxygen (% saturation) data were included in analyses (79% in 1996, 70% in 1997, and 89% in 1998). Mean DO was typically 50-100% saturation, with greatest DO (90-100% sat) in winter and least DO (50-85% sat) in summer. Minimum and maximum DO between 1996-1998 was 0.1% saturation (Jul 1997) and 489.1% (May 1997), respectively. Hypoxia was observed in five months (Jul, Sep 1997 and May, Jul, Aug 1998) and, when present, persisted for 10% of the first 48 hours post-deployment on average (Figure 132). Supersaturation was regularly observed in 1996 and 1997 and, when present, supersaturation persisted for 13.8% of the first 48 hours post-deployment (1996-1997) on average. Scatter plots suggest moderate to strong fluctuation (20-

80%) in daily and bi-weekly percent saturation during all seasons, with very strong fluctuation (> 100%) during episodic events in May and Aug 1996, May-Jul 1997, Mar 1998, and Jul-Sep 1998. Harmonic regression analysis attributed 62% of DO variance to interaction between 12.42 hour and 24 hour cycles, 21% of DO variance to 24 hour cycles and 17% of DO variance to 12.42 hour cycles.

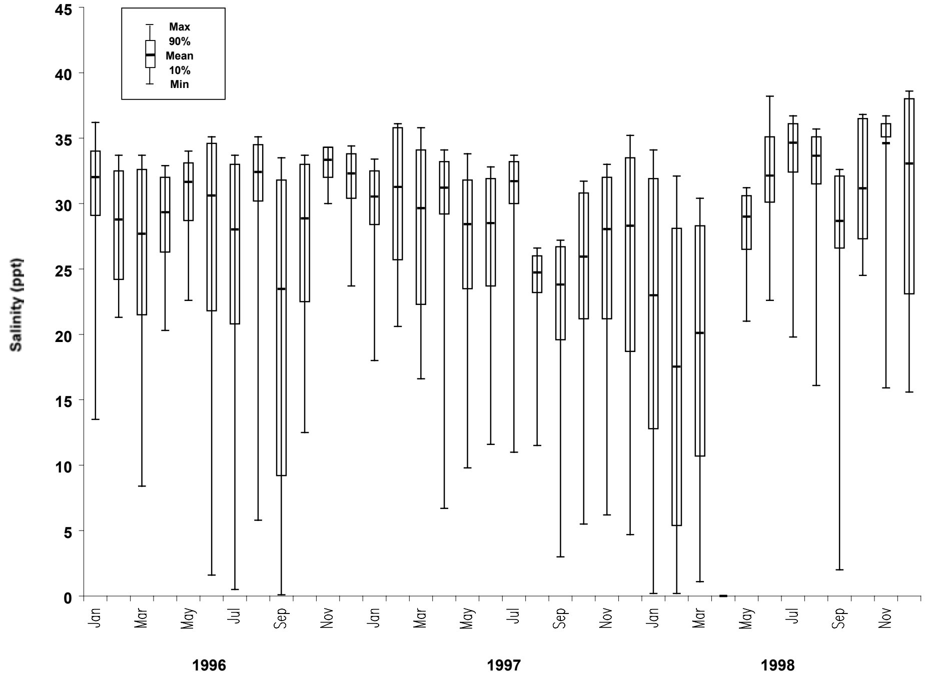


Figure 131. Salinity statistics at Oyster Landing, 1996-1998.

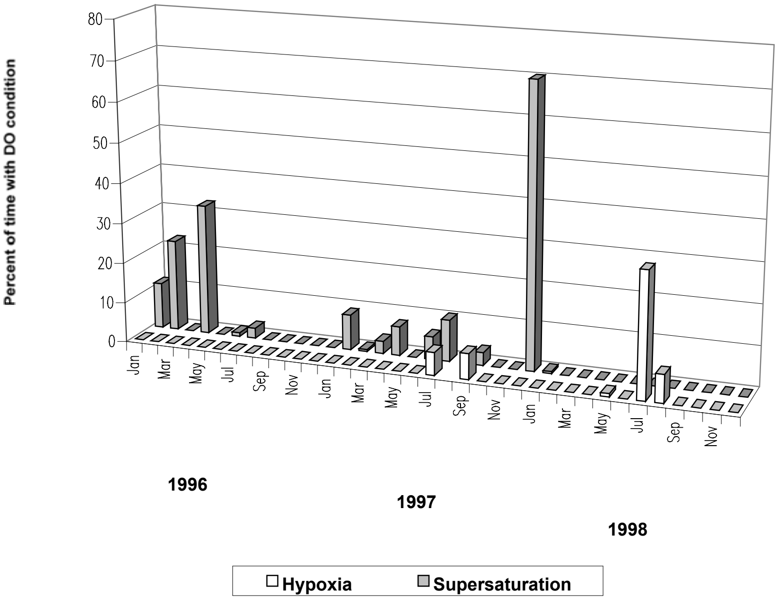


Figure 132. Dissolved oxygen extremes at Oyster Landing, 1996-1998.

Photosynthesis/Respiration

Over four fifths (88%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and were used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 28). Instrument drift during the duration of the deployments was not a significant problem at this site. Total respiration exceeded gross production at Oyster Landing; thus, the net ecosystem metabolism and P/R ratio indicated that this is a heterotrophic site (Figure 133). Temperature was significantly ($p<0.05$) correlated with gross production, total respiration and net ecosystem metabolism. Gross production and respiration increased as temperature increased, while net ecosystem metabolism became more heterotrophic as temperature increased. Salinity was significantly ($p<0.05$) correlated with gross production and total respiration. Gross production and total respiration increased as salinity increased. Thus, the metabolic rates generally followed a seasonal pattern with the lowest rates during the winter when temperature and salinity were low and the highest rates during summer months.

Table 28. Summary of metabolism data and statistics at Oyster Landing, 1996-1998.

Oyster Landing	mean	s.e.
Water depth (m)	1.46	
Net production gO_2/m3/d	0.84	0.06
Gross production gO_2/m3/d	3.63	0.10
Total respiration gO_2/m3/d	5.15	0.12
Net ecosystem metabolism g O_2/m3/d	-1.53	0.07
Net ecosystem metabolism g C/m2/y	-124	
P/R	0.7	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	88 %	
Paired t-test on gross production and total respiration	$p < 0.001$	
Correlation coefficient	Temperature	Salinity
Gross production	0.47	0.16
Total respiration	0.71	0.16
Net ecosystem metabolism	-0.53	ns

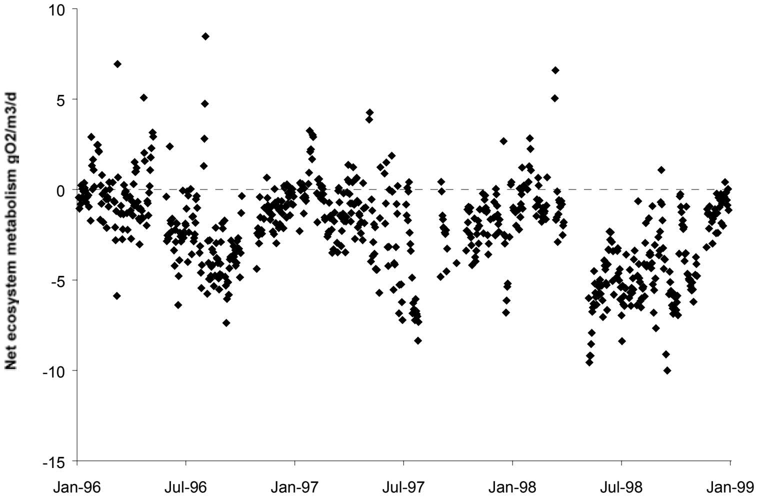


Figure 133. Net metabolism at Oyster Landing, 1996-1998.

North Inlet-Winyah Bay, Thousand Acre (NIWTA)

Characterization (Latitude = 33°18'02"N; Longitude = 79°15'4"W)

Tides at Thousand Acre are semidiurnal. The water body is ~1.5 km long (mainstream linear dimension), has an average depth of ~2.5 m, and an average width of ~8 m MHW. This monitoring site is located in a tidal creek at Thousand Acre marsh. The YSI was deployed approximately 30 m NE of the west bridge of Thousand Acre marsh, about 15 m from the mouth of the creek. The creek empties into the northeastern side of the middle portion of Winyah Bay. At the sampling site, creek depth is approximately 2 m MHW and creek width is approximately 10 m. Creek bottom habitats are predominantly fine sediments and detritus with no bottom vegetation. The dominant marsh vegetation near this site is *Spartina cynosuroides* and the dominant upland vegetation is pine forest. Georgetown, located 5 km upstream from the Thousand Acre site on the southern side of Winyah Bay, is the home port for a number of heavy industries including a steel plant, paper mill, chemical plant, and a coal-fired power plant. A sewage treatment plant that discharges into the bay is also located in Georgetown.

Descriptive Statistics

Sixty-five deployments were made at this site between Jan 1996 and Dec 1998, with equal coverage during all seasons (Figure 134). Mean deployment duration was 14.2 days. Only one deployment (May 1997) was less than 10 days.

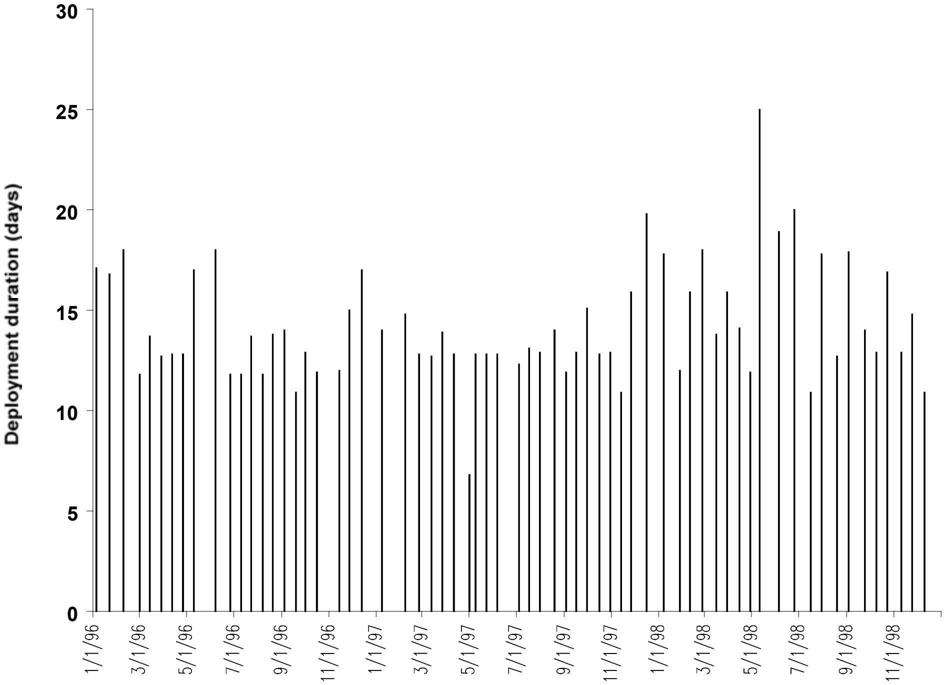


Figure 134. North Inlet-Winyah Bay, Thousand Acre deployments (1996-1998).

Eighty-five percent of annual depth data were included in analyses (84% in 1996, 79% in 1997, and 93% in 1998). Sensors were deployed at a mean depth of 1.2 m below the water surface and 0.3 m above the bottom sediment. Scatter plots suggest strong fluctuations (1.5-2 m) in daily and bi-weekly depth, with consistent amplitude in all seasons. Harmonic regression analysis attributed 83% of depth variance to 12.42 hour cycles, 10% of depth variance to interaction between 12.42 hour and 24 hour cycles, and 7% of depth variance to 24 hour cycles.

Eighty-five percent of annual water temperature data were included in analyses (84% in 1996, 79% in 1997, and 93% in 1998). Water temperature followed a seasonal cycle, with mean water temperatures 7-10°C in winter (1996, 1997) and 26-29°C in summer (Figure 135). Minimum and maximum water temperatures between 1996-1998 were 0.4°C (Feb 1996) and 36°C (Jul 1998), respectively. Scatter plots suggest strong fluctuations (≤ 10°C) in daily water temperature and even stronger fluctuations (≤ 15°C) in bi-weekly water temperatures during spring. Throughout the remainder of the year, daily and bi-weekly fluctuations were ≤ 5°C and ≤ 10°C, respectively. Harmonic regression analysis attributed 53% of temperature variance to interaction between 12.42 hour and 24 hour cycles, 35% of variance to 24 hour cycles, and 12% of variance to 12.42 hour cycles.

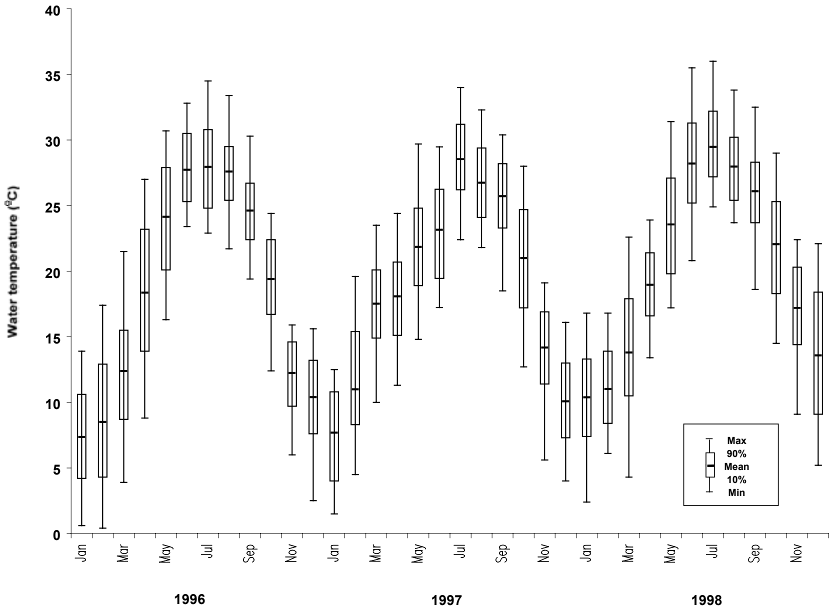


Figure 135. Water temperature statistics at Thousand Acre, 1996-1998.

Eighty-four percent of annual salinity data were included in analyses (84% in 1996, 79% in 1997, and 89% in 1998). Salinity followed a seasonal cycle, with mean salinity <5 ppt in winter, spring, and fall (except Nov 1996) and > 5 ppt in summer (Figure 136). Mean summer salinity in summer 1996-1997 was 5-10 ppt less than mean summer salinity in 1998. Mean salinity in fall 1998 remained elevated at 10-15 ppt, rather than decreasing to < 5 ppt as was the case in 1996-1997. Minimum salinity regularly approached 0 ppt in 1996-1997 and winter 1998. Maximum salinity between 1996-1998 was 33.4 ppt (Sep 1997). Scatter plots suggest strong (5-10 ppt) fluctuation in daily and bi-weekly salinity throughout most of the data set, with stronger (≥ 20 ppt) fluctuations during episodic events in Jul 1996 (Hurricane Bertha), Sep 1997, and Jul 1998. Harmonic regression analysis attributed 52% of salinity variance to 12.42 hour cycles, 29% of salinity variance to interaction between 12.42 hour and 24 hour cycles, and 19% of salinity variance to 24 hour cycles.

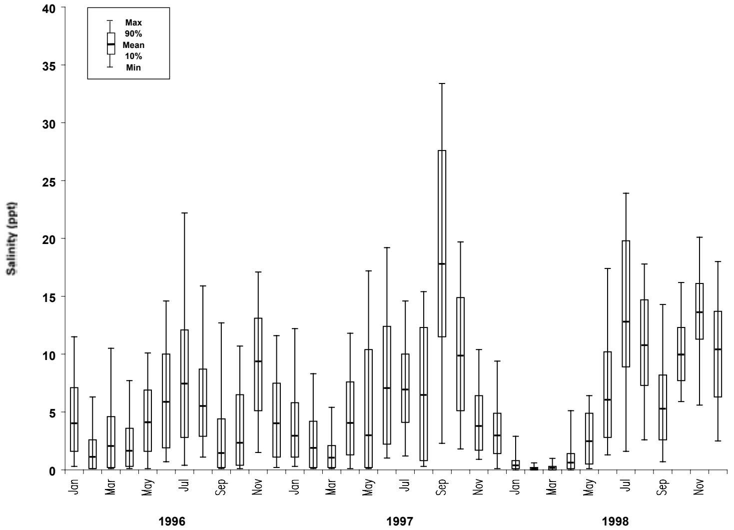


Figure 136. Salinity statistics at Thousand Acre, 1996-1998.

Seventy-seven percent of annual dissolved oxygen (% saturation) data were included in analyses (76% in 1996, 75% in 1997, and 79% in 1998). Mean DO was typically 50-100% saturation and followed a seasonal cycle. Mean DO was lowest in summer (50-85%, except Aug 1998) and greatest in winter (85-100%). Minimum and maximum DO between 1996-1998 was 0% saturation (Jul 1997) and 390.7% saturation (Aug 1998), respectively. Hypoxia was observed in the summer and, when present, hypoxia persisted for 12% of the first 48 hours post-deployment on average (Figure 137). Supersaturation was observed in the spring and summer and, when present, supersaturation persisted for 4% of the first 48 hours post-deployment on average. Scatter plots suggest moderate fluctuations (20-60%) in percent saturation over daily and bi-weekly intervals, with strong fluctuations (≥ 100%) during episodic events in summer. Harmonic regression analysis attributed 42% of DO variance to 12.42 hour cycles, 40% of DO variance to interaction between 12.42 hour and 24 hour cycles, and 20% of DO variance to 24 hour cycles.

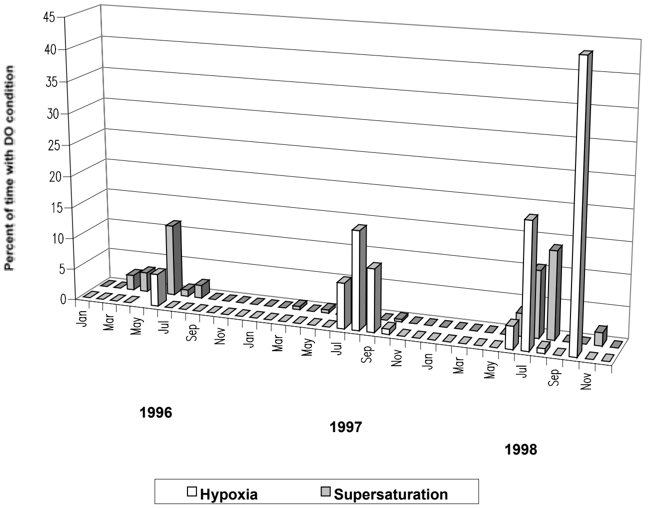


Figure 137. Dissolved oxygen extremes at Thousand Acre, 1996-1998.

Photosynthesis/Respiration

Nearly three quarters (73%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and were used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 29). Instrument drift during the duration of the deployments was not a significant problem at this site. Total respiration exceeded gross production at Thousand Acre Creek; thus, the net ecosystem metabolism and P/R ratio indicated that this is a very heterotrophic site (Figure 138). Temperature was significantly ($p<0.05$) correlated with gross production, total respiration and net ecosystem metabolism. Gross production and respiration increased as temperature increased, while net ecosystem metabolism became more heterotrophic as temperature increased. Salinity was significantly ($p<0.05$) correlated with gross production, total respiration, and net ecosystem metabolism. Gross production and total respiration increased as salinity increased, while net ecosystem metabolism became more heterotrophic as salinity increased. Thus, the metabolic rates generally followed a seasonal pattern with the lowest rates during the winter when temperature and salinity were low and the highest rates during summer months, although summer rates could be highly variable.

Table 29. Summary of metabolism data and statistics at Thousand Acre Creek, 1996-1998.

Thousand Acre Creek	mean	s.e.
Water depth (m)	1.23	
Net production gO_2/m3/d	0.11	0.08
Gross production gO_2/m3/d	2.74	0.13
Total respiration gO_2/m3/d	5.05	0.16
Net ecosystem metabolism g O_2/m3/d	-2.31	0.09
Net ecosystem metabolism g C/m2/y	-274	
P/R	0.54	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	73 %	
Paired t-test on gross production and total respiration	$p < 0.001$	
Correlation coefficient	Temperature	Salinity
Gross production	0.44	0.29
Total respiration	0.56	0.37
Net ecosystem metabolism	-0.34	-0.24

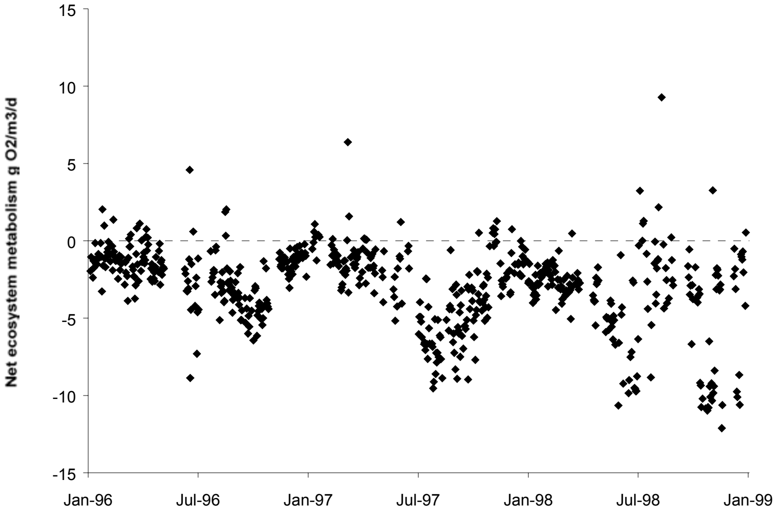
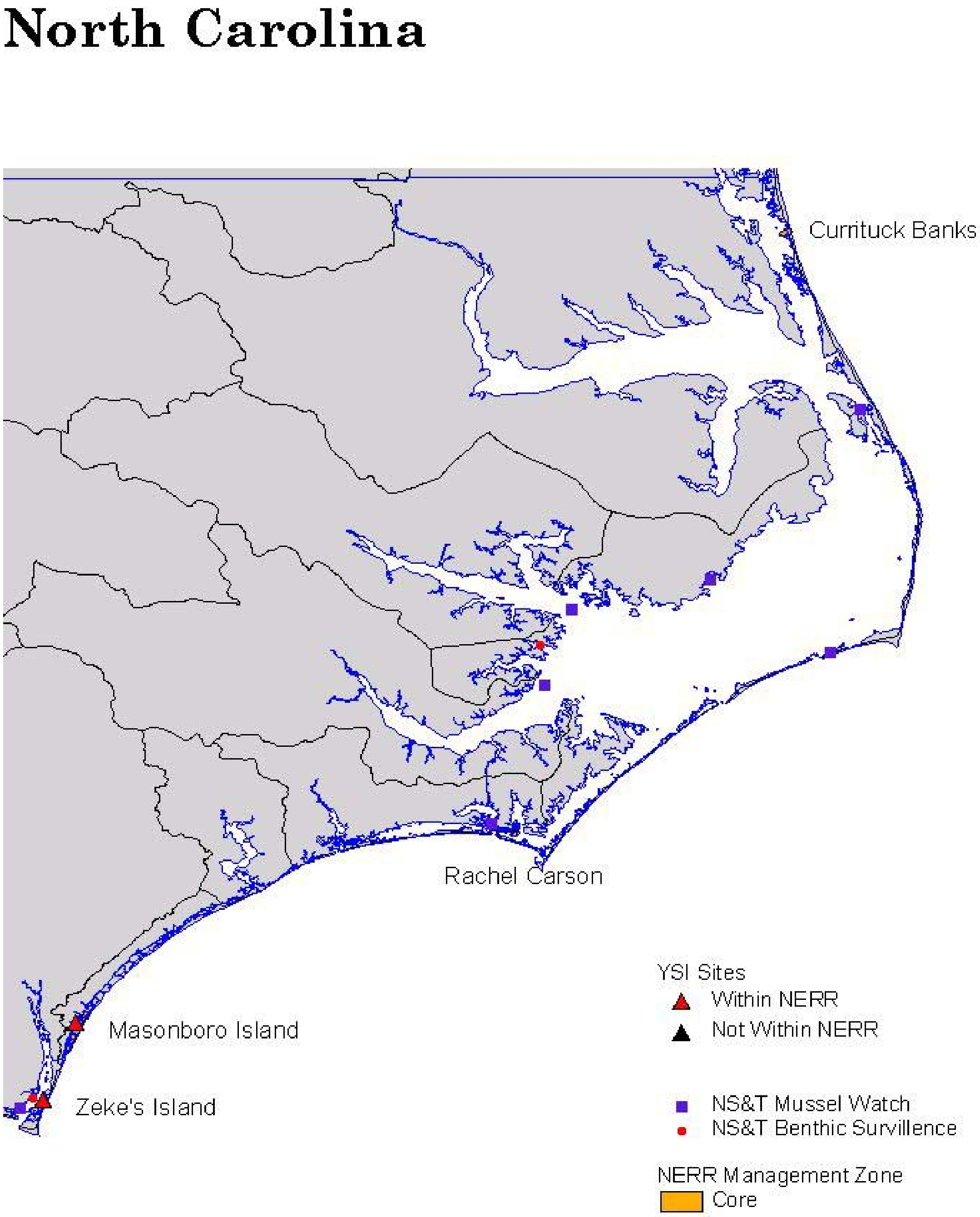


Figure 138. Net metabolism at Thousand Acre Creek, 1996-1998.



North Carolina, Masonboro Island (NOCMS)

Characterization (Latitude = 34° 09' 22"N; Longitude = 77° 51' 00"W)
Tides at Masonboro Island are semidiurnal. The Masonboro Island site is 0.72 km northeast from the mouth of Whiskey Creek, and east of the Intracoastal Waterway, in a small navigable channel called Research Creek. Research Creek connects the Intracoastal Waterway with a diffuse bay and marsh system west of Masonboro Island. Research Creek has an average depth of 1.0 m MHW (mean range = 0.75-1.5 m) and an average width of 20 m. At the sampling site, the depth is around 2.25 m MHW and the width is about 20 m. Creek bottom habitats are predominantly fine silt, sand and shell, with no bottom vegetation except for seasonal benthic algae. The dominant marsh vegetation near the sampling site is *Spartina* sp. Upland areas are dredge spoil islands with mixed bushes and small pine trees. Activities that potentially impact the site include recreational uses (fishing, jet skis, boating), dredging and dredge spoil deposition, and development. This site is relatively un-impacted by manmade perturbations.

Descriptive Statistics
Sixty-eight deployments were made at this site between Jan 1996 and Dec 1998, with equal coverage during all seasons (Figure 139). Mean deployment duration was 14.7 days. Only three deployments (Jan, Jul 1996 and Jan 1998) were less than five days.

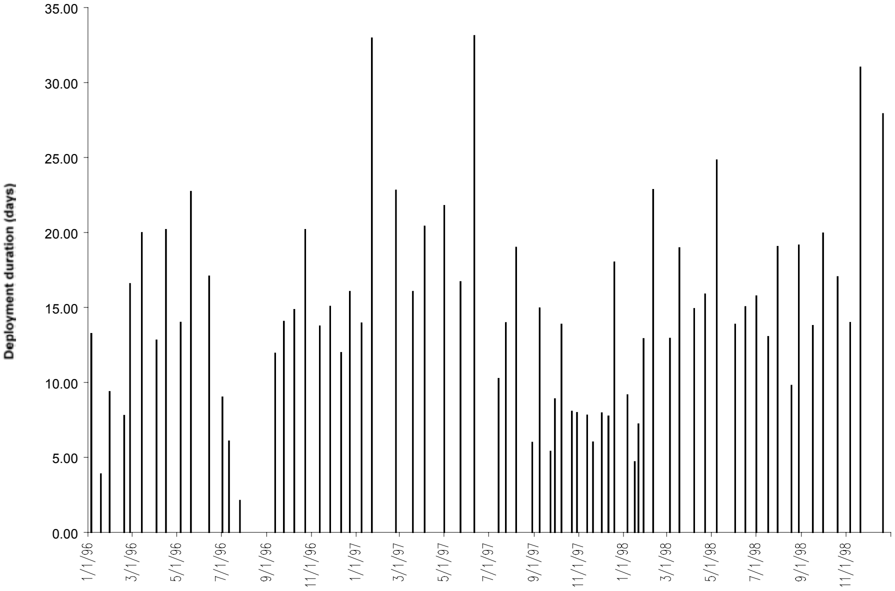


Figure 139. North Carolina NERR, Masonboro Island deployments (1996-1998).

Eighty-five percent of annual depth data were included in analyses (87% in 1996, 78% in 1997, and 91% in 1998). Sensors were deployed at a mean depth of 1.3 m below the water surface and about 0.1 m above the bottom sediment. Scatter plots suggest strong fluctuations (1-2 m) in depth during daily and bi-weekly intervals, with consistent amplitude throughout the data set. Harmonic regression analysis attributed 87% of depth variance to 12.42 hour cycles, 6% of depth variance to 24 hour cycles, and 7% of depth variance to interaction between 12.42 hour and 24 hour cycles.

Eighty-seven percent of annual water temperature data were included in analyses (87% in 1996, 83%

in 1997, and 91% in 1998). Water temperature followed a seasonal cycle, with mean water temperatures 10-12°C in winter (1997, 1998) and 25-28°C in summer (Figure 140). Mean water temperature in winter 1996 was slightly lower (8-11°C) than in winter 1997 and 1998. Minimum and maximum water temperatures between 1996-1998 were -0.4°C (Jan 1996) and 34.6°C (Jul 1998), respectively. Scatter plots suggest strong fluctuations (1-7°C) in daily water temperature and stronger fluctuations (3-15°C) in bi-weekly water temperatures, with strongest fluctuations in spring and fall. Harmonic regression analysis attributed 60% of temperature variance to interaction between 12.42 hour and 24 hour cycles, 25% of variance to 24 hour cycles, 15% of variance to 12.42 hour cycles.

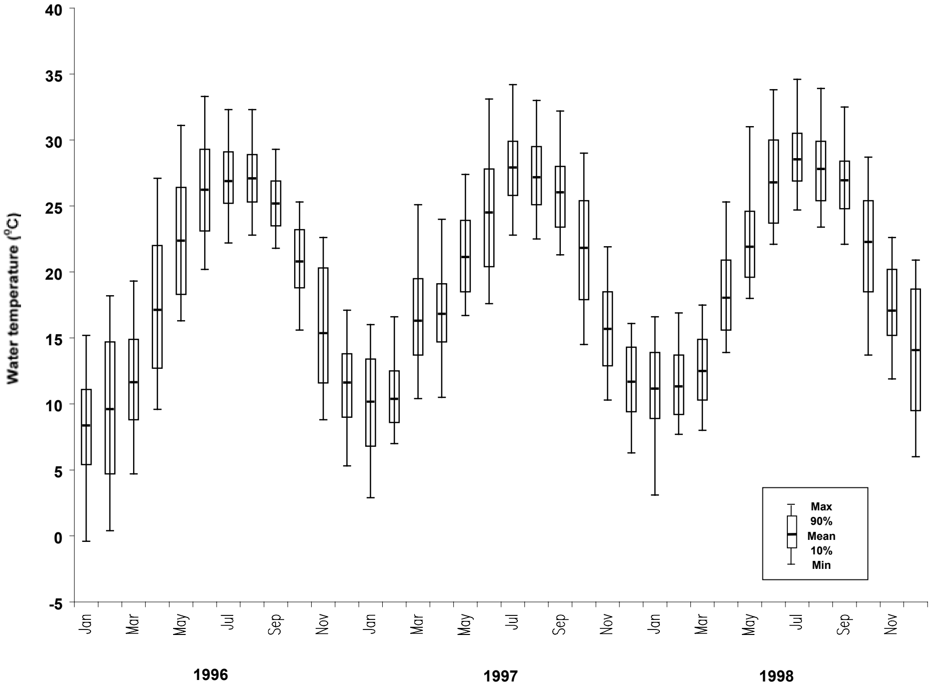


Figure 140. Water temperature statistics for Masonboro Island, 1996-1998.

Eighty-four percent of annual salinity data were included in analyses (86% in 1996, 80% in 1997, and 87% in 1998). Mean salinity throughout 1996 and 1997 (27-31 ppt) was greater than mean salinity in 1998 (23-29 ppt); however, large variances (10-15 ppt) were associated with mean salinity throughout the data set (Figure 141). Minimum and maximum salinity between 1996-1998 were 7.8 ppt (Sep 1998) and 37.2 ppt (Aug 1997), respectively. Scatter plots suggest strong fluctuations in daily and bi-weekly intervals equivalent to, or in excess of, annual variation in mean salinity. Harmonic regression analysis attributed 73% of salinity to 12.42 hour cycles, 17% of salinity variance to interaction between 12.42 hour and 24 hour cycles, and 10% of salinity variance to 24 hour cycles.

Seventy-one percent of annual dissolved oxygen (% saturation) data were included in analyses (79% in 1996, 58% in 1997, and 75% in 1998). Mean DO was typically 75-110% saturation. Mean DO below 50% saturation and above 120% saturation was never observed. Minimum and maximum DO between 1996-1998 was 2.4% saturation (Apr, May 1998) and 264.8% (Apr 1996), respectively. Hypoxia was observed in Apr 1998 and persisted for 1% of the first 48 hours post deployment (Figure 142). Supersaturation was regularly observed in 1996 and 1997, but less frequently observed in 1998.

When present, supersaturation persisted for 17% of the first 48 hours post-deployment on average. Scatter plots suggest moderate (20-60%) fluctuations in daily and bi-weekly percent saturation throughout most of the data set, with strong fluctuations (≥80%) observed during episodic events in spring in all years. Harmonic regression analysis attributed 63% of DO variance to interaction between 12.42 hour and 24 hour cycles, 29% of DO variance to 24 hour cycles, and 8% of DO variance to 12.42 hour cycles.

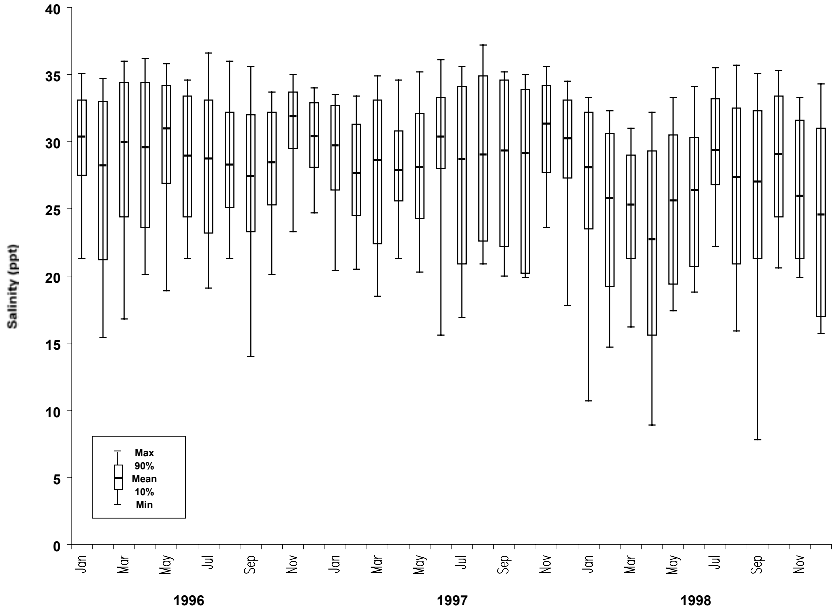


Figure 141. Salinity statistics at Masonboro Island, 1996-1998.

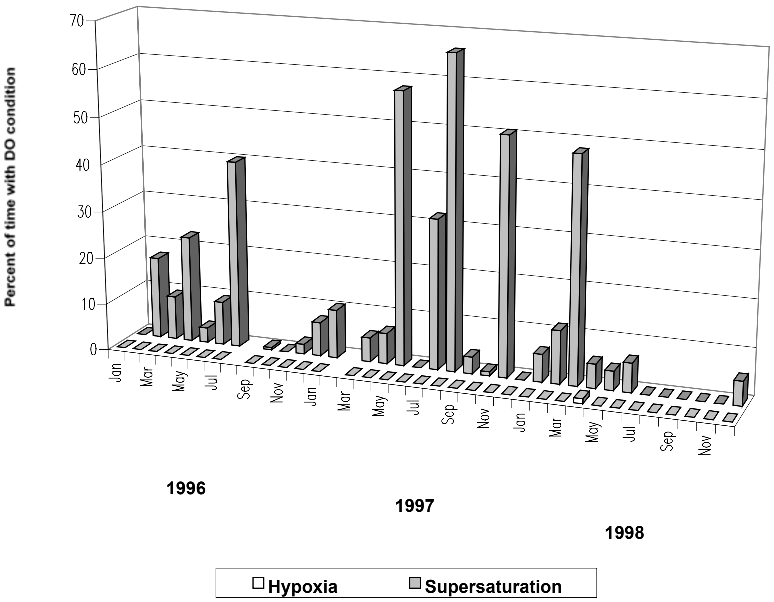


Figure 142. Dissolved oxygen extremes at Masonboro Island, 1996-1998.

North Carolina, Zeke's Island (NOCZI)

Characterization (Latitude = 33°56'24"N; Longitude = 77°56'28"W)

Tides at Zeke's Island are semidiurnal, with an average tidal range of 1.2-1.4 m. Zeke's Island Component is near the mouth of the Cape Fear River, east of the Intracoastal Waterway. The sampling site is at the East Crib of Zeke's Island which is located 1.8 km south of Federal Point boat launch in a tidal basin estuary and north of the New Inlet, which connects the estuary with the Atlantic Ocean. The East Crib is composed of rocks stabilizing a channel connecting the inner and outer basins of the Zeke's Island Component. The sampling site is at the confluence of several tidal channels with water depths between 0.5-2.0 m MHW. Creek bottom habitats are primarily sand with no bottom vegetation except for seasonal algae. Current flow through the area where the meter is placed can be fairly high. The dominant marsh vegetation near the sampling site is *Spartina* sp. The dominant upland vegetation includes scattered bushes (bay, myrtle, etc.) and pine trees. Most of the surrounding land is either in the Reserve or part of a state park system; therefore, the land use around this site is mostly recreational (fishing, jet skis, boating). This site is relatively un-impacted by manmade perturbations.

Descriptive Statistics

Sixty-four deployments were made at this site between Jan 1996 and Dec 1998, with equal coverage during all seasons (Figure 143). Mean deployment duration was 16.6 days. Only one deployment (Dec 1997) was less than five days

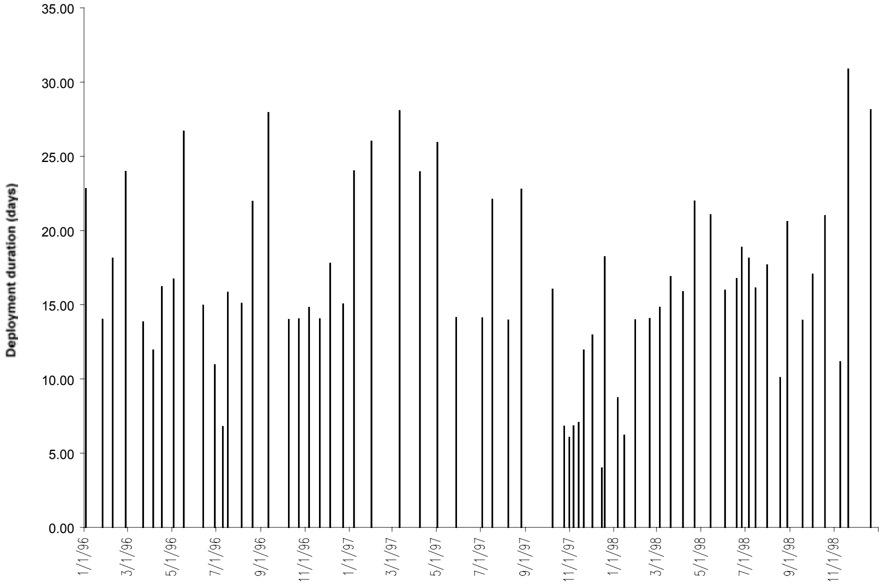


Figure 143. North Carolina NERR, Zeke's Island deployments (1996-1998).

Eighty-eight percent of annual depth data were included in analyses (94% in 1996, 79% in 1997, and 91% in 1998). Sensors were deployed at a mean depth of 1.5 m below the water surface and 0.1 m above the bottom sediment, except for Feb and Jun 1997 (mean depth ≤ 0.5 m below sea level). Scatter plots suggest strong fluctuations (≥ 2 m) in daily and bi-weekly water depth. Harmonic regression analysis attributed 89% of depth variance to 12.42 hour cycles, 5% of depth variance to 24 hour cycles, and 6% of depth variance to interaction between 12.42 hour and 24 hour cycles.

Eighty-eight percent of annual water temperature data were included in analyses (94% in 1996, 79% in 1997, and 91% in 1998). Water temperature followed a seasonal cycle, with mean water temperatures

10-11°C in winter (1997, 1998) and 25-28°C in summer (Figure 144). Mean water temperature in winter 1996 was more variable (8-13°C) than winter 1997-1998. Minimum and maximum water temperatures between 1996-1998 were -0.3°C (Jan 1996) and 33.1°C (Jul 1997), respectively. Scatter plots suggest strong fluctuations (≤ 5°C) in daily water temperature and even stronger fluctuations (5-10°C) in bi-weekly water temperatures in all seasons, particularly winter and fall. Harmonic regression analysis attributed 76% of temperature variance to 24 hour cycles, 18% of temperature variance to interaction between 12.42 hour and 24 hour cycles, and 6% of temperature variance to 12.42 hour cycles.

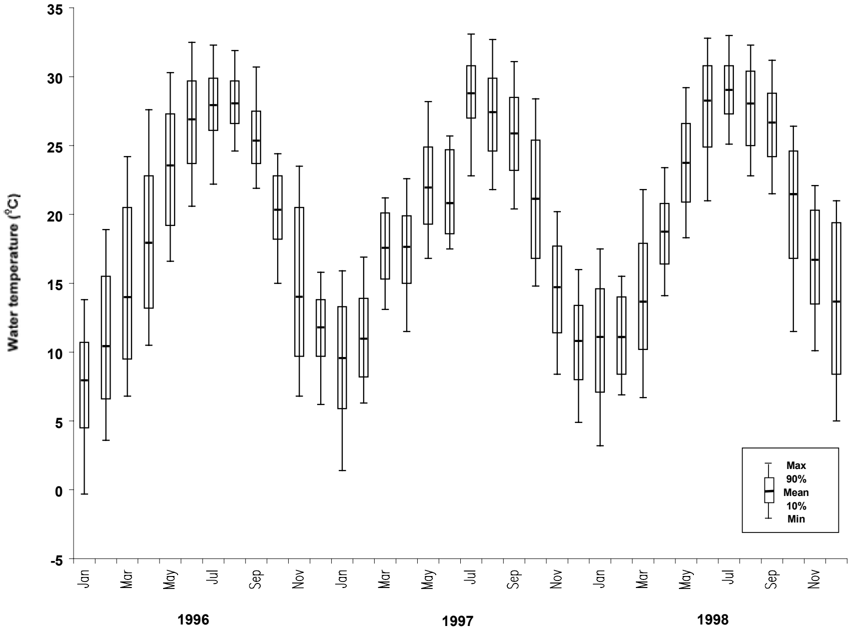


Figure 144. Water temperature statistics for Zeke's Island, 1996-1998.

Eighty-five percent of annual salinity data were included in analyses (89% in 1996, 79% in 1997, and 87% in 1998). Mean salinity followed a seasonal cycle, with lowest salinity in winter and greatest salinity in summer for 1997 and 1998 (Figure 145). Mean salinity in 1996 was 21-26 ppt throughout the year, but dropped abruptly (11-12 ppt) in Sep-Oct. Abrupt drop in salinity in Sep-Oct 1996 was likely due to Hurricane Fran which dumped excessive amounts of freshwater into inland tributaries and altered salinity for several weeks. Mean salinity was lowest in winter 1998 (5-7 ppt), which was also likely related to large freshwater input during this El Nino year. Minimum and maximum salinity between 1996-1998 was 1.6 ppt (Feb 1998) and 35.4 (Aug 1998), respectively. Scatter plots suggest strong fluctuations (5-10 ppt) in salinity throughout the data set, with extremely strong (15-25 ppt) fluctuations observed during episodic storm events in Sep 1996, May 1997, and Sep 1998. Harmonic regression analysis attributed 60% of salinity variance to 12.42 hour cycles, 26% of salinity variance to interaction between 12.42 hour and 24 hour cycles, and 14% of salinity variance to 24 hour cycles.

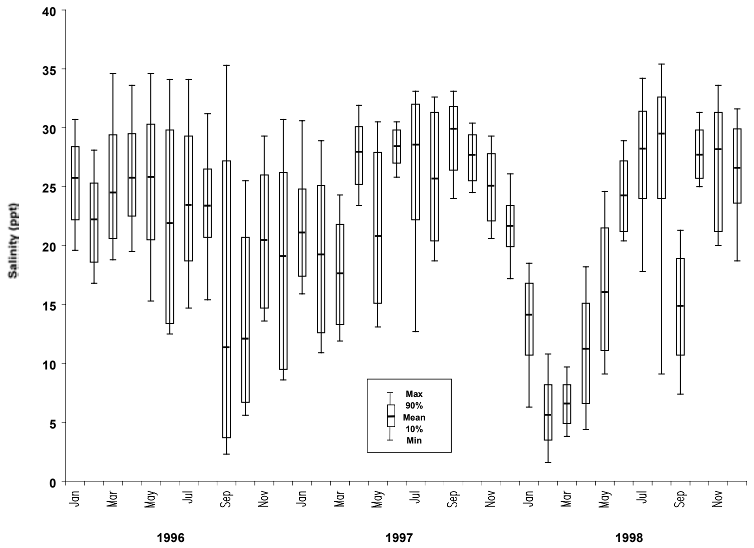


Figure 145. Salinity statistics for Zeke's Island, 1996-1998.

Seventy-three percent of annual dissolved oxygen data (% saturation) were included in analyses (79% in 1997, 66% in 1997, and 73% in 1998). Mean dissolved oxygen was 60-110% saturation throughout the data set. Minimum and maximum DO between 1996-1998 was 4.3% saturation (Jun 1996) and 232.9% saturation (Apr 1997), respectively. Hypoxia was observed in Jun 1998 and persisted for 17.7% of the first 48 hours post-deployment (Figure 146). Supersaturation was observed regularly in 1996 and 1997 and, when present, supersaturation persisted for 15% of the first 48 hours post-deployment on average. Moderate fluctuations (20-60%) in daily and bi-weekly percent saturation were observed throughout most of the data set; however, strong fluctuations (≥ 100%) were observed during episodic events in Jun 1996 and Jul, Sep 1998. Harmonic regression analysis attributed 60% of DO variance to 24 hour cycles, 18% of DO variance to 12.42 hour cycles, and 22% of DO variance to interaction between 12.42 hour and 24 hour cycles.

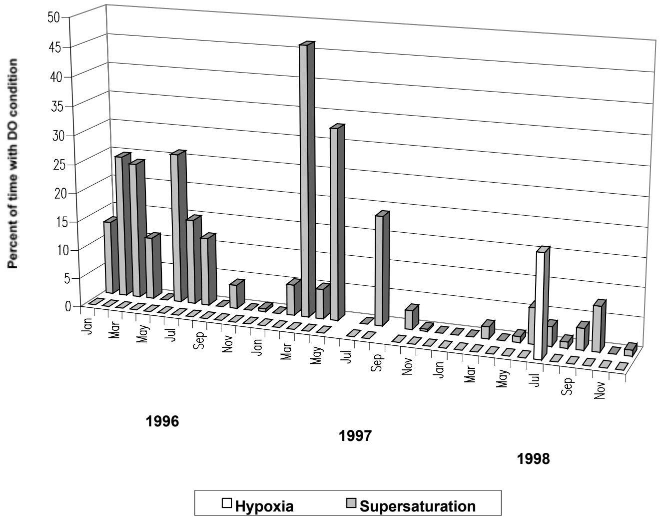
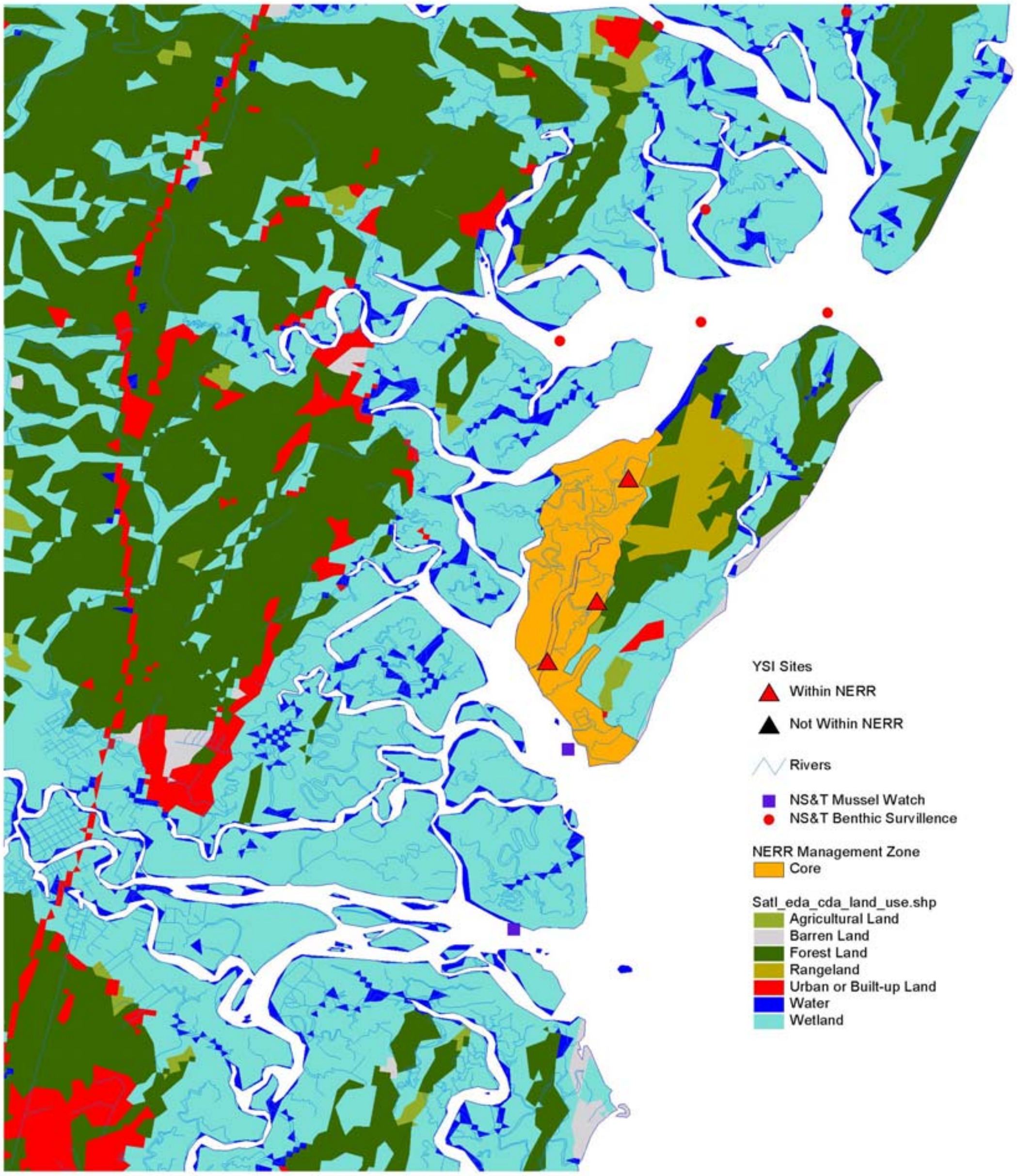


Figure 146. Dissolved oxygen extremes at Zeke's Island, 1996-1998.

Sapelo Island



Sapelo Island, Flume Dock (SAPFD)

Characterization (Latitude = 31°28' 58"N; Longitude = 81°17' 03"W)

Tides at Flume Dock are semidiurnal and range from 2 m to 3 m (average 2.4m). The monitoring site is located on the upper Duplin River on Sapelo Island, 100 m north of Moses Hammock. The water body is approximately 12 km long (mainstream linear dimension). At the sampling site, the depth is approximately 4 m MHW and the width is approximately 20 m MHW. Creek bottom habitats are predominanlty composed of a sand/mud mix with a high silt-clay composite and devoid of bentic macrophytes. The dominant marsh vegetation near the sampling site is *Spartina alterniflora* with pockets of *Juncus* sp. at the higher elevations of the basin. The dominant upland vegetation includes live oak (*Quercus virginiana*), laurel oak (*Quercus laurifolia*) and loblolly pine (*Pinus taeda*). Upland land use near the sampling site includes a primitive campground with an on-site septic system and intermittent upland logging activities. Activities that potentially impact the site include light boat traffic and possibly, logging activities with associated runoff.

Descriptive Statistics

Seventy-six deployments were made at this site between Jan 1996 and Dec 1998, with equal coverage during all seasons (Figure 147). Mean deployment duration was 13.7 days. Seven deployments (3 in 1996, 1 in 1997, and 3 in 1998) were less than 10 days.

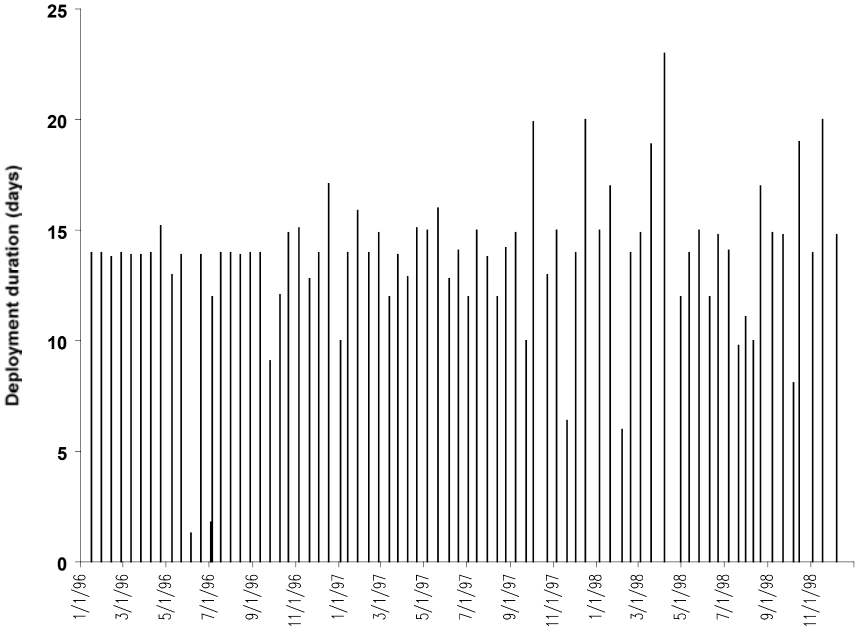


Figure 147. Sapelo Island, Flume Dock deployments (1996-1998).

Forty-two percent of depth data in 1996 were included in analyses; no depth data were collected in 1997 and 1998. Sensors were suspended from a floating platform approximately 6 m from the shoreline and deployed at a mean water depth of 1.8 m. Scatter plots suggest moderate fluctuation (0.5-1.0 m) in depth, except for Dec 1996 (> 1 m) and Jan, Mar 1996 (< 0.5 m). Because this sensor was suspended from a floating rather than a fixed platform, the depth data were not comparable to data from other sites. Harmonic regression analysis attributed 68% of depth variance to 12.42 hour cycles, 25% of depth variance to interaction between 12.42 hour and 24 hour cycles, and 7% of depth variance to 24 hour cycles.

Ninety-six percent of annual water temperature data were included in analyses (90% in 1996, 98% in 1997 and 1998). Water temperature followed a seasonal cycle, with mean water temperatures 12-14°C in winter and 28-30°C in summer (Figure 148). Minimum and maximum water temperatures between 1996-1998 were 6.7°C (Jan 1997) and 32.8°C (Aug 1997), respectively. Scatter plots suggest strong fluctuations (≤ 3°C) in daily water temperature and slightly stronger fluctuations (≤ 5°C) in bi-weekly water temperature throughout the data set. Harmonic regression analysis attributed 53% of temperature variance to interaction between 12.42 hour and 24 hour cycles, 34% of temperature variance to 24 hour cycles, and 13% of temperature variance to 12.42 hour cycles.

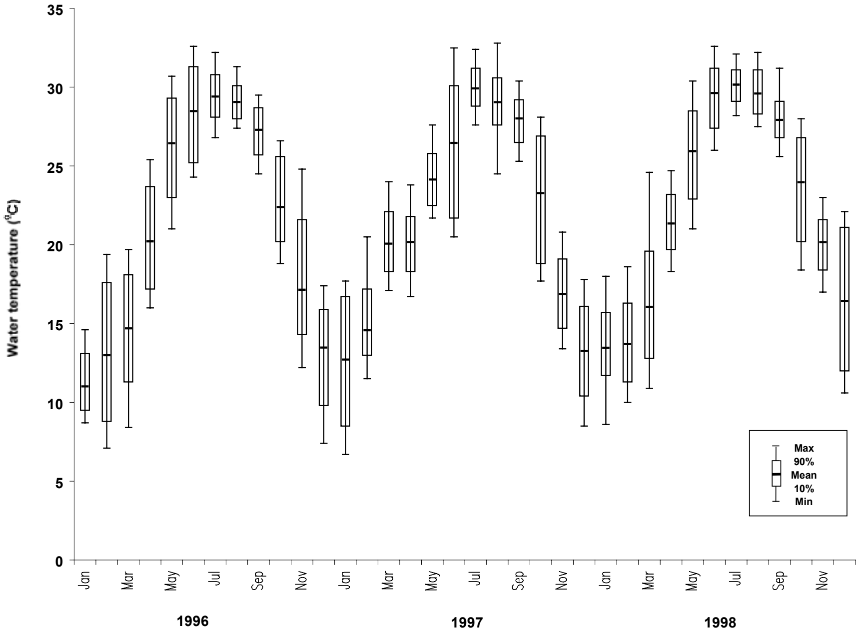


Figure 148. Water temperature statistics at Flume Dock, 1996-1998.

Ninety-five percent of annual salinity data were included in analyses (90% in 1996, 97% in 1997, and 98% in 1998). Mean salinity followed a seasonal cycle, with maximum annual salinity in summer and minimum annual salinity in winter (Figure 149). Mean winter salinity in 1998 (8-11 ppt) was substantially lower than mean winter salinity in 1996 and 1997 (16-23 ppt), which was probably due to increased rainfall and runoff during this El Nino winter. Mean summer salinity in all three summers was similar (25-27; 29 ppt). Minimum and maximum salinity between 1996-1998 was 4.3 ppt (Mar 1998) and 32.2 ppt (Jul 1996), respectively. Scatter plots suggest minor fluctuations (1 ppt) in daily salinity and moderate fluctuations (1-5 ppt) in bi-weekly salinity throughout the data set, with strong (>10 ppt) fluctuations observed for bi-weekly salinity during episodic events in Feb 1996, Aug and Oct 1997, and spring 1998. Harmonic regression analysis attributed 47% of salinity variance to 12.42 hour cycles, 36% of salinity variance to 24 hour cycles, and 17% of salinity variance to interaction between 12.42 hour and 24 hour cycles.

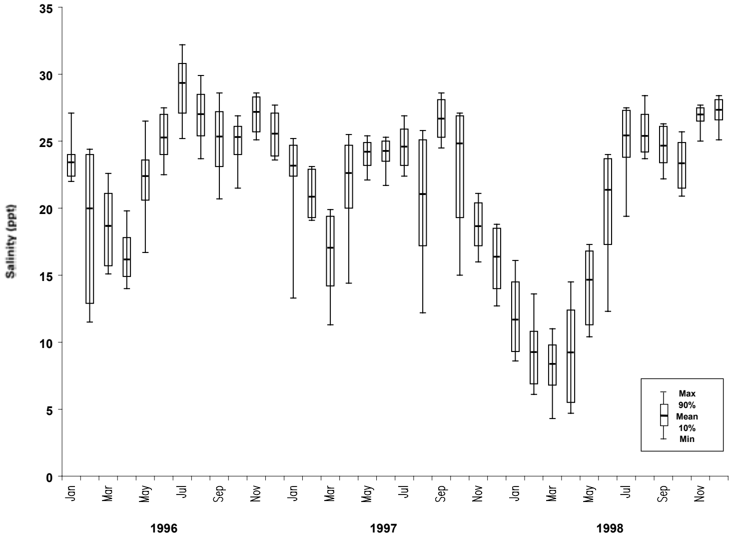


Figure 149. Salinity statistics at Flume Dock, 1996-1998.

Seventy-nine percent of annual dissolved oxygen (% saturation) data were included in analyses (81% in 1996, 1997 and 75% in 1998). Mean DO was 45-108% saturation throughout the data set and followed a seasonal cycle, with greatest DO (70-100% sat) in winter and least DO in summer (45-60% sat). Minimum and maximum DO between 1996-1998 was 1.5% saturation (May 1996) and 204.8% saturation (May 1996), respectively. Hypoxia was observed between May-Aug in 1996-1998 and, when present, hypoxia persisted for < 2% of the first 48 hours post-deployment on average (Figure 150). Supersaturation was observed in three months (May 1996, Jan 1997, and Aug 1998) and, when present, persisted for 17.4% of the first 48 hours post-deployment on average. Scatter plots suggest strong fluctuations (40-100%) in percent saturation throughout the data set, with >200% fluctuations observed in May 1996. Harmonic regression analysis attributed 49% of DO variance to interaction between 12.42 hour and 24 hour cycles, 35% of DO variance to 12.42 hour cycles, and 16% of DO variance to 24 hour cycles.

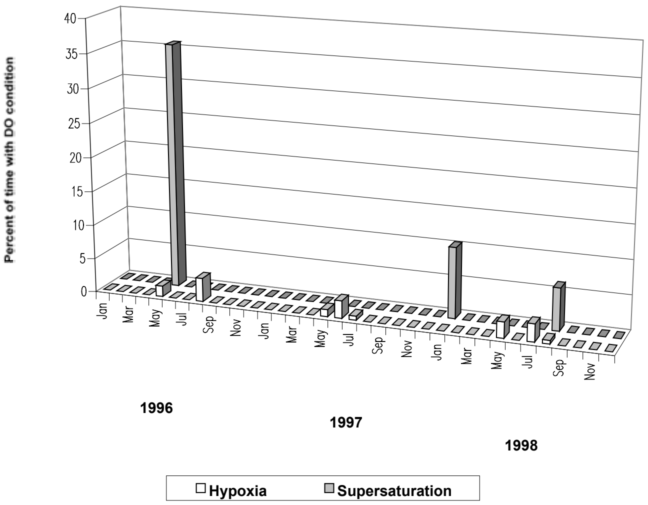


Figure 150. Dissolved oxygen extremes at Flume Dock, 1996-1998.

Sapelo Island, Marsh Landing (SAPML)

Characterization (Latitude = 31°25'04"N; Longitude = 81°17'46"W)
Tides at Marsh Landing are semidiurnal and range from 2 m to 3 m (average 2.4 m). The monitoring site is located on the lower Duplin River on Sapelo Island. The Duplin River is about 12 km long (mainstream linear dimension). At the sampling site, the depth is 7.5 m MHW and the width is approximately 130 m. Creek bottom habitats at the site are predominantly composed of sand with a slight mix of clay/silt. The dominant marsh vegetation near the sampling site is *Spartina alterniflora*. Upland vegetation is typified by maritime forest composed of live oak (*Quercus virginiana*), laurel oak (*Quercus laurifolia*) and loblolly pine (*Pinus taeda)*. Upland land use near the sampling site includes intermittent selective logging of mature (70 years old) loblolly pine and maintenance of a grass airstrip. Activities that potentially impact the site include fairly heavy boat traffic and possible nutrient/sediment impacts from upland runoff associated with logging activities. The monitoring site is located on a floating dock adjacent to the primary ferry dock for the island (100-120 residents). The ferry makes 2-3 round trips to the mainland and back each day.

Descriptive Statistics
Seventy-five deployments were made at this site between Jan 1996 and Dec 1998, with equal coverage during all seasons (Figure 151). Mean deployment duration was 13.7 days. Six deployments (2 in 1996, 1 in 1997, and 3 in 1998) were less than 10 days.

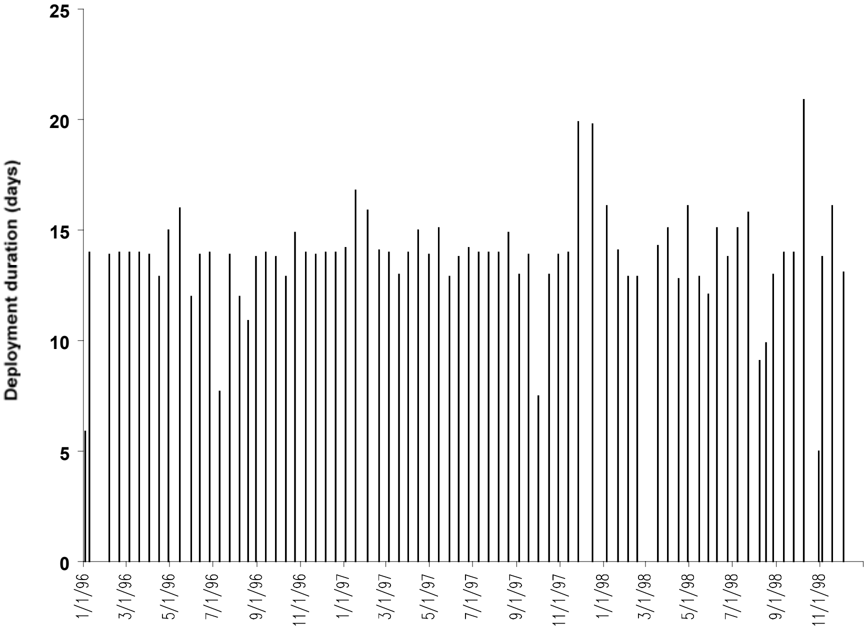


Figure 151. Sapelo Island, Marsh Landing deployments (1996-1998).

Forty-four percent of depth data from 1996 were included in analyses; no depth data were collected in 1997 and 1998. The meter probe was suspended from a floating dock at a mean deployment depth of 1.7 m. Scatter plots suggest minor fluctuation (≤ 0.25 m) in depth throughout 1996, except for May and Dec when depth varied 0.5-0.75 m. Because this sensor was suspended from a floating rather than a fixed platform, the depth data were not comparable to data from other sites. Harmonic regression analysis attributed 81% of depth variance to 12.42 hour cycles, 10% of depth variance to 24 hour cycles, and 9% of depth variance to interaction between 12.42 hour and 24 hour cycles.

Ninety-six percent of annual water temperature data were included in analyses (94% in 1996, 98% in 1997, and 95% in 1998). Water temperature followed a seasonal cycle, with mean water temperatures 11-13°C in winter and 27-29°C in summer (Figure 152). Minimum and maximum water temperatures between 1996-1998 were 7.3°C (Jan 1996) and 31.7°C (Jul 1998), respectively. Scatter plots suggest moderate fluctuations (≤ 2°C) in daily water temperature and strong fluctuations (≤ 7°C) in bi-weekly water temperature throughout the data set. Harmonic regression analysis attributed 37% of temperature variance to 12.42 hour cycles, 35% of temperature variance to 24 hour cycles, and 28% of temperature variance to interaction between 12.42 hour and 24 hour cycles.

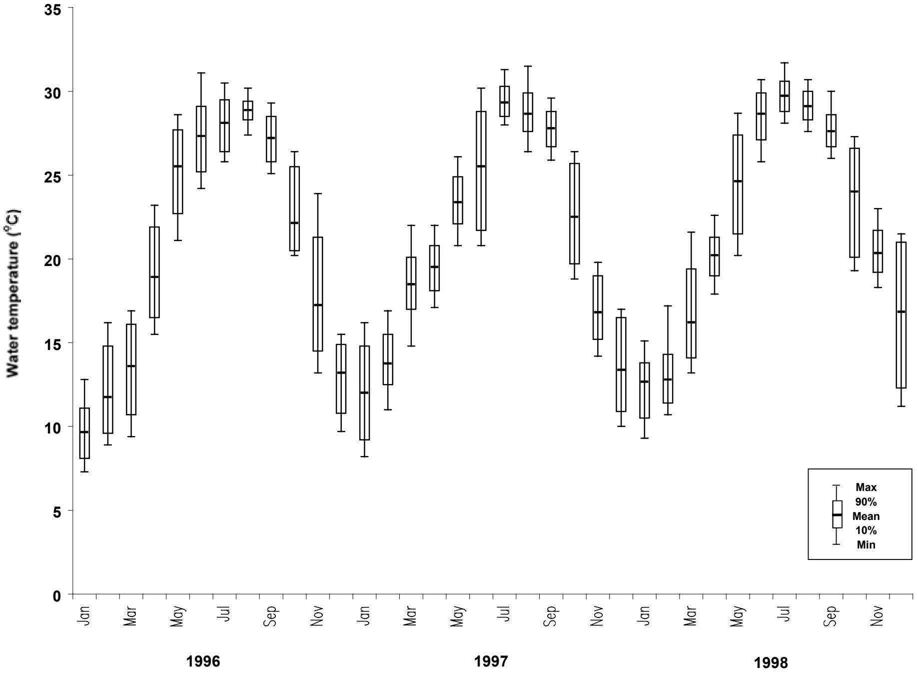


Figure 152. Water temperature statistics at Marsh Landing, 1996-1998.

Ninety-six percent of annual salinity data were included in analyses (94% in 1996, 98% in 1997, and 95% in 1998). Mean salinity followed a seasonal cycle, with lowest salinity in winter and greatest salinity in summer (Figure 153). Mean winter salinity in 1998 (10-15 ppt) was much lower than mean winter salinity in 1996-1997 (20-25 ppt) and was probably related to increased precipitation and runoff during the 1998 El Nino winter. Mean salinity in summer was similar in all three years (25-30 ppt). Minimum and maximum salinity between 1996-1998 was 1.8 ppt (Feb 1998) and 37.5 ppt (May 1996), respectively. Scatter plots suggest strong fluctuations (≤ 5 ppt) in daily salinity and even stronger fluctuations (≤ 10 ppt) in bi-weekly salinity in summer and fall. Strongest fluctuations (> 10 ppt) in bi-weekly salinity were observed in winter and spring. Harmonic regression analysis attributed 74% of salinity variance to 12.42 hour cycles, 14% of salinity variance to interaction between 12.42 hour and 24 hour cycles, and 12% of salinity variance to 24 hour cycles.

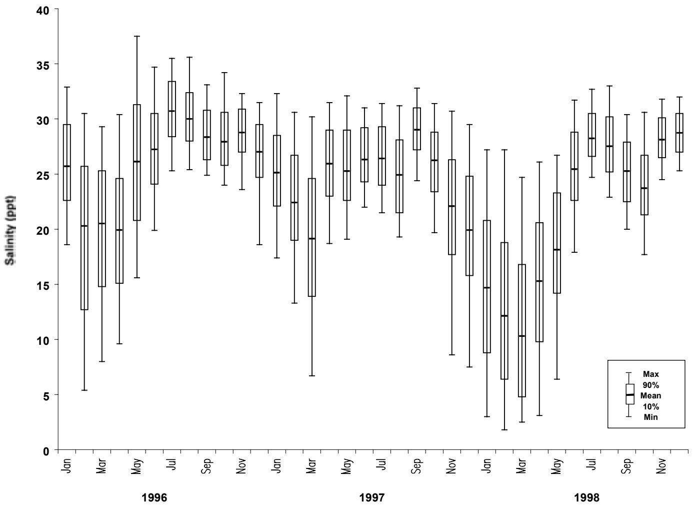


Figure 153. Salinity statistics at Marsh Landing, 1996-1998.

Eighty percent of annual dissolved oxygen (% saturation) data were included in analyses (76% in 1996, 94% in 1997, and 69% in 1998). Mean DO ranged from 64-109% saturation throughout the data set and followed a seasonal cycle. Mean DO was lowest in summer 1996-1997 (64-78% sat); however, mean DO was atypically elevated in Jun-Aug 1998 (87-98% sat). Mean DO in winter 1997-1998 was 72-94% saturation, substantially less than winter 1996 (103-109% sat). Minimum and maximum DO between 1996-1998 was 3.3% saturation (Sep 1998) and 179.5% saturation (Jul 1998), respectively. Persistent hypoxia was never observed (Figure 154). Supersaturation was observed in five months (May-Jun, Nov 1996; Nov 1997, and May 1998) and, when present, supersaturation persisted for 8.4% of the first 48 hours post-deployment on average. Scatter plots suggest moderate fluctuations (20-60%) in percent saturation throughout the data set. Harmonic regression analysis attributed 52% of DO variance to 12.42 hour cycles, 19% of DO variance to 24 hour cycles, and 29% of DO variance to interaction between 12.42 hour and 24 hour cycles.

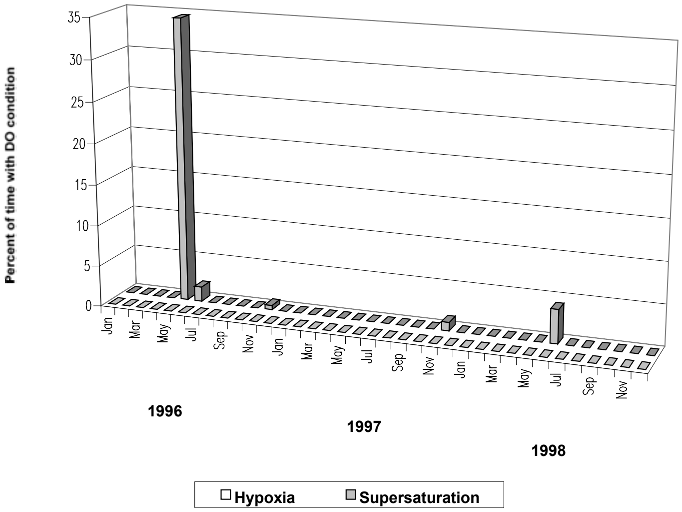
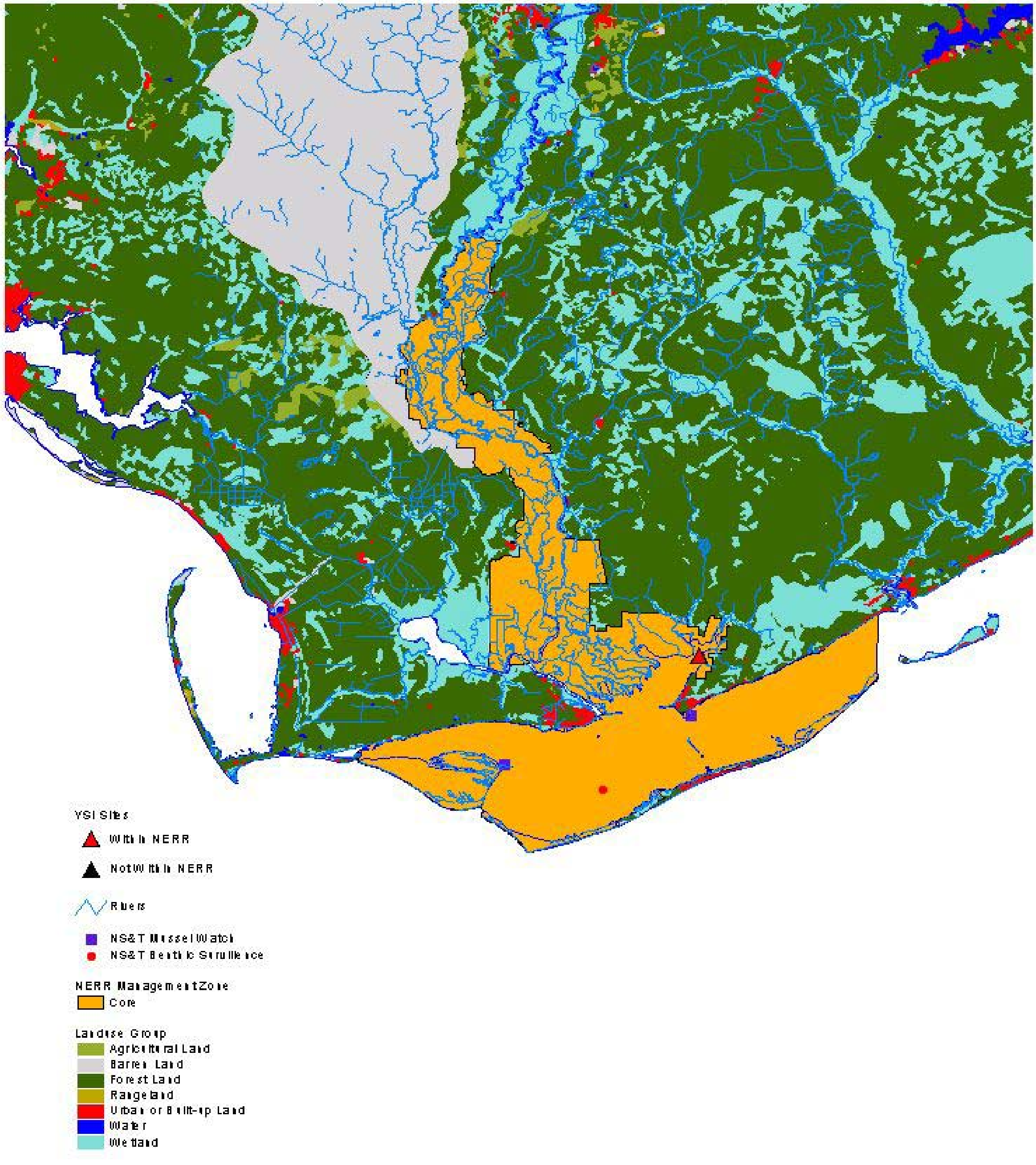


Figure 154. Dissolved oxygen extremes at Flume Dock, 1996-1998.

Apalachicola Bay



Apalachicola Bay, East Bay Bottom (APAEB)

Characterization (Latitude = 29°47'09"N; Longitude = 84°52'31"W)
East Bay is 8.2 km long, has an average depth of approximately 1 m MHW, and an average width of 1.8 km. At the sampling site, the depth is 2.2 m MHW and the width of the bay is 1 km. The tides in the system are mixed; thus, the number of tides can range from one to five tides during a 24 hour period and are not evenly distributed throughout the day. This site is in upper East Bay. The bottom habitat at this bay site is primarily soft silt and clay, with no bottom vegetation. The dominant marsh vegetation near the sampling site is *Juncus roemerianus* and *Cladium jamaicense*. The dominant upland vegetation is primarily pineland forests which includes slash pine, saw palmetto and sand pine. Upland land use near the sampling site includes conservation and silviculture, with some single-family residential homes in the lower East Bay area. The sampling site is influenced by local runoff from Tates Hell Swamp, the East Bay marshes, and distributary flow, some of which comes from the Apalachicola River via the East River. Tates Hell Swamp was ditched, diked, and altered back in the late 1960's and early 1970's by timber companies. These changes shortened the drainage period and allowed increased runoff with a concomitant decrease in pH and increase in color, which had a drastic affect on the biological communities in East Bay. Restoration of Tates Hell Swamp began in 1995 to reduce non-point source runoff.

Descriptive Statistics
Fifty-seven deployments were made at this site between January 1996 and November 1998, with equal coverage during all seasons (Figure 155). Mean deployment duration was 18 days. No deployments were less than 10 days.

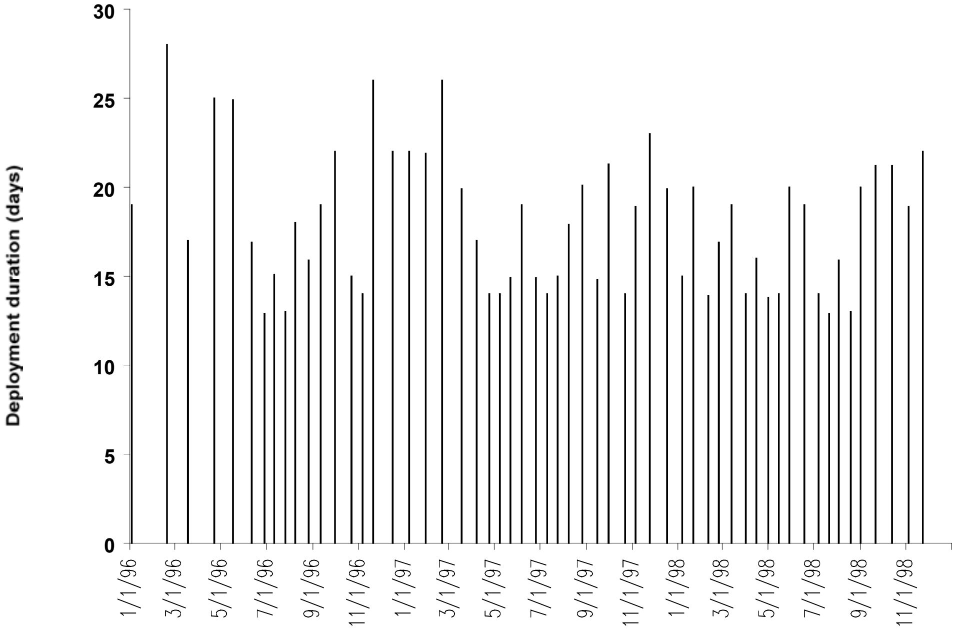


Figure 155. Apalachicola, East Bay bottom deployments (1996-1998).

Ninety-two percent of annual depth data were included in analyses (83% in 1996, 99.7% in 1997, and 94% in 1998). Sensors were deployed at a mean depth of 1.8 m below the water surface. Moderate fluctuations (0.5-1 m) were evident for daily and bi-weekly cycles from scatter plots. Harmonic regression analysis attributed 54% of depth variance to interaction between 12.42 hour and 24 hour cycles, 24% of depth variance to 12.42 hour cycles, and 22% of depth variance to 24 hour cycles.

Ninety-six percent of annual temperature data were included in analyses (87% in 1996, 99.7% in 1997, and 99.5% in 1998). Water temperature followed a seasonal cycle, with mean water temperature 14-16°C in the winter and 28-30°C in the summer (Figure 156). Minimum and maximum water temperatures were 5.7°C (Jan, Mar 1996) and 33.2°C (Aug 1998), respectively. Scatter plots suggest strong fluctuation (2°C) in daily water temperature and even stronger fluctuation (5-10°C) in bi-weekly water temperature, with greatest variability in fall and winter. Harmonic regression analysis attributed 61% of temperature variance to 24 hour cycles, 36% of temperature variance to interaction between 12.42 hour and 24 hour cycles, and 3% of temperature variance to 12.42 hour cycles.

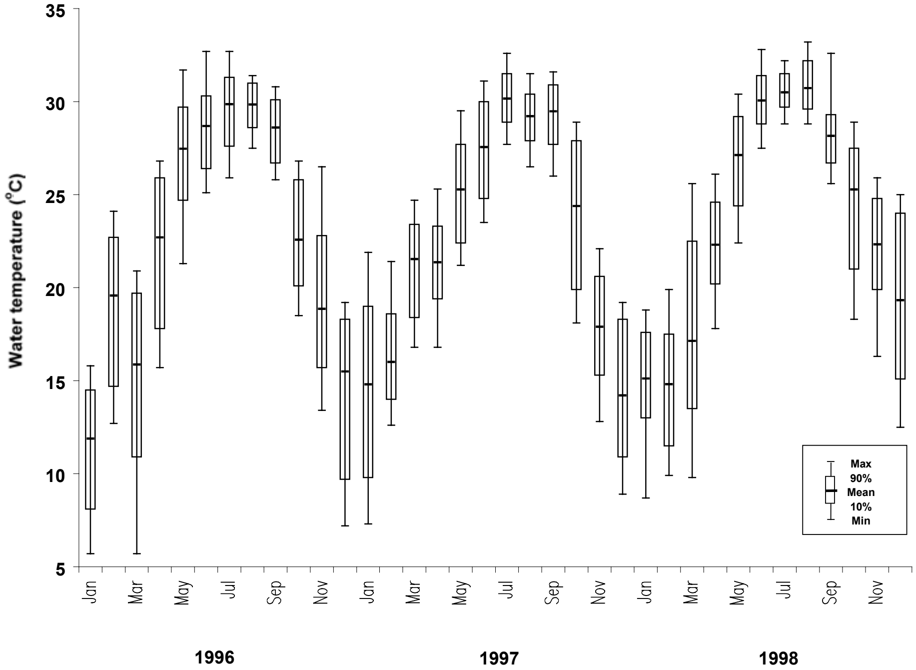


Figure 156. Water temperature statistics for East Bay bottom, 1996-1998.

Ninety-six percent of annual salinity data were included in analyses (87% in 1996, 99.7% in 1997, and 99.5% in 1998). Mean salinity followed a seasonal cycle; however large variances in salinity values were associated with mean readings (Figure 157). Mean salinity was greatest in Sep-Oct (15-18 ppt) and least in winter and spring (<2 ppt) in 1996 and 1998. Mean salinity in fall 1998 remained elevated and did not decrease below 14 ppt as was observed in fall 1996 and 1998. Minimum and maximum salinity observed between 1996-1998 was 0 ppt and 32.2 ppt, respectively. Scatter plots suggest daily and bi-weekly salinity fluctuations (5-15 ppt) were comparable to annual variation in mean salinity readings (0-18 ppt) and occurred throughout the year. Harmonic regression analysis attributed 60% of salinity variance to interaction between 12.42 hour and 24 hour cycles, 31% of salinity variance to 24 hour cycles, and 9% of salinity variance to 12.42 hour cycles.

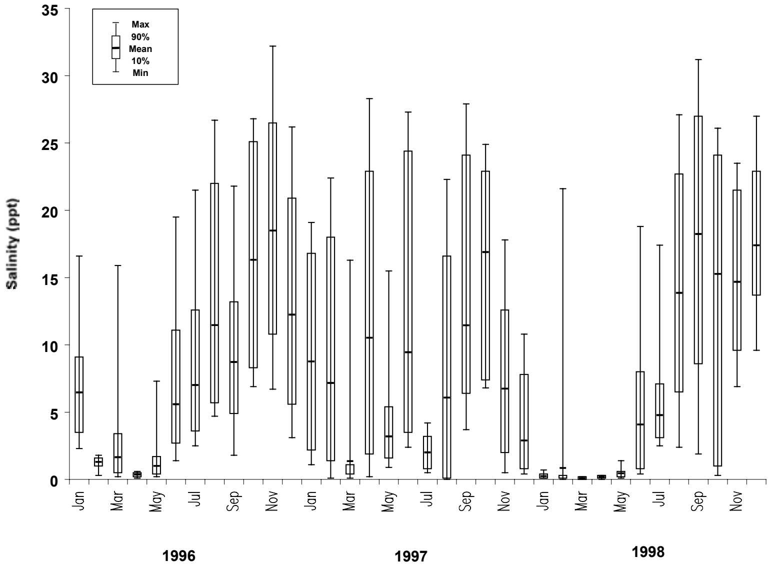


Figure 157. Salinity statistics for East Bay bottom, 1996-1998.

Fifty-one percent of annual dissolved oxygen (% saturation) data were included in analyses (37% in 1996, 47% in 1997, and 71% in 1998). Mean DO was lowest (50-74% saturation) in September and greatest (83-127% saturation) in Jan-Mar. On one occasion (Mar 1996), DO exceeded 180% saturation and on several occasions DO was less than 10% saturation. Minimum and maximum DO between 1996-1998 was 2% (Sep 1997) and 185.4% (Mar 1996), respectively. Hypoxia was only observed in Aug 1997 and persisted for 32% of the first 48 hours post-deployment (Figure 158). Supersaturation was frequently observed in all seasons and, when present, persisted 32% of the first 48 hours post-deployment on average. Scatter plots suggest minor fluctuation (20%) in daily DO readings and moderate fluctuation (≥50%) in bi-weekly DO in all seasons. Harmonic regression analysis attributed 41% of DO variance to 24 hour cycles, 15% of DO variance to 12.42 hour cycles, and 44% of DO variance to interaction between 12.42 hour and 24 hour cycles.

Photosynthesis/Respiration

Over two thirds (66%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor). During winter when river flow was high, the data were less likely to fit the assumptions. In addition, instrument drift was a problem at this site. There was a significant difference in total respiration rates between the first 2 days of the deployment and the total length of the deployment. Because of this, only the first 2 days of each deployment (8% of the observations) were used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 30). Respiration rates exceeded production rates at East Bay bottom; thus, the net ecosystem metabolism and P/R ratio indicated that this is a heterotrophic site (Figure 159). Temperature was significantly ($p<0.05$) correlated with gross production and total respiration, but not net ecosystem metabolism. Gross production and respiration increased as temperature increased. Metabolic rates generally followed a seasonal pattern with the highest rates during summer months and the lowest rates during winter. Salinity was significantly ($p<0.05$) correlated with gross production, total respiration and net ecosystem metabolism. Metabolic rates were higher, but net ecosystem metabolism was more autotrophic at higher salinity.

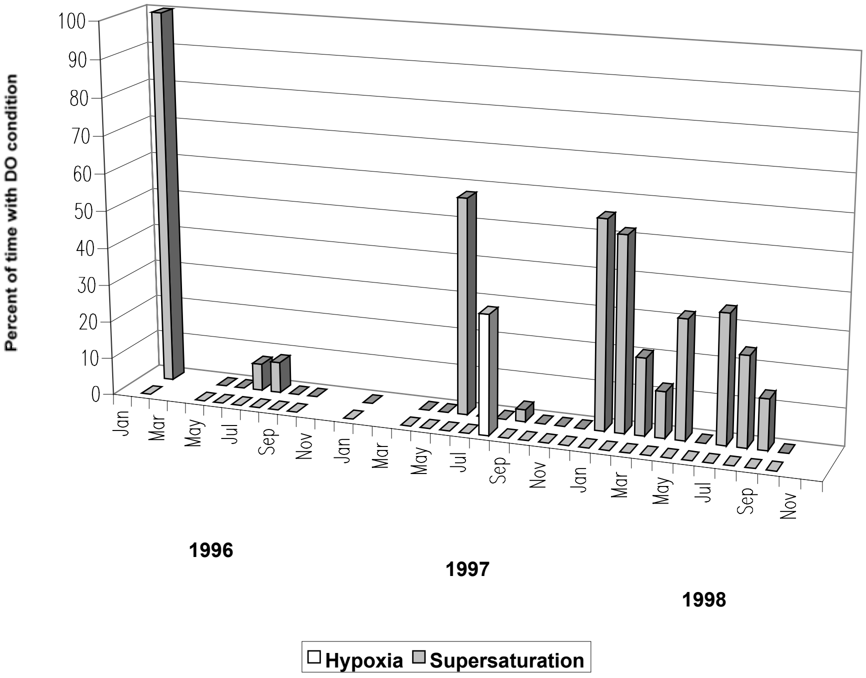


Figure 158. Dissolved oxygen extremes for East Bay bottom, 1996-1998.

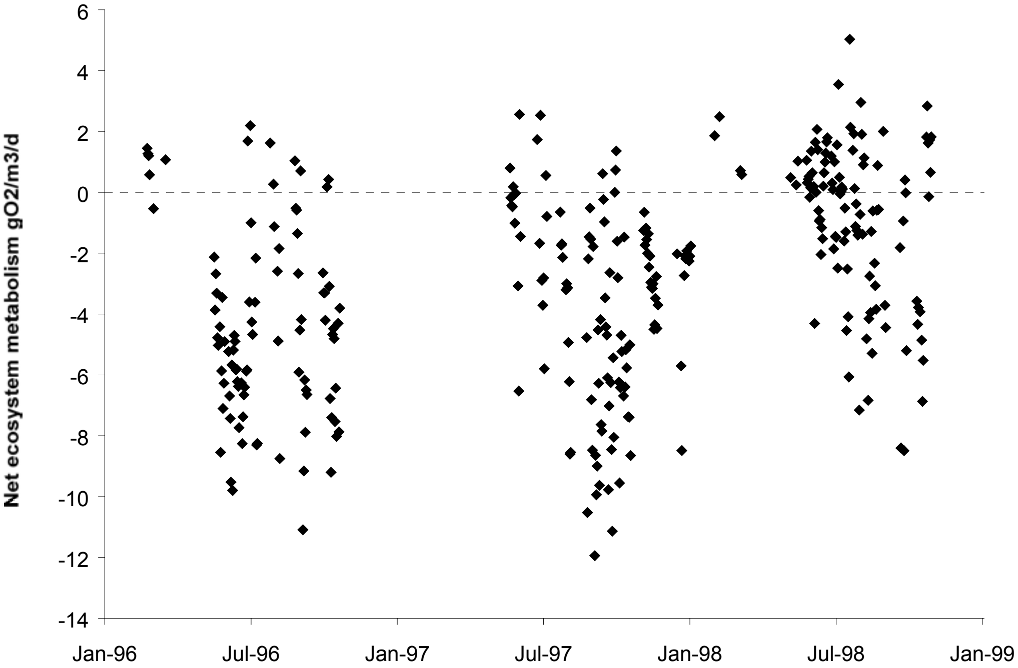


Figure 159. Net metabolism at Apalachicola Bay bottom, 1996-1998.

Table 30. Summary of metabolism data and statistics at Apalachicola Bay bottom, 1996-1998.

Bottom	mean	s.e.
Water depth (m)	2.0	
Net production gO_2/m3/d	0.50	0.08
Gross production gO_2/m3/d	2.92	0.12
Total respiration gO_2/m3/d	4.48	0.17
Net ecosystem metabolism g O_2/m3/d	-1.56	0.12
Net ecosystem metabolism g C/m2/y	-344	
P/R	0.65	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	$p<0.001$	
Net ecosystem metabolism	ns	
Percent useable observations	66%,8%	
Paired t-test on gross production and total respiration	ns	
Correlation coefficient	Temperature	Salinity
Gross production	0.27	0.20
Total respiration	0.23	0.29
Net ecosystem metabolism	ns	0.22

<u>Apalachicola Bay, East Bay Surface (APAEB)</u>

Characterization -- See characterization for East Bay Bottom

Descriptive Statistics

Fifty-eight deployments were made at this site between January 1996 and November 1998, with equal coverage during all seasons (Figure 160). Mean deployment duration was 17.9 days. Only one deployment (Mar 1998) was less than 10 days.

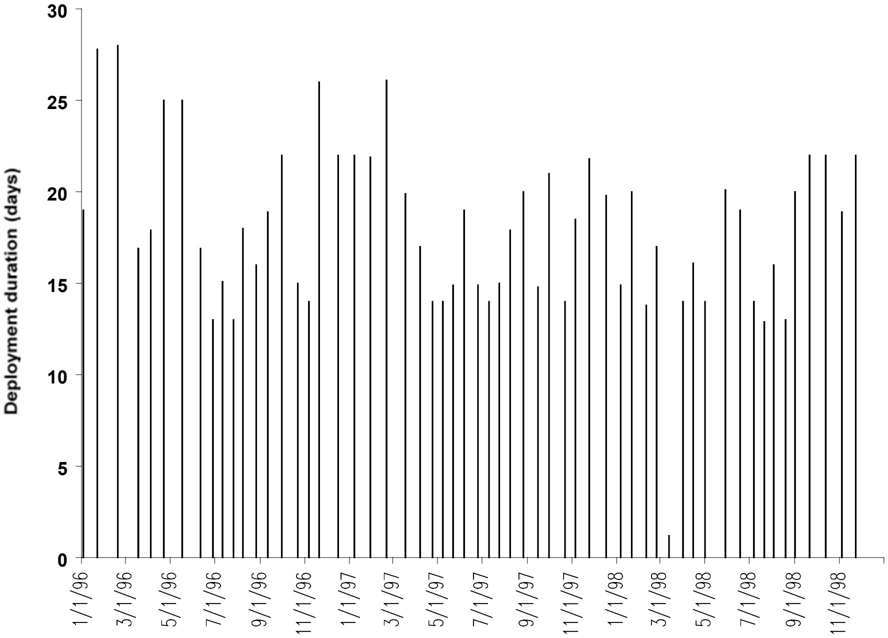


Figure 160. Apalachicola, East Bay surface deployments, 1996-1998.

Ninety-six percent of annual depth data were included in analyses (96% in 1996, 97% in 1997, and 79% in 1998). Sensors were deployed at a mean depth of 0.6 m below the water surface. Strong fluctuations (0.75-1.25 m) were evident in 1996 and 1997. In 1998, fluctuations in depth were closer to 0.5 m, with notable exceptions in Jan-Mar and Sep when fluctuations ranged from 1.5-3.7 m. Harmonic regression analysis attributed 25% of depth variance to 12.42 hour cycles, 53% of variance to interaction between 12.42 hour and 24 hour cycles, and 22% of variance to 24 hour cycles.

Ninety percent of annual water temperature data were included in analyses (94% in 1996, 95% in 1997, and 80% in 1998). Water temperature followed an expected seasonal cycle, with mean water temperatures 13-15°C in winter and 28-30°C in summer (Figure 161). Minimum and maximum water temperatures between 1996-1998 were 2.9°C (Jan 1996) and 33.6°C (Aug 1998), respectively. Scatter plots suggest strong fluctuation (3°C) in daily water temperature and even stronger fluctuation (5-10°C) in bi-weekly water temperatures in all seasons, with greatest variability in fall and winter. Harmonic regression analysis attributed 55% of temperature variance to 24 hour cycles, 40% of temperature variance to interaction between 12.42 hour and 24 hour cycles, and 5% of temperature variance to 12.42 hour cycles.

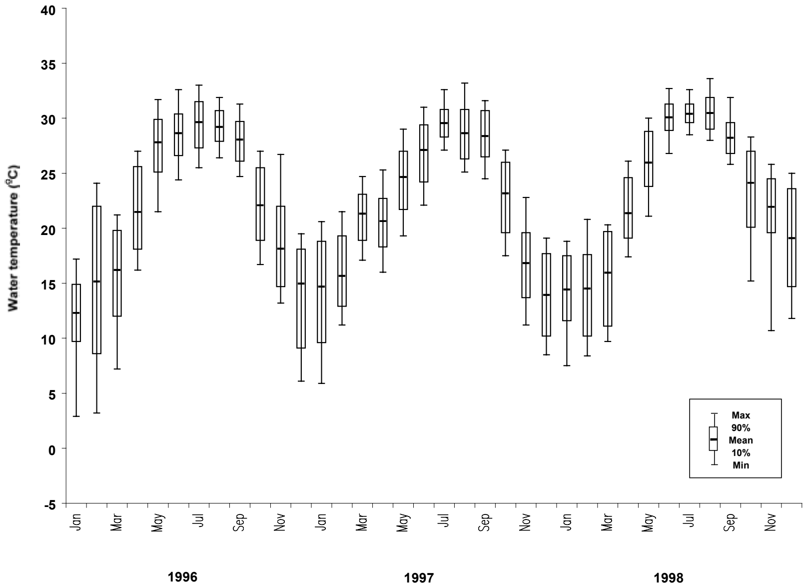


Figure 161. Water temperature statistics for East Bay surface, 1996-1998.

Eighty-nine percent of annual salinity data were included in analyses (94% in 1996, 95% in 1997, and 78% in 1998). Mean salinity followed a seasonal cycle; however, large variances were associated with mean salinity (Figure 162). Mean salinity was greatest in Oct-Nov (14-15 ppt) and least in winter/spring (<1 ppt). In fall 1998, mean salinity remained elevated between 11-15 ppt rather than decrease to 5-8 ppt as observed in fall 1996-97. Minimum and maximum salinity was 0 ppt and 30.6 ppt, respectively. Strong fluctuations in daily and bi-weekly salinity were observed year round and were comparable to, and occasionally exceeded, annual variation in mean salinity (0-15 ppt). Harmonic regression analyses attributed 69% of salinity variance to interaction between 12.42 hour and 24 hour cycles, 22% of variance to 24 hour cycles, and 9% of variance to 12.42 hour cycles.

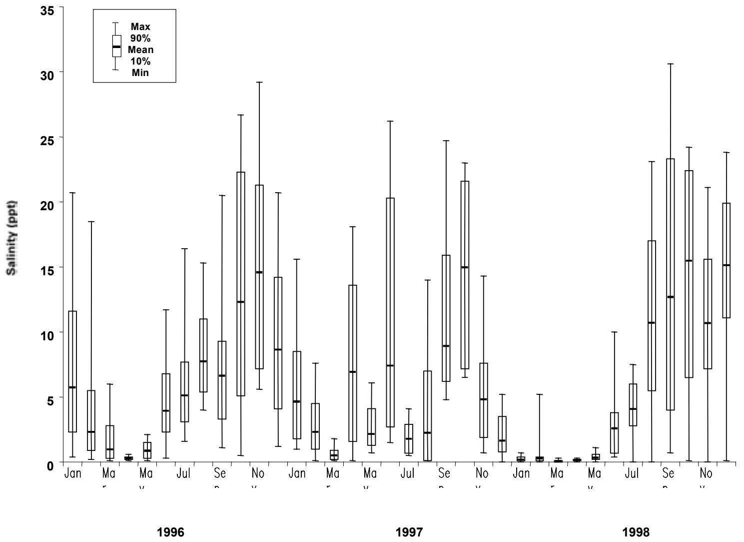


Figure 162. Salinity statistics for East Bay surface, 1996-1998.

Sixty-eight percent of annual dissolved oxygen (% saturation) data were included in analyses (68% in 1996, 64% in 1997, and 72% in 1998). Dissolved oxygen did not follow a well-defined seasonal pattern and mean DO readings were typically between 75-100% saturation. Hypoxia was infrequently observed (4 events) and lasted, when present, about 5% of the first 48 hours post-deployment on average (with one notable exception in Aug 1997, Figure 163). Supersaturation was frequently observed and, when present, lasted 23% of the first 48 hours post-deployment on average. Scatter plots indicate that DO often fluctuated dramatically (≥20% sat) on daily cycles and even more dramatically (40-150% sat) on bi-weekly cycles. Strongest fluctuations in daily and bi-weekly DO occurred in spring/summer 1996 and 1997. Harmonic regression analysis attributed 53% of DO variance to interaction between 12.42 hour and 24 hour cycles, 37% of DO variance to 24 hour cycles, and 10% of DO variance to 12.42 hour cycles.

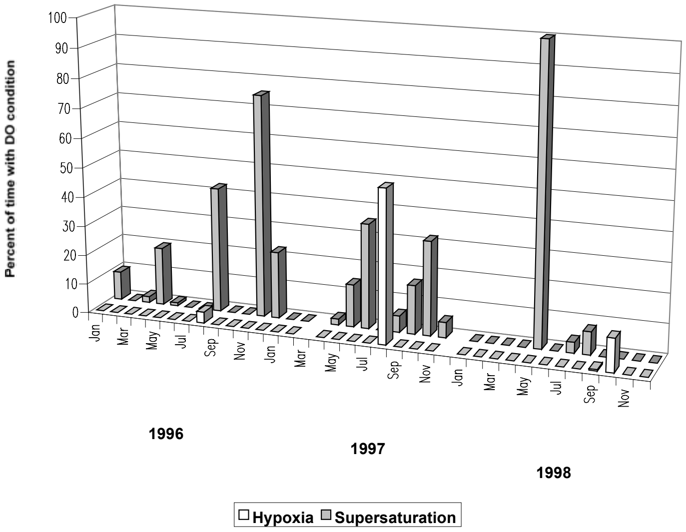


Figure 163. Dissolved oxygen extremes, East Bay surface, 1996-1998.

Photosynthesis/Respiration
Nearly three quarters (73%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and were used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 31). Instrument drift during the duration of the deployments was not a significant problem at this site. Respiration rates exceeded production rates at East Bay surface; thus, the net ecosystem metabolism and P/R ratio indicated that this is a heterotrophic site (Figure 164). Temperature was significantly ($p<0.05$) correlated with gross production, total respiration and net ecosystem metabolism. Gross production and respiration increased as temperature increased, while net ecosystem metabolism became more heterotrophic as temperatures increased. Salinity was significantly ($p<0.05$) correlated with gross production, but not respiration or net ecosystem metabolism. Gross production was higher at higher salinity. Metabolic rates were generally the highest rates during summer months and the lowest during winter when temperature and salinity were low and river flow was high.

Table 31. Summary of metabolism data and statistics at Apalachicola Bay surface, 1996-1998.

Surface	mean	s.e.
Water depth (m)	2.00	
Net production $gO_2/m3/d$	0.39	0.06
Gross production $gO_2/m3/d$	2.22	0.08
Total respiration $gO_2/m3/d$	3.50	0.11
Net ecosystem metabolism g $O_2/m3/d$	-1.28	0.09
Net ecosystem metabolism g C/m2/y	-112	
P/R	0.64	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	77	
Paired t-test on gross production and total respiration	$p<0.001$	
Correlation coefficient	Temperature	Salinity
Gross production	0.39	0.19
Total respiration	0.32	0.11
Net ecosystem metabolism	-0.12	ns

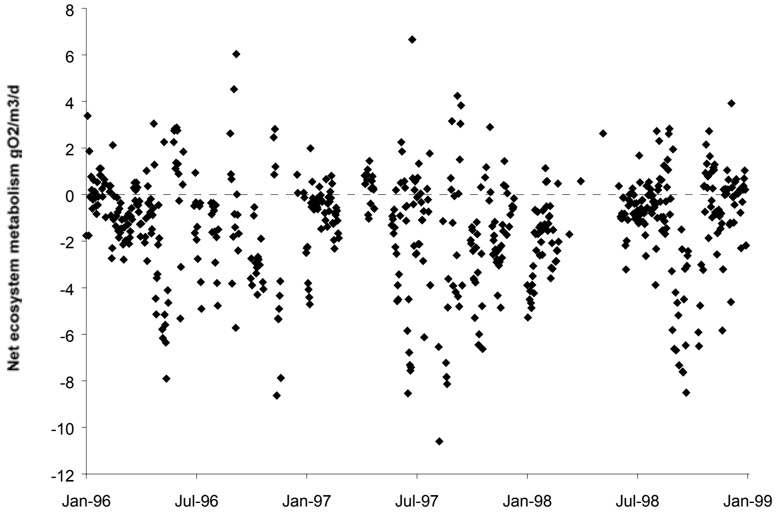
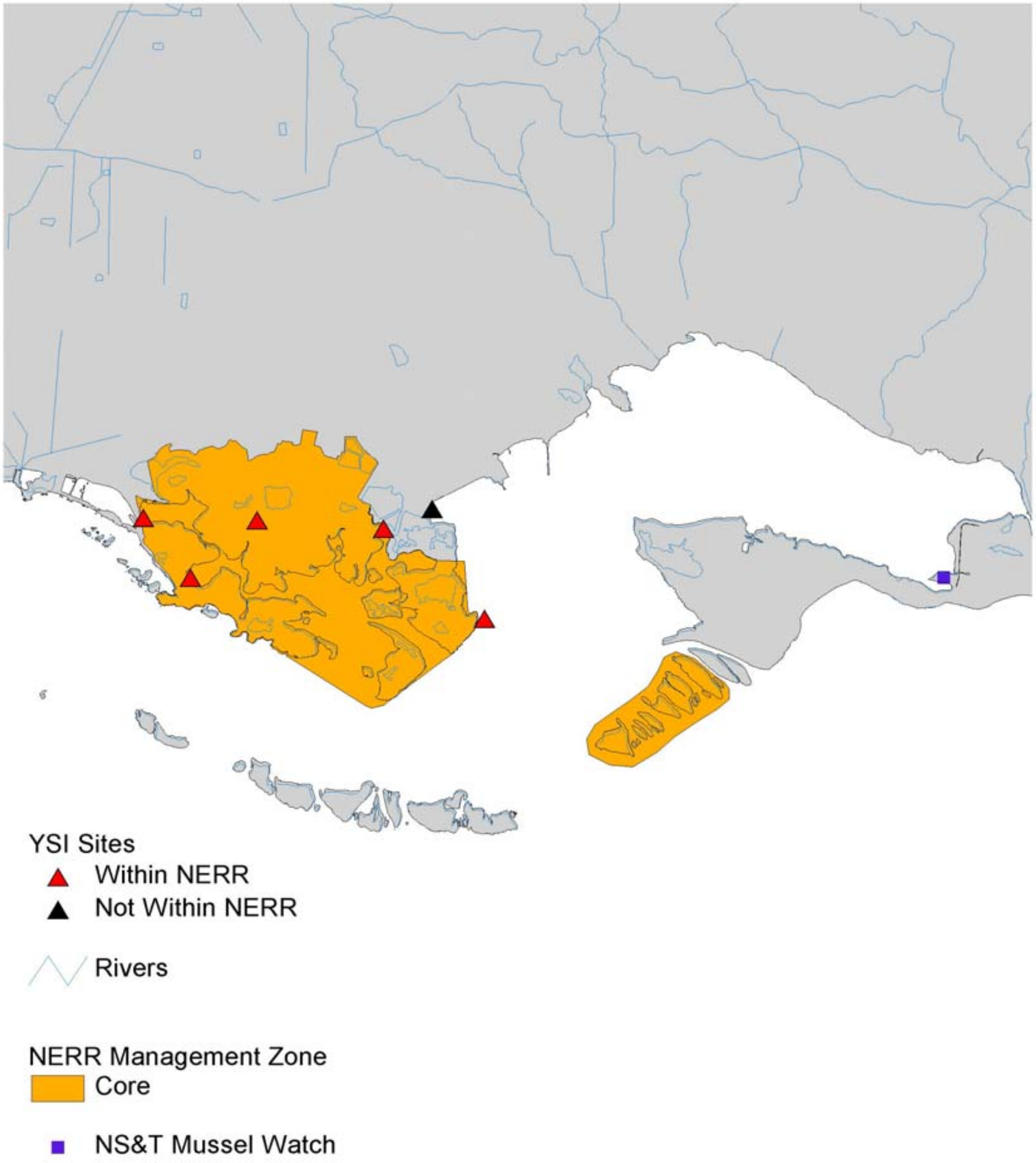


Figure 164. Net metabolism at Aplachicola Bay surface, 1996-1998.

Jobos Bay


YSI Sites
▲ Within NERR
▲ Not Within NERR
Rivers
NERR Management Zone
Core
■ NS&T Mussel Watch

Jobos Bay, Station 9 (JOB09)

Characterization (Latitude = 17° 56' 37 " N; Longitude = 66° 14' 19" W)
Tides in Jobos Bay are diurnal and range from 0.30 m to 0.36 m. The lagoon is 0.26 km long (mainstream linear dimension) with an average depth of 1 m MHW and an average width of 115 m. At the sampling site, the depth is 1 m MHW and the width is 60 m. This site is located on a mangrove channel, where no main streams are found. Groundwater infiltrates into the sea and is the main source of fresh water. Creek bottom habitats are predominantly silt-clay, with no bottom vegetation. The dominant marsh vegetation near the sampling site is red mangrove. Upland land use near the sampling site includes a power plant and, further upland, a landfill and poultry processing plant. Activities that potentially impact the site include runoff from old deposits of dredge material. This sampling station is subject to runoff and potential spills contamination from the Electric Power Thermoelectric Plant. Station nine was historically used as a disposal site for the residues from a now defunct sugar mill operation, which might have been a high source of organic matter into the sediments.

Descriptive Statistics
Thirty-four deployments were made at this site between Jan-Dec 1996, Mar, Apr, Jun, and Nov 1997, and Apr-Jun, Aug, and Oct-Nov 1998 (Figure 165). Mean deployment duration was 14.5 days. Seven deployments (Aug 1996; Jun 1997; May, Jun, Aug, and Oct 1998) were less than 10 days.

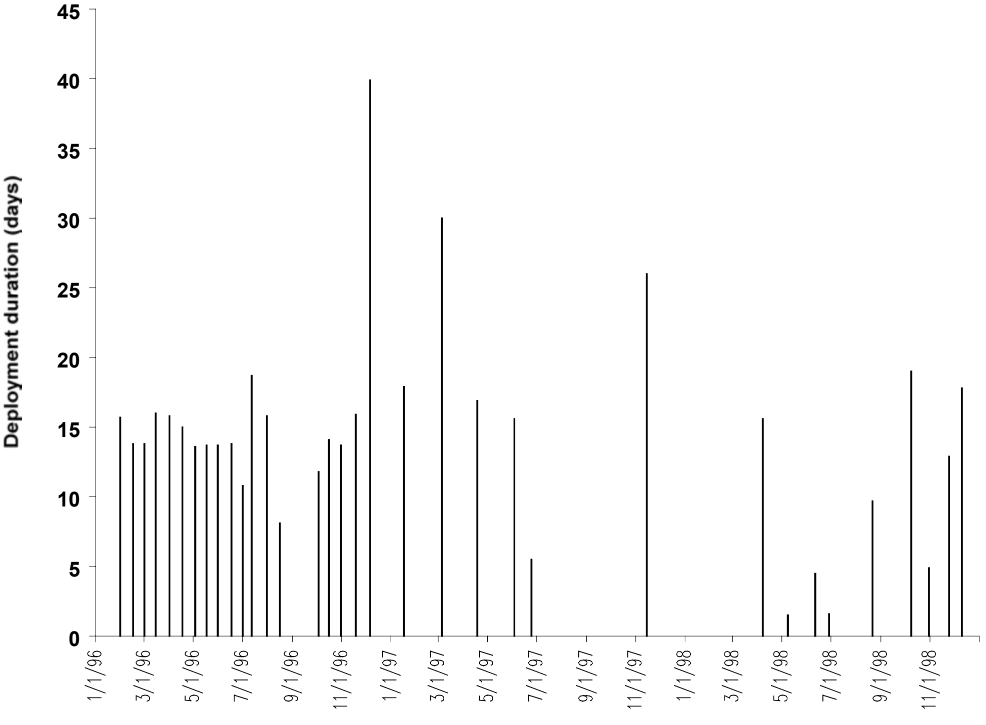


Figure 165. Jobos Bay, Station 9 deployments (1996-1998).

Forty-eight percent of annual depth data were included in analyses (85% in 1996, 34% in 1997, and 24% in 1998). Sensors were deployed at a mean depth of 0.5 m below the water surface and 0.3 m above the bottom sediment. Minor fluctuations (0.2-0.4 m) were observed from scatter plots throughout the data set, except for Jan 1997 when fluctuations approached 0.8 m. Harmonic regression analysis attributed 54% of depth variance to interaction between 12.42 hour and 24 hour cycles, 44% of depth variance to 24 hour cycles, and 2% of depth variance to 12.42 hour cycles.

Forty-eight percent of annual water temperature data were included in analyses (85% in 1996, 34% in 1997, and 24% in 1998). Water temperature followed a seasonal cycle; however, magnitude of mean annual water temperature fluctuation was < 5°C (Figure 166). Mean water temperature was 30-31°C in summer and 26-27°C in winter. Minimum and maximum water temperatures between 1996 and 1998 were 20.9°C (Oct 1998) and 35.4°C (Jun 1998), respectively. Scatter plots suggest daily and bi-weekly fluctuations in water temperatures equivalent to annual variation in mean water temperature. Harmonic regression analysis attributed 84% of temperature variance to 24 hour cycles, 15% of temperature variance interaction between 12.42 hour and 24 hour cycles, and 1% of temperature variance to 12.42 hour cycles.

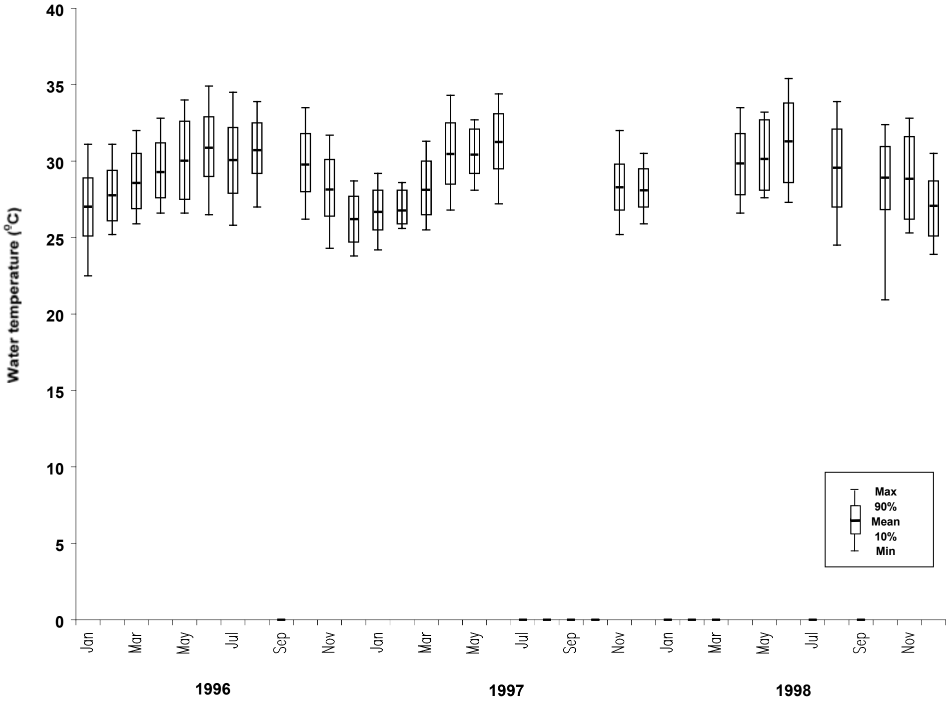


Figure 166. Water temperature statistics for Jobos Bay, Station 9, 1996-1998.

Forty percent of annual salinity records were included in analyses (80% in 1996, 24% in 1997, and 15% in 1998). Salinity followed a weak seasonal cycle, with greatest mean salinity (38-40 ppt) in spring and 35-36 ppt the rest of the year (Figure 167). Mean salinity was greater in 1998 (38-43 ppt, with 52 ppt recorded in May) than in 1996-1997. Minimum and maximum salinity between 1996-1998 was 22.7 ppt (Dec 1996) and 53.8 ppt (May 1998), respectively. Scatter plots suggest minor fluctuations in daily salinity and bi-weekly salinity equivalent to annual variation in mean salinity. Harmonic regression analysis attributed 52% of salinity variance to interaction between 12.42 hour and 24 hour cycles, 42% of variance to 24 hour cycles, and 6% of variance to 12.42 hour cycles.

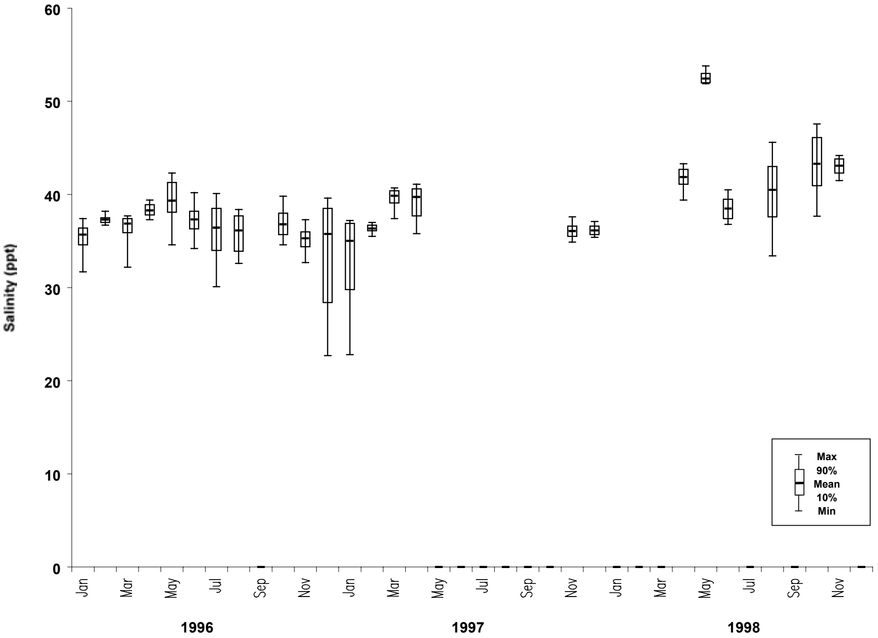


Figure 167. Salinity statistics for Jobos Bay, Station 9, 1996-1998.

Twenty-eight percent of annual dissolved oxygen (% saturation) data were included in analyses (65% in 1996 and 9% in 1997 and 1998). Mean DO was typically 55-85% saturation throughout the data set. Mean DO below 50% saturation was observed on four occasions (May, Aug 1996 and Jan, Nov 1997). Mean DO above 100% saturation was observed on three occasions (Oct 1996 and Jun, Dec 1998). Hypoxia was frequently observed, primarily in spring/summer 1996. When present, hypoxia persisted for 31% of the first 48 hours post-deployment on average (Figure 168). Supersaturation was frequently observed, primarily in 1998. When present, supersaturation persisted for 28% of the first 48 hours post-deployment on average. Scatter plots suggest very strong fluctuations (≥ 80%) in percent saturation at both daily and bi-weekly intervals. Harmonic regression analysis attributed 61% of DO variance to 24 hour cycles, 34% of DO variance to interaction between 12.42 hour and 24 hour cycles, and 5% of DO variance to 12.42 hour cycles.

Photosynthesis/Respiration

Almost all (97%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and were used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 32). Instrument drift during the duration of the deployments was not a significant problem at this site. Total respiration greatly exceeded gross production at Station 9; thus, the net ecosystem metabolism and P/R ratio indicated that this is a very heterotrophic site (Figure 169). Temperature was significantly ($p<0.05$) correlated with gross production, total respiration and net ecosystem metabolism. Gross production and respiration increased as temperature increased, while net ecosystem metabolism became more heterotrophic as temperature increased. Salinity was significantly ($p<0.05$) correlated with gross production, total respiration and net ecosystem metabolism. Gross production and respiration increased as salinity increased, while net ecosystem metabolism became more heterotrophic as salinity increased.

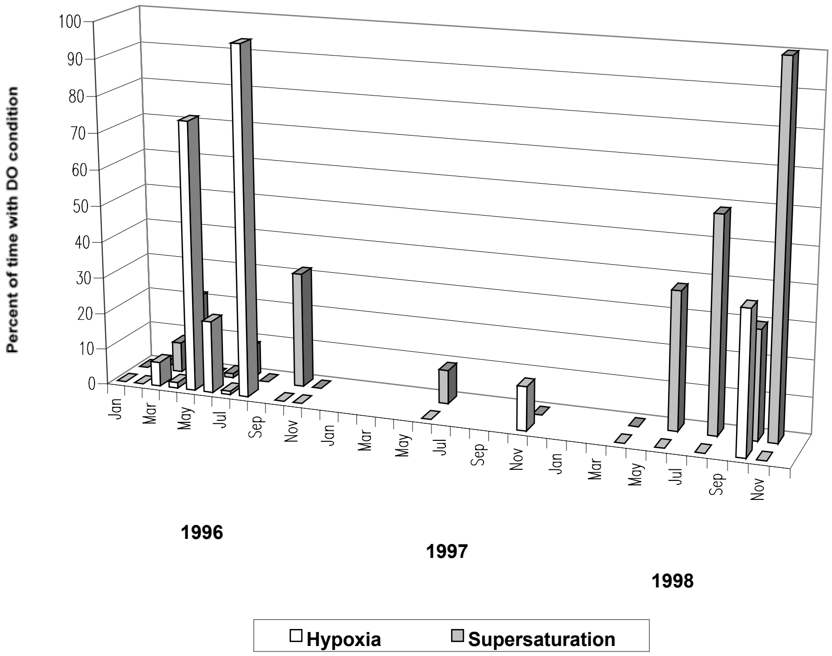


Figure 168. Dissolved oxygen extremes at Jobos Bay, Station 9, 1996-1998.

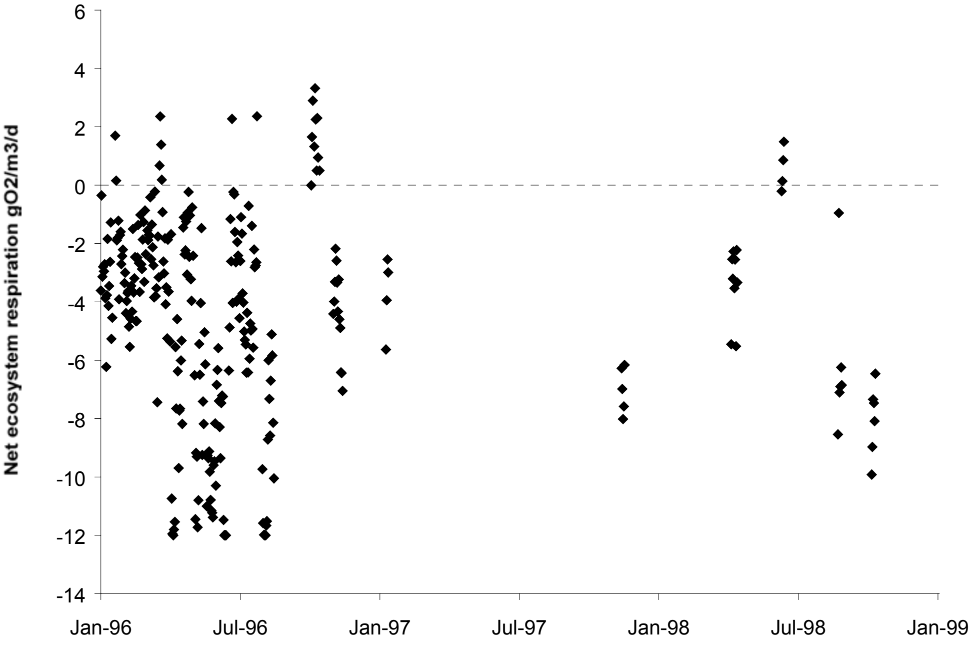


Figure 169. Net metabolism at Jobos Bay, Station 9, 1996-1998.

Table 32. Summary of metabolism data and statistics at Jobos Bay, Station 9, 1996-1998.

Station 9	mean	s.e.
Water depth (m)	1.0	
Net production gO_2/m3/d	0.33	0.16
Gross production gO_2/m3/d	5.63	0.19
Total respiration gO_2/m3/d	10.16	0.26
Net ecosystem metabolism g O_2/m3/d	-4.52	0.22
Net ecosystem metabolism g C/m2/y	-426	
P/R	0.55	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	97 %	
Paired t-test on gross production and total respiration	$p < 0.001$	
Correlation coefficient	Temperature	Salinity
Gross production	0.30	0.14
Total respiration	0.41	0.31
Net ecosystem metabolism	-0.23	-0.25

Jobos Bay, Station 10 (JOB10)

Characterization (Latitude = 17°56' 20" N; Longitude = 66°15' 27" W)

Tides in Jobos Bay are diurnal and range from 0.30 m to 0.36 m. The lagoon is 0.434 km long (mainstream linear dimension) with an average depth of 1.5 m MHW. At the sampling site, the depth is 1.5 m MHW and the width is 196 m. Creek bottom habitats are predominantly sandy silt-clay, with small patches of *Thalassia testudinum* (seagrass). The dominant marsh vegetation near the sampling site is red mangrove. The upland area is a salt flat with mangroves, white sand beach and *Thalassia* beds west of the site. Jobos Bay is un-impacted by human activities.

Descriptive Statistics

Twenty-nine deployments were made at this site between Feb-Dec 1996, Apr-May and Nov-Dec 1997, and Jan, Jun-Aug, Oct, Dec 1998 (Figure 170). Mean deployment duration was 14.1 days. Five deployments (Nov 1996, 1997; Jun-Aug 1998) were less than 10 days, one of which (Jun 1998) was less than one day.

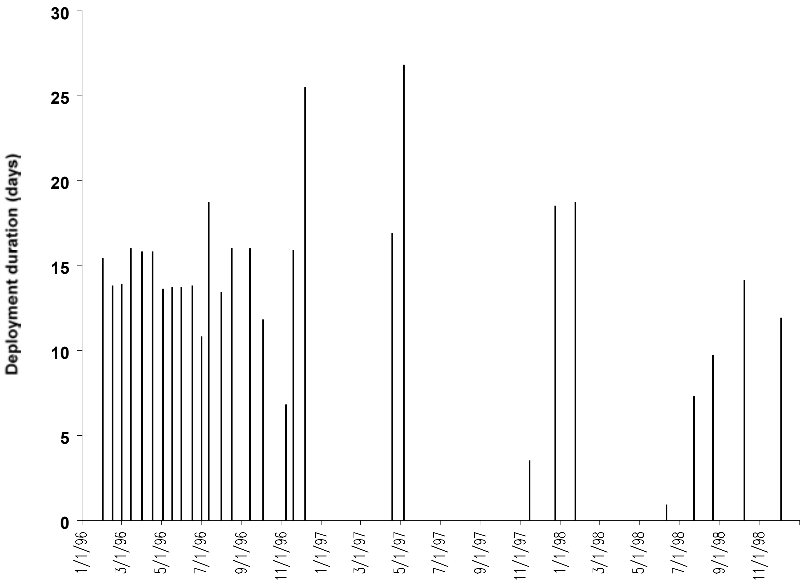


Figure 170. Jobos Bay, Station 10 deployments (1996-1998).

Thirty-seven percent of annual depth data were included in analyses (77% in 1996, 15% in 1997, and 20% in 1998). Sensors were deployed at a mean depth of 0.7 m below the water surface and 0.3 m above the bottom sediment. Minor fluctuations (0.2-0.4 m) in daily and bi-weekly depth were evident from scatter plots, except for Dec 1998 when moderate (0.7 m) fluctuations were observed. Harmonic regression analysis attributed 60% of depth variance to interaction between 12.42 hour and 24 hour cycles, 39% of variance to 24 hour cycles, and 1% of variance to 12.42 hour cycles.

Thirty-seven percent of annual water temperature data were included in analyses (77% in 1996, 15% in 1997, and 20% in 1998). Water temperature followed a seasonal cycle; however, magnitude of mean annual water temperature fluctuation was <5°C (Figure 171). Mean water temperature was 30-31°C in summer and 26-28°C in spring and fall. Minimum and maximum water temperatures between 1996 and 1998 were 24.7°C (Jan 1998) and 33.4°C (May 1996), respectively. Scatter plots suggest daily and bi-weekly fluctuations in water temperatures equivalent to annual variation in mean water temperature. Harmonic regression analysis attributed 92% of temperature variance to 24 hour cycles, 7% of temperature variance to interaction between 12.42 hour and 24 hour cycles, and 1% of temperature variance to 12.42 hour cycles.

Twenty-eight percent of annual salinity data were included in analyses (77% in 1996, 1% in 1997, and 6% in 1998). In 1996, mean salinity followed a weak seasonal cycle, with greatest mean salinity (39 ppt) in spring and least mean salinity (30-35 ppt) in summer (Figure 172). Observations of salinity were too limited in 1997-1998 to describe seasonal patterns. Minimum and maximum salinity between 1996-1998 were 16.7 ppt (Sep 1996) and 42.8 ppt (Oct 1998), respectively. Scatter plots suggest minor (<1 ppt) variance in daily salinity, with stronger (1-3 ppt) variance in bi-weekly salinity. During episodic events (Jul, Sep 1996), salinity fluctuated by ≤ 10 ppt. Harmonic regression analysis attributed 54% of salinity variance to 24 hour cycles, 35% of salinity variance to interaction between 12.42 hour and 24 hour cycles, and 11% of salinity variance to 12.42 hour cycles.

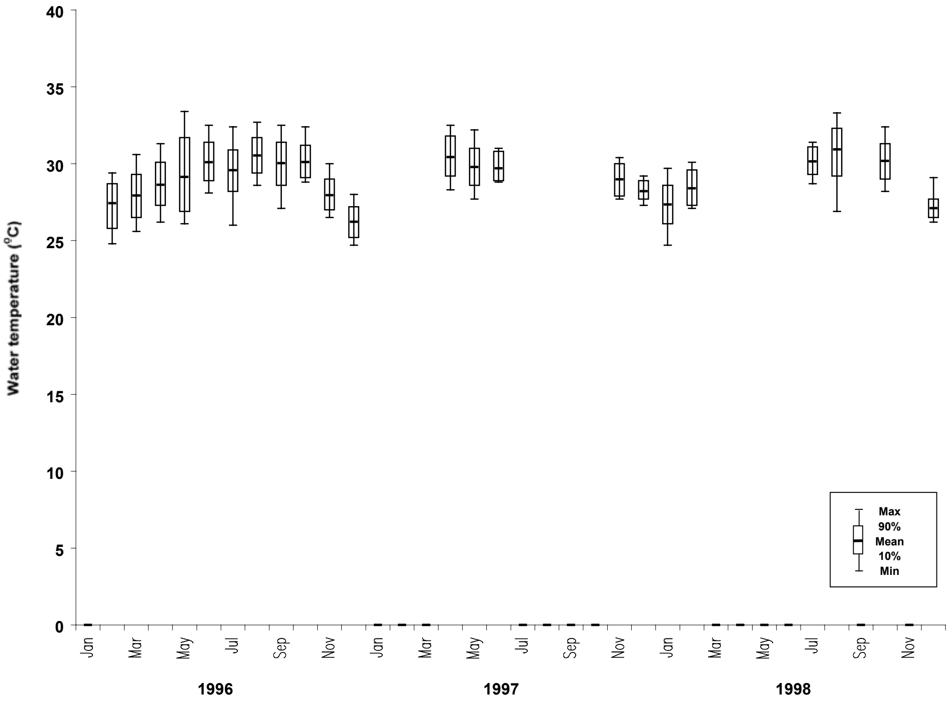


Figure 171. Water temperature statistics for Jobos Bay, Station 10, 1996-1998.

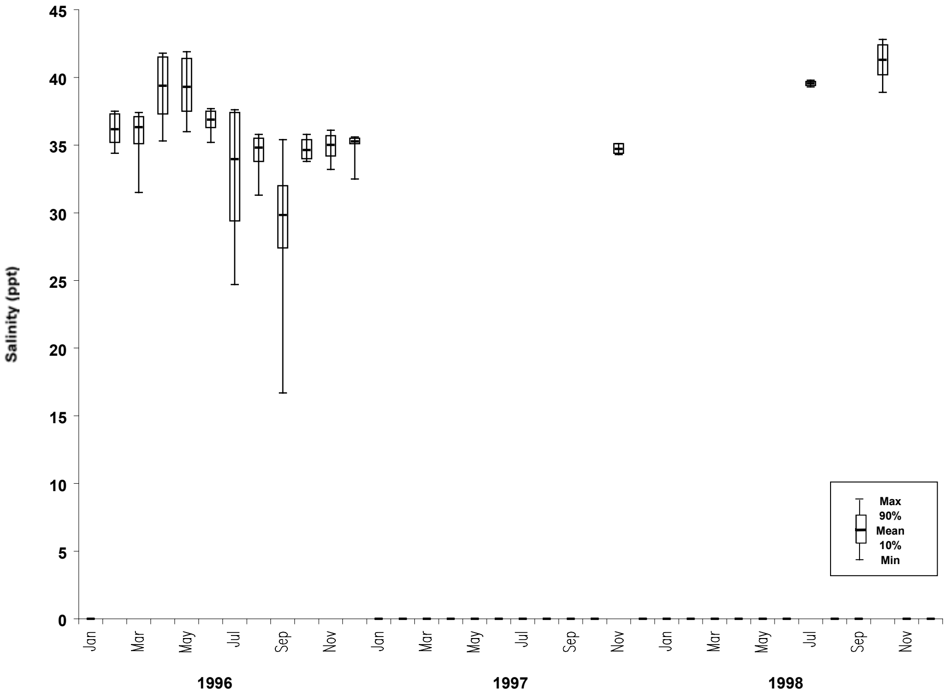


Figure 172. Salinity statistics for Jobos Bay, Station 10, 1996-1998.

Thirty-two percent of annual dissolved oxygen (% saturation) data were included in analyses (75% in 1996, 12% in 1997, and 11% in 1998). Mean DO was typically 60-100% saturation throughout the data set. Mean DO below 50% saturation was observed on two occasions (Oct 1996, Nov 1998). Mean DO above 100% saturation was observed on three occasions (Jul 1996 and Feb, Oct 1998). Minimum and maximum DO between 1996-1998 was 0% saturation (Sep-Oct 1996) and 498% saturation (Feb 1998), respectively. Hypoxia was observed in two months (Sep, Oct 1996) and persisted for 37% and 2% of the first 48 hours post-deployment, respectively (Figure 173). Supersaturation was frequently observed in 1996 and 1997, but never observed in 1998. When present, supersaturation persisted for 16% of the first 48 hours post-deployment on average. Scatter plots suggest moderate fluctuations (40-80%) in percent saturation at both daily and bi-weekly intervals throughout most of the data set. Harmonic regression analysis attributed 50% of DO variance to interaction between 12.42 hour and 24 hour cycles, 46% of DO variance to 24 hour cycles, and 4% of DO variance to 12.42 hour cycles.

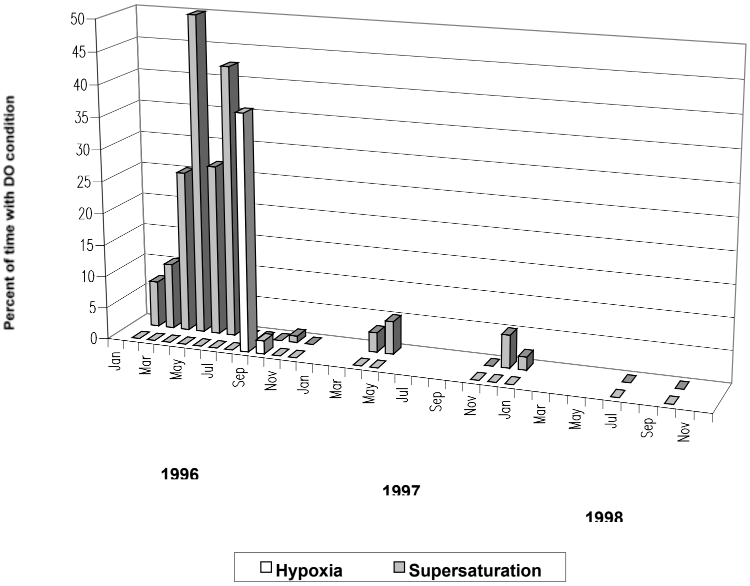


Figure 173. Dissolved oxygen extremes at Jobos Bay, Station 10, 1996-1998.

Photosynthesis/Respiration

Nearly all (94%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and were used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 33). Instrument drift during the duration of the deployments was not a significant problem at this site. Total respiration exceeded gross production at Station 10; thus, the net ecosystem metabolism and P/R ratio indicated that this is a heterotrophic site (Figure 174). Temperature was significantly ($p<0.05$) correlated with gross production and total respiration, but not net ecosystem metabolism. Gross production and respiration increased as temperature increased. Salinity was significantly ($p<0.05$) correlated with respiration and net ecosystem metabolism. Respiration decreased as salinity increased, while net ecosystem metabolism became more autotrophic as salinity increased.

Table 33. Summary of metabolism data and statistics at Jobos Bay, Station 10, 1996-1998.

Station 10	mean	s.e.
Water depth (m)	1.5	
Net production gO_2/m3/d	0.83	0.11
Gross production gO_2/m3/d	3.23	0.10
Total respiration gO_2/m3/d	4.50	0.12
Net ecosystem metabolism g O_2/m3/d	-1.28	0.11
Net ecosystem metabolism g C/m2/y	-95	
P/R	0.72	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	94 %	
Paired t-test on gross production and total respiration	$p < 0.001$	
Correlation coefficient	Temperature	Salinity
Gross production	0.22	ns
Total respiration	0.21	-0.20
Net ecosystem metabolism	ns	0.21

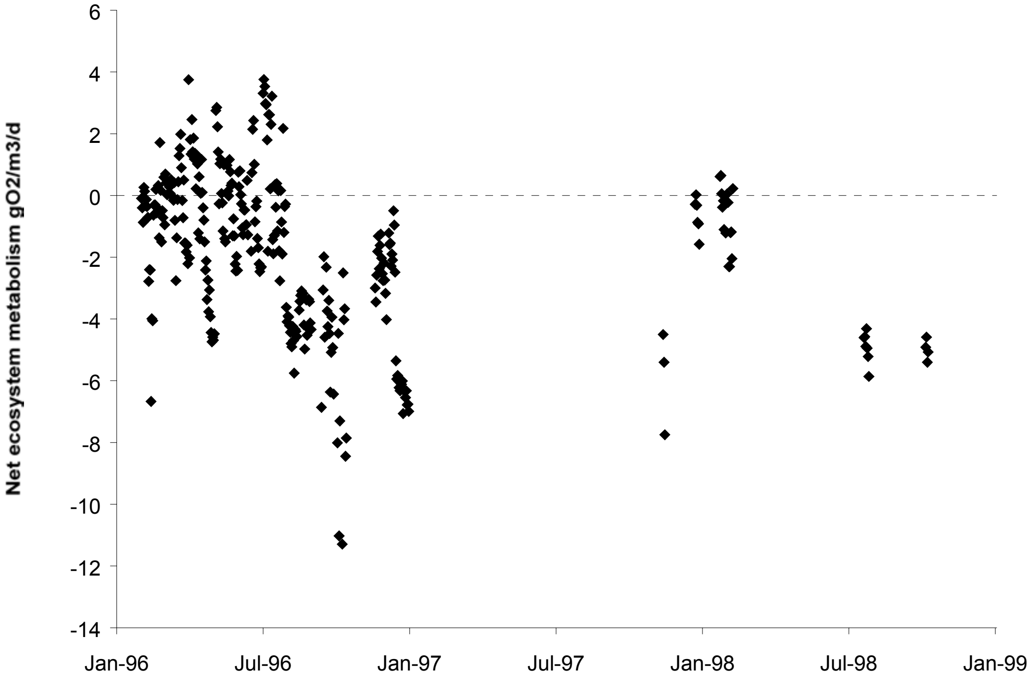
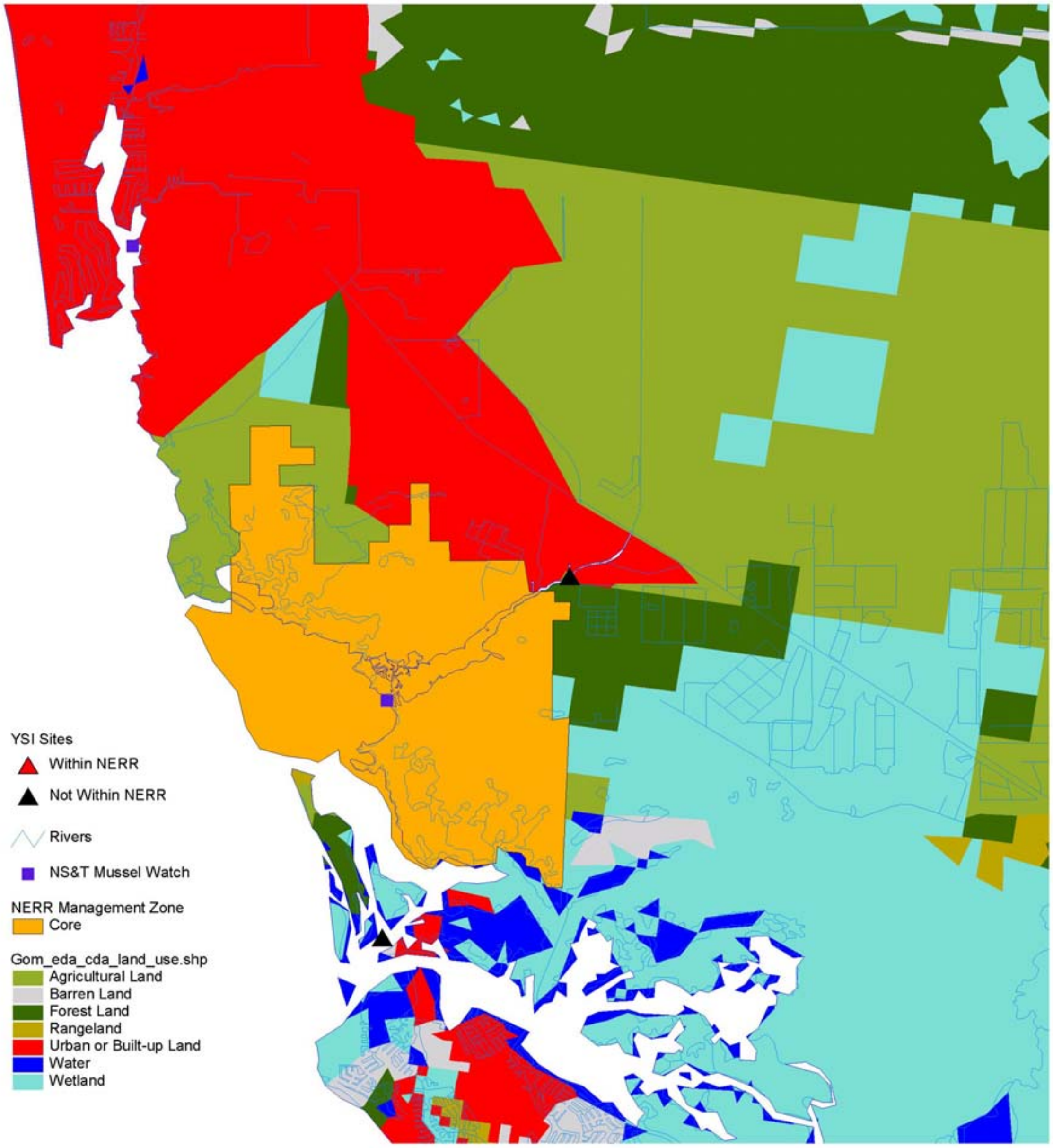


Figure 174. Net metabolism at Jobos Bay, Station 10, 1996-1998.

Rookery Bay


YSI Sites
Within NERR
Not Within NERR
Rivers
NS&T Mussel Watch
NERR Management Zone
Core
Gom_eda_cda_land_use.shp
Agricultural Land
Barren Land
Forest Land
Rangeland
Urban or Built-up Land
Water
Wetland

Rookery Bay, Blackwater River (RKBBR)

Characterization (Latitude = 25° 58'04" N; Longitude = 81° 35'27" W)
Tides at Blackwater River are mixed and range from 0 m to 1.71 m (average 0.73 m). The monitoring site is located 2.1 km downstream of the headwaters (near a dredged boat basin) at a juncture leading to a small bay named Mud Bay. Blackwater River is roughly 7.5 km long (mainstream linear dimension), has an average mid-channel depth of 2 m MHW, and an average width of 193 m. At the sampling site, the water depth is approximately 2 m MHW and the width is 35 m. This site is located within the mesohaline region of the estuary. Creek bottom habitats are predominantly fine sand and there is no bottom vegetation. The dominant bank vegetation near the sampling site is red mangrove. The dominant natural vegetation of the watershed is hydric pine and cypress. Upland land use near the sampling site includes Collier Seminole State Park and a boat basin located approximately 2.1 km upstream. Activities that potentially impact the site include agricultural runoff, runoff from a two-lane highway (SR 41) and altered flow regimes in the watershed due to canals. The Blackwater River watershed is managed by public ownership (90%) and much of this protected area has intact cypress sloughs and other wetland vegetation. Due to greater natural mangrove buffer and less intensive watershed land uses, the Blackwater system represents a more pristine estuarine habitat relative to Henderson Creek.

Descriptive Statistics
Twenty-one deployments were made at this site between Feb-Dec 1998, with equal coverage during all seasons (Figure 175). Mean deployment duration was 14.3 days. Only one deployment (Sep) was less than 10 days.

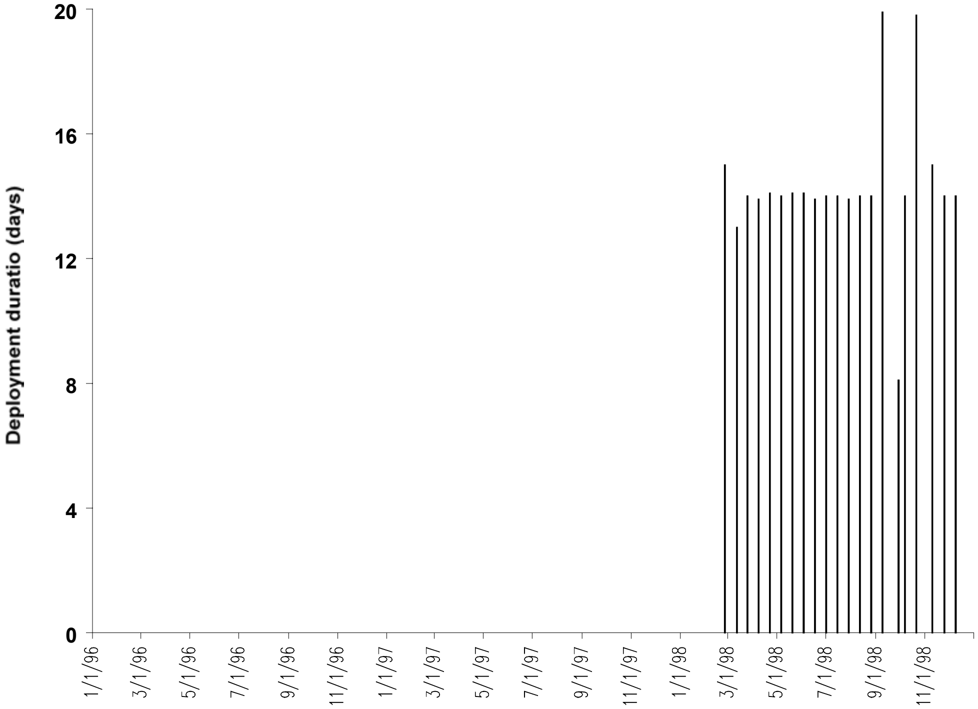


Figure 175. Rookery Bay, Blackwater River deployments (1996-1998).

Eighty-five percent of depth data in 1998 were included in analyses. Sensors were deployed at a mean depth of 1.7 m below the water surface and 0.2 m above the bottom sediment. Scatter plots suggest moderate daily and bi-weekly fluctuations (0.5-0.8 m) throughout 1998. Harmonic regression analysis attributed 46% of depth variance to 12.42 hour cycles, 43% of depth variance to interaction between 12.42 hour and 24 hour cycles, and 11% of depth variance to 24 hour cycles.

Eighty-five percent of water temperature data in 1998 were included in analyses. Water temperature followed a seasonal cycle, with mean water temperatures 22-25°C in spring and fall and 28-31°C in summer (Figure 176). Minimum and maximum water temperature between 1996-1998 was 15°C (Mar 1998) and 35.4°C (Jul 1998), respectively. Scatter plots suggest strong fluctuations (2-4°C) in daily water temperature, with stronger fluctuations (4-10°C) in bi-weekly water temperature. Harmonic regression analysis attributed 51% of temperature variance to interaction between 12.42 hour and 24 hour cycles, 40% of variance to 24 hour cycles, and 9% of variance to 12.42 hour cycles.

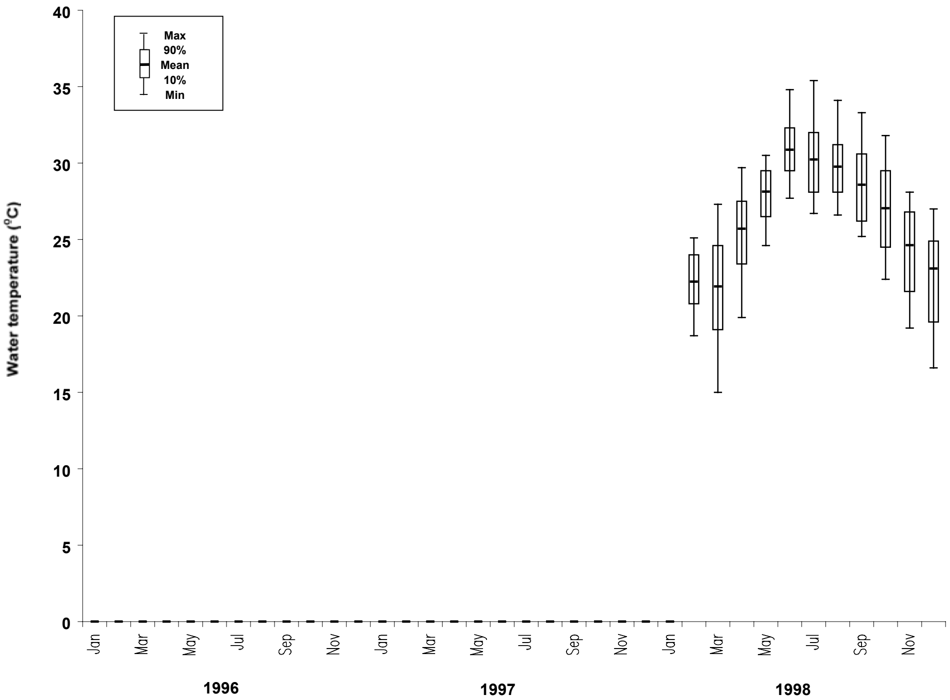


Figure 176. Water temperature statistics at Blackwater River, 1996-1998.

Eighty-five percent of salinity data in 1998 were included in analyses. Salinity followed a seasonal cycle, with mean salinity 27-33 ppt in Apr-Jun and 9-13 ppt in Aug-Nov; however, large variances (15-25 ppt) were associated with mean salinity values throughout the data set (Figure 177). Minimum and maximum salinity in 1998 was 1.4 ppt (Sep) and 36 ppt (May), respectively. Scatter plots suggest large fluctuations (≤ 5 ppt) in daily salinity and even larger fluctuations (5-15 ppt) in bi-weekly salinity. Harmonic regression analysis attributed 47% of salinity variance to interaction 12.42 hour and 24 hour cycles, 38% of salinity variance to 12.42 hour cycles, and 15% of salinity variance to 24 hour cycles.

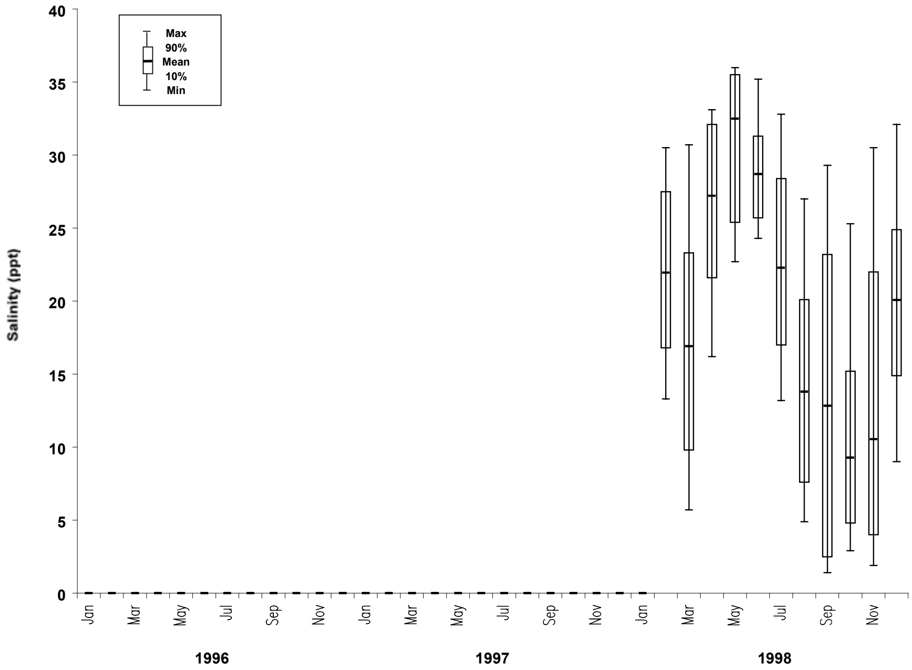


Figure 177. Salinity statistics at Blackwater River, 1996-1998.

Sixty-one percent of dissolved oxygen (% saturation) data in 1998 were included in analyses. Mean DO was greatest in Mar-Jun (36-60% sat) and least in Jul-Oct (16-20% sat). Mean DO < 1% saturation and was observed in Jul, Aug, and Oct. Mean DO was 54-130% saturation. Hypoxia was observed from May to Dec and, when present, persisted for 45.8% of the first 48 hours post-deployment (Figure 178). Supersaturation was only observed in Mar 1998 and persisted for 2% of the first 48 hours post-deployment. With exception of Mar 1998, fluctuations in daily and bi-weekly percent saturation were 20-100%. Harmonic regression analysis attributed 61% of DO variance to interaction between 12.42 hour and 24 hour cycles, 22% of DO variance to 24 hour cycles, and 17% of DO variance to 12.42 hour cycles.

Photosynthesis/Respiration

Over three quarters (79%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and was used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 34). Instrument drift during the duration of the deployments was not a significant problem at this site. Total respiration greatly exceeded gross production at Blackwater River; thus, the net ecosystem metabolism and P/R ratio indicated that this was the most heterotrophic site in the Reserve system (Figure 179). In addition to being the most heterotrophic site, this was also the only site that never had a single day when it was autotrophic. Temperature was significantly ($p<0.05$) correlated with total respiration and net ecosystem metabolism. Respiration increased as temperature increased, while net ecosystem metabolism became more heterotrophic as temperature increased. Salinity was significantly ($p<0.05$) correlated with gross production and net ecosystem metabolism. Gross production increased as salinity increased, while net ecosystem became more autotrophic as salinity increased.

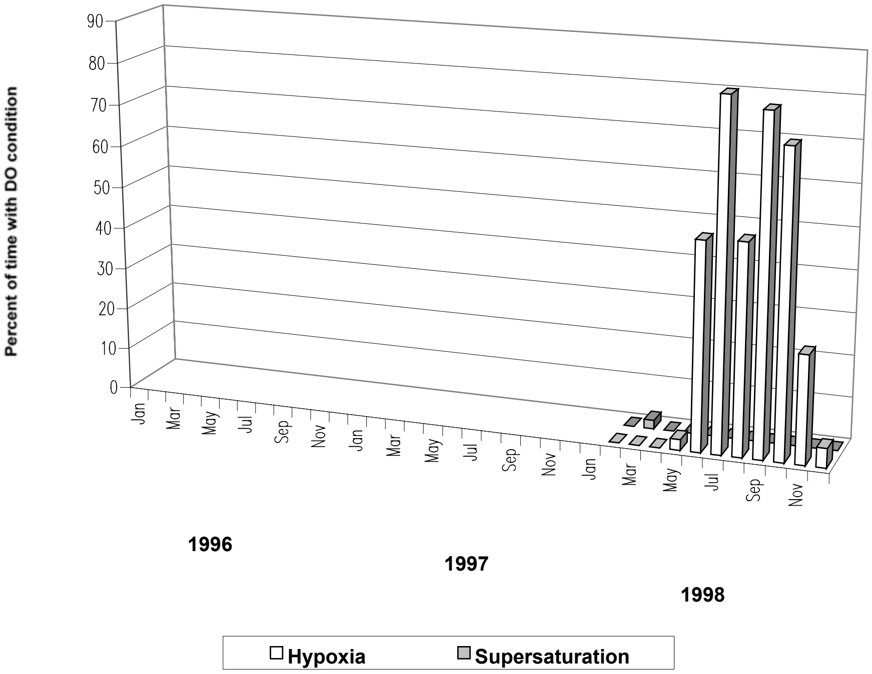


Figure 178. Dissolved oxygen extremes at Blackwater River, 1996-1998.

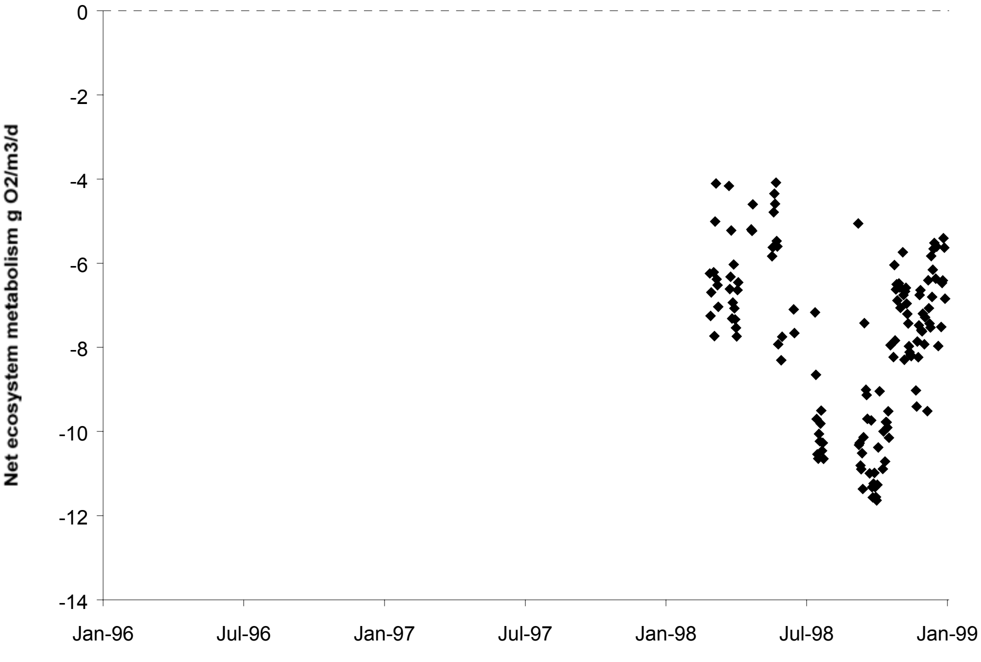


Figure 179. Net metabolism at Blackwater River, 1996-1998.

Table 34. Summary of metabolism data and statistics at Blackwater River, 1996-1998.

Blackwater River	mean	s.e.
Water depth (m)	2.0	
Net production gO_2/m3/d	-0.78	0.10
Gross production gO_2/m3/d	2.21	0.15
Total respiration gO_2/m3/d	6.14	0.15
Net ecosystem metabolism g O_2/m3/d	-3.92	0.09
Net ecosystem metabolism g C/m2/y	-1074	
P/R	0.36	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	79 %	
Paired t-test on gross production and total respiration	$p < 0.001$	
Correlation coefficient	Temperature	Salinity
Gross production	ns	0.24
Total respiration	0.36	ns
Net ecosystem metabolism	-0.51	0.48

Rookery Bay, Upper Henderson Creek (RKBUH)

Characterization (Latitude = 26° 02' 56" N; Longitude = 81° 42' 04" W)

Tides at Upper Henderson Creek are mixed and range from 0 m to 2.76 m (average 1.06 m). The monitoring site is located in upper Henderson Creek, approximately 130 m downstream of a four-lane highway (SR 951) that crosses the creek. The creek is 4.4 km long (mainstream linear dimension), has an average mid-channel depth of approximately 2 m MHW, and an average width of 239 m. At the sampling site, the depth is 2 m MHW and the width is 40 m. This site is within the mesohaline region of the estuary. Creek bottom habitats are predominantly fine sand and there is no bottom vegetation. The dominant marsh vegetation near the sampling site is red mangrove. The dominant natural vegetation of the watershed is hydric pine and cypress. Upland land use near the sampling site includes residential areas with septic systems. Watershed activities that potentially impact the site include non-point source pollution from road runoff, drift of mosquito control pesticides, runoff from upstream agricultural areas and leachate from nearby residential septic systems. The amount of water released from this weir can sometimes overwhelm natural tidal salinity patterns. The historic Henderson Creek watershed is approximately 50% under public ownership and much of this protected area has intact cypress sloughs and other wetland vegetation. Canals and water use for agriculture and human consumption have altered the hydroperiod of this watershed. Consequently, the Henderson watershed receives non-point source pollutant runoff from a variety of sources.

Descriptive Statistics

Fifty-two deployments were made at this site between Nov 1996 and Dec 1998, with equal coverage during all seasons (Figure 180). Mean deployment duration was 14.9 days and only two deployments (Nov 1996, Sep 1998) were less than 10 days.

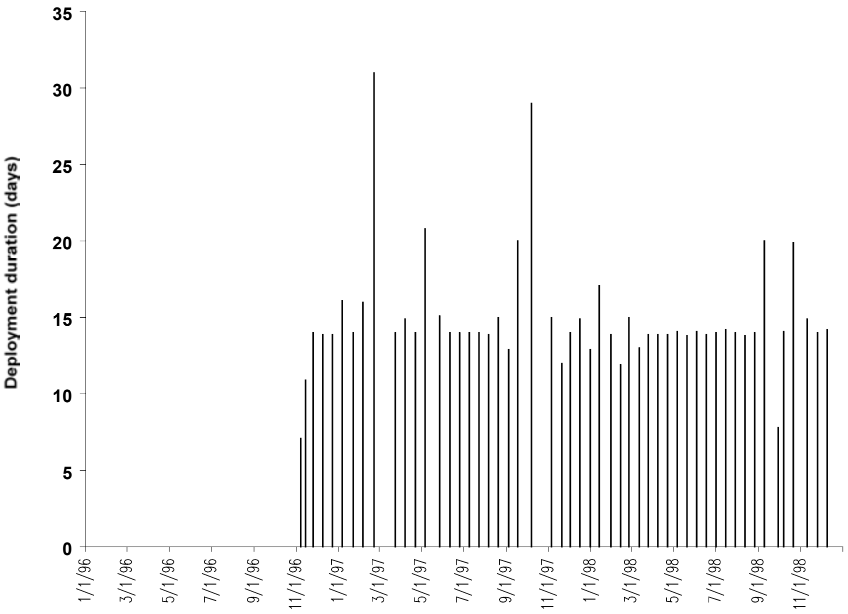


Figure 180. Rookery Bay, Upper Henderson Creek deployments (1996-1998).

Sixty-eight percent of annual depth data were included in analyses (15% in 1996, 94% in 1997, and 95% in 1998). Sensors were deployed at a mean depth of 1 m below the water surface and 0.2 m above the bottom sediment. Scatter plots suggest strong fluctuations (1-1.2 m) in depth throughout the data set. Harmonic regression analysis attributed 45% of depth variance to interaction between 12.42 hour and 24 hour cycles, 41% of depth variance to 12.42 hour cycles, and 14% of depth variance to 24 hour cycles.

Sixty-eight percent of annual water temperature data were included in analyses (15% in 1996, 94% in 1997, and 95% in 1998). Water temperature followed a seasonal cycle, with mean water temperatures 21-24°C in winter and 29-30°C in summer (Figure 181). Minimum and maximum water temperatures between 1996-1998 were 13.3°C (Jan 1997) and 34.1°C (Jul 1998), respectively. Scatter plots suggest strong fluctuations (≤ 3°C) in daily water temperature and even stronger fluctuations (5-10°C) throughout the data set, with strongest fluctuations in winter. Harmonic regression analysis attributed 56% of temperature variance to interaction between 12.42 hour and 24 hour cycles, 33% of temperature variance to 24 hour cycles, and 11% of temperature variance to 12.42 hour cycles.

Sixty-seven percent of annual salinity data were included in analyses (14% in 1996, 94% in 1997, and 95% in 1998). Salinity at this site is affected by alterations in natural timing and quantities of freshwater inflow due to the operation of a weir that is situated at the creek's headwaters. Mean salinity was least in summer (5-10 ppt) and greatest in winter (28 ppt, 1997), although mean winter salinity was much greater in 1998 (10-15 ppt) than in 1997 (Figure 182). Scatter plots suggest strong fluctuations (5-10 ppt) in salinity, with very strong fluctuations (≥ 15 ppt) during episodic events in Jul, Aug, Oct and Dec 1997 and most of 1998. Harmonic regression analysis attributed 65% of salinity variance to interaction between 12.42 hour and 24 hour cycles, 19% of salinity variance to 24 hour cycles, and 16% of salinity variance to 12.42 hour cycles.

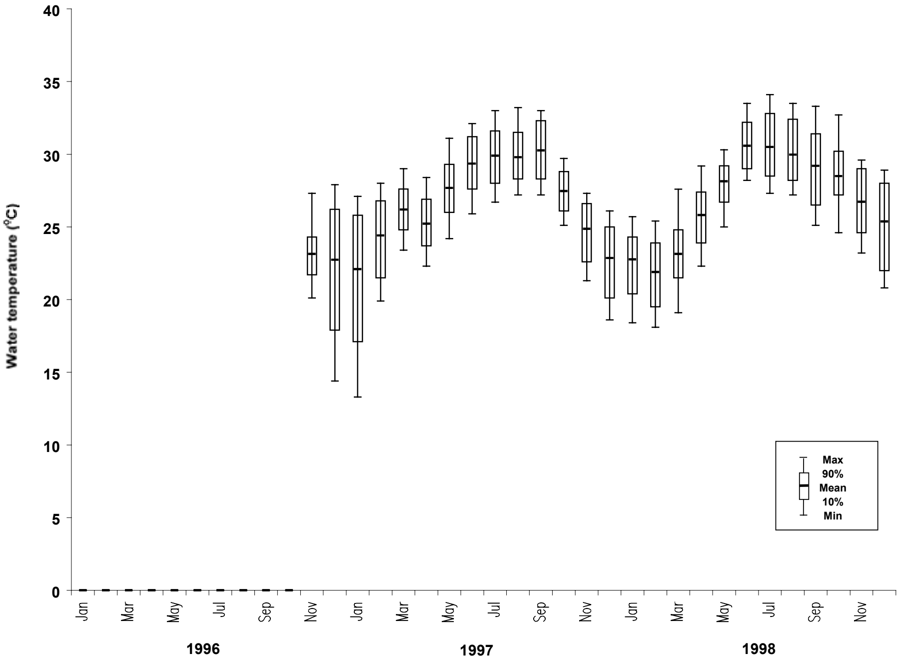


Figure 181. Water temperature statistics at Upper Henderson Creek, 1996-1998.

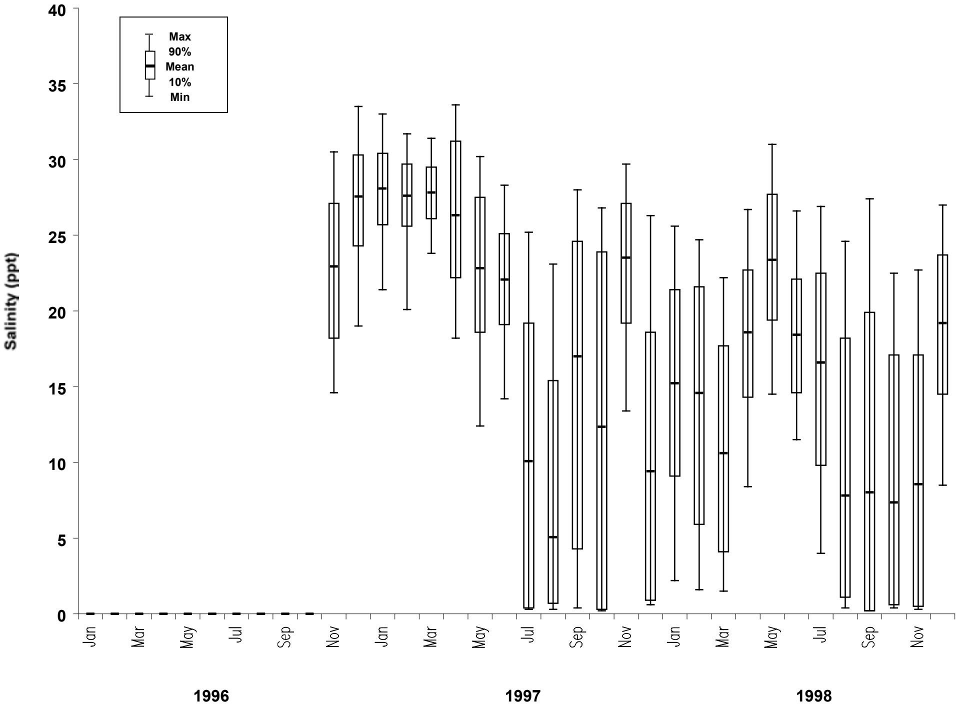


Figure 182. Salinity statistics at Upper Henderson Creek, 1996-1998.

Fifty-two percent of annual dissolved oxygen (% saturation) data were included in analyses (15% in

1996, 77% in 1997, and 65% in 1998). Mean DO followed a seasonal cycle, with mean DO between 50-100% saturation in winter and spring and mean DO between 30-50% saturation in summer (except Aug 1997) and fall. Minimum and maximum DO between 1996-1998 was 0% saturation (Jul 1997, Mar-May 1998) and 285.3% saturation (Dec 1996), respectively. Hypoxia was regularly observed in 1998 and summer 1997 (Figure 183). When present, hypoxia persisted for 21.8% of the first 48 hours post-deployment on average. Supersaturation was only observed in Dec and Jan and, when present, supersaturation persisted for 15.8% of the first 48 hours post-deployment on average. Scatter plots suggest strong fluctuations (40-100%) in percent saturation throughout the data set. Harmonic regression analysis attributed 49% of DO variance to interaction between 12.42 hour and 24 hour cycles, 40% of DO variance to 24 hour cycles, and 11% of DO variance to 12.42 hour cycles.

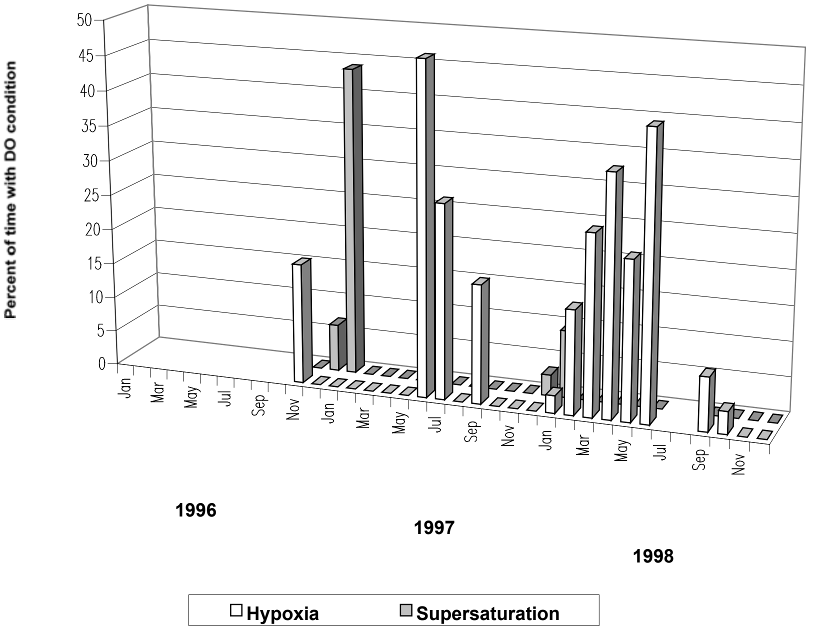


Figure 183. Dissolved oxygen extremes at Upper Henderson Creek, 1996-1998.

Photosynthesis/Respiration

Over four fifths (88%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor); however, instrument drift was a problem at this site. There was a significant difference in total respiration rates between the first 2 days of the deployment and the total length of the deployment. Because of this only the first 2 days of each deployment (14% of the observations) were used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 35). Total respiration greatly exceeded gross production at Upper Henderson; thus, the net ecosystem metabolism and P/R ratio indicated that this was one of the most heterotrophic sites in the Reserve system (Figure 184). Temperature was significantly ($p<0.05$) correlated with total respiration and net ecosystem metabolism. As temperature increased, respiration and net ecosystem metabolism became more. Salinity was not significantly ($p<0.05$) correlated with any metabolic measurement.

Table 35. Summary of metabolism data and statistics at Upper Henderson Creek, 1996-1998.

Upper Henderson	mean	s.e.
Water depth (m)	2.0	
Net production gO_2/m3/d	-0.47	0.17
Gross production gO_2/m3/d	3.10	0.24
Total respiration gO_2/m3/d	5.2	0.28
Net ecosystem metabolism g O_2/m3/d	-4.72	0.28
Net ecosystem metabolism g C/m2/y	-577	
P/R	0.60	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	$p < 0.001$	
Percent useable observations	88 %, 14 %	
Paired t-test on gross production and total respiration	$p < 0.001$	
Correlation coefficient	Temperature	Salinity
Gross production	ns	ns
Total respiration	0.30	ns
Net ecosystem metabolism	-0.47	ns

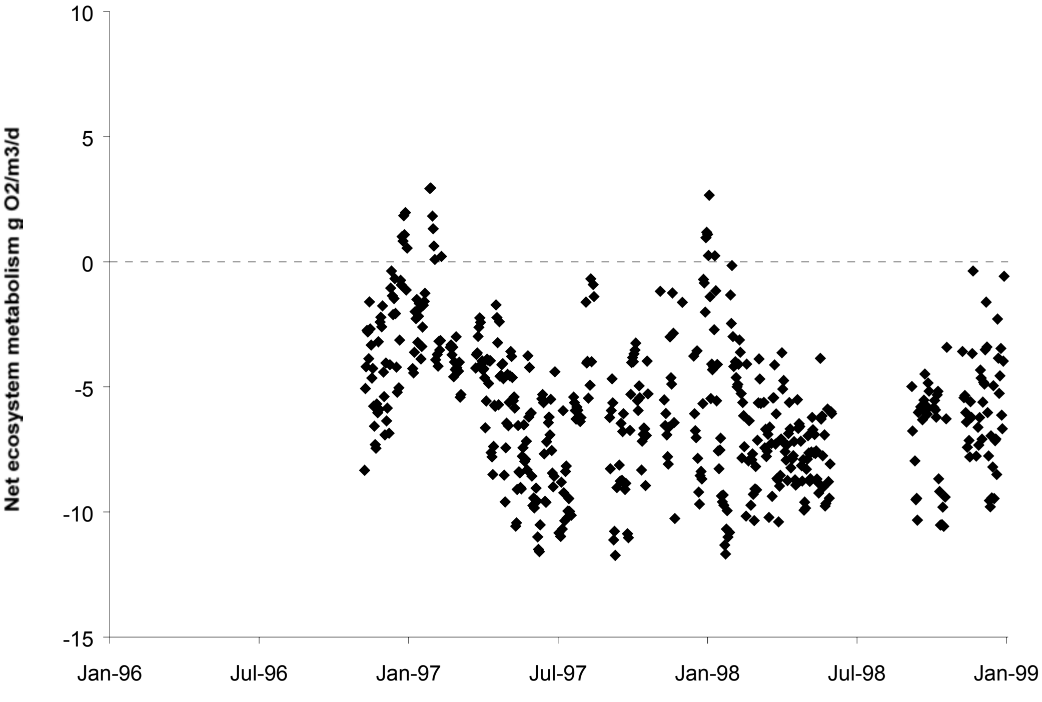
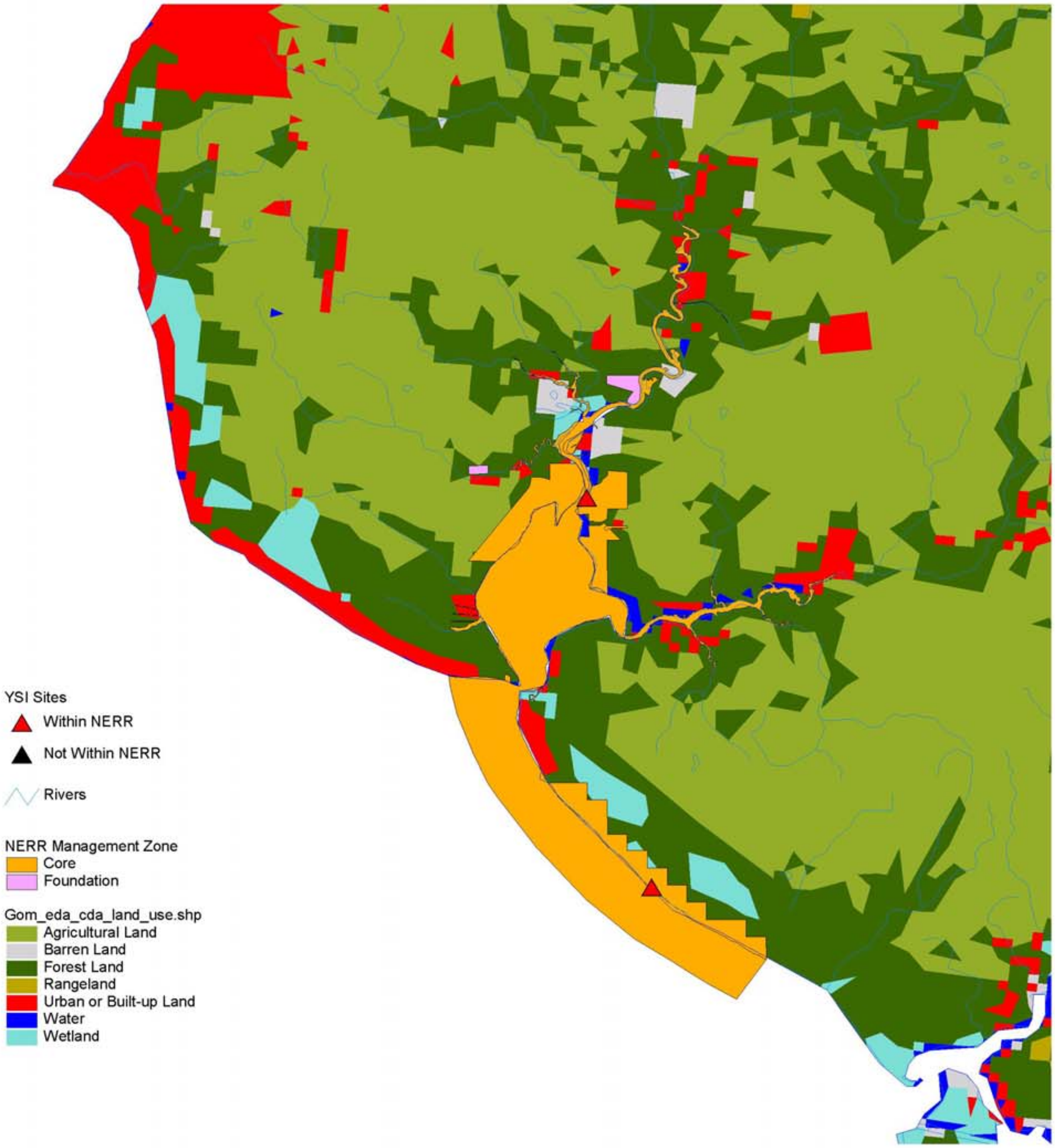


Figure 184. Net metabolism at Upper Henderson Creek, 1996-1998.

Weeks Bay


YSI Sites
Within NERR
Not Within NERR
Rivers
NERR Management Zone
Core
Foundation
Gom_eda_cda_land_use.shp
Agricultural Land
Barren Land
Forest Land
Rangeland
Urban or Built-up Land
Water
Wetland

Weeks Bay, Fish River (WKBFR)

Characterization (Latitude = 30°24'58"N; Longitude = 87°49'22"W)

Tides at the Fish River site are diurnal and range from 0.2 m to 0.6 m (average 0.4 m). The monitoring site is located at the mouth of Fish River. Fish River is 46 km long (mainstream linear dimension), has an average depth of 3 m MHW, and an average width of 150 m. At the sampling site, the depth is 2 m MHW and the width is 120 m. Creek bottom habitats are predominantly sandy-silt, with *Vallisineria* sp. growing near the monitoring site. The dominant marsh vegetation near the sampling site is *Spartina cynosuroides*. The dominant upland vegetation includes *Pinus taeda* and *Magnolia virginiana*. Upland land use near the sampling site includes some residential use. Activities that potentially impact the site include high non-point source nutrient loading and increased sedimentation due to disturbed soil caused by new home construction sites.

Descriptive statistics

Seventy-five deployments were made at this site between Jan 1996 and Dec 1998, with equal coverage during all seasons (Figure 185). Mean deployment duration was 13.8 days. Five deployments (Aug and Dec 1996, Apr and May 1997, and Jan 1998) were less than 10 days.

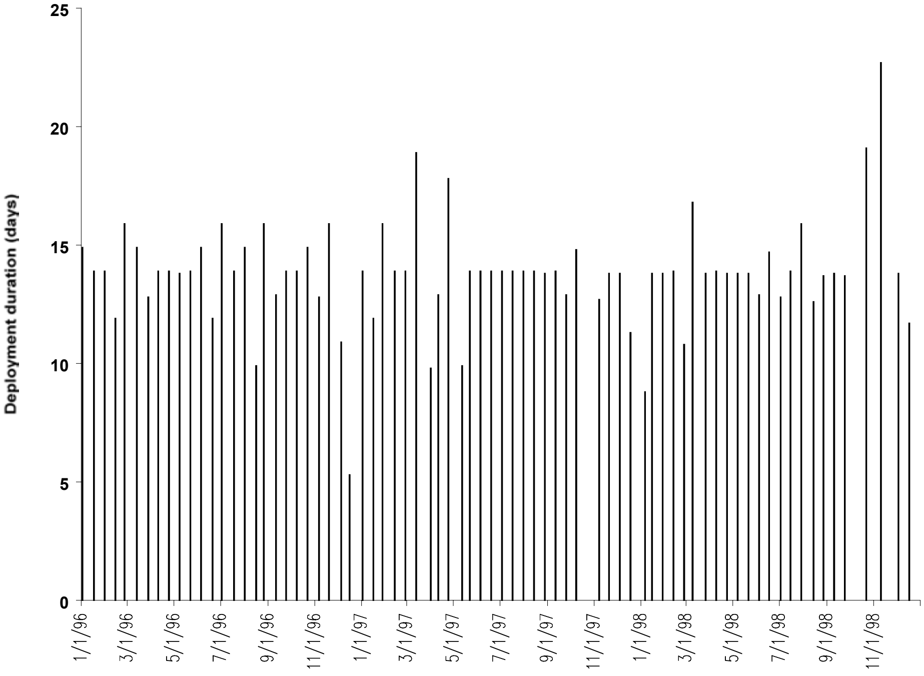


Figure 185. Weeks Bay, Fish River deployments (1996-1998).

Ninety-five percent of annual depth data were included in analyses (97% in 1996, 94% in 1997 and 1998). Sensors were deployed at a mean depth of 1.9 m below the water surface and 0.5 m above the bottom sediment. Scatter plots suggest moderate depth fluctuations (0.5 – 0.7 m) in summer (except for Jun 1997 and Sep 1998) and strong depth fluctuations (~ 1 m) throughout the remainder of the year. Harmonic regression analysis attributed 82% of depth variance to interaction between 12.42 hour and 24 hour cycles, 16% of variance to 24 hour cycles, and 2% of depth variance to 12.42 hour cycles.

Ninety-five percent of annual water temperature data were included in analyses (97% in 1996, 94% in 1997 and 1998). Water temperature followed a seasonal cycle, with mean water temperature 13-15°C in winter and 28-30°C in summer (Figure 186). Minimum and maximum water temperature between 1996-1998 was 6.2°C (Feb 1996) and 33.7°C (Aug 1998), respectively. Decline in mean water temperature in fall 1997 was more abrupt than in fall 1996 and fall 1997. Scatter plots suggest moderate fluctuations (≤ 3°C) in daily water temperature and strong fluctuations (3-8°C) in bi-weekly water temperature throughout the data set, with strongest fluctuations (8-14°C) observed during episodic events in winter 1996 and 1997. Harmonic regression analysis attributed 70% of temperature variance to interaction between 12.42 hour and 24 hour cycles, 25% of temperature variance to 24 hour cycles, and 5% of temperature variance to 12.42 hour cycles.

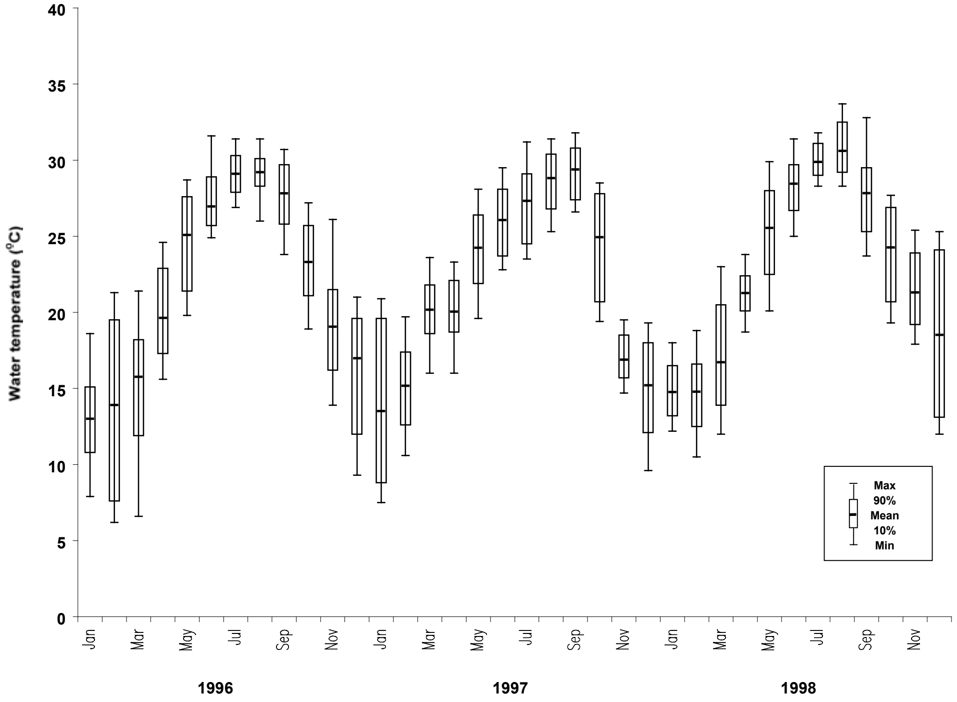


Figure 186. Water temperature statistics at Fish River, 1996-1998.

Ninety-four percent of annual salinity data were included in analyses (97% in 1996, 94% in 1997, and 90% in 1998). Mean salinity followed a seasonal cycle (Figure 187). Mean salinity was greatest in summer and fall (7-13 ppt) and least in winter and spring (0-3 ppt). Minimum salinity regularly approached 0 ppt in winter and spring. Maximum salinity was 17.6 ppt (Oct 1997). Scatter plots suggest daily and bi-weekly salinity fluctuations equivalent to, or in excess of, seasonal ranges in salinity (3 ppt for winter/spring, 6 ppt for summer/fall) throughout the data set except for Apr-Jun 1996, Jun-Jul 1997, and Jan-Jun 1998. Harmonic regression analysis attributed 75% of salinity variance to interaction between 12.42 hour and 24 hour cycles, 19% of salinity variance to 24 hour cycles, and 6% of salinity variance to 12.42 hour cycles.

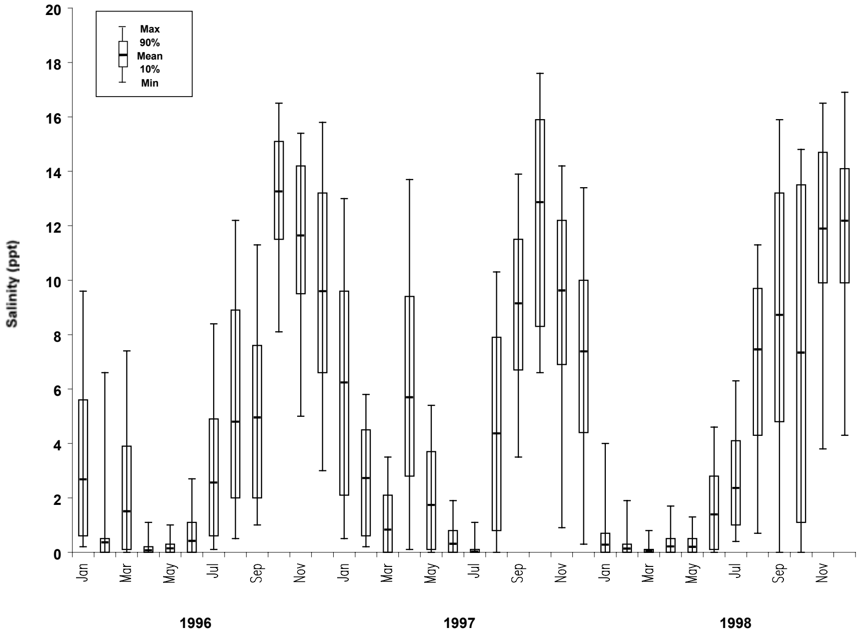


Figure 187. Salinity statistics at Fish River, 1996-1998.

Eighty-two percent of annual dissolved oxygen (% saturation) data were included in analyses (92% in 1996, 91% in 1997, and 63% in 1998). Mean DO was 52-113% saturation throughout the data set, except for Sep 1997 when mean DO was 36% saturation. Mean DO was greatest in fall, winter, and spring (78-113% sat) and least in summer (36-79% sat). Hypoxia was observed in Jan and Sep 1997 and persisted for 39.2% and 1.5% of the first 48 hours post-deployment, respectively (Figure 188). Supersaturation was regularly observed in 1996, less frequently observed in 1997, and infrequently observed in 1998. When present, supersaturation persisted for 14% of the first 48 hours post-deployment on average. Scatter plots suggest moderate fluctuations (20-80%) in percent saturation in winter and spring 1996, summer 1997, and winter and spring 1998. Strong fluctuations (80-180%) in percent saturation were observed in summer and fall 1996, winter, spring and fall 1997, and fall 1998. Harmonic regression analysis attributed 62% of DO variance to interaction between 12.42 hour and 24 hour cycles, 28% of variance to 24 hour cycles, and 10% of DO variance to 12.42 hour cycles.

Photosynthesis/Respiration

Over three quarters (78%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor); however, instrument drift was a problem at this site. There was a significant difference in total respiration rates between the first 2 days of the deployment and the total length of the deployment. Because of this only the first 2 days of each deployment (12% of the observations) were used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 36). Total respiration exceeded gross production at Fish River; thus, the net ecosystem metabolism and P/R ratio indicated that this was a heterotrophic site (Figure 189). Temperature was not significantly ($p<0.05$) correlated with any metabolic measurement. Salinity was significantly ($p<0.05$) correlated with gross production and net ecosystem metabolism. Gross production decreased as salinity increased, while net ecosystem metabolism became more autotrophic as salinity increased.

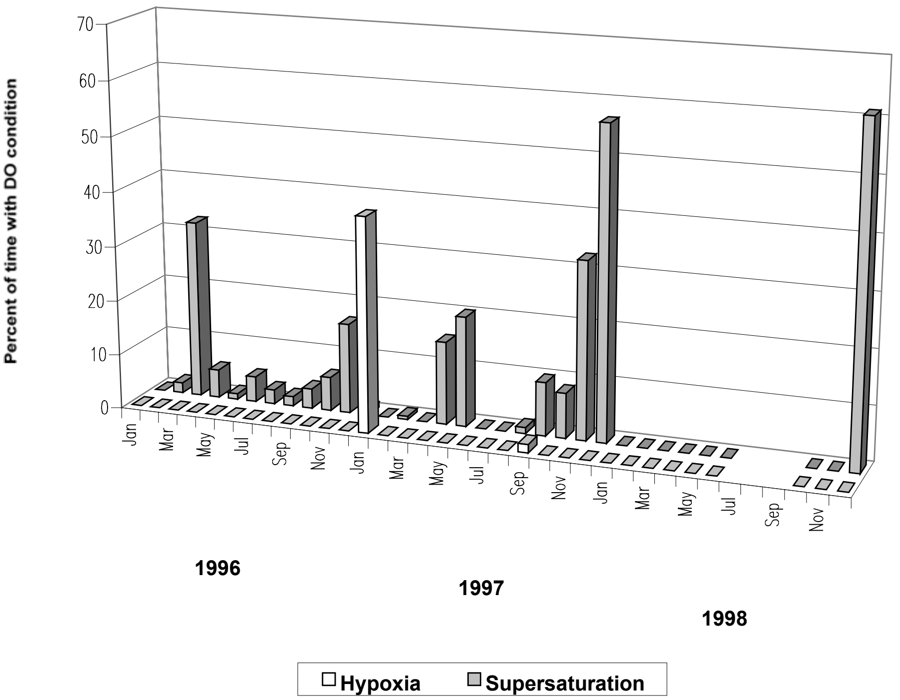


Figure 188. Dissolved oxygen extremes at Fish River, 1996-1998.

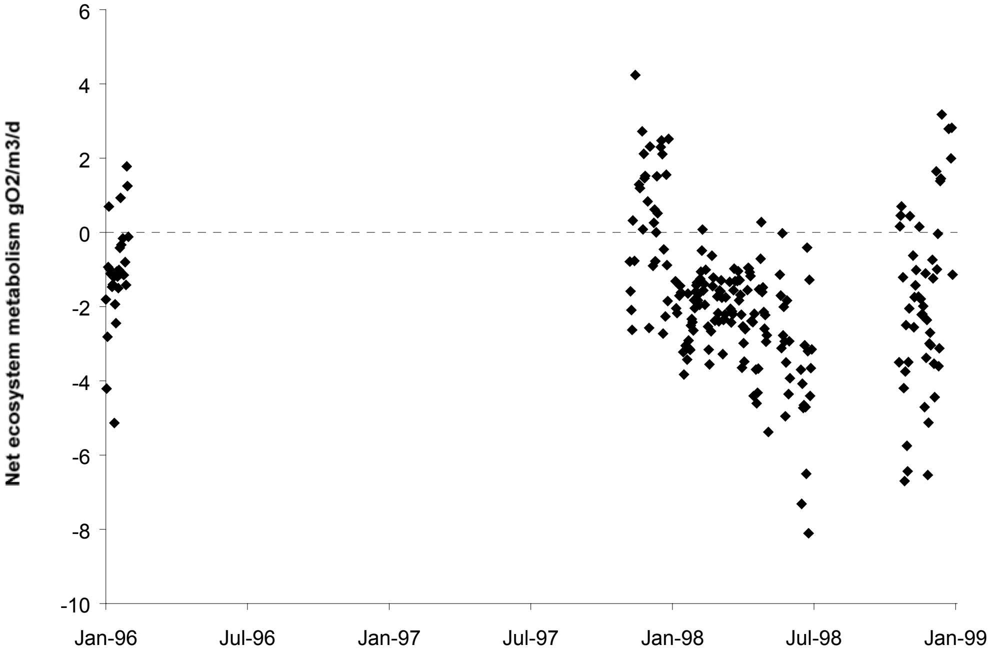


Figure 189. Net metabolism at Fish River, 1996-1998.

Table 36. Summary of metabolism data and statistics at Fish River, 1996-1998.

Fish River	mean	s.e.
Water depth (m)	2.0	
Net production gO_2/m3/d	0.54	0.24
Gross production gO_2/m3/d	1.54	0.22
Total respiration gO_2/m3/d	2.40	0.21
Net ecosystem metabolism g O_2/m3/d	-0.86	0.24
Net ecosystem metabolism g C/m2/y	-129	
P/R	0.64	
Statistical results		
Drift – paired t-test		
Gross production	$p = 0.002$	
Total respiration	$p = 0.02$	
Net ecosystem metabolism	ns	
Percent useable observations	78 %, 12 %	
Paired t-test on gross production and total respiration	$p < 0.001$	
Correlation coefficient	Temperature	Salinity
Gross production	ns	0.37
Total respiration	ns	ns
Net ecosystem metabolism	ns	0.38

Weeks Bay, Weeks Bay (WKBWB)

Characterization (Latitude = 30°22’51”N; Longitude = 87°49’58”W)
Tides at Weeks Bay site are diurnal and range from 0.2 m to 0.6 m (average 0.4 m). The monitoring site is located near the southeastern shore of Weeks Bay, about 0.5 km from the mouth of the estuary. The bay is 3.4 km long (mainstream linear dimension), has an average depth of 1.4 m MHW, and an average width of 1500 m. At the sampling site, the depth is 0.9 m MHW and the width is 400 m. Creek bottom habitats are predominantly sand-silt, with no submerged aquatic vegetation. The dominant marsh vegetation near the sampling site (0.5 km away) is *Spartina alternifolia*. The dominant upland vegetation includes *Quercus virginiana* and *Pinus taeda*. Upland land use near the sampling site is almost exclusively residential development, with some agriculture inland. Activities that potentially impact the site include non-point source nutrient loading, and increased sedimentation due to disturbed soil caused by new home construction sites.

Descriptive statistics
Seventy-two deployments were made at this site between Jan 1996 and Dec 1998, with equal coverage during all seasons (Figure 190). Mean deployment duration was 14.3 days. Only three deployments (Apr 1997, Sep 1997, Jan 1998) were less than 10 days.

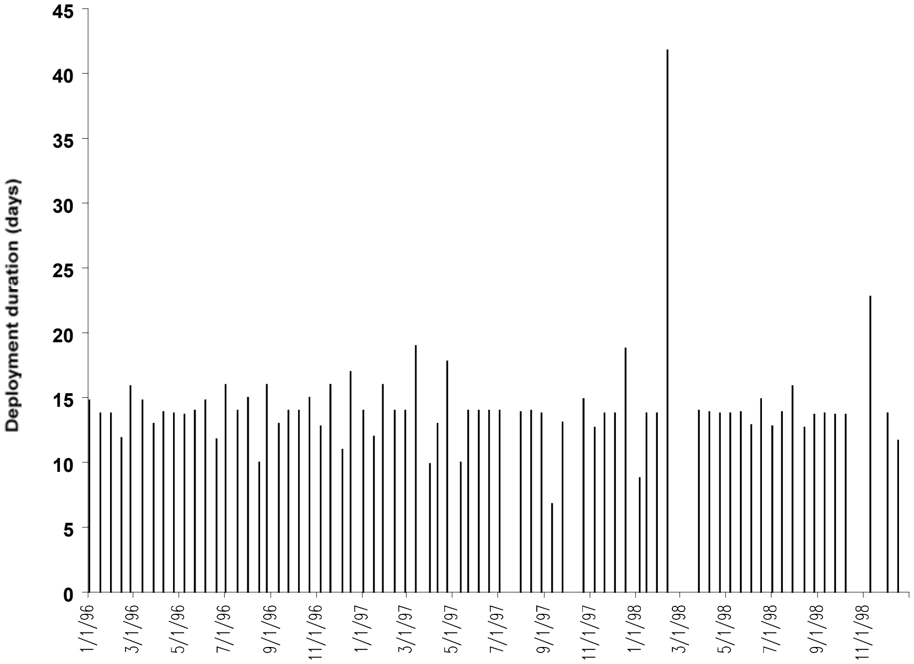


Figure 190. Weeks Bay, Weeks Bay deployments (1996-1998).

Ninety-one percent of annual depth data were included in analyses (99% in 1996, 86% in 1997 and 1998). Sensors were deployed at a mean depth of 0.6 m below the water surface and 0.5 m above the bottom sediment. Scatter plots suggest moderate fluctuations (≤ 1 m) in daily and bi-weekly depth readings throughout the data set, except for Sep 1998 when depth fluctuated almost 2 m. Harmonic regression analysis attributed 79% of depth variance to interaction between 12.42 hour and 24 hour cycles, 20% of depth variance to 24 hour cycles, and 1% of depth variance to 12.42 hour cycles.

Ninety-one percent of annual water temperature data were included in analyses (99% in 1996, 86% in 1997 and 1998). Mean water temperature followed a seasonal cycle, with typical water temperatures 13-15°C in winter and 28-31°C in summer (Figure 191). Minimum and maximum water temperature between 1996-1998 was 1.6°C (Feb 1996) and 35.4°C (Jul 1998), respectively. Scatter plots suggest moderate fluctuations (1-3°C) in daily water temperature and strong fluctuations (3-6°C) in bi-weekly water temperature throughout the data set, with strongest fluctuations (6-14°C) in bi-weekly water temperatures during episodic events in fall and winter. Harmonic regression analysis attributed 49% of temperature variance to interaction between 12.42 hour and 24 hour cycles, 47% of temperature variance to 24 hour cycles, and 4% of temperature variance to 12.42 hour cycles.

Ninety-one percent of annual salinity data were included in analyses (99% in 1996, 86% in 1997 and 1998). Mean salinity followed a seasonal cycle, with typical salinity 2-6 ppt in winter and spring and 10-15 ppt in summer and fall (Figure 192). Minimum salinity between 1996-1998 regularly approached 0 ppt in winter and spring. Maximum salinity between 1996-1998 was 22 ppt (Nov 1996). Scatter plots suggest strong variance in bi-weekly salinity equivalent to, or in excess of, annual variation in mean salinity in winter, summer, and fall 1996, all of 1997 except Jun and Jul, and all of 1998 except for Mar and Apr. Harmonic regression analysis attributed 65% of salinity variance to interaction between 12.42 hour and 24 hour cycles, 30% of salinity variance to 24 hour cycles, and 5% of salinity variance to 12.42 hour cycles.

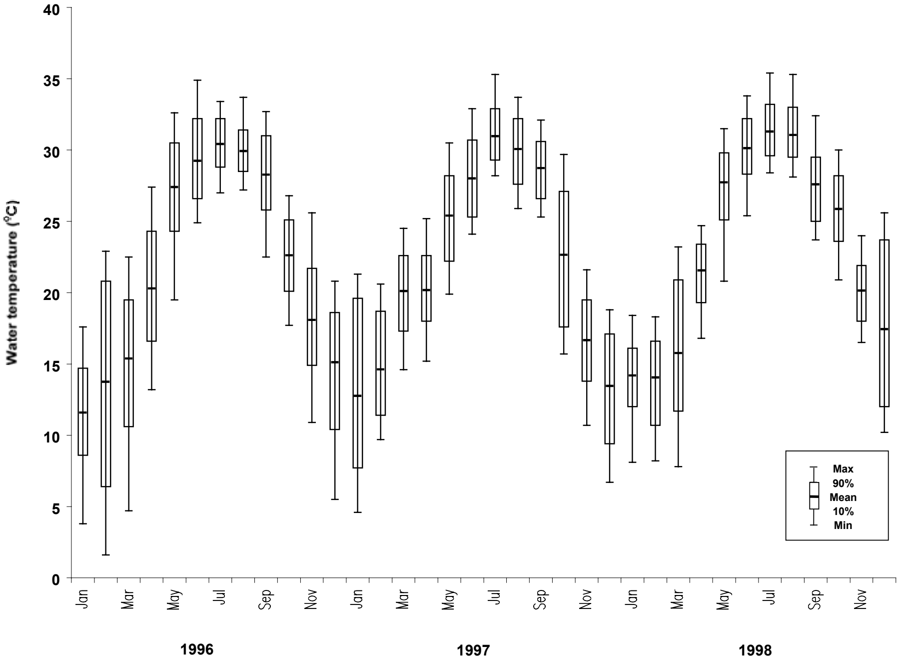


Figure 191. Water temperature statistics at Weeks Bay, 1996-1998.

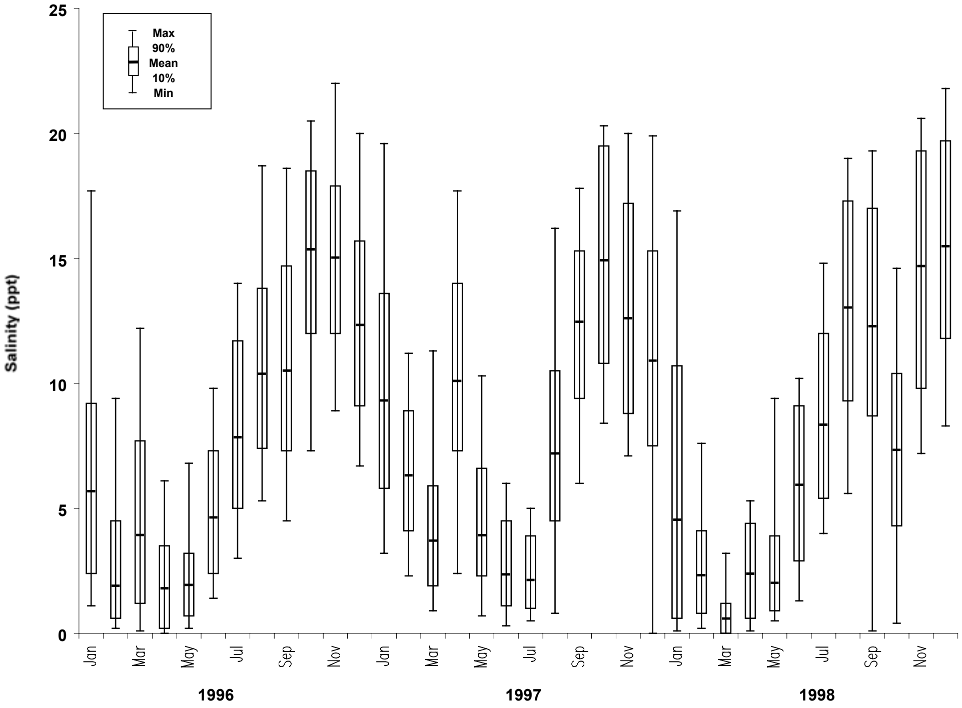


Figure 192. Salinity statistics at Weeks Bay, 1996-1998.

Seventy-six percent of annual dissolved oxygen (% saturation) data were included in analyses (88% in 1996, 74% in 1997, and 67% in 1998). Mean DO was 60-117% saturation throughout the data set, except for Jul (34% sat) and Nov-Dec (127-136% sat) 1997. Mean DO was greatest in winter, spring, and fall (67-136% sat) and least in summer (34-93% sat). Minimum and maximum DO between 1996-1998 was 0% saturation (Apr, Jun-Jul 1997) and 193.7% saturation (Jun 1998), respectively. Persistent hypoxia was never observed, but supersaturation was regularly observed (Figure 193). Scatter plots suggest moderate fluctuations (40-80%) in percent saturation in winter 1996 and 1998, with strong fluctuations (80-180%) throughout the data set. Harmonic regression analysis attributed 60% of DO variance to interaction between 12.42 hour and 24 hour cycles, 32% of DO variance to 24 hour cycles, and 8% of DO variance to 12.42 hour cycles.

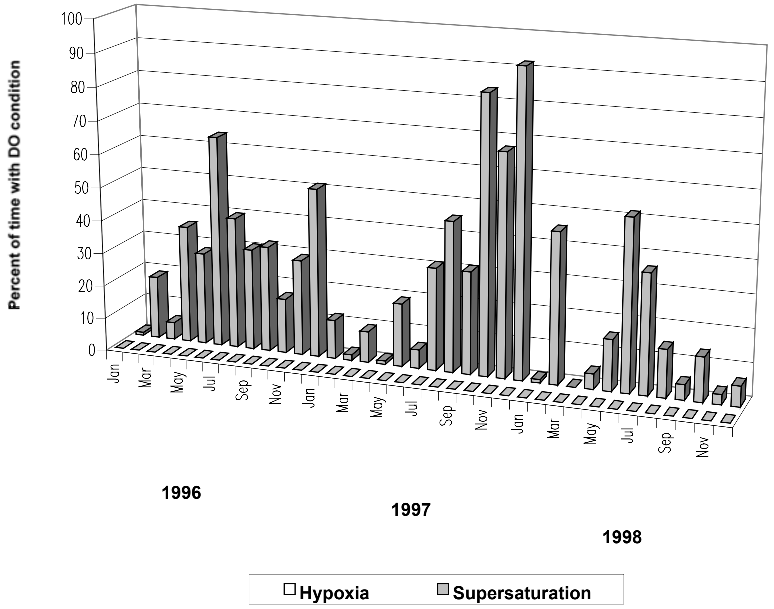


Figure 193. Dissolved oxygen extremes at Weeks Bay, 1996-1998.

Photosynthesis/Respiration

Three quarters (75%) of the data used to calculate the metabolic rates fit the basic assumption of the method (heterogeneity of water masses moving past the sensor) and was used to estimate net production, gross production, total respiration and net ecosystem metabolism (Table 37). Total respiration exceeded gross production at Weeks Bay; thus, the net ecosystem metabolism and P/R ratio indicated that this was a heterotrophic site (Figure 194). Temperature was significantly ($p<0.05$) correlated with gross production and total respiration. Gross production increased as temperature increased, while net ecosystem metabolism became more heterotrophic as temperature increased. Salinity was significantly ($p<0.05$) correlated with net ecosystem metabolism. Net ecosystem metabolism became more heterotrophic as salinity increased. Thus, the metabolic rates generally followed a seasonal pattern with the lowest rates during the winter when temperature and salinity were low and the highest rates during summer months, although summer rates could be highly variable.

Table 37. Summary of metabolism data and statistics at Weeks Bay, 1996-1998.

Weeks Bay	mean	s.e.
Water depth (m)	1.3	
Net production $gO_2/m3/d$	1.31	0.29
Gross production $gO_2/m3/d$	3.62	0.48
Total respiration $gO_2/m3/d$	4.3	0.48
Net ecosystem metabolism g $O_2/m3/d$	-0.78	0.32
Net ecosystem metabolism g C/m2/y	40	
P/R	0.84	
Statistical results		
Drift – paired t-test		
Gross production	ns	
Total respiration	ns	
Net ecosystem metabolism	ns	
Percent useable observations	75 %	
Paired t-test on gross production and total respiration	$p < 0.001$	
Correlation coefficient	Temperature	Salinity
Gross production	0.68	ns
Total respiration	0.64	ns
Net ecosystem metabolism	ns	-0.33

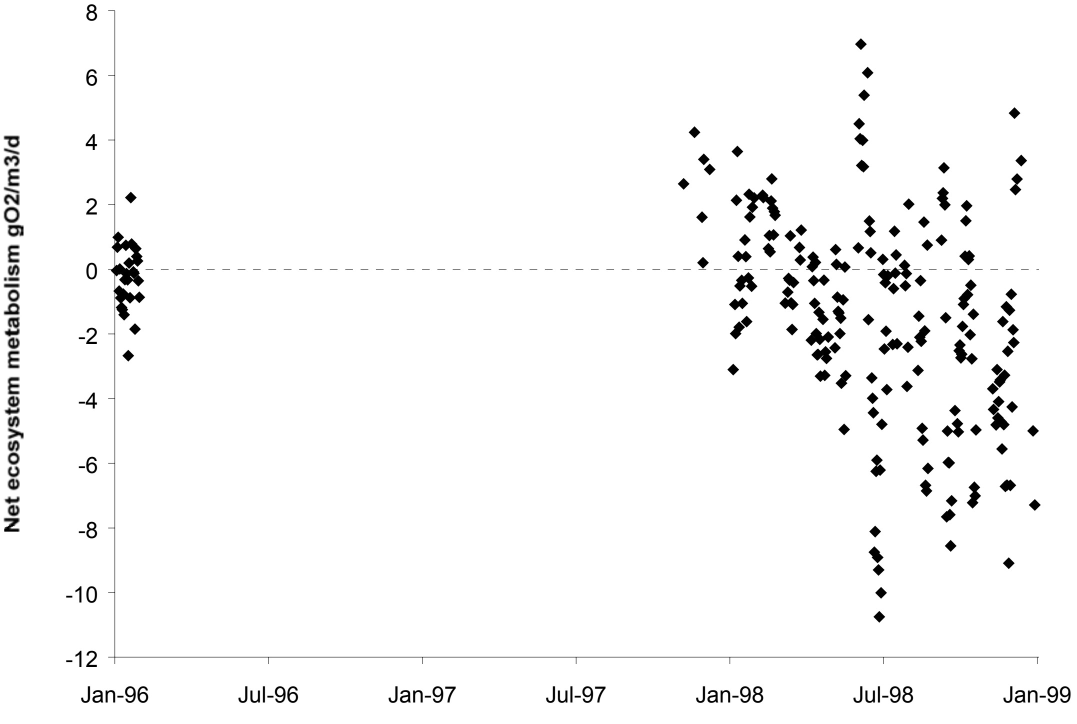


Figure 194. Net metabolism at Weeks Bay, 1996-1998.

Reserve comparisons

Summer

Mean salinity, salinity range, and frequency of hypoxia and supersaturation were compared among sites within a reserve for summer (June 21-Sept. 21) 1997-98 using t-tests. Mean salinity and mean salinity range were significantly different for most sites and reserves (Table 38). No significant differences in mean salinity were observed for the Chesapeake Bay-MD, Jobos Bay, and Narragansett Bay reserves. No significant differences in mean salinity range were observed for the ACE Basin, Apalachicola Bay, Hudson River, Narragansett Bay and North Inlet reserves. Few significant differences were detected for hypoxia or supersaturation. Hypoxia was significantly different among sites at the Delaware Bay, Elkhorn Slough, Padilla Bay and Rookery Bay reserves (Table 39). Supersaturation was significantly different among sites within the Chesapeake Bay-VA, Elkhorn Slough, Jobos Bay, Tijuana River, and Weeks Bay reserves (Table 39).

Seasonal

Seasonal patterns in the percent of time (first 48 hours post-deployment) that hypoxia and supersaturation occurred when data from all reserves were combined. Hypoxia was most prevalent in summer, while supersaturation was most prevalent in spring (Figure 195).

Analysis of frequency of hypoxia revealed few seasonal differences at the reserve level. The only reserves for which significant seasonal hypoxic conditions occurred were in the ACE Basin, North Inlet, Padilla Bay, Rookery Bay and Tijuana River reserves (Table 40). At these reserves, hypoxia was greatest in summer, with the exception of Padilla Bay where hypoxia was most prevalent in fall. Within reserves, significant seasonal differences in the frequency of hypoxia occurred at the Oyster Landing and Thousand Acre sites (North Inlet), Joe Leary Slough (Padilla Bay), Blackwater River and Upper Henderson sites (Rookery Bay) and Oneonta Slough and Tidal Linkage sites (Tijuana River). Hypoxic conditions were most prevalent at both North Inlet and Tijuana sites and at the Blackwater River site in summer. At the Upper Henderson site (Rookery Bay), hypoxia occurred with greatest frequency in spring. Hypoxia was most prevalent at Joe Leary Slough (Padilla Bay) in fall.

Analysis of frequency of supersaturation revealed few seasonal differences at the reserve level. The only reserves where significant seasonal supersaturation occurred were Padilla Bay, South Slough, Tijuana, and Weeks Bay (Table 40). For these reserves, supersaturation occurred with the greatest frequency during spring, except for Weeks Bay where supersaturation was most prevalent in fall. At sites within reserves, significant seasonal differences in supersaturation occurred at East Bay Surface (Apalachicola), Blackbird Landing (Delaware Bay), Bayview Channel (Padilla Bay), Stengstacken Arm (South Slough), Head of Tide (Wells), and Fish River and Weeks Bay (Weeks Bay). Supersaturation was most prevalent at East Bay Surface, Bayview Channel, and Stengstacken in spring, while supersaturation occurred most frequently at Weeks Bay sites in fall. Supersaturation was most prevalent at the Head of Tide site in summer and most prevalent at the Blackbird Landing site in fall and spring.

Analysis of salinity revealed significant differences at the reserve level. Lowest mean salinity was generally observed in winter or spring, depending upon reserve site. Analysis of mean salinity at each site within a reserve indicated that significant differences were observed for all sites except for Tivoli South in the Hudson River NERR (Table 41). Analysis of salinity range indicated significant differences for all reserves except Chesapeake Bay-VA, Hudson River, Jobos Bay, North Inlet, and Waquoit Bay (Table 41). The season when lowest mean salinity range occurred varied by reserve. Seasonal differences in salinity range were found for all sites except for Hudson River sites, Station 10 at Jobos Bay, State Route 2 at Old Woman Creek, and Central Basin at Waquoit Bay (Table 41).

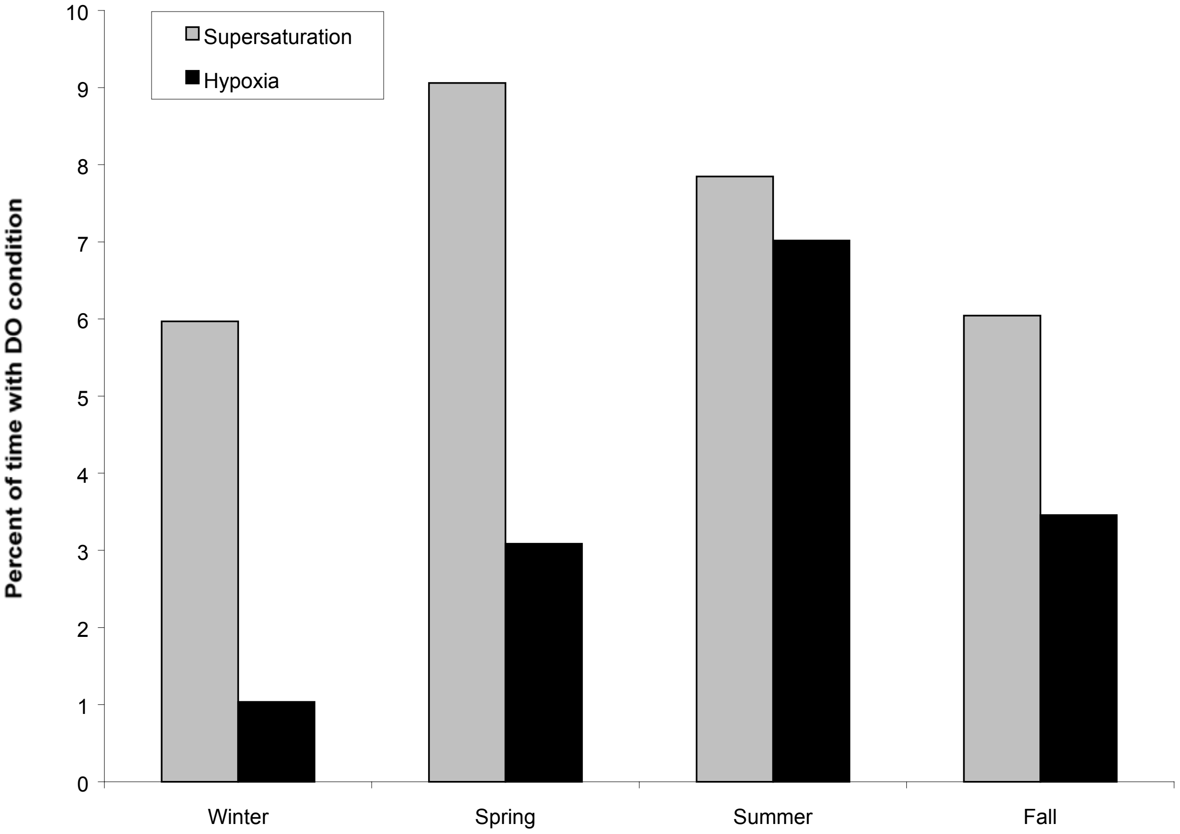


Figure 195. Seasonal patterns of mean hypoxia and supersaturation for all sites, 1997-1998.

Table 38. Results of statistical analysis to determine significant differences in mean salinity and salinity range between sites within each Reserve (* t-test for unequal variances; ** p < 0.05).

Site	Mean	df	t-stat	p-value	Range	df	t-stat	p-value
ELKAP	32.67	200.7*	5.783*	0**	2.04	332	7.64	0**
ELKSM	31.10				1.25			
PDBBY	28.23	306.9*	86.00*	0**	1.22	205.4*	-82.75*	0**
PDBJL	10.68				18.26			
SOSSE	No Data				No Data			
SOSWI	No Data				No Data			
TJROS	31.21	233.9	8.193	0**	1.96	148*	-14.08*	0**
TJRTL	29.83				5.49			
GRBGB	24.99	232.8*	6.682*	0**	1.81	202.4*	-31.28*	0**
GRBSQ	19.84				10.12			
HUDSK	0.19	122*	45.761*	0**	0.00	122*	1.75*	0.08
HUDTS	0.10				0.00			
NARPC	27.71	217	-1.874	0.06	1.51	216.4*	1.92*	0.06
NARTW	28.39				1.19			
OWCSU	0.25	355.3*	18.98*	0**	0.02	351.4*	-2.88*	0**
OWCWM	0.16				0.03			
WQBCB	No Data				No Data			
WQBMP	No Data				No Data			
WELHT	6	201.3*	-46.88*	0**	9.91	312.1*	7.14*	0**
WELIN	30.53				4.45			
CBMJB	0.19	203.8*	-1.06*	0.29	0.04	127*	-7.55*	0**
CBMPR	0.20				0.14			
CBVGI	19.27	268	23.68	0**	0.62	251.3*	-43.31*	0**
CBVTC	12.27				6.94			
DELBL	3.94	329.8*	-41.88*	0**	1.45	197.8*	-42.30*	0**
DELSL	13.32				11.67			
MULB6	29.22	294.3*	94.30*	0**	3.23	300.4*	-15.90*	0**
MULBA	4.71				7.28			
ACEBB	32.48	269	10.07	0**	5.29	269	-0.55	0.58
ACESP	29.41				5.54			
NIWOL	30.41	330	39.51	0**	4.11	253.3*	-1.48*	0.14
NIWTA	9.76				4.74			
NOCMS	28.44	291.6*	3.68*	0**	4.89	275.0*	3.47*	0**
NOCZI	26.35				3.55			
SAPFD	24.46	366	-11.57	0**	1.25			
SAPML	26.84				5.37			
APAEB	8.65	335.2*	3.46*	0.00**	2.98	370	-1.01	0.31
APAES	6.26				3.39			
JOB09	40.54	13.07*	1.89*	0.08	2.35	13.2*	3.67*	0**
JOB10	39.55				0.25			
RKBBR	19.15	198.2*	7.91*	0**	8.26	276.5*	-6.37*	0**
RKBUH	12.10				11.19			
WKBFR	4.51	354	-10.33	0**	2.25	385.4*	-13.94*	0**
WKBWB	8.88				5.33			

Table 39. Results of statistical analysis to determine significant differences in percent of deployment (first 48 h) with hypoxia (<28% saturation) or supersaturation (>120% saturation) between sites within a Reserve, Jul-Aug 1997 and 1998 (* t-test for unequal variances; ** p < 0.05).

Site	Hypoxia	df	t-stat	p-value	Supersaturation	df	t-stat	p-value
ELKAP	20.62	6*	3.94*	0.01**	30.19	6.09*	8.52*	0**
ELKSM	0				0.29			
PDBBY	0	11*	-2.55*	0.03**	6.19	16	0.90	0.38
PDBJL	2.58				2.92			
SOSSE	No Data				No Data			
SOSWI	No Data				No Data			
TJROS	23.14	18	-0.92	0.37	12.16	9.56*	-3.89*	0**
TJRTL	30.19				19.25			
GRBGB	0				3.09	10*	1.49*	0.17
GRBSQ	0				0			
HUDSK	0	9*	-1.40*	0.19	0	9*	-1.00*	0.34
HUDTS	0.31				0.31			
NARPC	1.18	7	0.06	0.95	7.80	7	0.71	0.50
NARTW	0.03				0			
OWCSU	12.85	14.98*	1.76*	0.10	1.86	33	-0.67	0.50
OWCWM	2.32				3.97			
WQBCB	No Data				No Data			
WQBMP	No Data				No Data			
WELHT	0	4*	-1.58*	0.19	1.80	7	-0.55	0.60
WELIN	7.93				3.71			
CBMJB	No Data				No Data			
CBMPR	No Data				No Data			
CBVGI	0	17	-1.20	0.25	20.65	28	2.40	0.02*
CBVTC	0.69				6.30			
DELBL	20.96	11.08*	2.04*	0.04**	0.60	18.02*	-0.70*	0.49
DELSL	1.03				1.51			
MULB6	0				4.14	16	0.65	0.52
MULBA	0				1.83			
ACEBB	0.78	13.72*	-1.19*	0.26	6.8	9.19*	1.94*	0.08
ACESP	2.6				0.34			
NIWOL	9.08	16	-0.23	0.82	3.09	16	-0.98	0.34
NIWTA	10.42				6.19			
NOCMS	0				13.01	19	0.46	0.65
NOCZI	0				7.74			
SAPFD1	0.66	10*	1.41*	0.19	1.12	21	0.69	0.50
SAPML	0				0.34			
APAEB	3.19	20	-0.54	0.60	19.59	12.86*	1.43*	0.18
APAES	8.09				7.89			
JOB09	40.54	13.07*	1.89*	0.08	2.35	13.17*	3.67*	0**
JOB10	39.55				0.25			
RKBBR	65.46	8	3.4	0.01**	0			
RKBUH	20.03				0			
WKBFR	0				3.78	13	-4.60	0**
WKBWB	0				32.65			

Table 40. Results of statistical analyses to determine differences in hypoxia and supersaturation (first 48 h) among sites within a Reserve and between seasons at each site and each Reserve ($^{\#}$statistic used was χ^2, One-Way ANOVA (F) or *t-test for unequal variances; ** $p < 0.05$).

		Hypoxia			**Supersaturation**		
Reserve		*df*	*statistic*$^{\#}$	*p-value*	*df*	*statistic*$^{\#}$	*p-value*
Elkhorn Slough							
	Sites	27.0*	4.7*	0**	44.2*	3.8*	0**
	Overall	3	3.8	0.29	3/44	0.8 (F)	0.48
	ELKAP	3/21	2.8 (F)	0.07	3	7.0	0.07
	ELKSM	3	0.1	0.99	3	3.6	0.31
Padilla Bay							
	Sites	44*	-4.9*	0**	20.08*	2.5*	0.02**
	Overall	3	8.2	0.04**	3	17.7	0**
	PDBBY	--	------	------	3	15.5	0**
	PDBJL	3	10.7	0.01**	3	7.8	0.05
South Slough							
	Sites	10	0.6	0.59	100.0	0.98	
	Overall	2	2.0	0.37	2	9.3	0.01**
	SOSSE	2	2.0	0.37	2	6.6	0.04**
	SOSWI	--	-------	------	--	------	-------
Tijuana R. Estuary							
	Sites	58.7*	-1.7*	0.10	72	-2.4	0.02**
	Overall	3	30.4	0**	3/70	2.9 (F)	0.04**
	TJROS	3	17.7	0**	3	7.7	0.05
	TJRTL	3/29	6.5 (F)	0**	3/29	2.3 (F)	0.10
Great Bay							
	Sites	--	-------	------	40	1.0	0.34
	Overall	--	-------	------	2	2.9	0.24
	GRBGB	--	-------	------	2/22	0.5 (F)	0.61
	GRBSQ	--	-------	------	2	3.6	0.17
Hudson River							
	Sites	28*	-1.4*	0.19	28*	-1.3*	0.21
	Overall	3	5.0	0.17	3	0.6 (F)	0.65
	HUDSK	--	-------	------	--	--------	------
	HUDTS	2	5.4	0.06	2	1.5	0.48
Narragansett Bay							
	Sites	35	0.2	0.85	35	0.9	0.39
	Overall	3	7.5	0.06	3	2.8	0.43
	NARPC	3	3.5	0.32	3	4.8	0.19
	NARTW	3	4.0	0.26	3/6	0.4 (F)	0.76
Old Woman Creek							
	Sites	31.5*	1.7*	0.10	1/59	1.4 (F)	0.25
	Overall	2/62	0.4 (F)	0.70	2/62	0.2 (F)	0.80
	OWCSU	2/27	0.2 (F)	0.83	2/27	0.2 (F)	0.82
	OWCWM	2	5.3	0.07	2/32	0.1	0.88
Waquoit Bay							
	Sites	--	-------	------	19.9*	6.0*	0**
	Overall	--	-------	------	2/19	3.0 (F)	0.07
	WQBCB	--	-------	------	2/17	1.6 (F)	0.22
	WQBMP		fall data only			fall data only	
Wells							
	Sites	17.1*	-2.3*	0.03**	28	-1.0	0.33
	Overall	3	0.8	0.84	3	4.8	0.18
	WELHT	2	2.0	0.37	2	6.8	0.03*
	WELIN	3	1.6	0.66	3	3.0	0.40
Chesapeake Bay, MD							
	Sites		No Data			No Data	
	Overall		No Data			No Data	
	CBMJB		No Data			No Data	
	CMBPR		No Data			No Data	

Table 40. Continued.

	Hypoxia			Supersaturation		
Reserve	*df*	*statistic*$^{\#}$	*p-value*	*df*	*statistic*$^{\#}$	*p-value*
Chesapeake Bay, VA						
Sites	51.5*	-1.7*	0.10	84	3.6	0**
Overall	3	3.4	0.33	3	3.3	0.35
CBVGI	3	2.4	0.50	3/33	0.7 (F)	0.54
CBVTC	3	5.6	0.13	3/45	0.4 (F)	0.77
Delaware Bay						
Sites	44.3*	2.1*	0.04**	52.5*	2.1*	0.04**
Overall	3	5.3	0.15	3	4.4	0.22
DELBL	3	5.5	0.14	3	8.4	0.04**
DELSL	3	1.4	0.70	3	2.1	0.56
Jacques Cousteau - Mullica River						
Sites	--	-------	------	62	0.6	0.53
Overall	--	-------	------	3	4.3	0.23
MULB6	--	-------	------	3/29	0.6 (F)	0.65
MULBA	--	-------	------	3	3.7	0.29
ACE Basin						
Sites	31.7*	-1.2*	0.25	27.2*	1.9*	0.07
Overall	3	8.7	0.03**	3	1.9	0.59
ACEBB	3	2.5	0.47	3	2.0	0.57
ACESP	3	6.9	0.08	3/24	0.4 (F)	0.78
North Inlet-Winyah Bay						
Sites	81	-1.0	0.33	81	0.9	0.37
Overall	3	39.1	0**	3/79	0.5 (F)	0.69
NIWOL	3	12.8	0.01**	3/39	0.3 (F)	0.81
NIWTA	3	23.3	0**	3	5.6	0.14
North Carolina						
Sites	84	0.9	0.35	72.3	1.5	0.14
Overall	3	4.1	0.26	3	0.7 (F)	0.57
NOCMS	3	4.1	0.25	3/42	0.2 (F)	0.91
NOCZI	--	------	------	3/36	0.8 (F)	0.49
Sapelo Island						
Sites	42*	2.2*	0.03**	45.2*	1.1*	0.28
Overall	3	6.2	0.10	3/81	0.4 (F)	0.75
SAPFD	3	7.1	0.07	3/39	0.6	0.65
SAPML	--	-------	------	3	2.1	0.56
Apalachicola						
Sites	58	-0.6	0.54	46.6*	1.4*	0.17
Overall	3	4.8	0.19	3	5.3	0.15
APAEB	3/23	0.5 (F)	0.66	3	4.7	0.20
APAES	3/29	0.5 (F)	0.67	3	8.4	0.04**
Jobos Bay						
Sites	7*	1.2*	0.27	7.1*	2.1*	0.08
Overall	3/11	0.7 (F)	0.60	3/11	0.3 (F)	0.82
JOB09	2	3.8	0.15	2/5	0.8	0.50
JOB10	--	-------	------	3/3	4.3 (F)	0.65
Rookery Bay						
Sites	20.9*	2.2*	0.04**	57	-0.8	0.45
Overall	3	9.9	0.02**	3	3.8	0.28
RKBBR	3/14	5.6 (F)	0.01**	3	5.0	0.17
RKBUH	3	10.0	0.02**	3	1.6	0.66
Weeks Bay						
Sites	40*	1.0*	0.31	80*	-2.0*	0.05
Overall	3	2.1	0.56	3	17.5	0**
WKBBR	3	2.7	0.45	3	12.0	0.01**
WKBFR	--	-------	------	3	9.5	0.02**

Table 41. Results of statistical analyses to determine differences in salinity and salinity range among sites within a reserve and between seasons at each site and each Reserve ($^{\#}$statistic used was χ^2, One-Way ANOVA (F), or * t-test for unequal variances; ** $p < 0.05$).

		Salinity			**Salinity Range**	
Reserve	*df*	*statistic*$^{\#}$	*p-value*	*df*	*statistic*$^{\#}$	*p-value*
Elkhorn Slough						
Sites	1126.5*	-1.2*	0.23	1348 3.8	0**	
Overall	3	476.2	0**	3	334.2	0**
ELKAP	3	303.7	0**	3	158.2	0**
ELKSM	3	158.8	0**	3	196.0	0**
Padilla Bay						
Sites	1096*	136.9*	0**	795.6*	-110.1*	0**
Overall	3	78.3	0**	3	15.1	0**
PDBBY	3	149.6	0**	3	62.9	0**
PDBJL	3	195.7	0**	3	57	0**
South Slough						
Sites	427.4*	1.4*	0.17	427.9*	0.9*	0.37
Overall	2	115.2	0**	2	105.1	0**
SOSSE	2	86.6	0**	2/193	54.3 (F)	0**
SOSWI	2	44.6	0**	2	66.7	0**
Tijuana R. Estuary						
Sites	993.6*	6.1*	0**	1092.0*	-6.83*	0**
Overall	3	179.2	0**	3	159.8	0**
TJROS	3	112.3	0**	3	195.3	0**
TJRTL	3	119.5	0**	3	18.0	0**
Great Bay						
Sites	541.7*	9.3*	0**	405.2*	-34.6*	0**
Overall	2	288.8	0**	2	14.6	0**
GRBGB	2	260.4	0**	2	185.5	0**
GRBSQ	2/310	219.8 (F)	0**	2	21.6	0**
Hudson River						
Sites	388.6*	32.4*	0**	510.8*	3.5*	0**
Overall	2	64.2	0**	2	5.0	0.08
HUDSK	2	194	0**	2	3.55	0.17
HUDTS	2	3.39	0**	2	3.37	0.19
Narragansett Bay						
Sites	817.8*	-12.1*	0**	976.3*	1.1*	0.28
Overall	3	385.4	0**	3	289.4	0**
NARPC	3	302.9	0**	3	166.6	0**
NARTW	3	167.1	0**	3	141.5	0**
Old Woman Creek						
Sites	761.6*	28.6*	0**	810.8*	-5.8*	0**
Overall	2	11.1	0**	2	30.3	0*
OWCSU	2	10.5	0.01*	2	3.6	0.17
OWCWM	2	9.7	0.01*	2	38.3	0*
Waquoit Bay						
Sites	120.7*	-0.7*	0.47	75.1*	2.8*	0.01*
Overall	2/335	45.9 (F)	0**	2	3.7	0.16
WQBCB	2/288	48.8 (F)	0**	2	2.5	0.29
WQBMP		fall data only			fall data only	
Wells						
Sites	639.1*	-104.8*	0**	945.4*	2.4*	0.20*
Overall	3	220.4	0**	3	45.5	0**
WELHT	3	150.9	0**	3	80.7	0**
WELIN	3	137.5	0**	3	19.3	0**
Chesapeake Bay, MD						
Sites	272.1*	-3.6*	0**	181.52*	-9.8*	0**
Overall	2	35.4	0**	2	16.3	0**
CBMJB	2	34.8	0**	2	14.6	0**
CMBPR	2	15.4	0**	2	15.9	0**

Table 41. Continued.

		Salinity			**Salinity Range**	
Reserve	*df*	*statistic*$^{\#}$	*p-value*	*df*	*statistic*$^{\#}$	*p-value*
Chesapeake Bay, VA						
Sites	1102	35.8	0**	866.5*	-57.1*	0**
Overall	3	435.0	0**	3	5.5	0.14
CBVGI	3	316.1	0**	3	86.2	0**
CBVTC	3	469.1	0**	3	234.8	0**
Delaware Bay						
Sites	1027.8*	-34.2*	0**	824.2*	-76.4*	0**
Overall	3	448.8	0**	3	80.4	0**
DELBL	3	497.9	0**	3	386.6	0**
DELSL	3	347.2	0**	3	46.0	0**
Jacques Cousteau - Mullica River						
Sites	1077.9*	171.4*	0**	1208.1*	1.82*	0.07
Overall	3	93.9	0**	3	45.4	0**
MULB6	3	213.1	0**	3	309.4	0**
MULBA	3	399.1	0**	3	377.9	0**
ACE Basin						
Sites	981*	10.2*	0**	1098	-0.1	0.94
Overall	3	368.9	0**	3	103.1	0**
ACEBB	3	281.9	0**	3/631	9.9 (F)	0**
ACESP	3	158.2	0**	3	51.8	0**
North Inlet-Winyah Bay						
Sites	1277.9*	74.4*	0**	839.0*	9.8*	0**
Overall	3	82.9	0**	3	3.6	0.30
NIWOL	3	51.0	0**	3	99.1	0**
NIWTA	3	363.5	0**	3	184.2	0**
North Carolina						
Sites	932.8*	16.5*	0**	949.9*	14.7*	0**
Overall	3	142.9*	0**	3	199.9	0**
NOCMS	3	25.4	0**	3	107.4	0**
NOCZI	3	241.5	0**	3	133.1	0**
Sapelo Island						
Sites	1403.6*	-8.6*	0**	831.3*	-40.8*	0**
Overall	3	502.6	0**	3	55.1	0**
SAPFD	3	278.3	0**	3/714	13.7 (F)	0**
SAPML	3	266.3	0**	3	274.7	0**
Apalachicola						
Sites	1360.4*	4.7*	0**	1397	-0.3	0.76
Overall	3/1395	213.7 (F)	0**	3	257.5	0**
APAEB	3	228.2	0**	3	124.9	0**
APAES	3/665	111.4 (F)	0**	3	136.0	0**
Jobos Bay						
Sites	53.5*	-0.7*	0.47	67.1*	6.0*	0**
Overall	3	25.9	0**	3/180	0.9 (F)	0.43
JOB09	3	25.9	0**	3/152	7.0 (F)	0**
JOB10	1	4.1	0.04**	1/26	1.6 (F)	0.22
Rookery Bay						
Sites	1002	5.0	0**	739.7*	-7.5*	0**
Overall	3	330.1	0**	3	152.8	0**
RKBBR	3	179.4	0**	3	118.1	0**
RKBUH	3	202.1	0**	3	94.9	0**
Weeks Bay						
Sites	1327	-13.06	0**	1114.7*	-18.2*	0**
Overall	3	559.9	0**	3	302.4	0**
WKBBR	3	308.6	0**	3	158.5	0**
WKBFR	3	300.0	0**	3	213.5	0**

Inter-annual

Summer hypoxia (Jul-Aug) varied at reserve sites among years (1997-1998). Few sites experienced hypoxia for more than 20% of the first 48 hours post-deployment. In 1997, four sites (Blackbird Landing, Delaware Bay; Tidal Linkage, Tijuana River; State Route 2, Old Woman Creek; and East Bay Surface, Apalachichola Bay) experienced hypoxia for >20% of the first 48 hours post-deployment (Figure 196). In 1998, the Tidal Linkage site and four additional sites (Oneonta Sough, Tijuana Riveder; Jug Bay, Chesapeake Bay-MD; Oyster Landing, North Inlet-Winyah Bay; and Azevedo Pond, Elkhorn Slough) experienced hypoxia for >20% of the first 48 hours post-deployment. In 1998, one site (Blackwater River, Rookery Bay) experienced hypoxia > 80% of the first 48 hours post-deployment. Correlation of percent of time with hypoxia and supersaturation among years (1997 and 1998) was performed to determine whether consistent annual patterns existed. Analysis using Kendall's tau indicated no significant correlation (τ=0.28, p=0.054) for hypoxia during the first 48 hours post-deployment in summer (July and August) 1997 and 1998. A significant, positive correlation (τ= 0.48, p=0.002) was found for increasing hypoxia during the first 14 days post-deployment during these years.

Three sites (Central Basin, Waquoit Bay; Weeks Bay; and Azevedo Pond, Elkhorn Slough) experienced supersaturation for more than 20% of the first 48 hours post-deployment in both Jul-Aug 1997 and 1998. One additional site in 1997 (Taskinas Creek, Chesapeake Bay-VA) and two additional sites in 1998 (Station 9 at Jobos Bay, data only available for August 1998; and East Bay Bottom, Apalachichola Bay) experienced supersaturation for more than 20% of the first 48 hours post-deployment (Figure 197). Results of correlation analysis for supersaturation indicated no significance during the first 48 hours post-deployment (τ=0.16, p=0.25) or for data collected during the first 14 days post-deployment (τ=0.08, p=0.55). Not surprisingly, the association for hypoxia and supersaturation data taken within 2 days post-deployment was highly correlated with those data taken within 14 days after deployment (Table 42). Hypoxia during the first 48 hours and first 14 days post-deployment was correlated regardless of year, whereas supersaturation during the first 48 hours and first 14 days post-deployment data was only correlated within the same year.

Table 42. Results of Kendall's tau correlation analysis (τ and p) for hypoxia and supersaturation from data taken within 48 h post-deployment and 14 days post-deployment for summer (July and August) 1997 and 1998.

Variable	2 d Hypox 97	2 d Hypox 98	2 d Supersat. 97	2 d Supersat 98
14 d Hypox 97	0.73 (0.001)	0.29 (0.03)		
14 d Hypox 98	0.38 (0.006)	0.72 (0.000)		
14 d Supersat 97			0.74 (0.001)	0.07 (0.58)
14 d Supersat 98			0.09 (0.44)	0.67 (0.001)

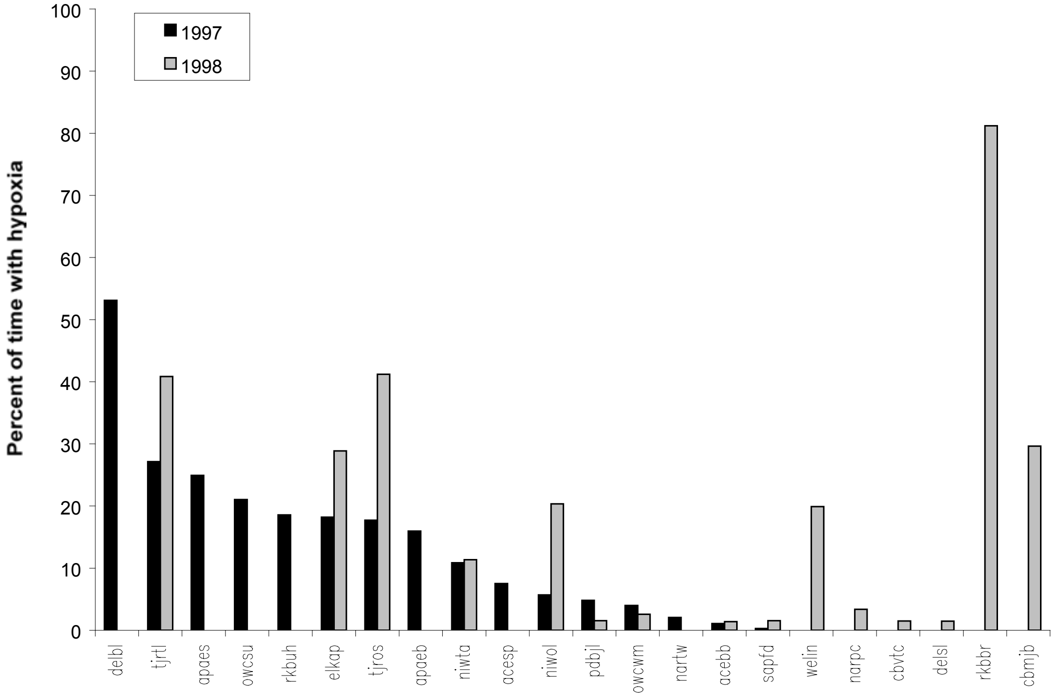


Figure 196. Percent of first 48 hours post-deployment with hypoxia, Jul and/or Aug 1997-1998. If sites are not listed, no data was available for either Jul or Aug in either year.

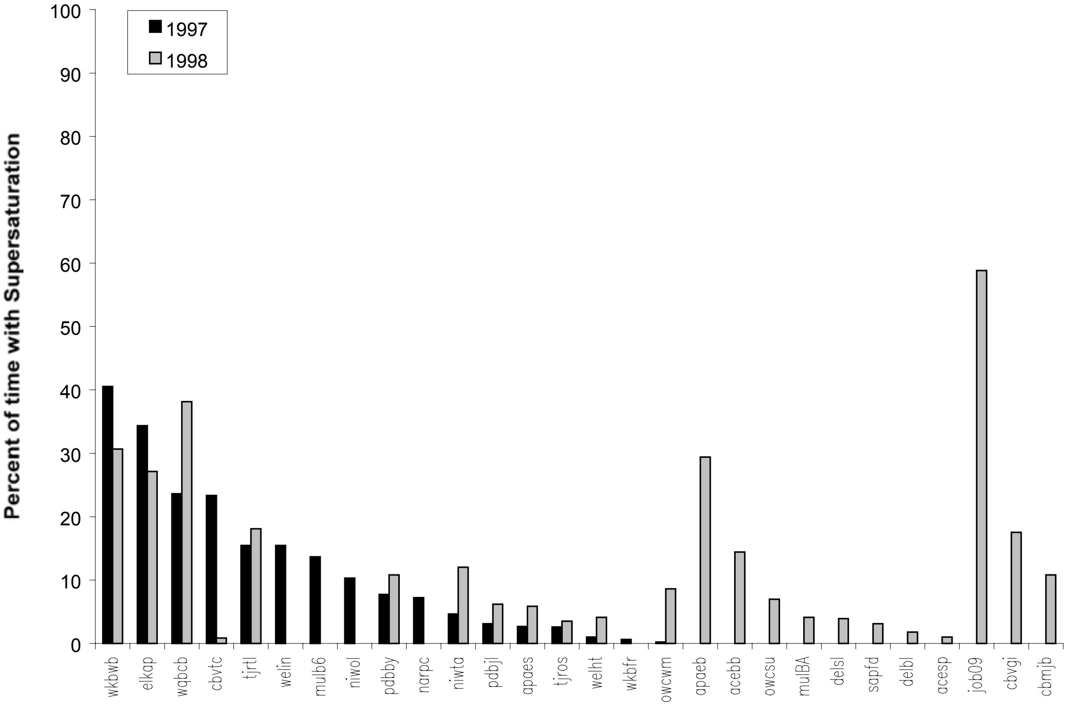


Figure 197. Percent of first 48 hours post-deployment with supersaturation, Jul and/or Aug 1997-1998. If sites are not listed, no data was available for either Jul or Aug in either year.

Duration of hypoxia

Hypoxia occurred throughout all geographic regions in the NERR System. Between 1996-1998, 765 hypoxic events were observed during the first 48 hours post-deployment, with at least one event observed at almost all NERR sites. Hypoxia was most frequently observed at West Coast Reserves (40%), followed by Reserves in the Gulf of Mexico and Caribbean (22%). East Coast Reserves (Southeast, Mid-Atlantic, and Northeast/Great Lakes) contributed similarly to overall hypoxic events (10-16%) and represented the least frequent occurrence of hypoxia geographically (Table 43).

Between 1996-1998, 307 hypoxic events were observed at reserves on the West Coast, 60% of which lasted less than 4 hours (Table 43). Exceptional hypoxia at West Coast sites was primarily due to site selection, limited flushing due to tidal gates and deployment in pond systems. Twenty-six percent of hypoxic events lasted 4-8 hours and 11% of hypoxic events lasted 8-12 hours. Only three percent of hypoxic events lasted between 12-20 hours, and no hypoxic events longer than 24 hours were observed. Hypoxia was observed at all sites in this region except for Bayview Channel (Padilla Bay) and South Marsh (Elkhorn Slough).

Ninety hypoxic events were observed at reserves in the Northeast Coast and Great Lakes region, 87% of which lasted less than 4 hours (Table 43). Seven percent of hypoxic events lasted 4-8 hours and four percent of hypoxic events lasted 8-12 hours. Only one percent of hypoxic events lasted as long as 20 hours and one percent of hypoxic events lasted longer than 24 hours. Hypoxia occurred at all sites in this region except for both sites at the Great Bay reserve.

One hundred twenty-five hypoxic events were observed at reserves in the Mid-Atlantic Coast region, 73% of which lasted less than 4 hours (Table 43). Twenty-one percent of hypoxia events lasted 4-8 hours and three percent of hypoxia events lasted 8-12 hours. Only two percent of hypoxic events lasted 12-16 hours and one percent of hypoxic events lasted longer than 24 hours. Hypoxia occurred at all sites in this region except for both sites at the Jacques Cousteau Reserve at Mullica River, NJ.

Seventy-eight hypoxic events were observed at reserves in the Southeast Coast region, 83% of which lasted less than 4 hours (Table 43). Fourteen percent of hypoxic events lasted 4-8 hours and one percent of hypoxic events lasted 8-12 hours. Only one percent of hypoxic events lasted longer than 24 hours. Hypoxia was observed at all sites in this region except for the Marsh Landing site at the Sapelo Island, GA, reserve and the Zeke's Island site at the North Carolina Reserve.

One hundred sixty-five hypoxic events were observed at reserves in the Gulf of Mexico and Caribbean Sea, 69% of which lasted less than 4 hours (Table 43). Sixteen percent of hypoxic events lasted 4-8 hours and six percent of hypoxic events lasted 8-12 hours. Six percent of hypoxic events lasted between 12-24 hours and three percent of hypoxic events lasted longer than 24 hours. Hypoxia was observed at all sites in this region except for the Weeks Bay site.

Not all reserves collected similar quantities of data during the same time of the year; thus, an index was developed to predict duration and magnitude of hypoxia on an annual basis, according to the frequency and duration of observed hypoxic events at sites, and is presented in Figures 198-202.

Table 43. Frequency of occurrence and duration of hypoxia at NERR sites, 1996-1998.

Region	N	%N	<4 h	4-8 h	8-12 h	12-16 h	16-20 h	20-24 h	>24 h
West Coast	307	40	0.60	0.26	0.11	0.02	0.01	0.00	0.00
Northeast	90	12	0.87	0.07	0.04	0.00	0.01	0.00	0.01
Mid-Atlantic	125	16	0.73	0.21	0.03	0.02	0.00	0.00	0.01
Southeast	78	10	0.83	0.14	0.01	0.00	0.00	0.00	0.01
Gulf/Carib.	165	22	0.69	0.16	0.06	0.02	0.03	0.01	0.03
	765	Mean	0.75	0.17	0.05	0.01	0.01	0.00	0.01

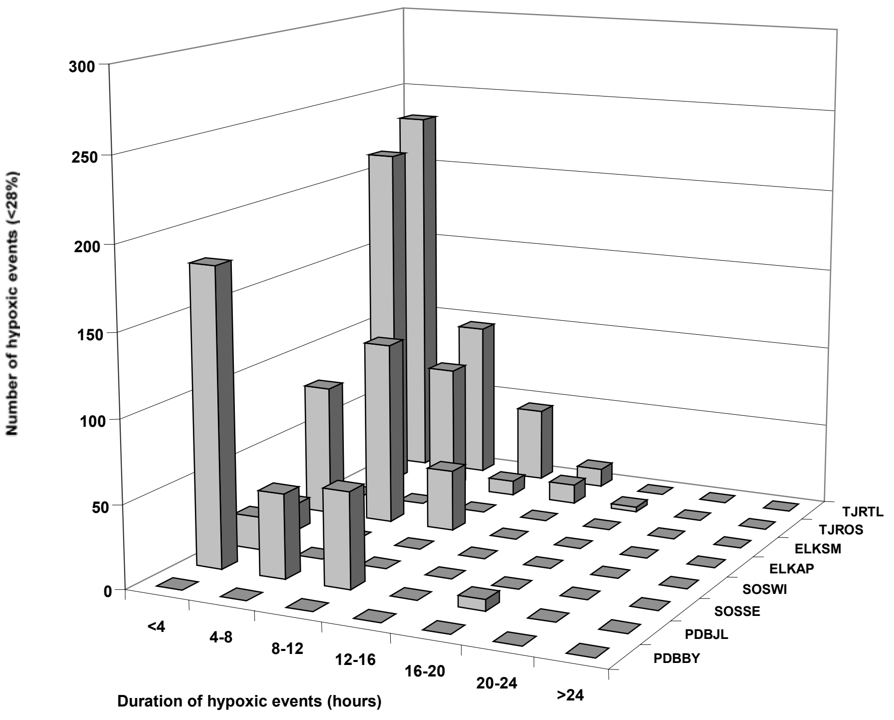


Figure 198. Predicted annual occurrence and duration of hypoxia at West Coast NERRs.

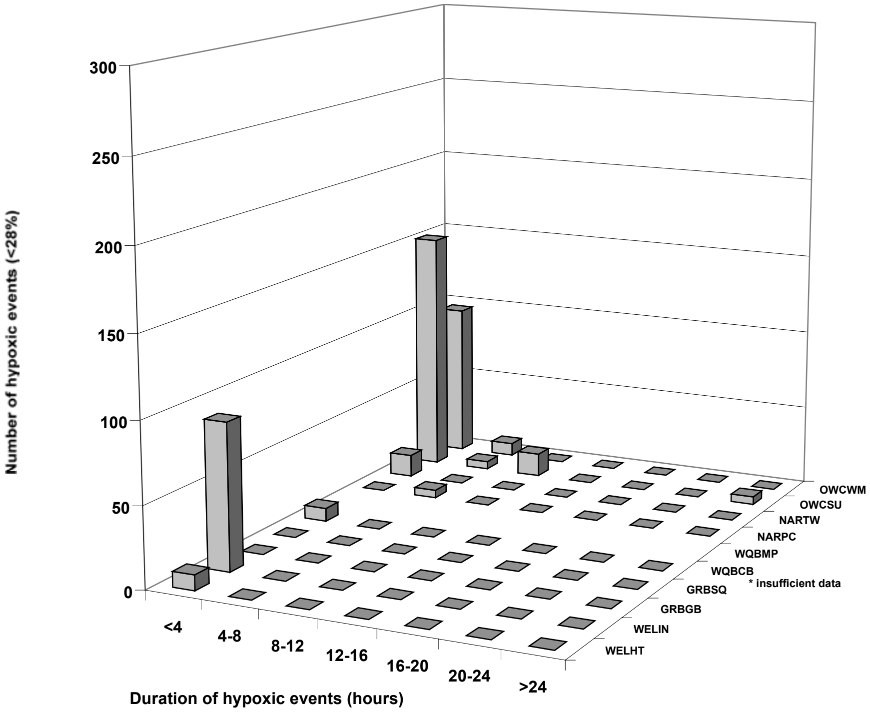


Figure 199. Predicted annual occurrence and duration of hypoxia at Northeast Coast and Great Lakes NERRs.

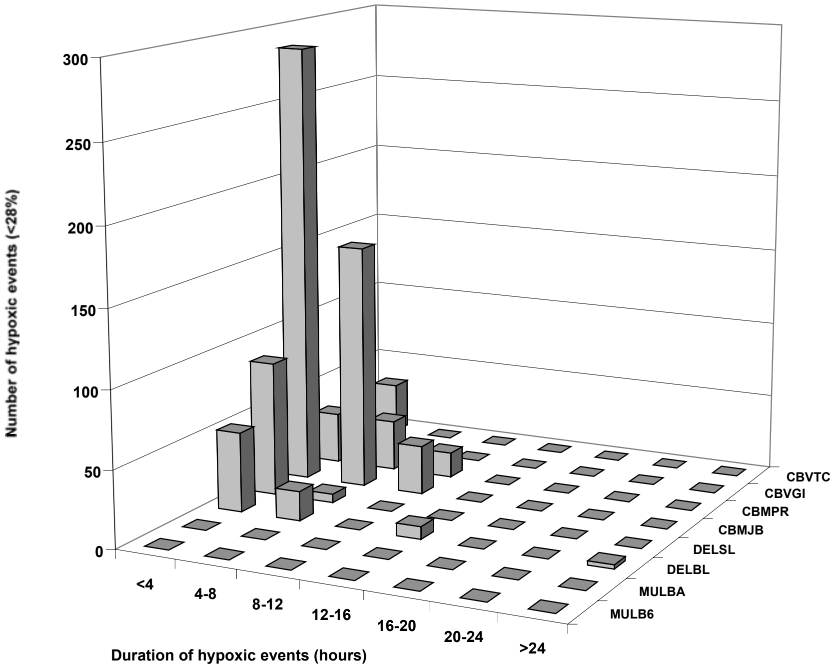


Figure 200. Predicted annual occurrence and duration of hypoxia at Mid-Atlantic NERRs.

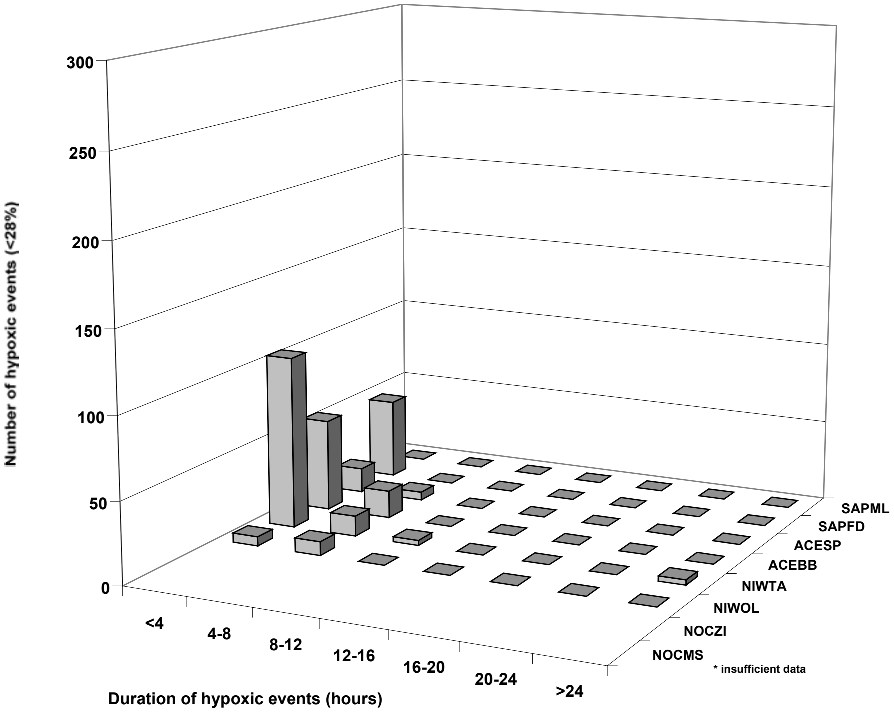


Figure 201. Predicted annual occurrence and duration of hypoxia at Southeast Coast NERRs.

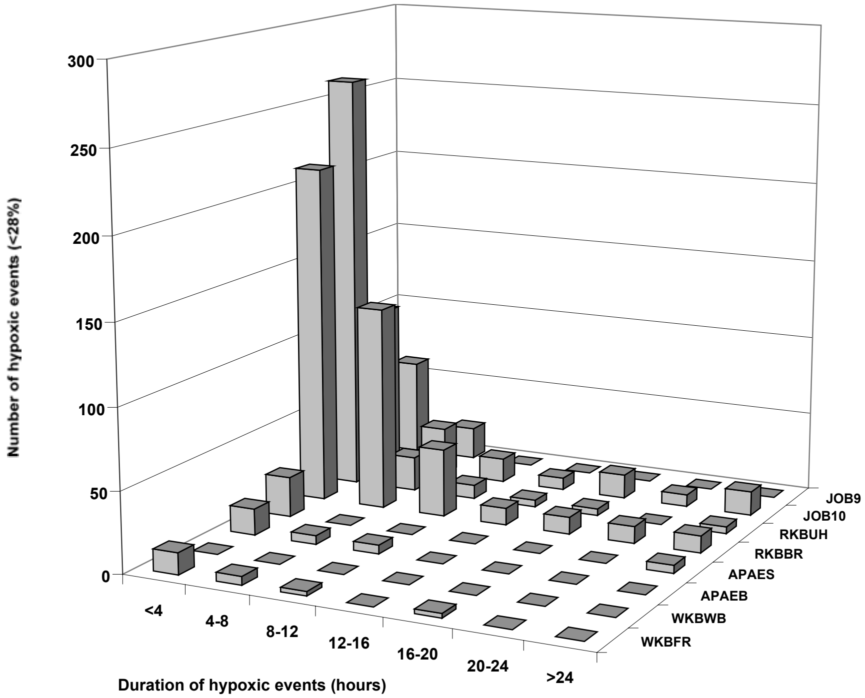


Figure 202. Predicted annual occurrence and duration of hypoxia at Gulf of Mexico and Caribbean NERRs.

System-level analysis

Depth, temperature, salinity, and dissolved oxygen

Examination of the average conditions experienced at water quality monitoring sites in the National Estuarine Research Reserves revealed interesting patterns among geographic regions. Most of the sites are shallow, with mean depth for 35 of the 44 sites < 2 m (Figure 203). All sites located in the Southeast (NC, SC, and GA), Gulf and Caribbean averaged < 2 m in depth. At two Reserves (Great Bay and Narragansett Bay), water depths greater than 4 m were sampled.

Not surprisingly, temperature extremes at water quality sites were indicative of the climate within the region. Reserves where mean water temperature ≥ 25°C persisted for more than 25 % of the year were located in the Southeast, Gulf Coast and Caribbean. At Jobos Bay, Puerto Rico, water temperature was ≥ 25°C for more than 95% of the year (Figure 204). Low temperature extremes (≤ 10°C) occurred at all reserves. At two sites on the west coast (South Slough and Padilla Bay), two sites in the Northeast (Wells and Narragansett Bay), and three sites in the mid-Atlantic region (Mullica River, Delaware Bay, and Chesapeake Bay-VA), water temperature remained ≤ 10°C for more than 25% of the year.

Salinity conditions at the NERR water quality sites were indicative of the differences in estuarine morphology, freshwater inflow, evaporative processes, and degree of ocean exchange present in the NERRs. Mean salinity was < 8 ppt at 14 sites, 8-28 ppt at 16 sites, and >28 ppt at the remaining 14 sites. Annual salinity variation at most NERR sites was highly variable, expect for three reserves (Hudson River, Old Woman Creek and Chesapeake Bay-MD) which were characterized by low salinity or freshwater conditions (Figure 205).

Hypoxia and supersaturation occurred throughout the reserve system, regardless of geographic region. When present, hypoxia persisted on average less than 15% of the first 48 hours post-deployment at all sites, except for Oneonta Slough and Tidal Linkage (Tijuana River), Azevedo Pond (Elkhorn Slough), and Blackbird Landing (Delaware Bay). At these four sites, hypoxia persisted between 23-35% of the first 48 hours post-deployment on average. Hypoxia was negatively correlated (R=-0.54, df=44, p=0.000) with latitude, positively correlated (R= 0.57, df=44, p=0.000) with warm water temperature (≥ 25°C), and negatively correlated (R= -0.44, df=44, p=0.003) with cold water temperature (≤ 10°C). These findings collectively suggest that hypoxia is most likely to be experienced at sites with sustained warm water events and least likely to be experienced at sites with sustained cold water events. All sites that experienced hypoxia also experienced supersaturation. Six sites (Bayview Channel, Padilla Bay; Central Basin, Waquoit Bay; and both sites at the Mullica River and Weeks Bay reserves) experienced supersaturation, but did not experience hypoxia in July-August 1997-98 (Figure 206). Supersaturation was not significantly correlated with water depth, temperature, or salinity.

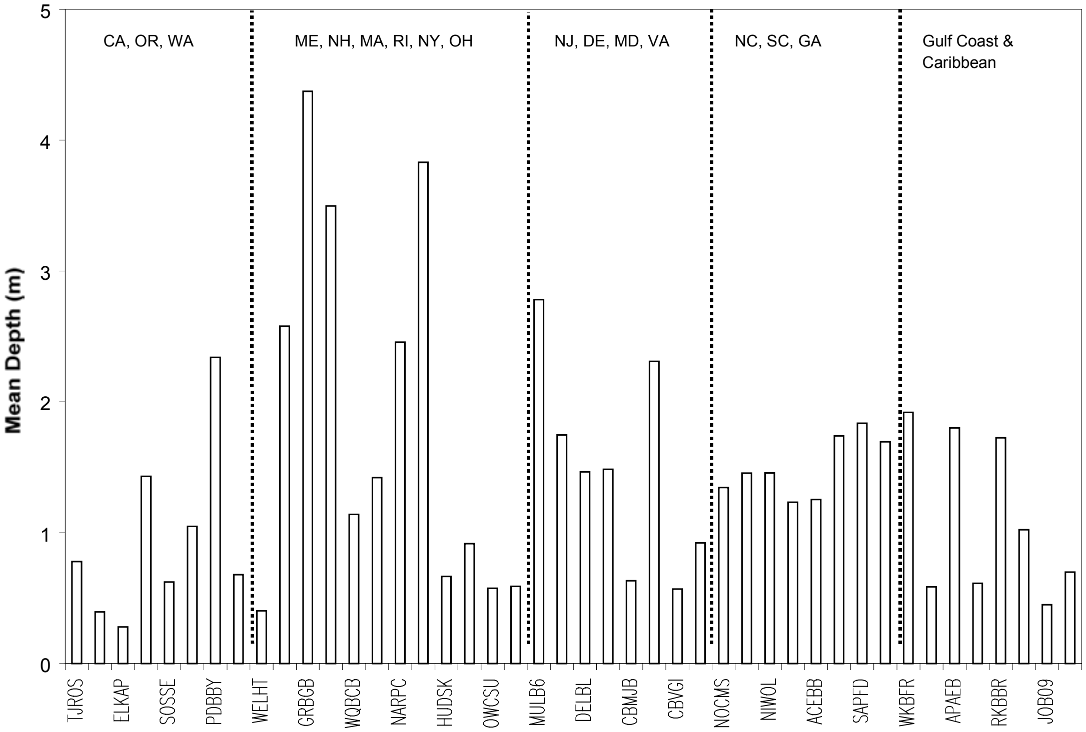


Figure 203. Mean depth of instrument deployment at NERR sites between 1996-1998. Note: For each Reserve, the first site is labeled and the second site is not labeled.

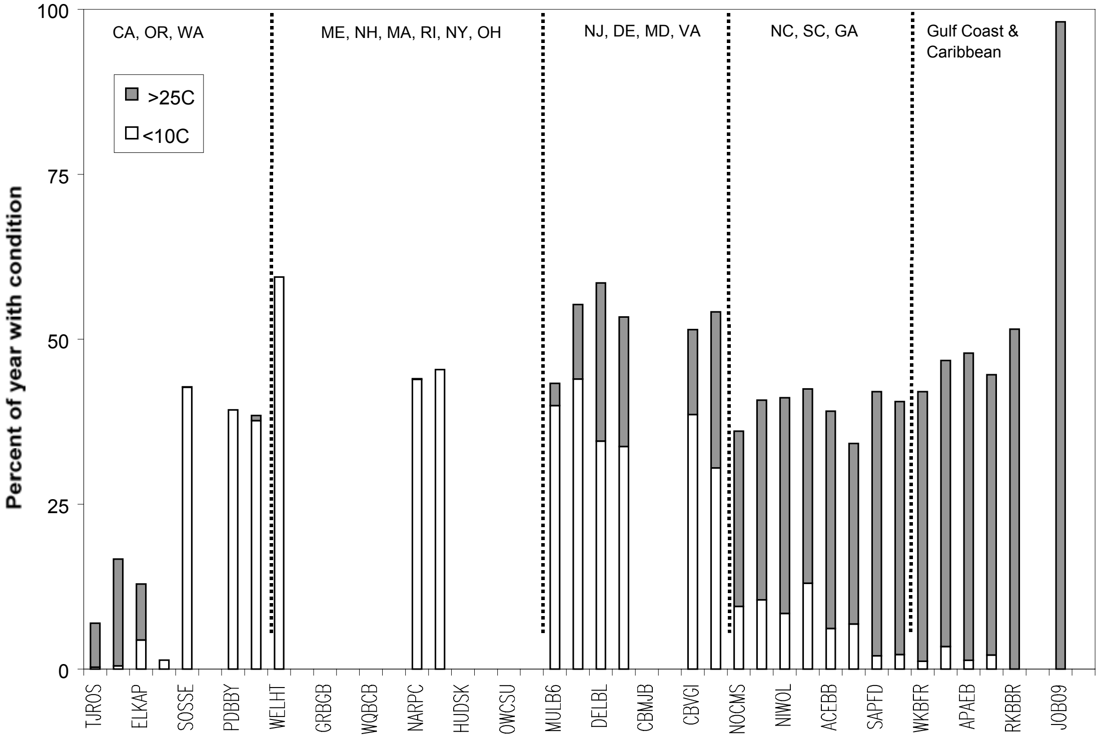


Figure 204. Water temperature extremes at NERR sites with year-round sampling, 1996-1998. Note: For each Reserve, the first site is labeled and the second site is not labeled.

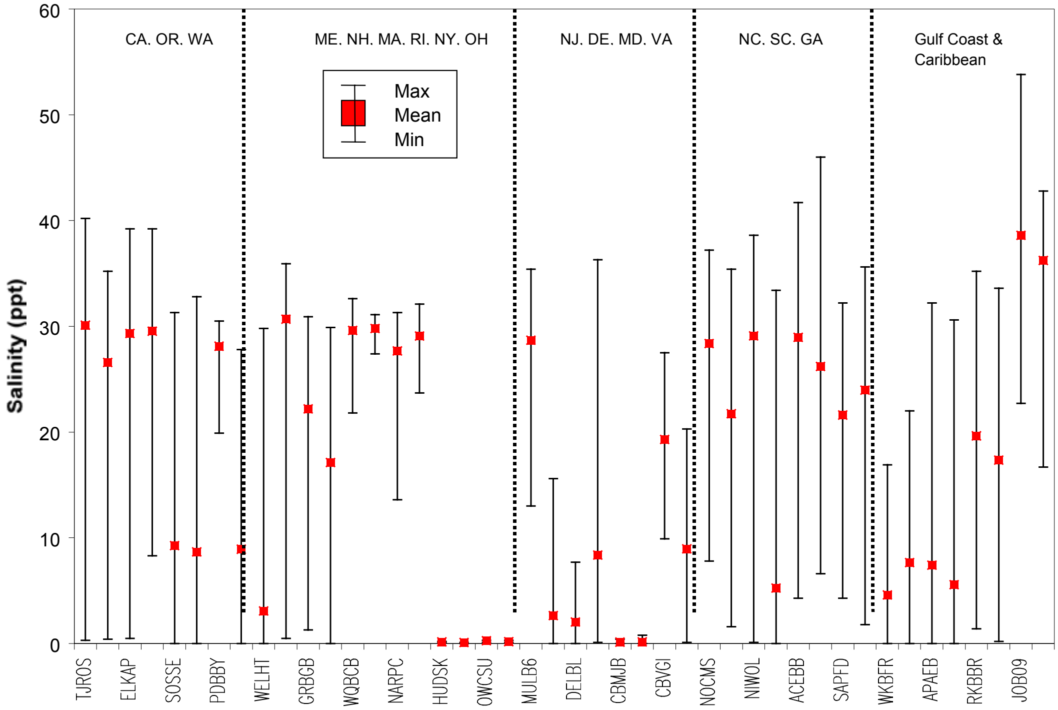


Figure 205. Mean, maximum, and minimum salinity at NERR sites between 1996-1998. Note: For each Reserve, the first site is labeled and the second site is not labeled.

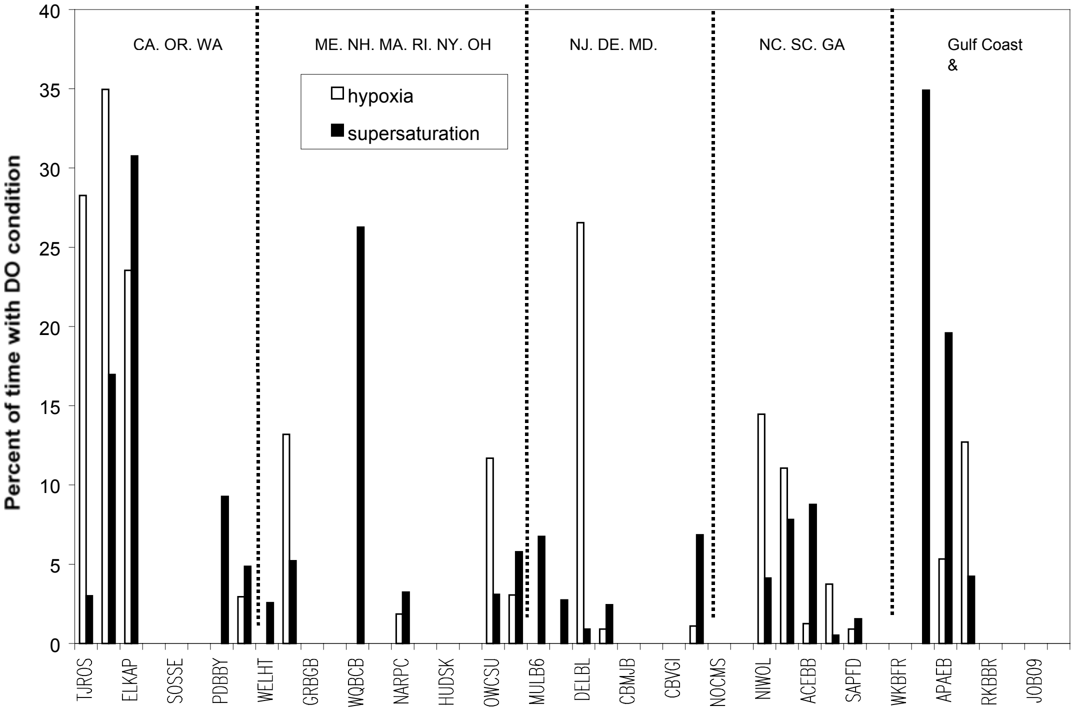


Figure 206. Mean hypoxia and supersaturation during the first 48 hours post-deployment for sites in Jul-Aug 1997 and 1998. If sites did not collect data in both years, no data are listed. Note: The first site for each reserve is labeled and the second site is not labeled.

Cluster Analysis

Cluster analysis was used to group the 44 sites in the NERR SWMP according to physical, chemical, geological, and geographical attributes (Tables 44-45). Four site groupings were identified from cluster analysis (Figure 207). Three of the groups appeared to correspond to geographical region and latitude. Group 1 was a large grouping, primarily consisting of sites located on the northeast and mid-Atlantic seaboard. Two West Coast reserves, located at similar latitudes as northeast and mid-Atlantic reserves, were also included in this group. Sites belonging to group 2 were primarily located in the Southeast, except for the Mullica River-Buoy 126 site in New Jersey. The third group was primarily comprised of sites located in the Gulf of Mexico; however, three freshwater sites (both sites at the Chesapeake Bay-MD reserve and State Route 2, Old Woman Creek) also clustered with this group. Group four sites consisted of sites from the two southernmost West Coast reserves (Elkhorn Slough and Tijuana River Estuary), along with the Jobos Bay reserve in Puerto Rico and the Big Bay (ACE Basin) site in South Carolina.

With the exception of eight reserves (Padilla Bay, Wells, Hudson River, Old Woman Creek, Mullica River, North Inlet-Winyah Bay, ACE Basin, and Weeks Bay), sites within a reserve were more similar to each other than to other sites located in other reserves. Within group 1, Bayview Channel in the Padilla Bay reserve was more similar to sites in Waquoit Bay and Narragansett Bay than to the Joe Leary Slough site in Padilla Bay. Joe Leary Slough was most similar to the Sawkill Creek site at Hudson River. Similarly, the Head of Tide site in the Wells reserve was more similar to the Lower Bank (Jacques Cousteau-Mullica River) and the State Route 6 (Old Woman Creek) sites than it was to the Inlet site in the Wells reserve. Within group 2, Buoy 126 (Jacques Cousteau-Mullica River) was most similar to sites in North Carolina. Within group 3, the Weeks Bay site (Weeks Bay) was more similar to sites in group 3 than the Fish River site (Weeks Bay). Within group 4, Big Bay Creek (ACE Basin) was most similar to both sites in the Tijuana River Estuary NERR. Similarity between these sites was primarily due to similar attributes such as high frequency (30% of data) with warm water temperature (> 25°C), similar salinity (>28 ppt), and similar land usage and habitat characteristics (>50% developed and <50% forested). Furthermore, the Big Bay site and both sites in the Tijuana River were located within two minutes of latitude from each other (32°10’N vs. 32°12’N).

The dendrogram of site attributes produced three major groupings (Figure 208). Within group 1, impervious surface and habitat were most similar. Within group 2, hypoxia and warm water temperature (≥ 25°C) were most similar, which reinforces the correlative relationship previously noted between hypoxia and warm water temperatures.

Table 44. Input source attributes for NERR sites (data from Attributes Survey, Appendix A).

Site	Waterbody	Impervious Surface	Land Use	Habitat	Soil Type	Annual Precipitation
elkap	small	2-20%	>20% harvested/developed	>50% vegetation	clay loam	0.5-1.3 m
elksm	large	2-20%	>20% harvested/developed	>50% vegetation	clay loam	0.5-1.3 m
pdbby	main	<2%	>20% harvested/developed	>50% veg/harvested	clay loam	0.5-1.3 m
pdbjl	small	<2%	>20% harvested/developed	>50% veg/harvested	clay loam	0.5-1.3 m
sosse	large	< 2%	>20% harvested/developed	>50% veg/harvested	sand loam	> 1.3 m
soswi	large	< 2%	>20% harvested/developed	>50% veg/harvested	sand loam	> 1.3 m
tjros	small	>20%	<20% harvested/developed	>50% developed	clay loam	< 0.5 m
tjrtl	small	>20%	<20% harvested/developed	>50% developed	clay loam	< 0.5 m
grbgb	main	2-20%	<20% harvested/developed	>50% vegetation	sand/clay loam; granite	0.5-1.3 m
grbsq	large	2-20%	<20% harvested/developed	>50% vegetation	sand/clay loam; granite	0.5-1.3 m
hudsk	large	2-20%	>20% harvested/developed	>50% veg/harvested	sand loam	0.5-1.3 m
hudts	main	2-20%	>20% harvested/developed	>50% veg/harvested	clay loam	0.5-1.3 m
narpc	main	< 2%	>20% harvested/developed	> 50% vegetation	sand loam	0.5-1.3 m
nartw	main	< 2%	>20% harvested/developed	> 50% vegetation	sand loam	0.5-1.3 m
owcsu	main	<2%	>20% harvested/developed	>50% vegetation	clay loam	0.5-1.3 m
owcwm	main	<2%	>20% harvested/developed	>50% vegetation	clay loam	0.5-1.3 m
wqbcb	main	2-20%	>20% harvested/developed	>50% vegetation	sand loam	0.5-1.3 m
wqbmp	main	2-20%	>20% harvested/developed	>50% vegetation	sand loam	0.5-1.3 m
welht	large	2-20%	<20% harvested/developed	>50% veg/harvested	soft mud, sand, and rocky	0.5-1.3 m
welin	main	<20%	>20% harvested/developed	>50% developed	sand loam	0.5-1.3 m
cbmjb	main	<2%	>20% harvested/developed	>50% veg/harvested	sand loam	0.5-1.3 m
cbmpr	main	<2%	>20% harvested/developed	>50% veg/harvested	sand loam	0.5-1.3 m
cbvgi	main	<2%	no harvested/developed land	>50% vegetation	sand loam	0.5-1.3 m
cbvtc	small	<2%	<20% harvested/developed	>50% vegetation	sand loam	0.5-1.3 m
delbl	main	<2%	>20% harvested/developed	>50% veg/harvested	clay loam	0.5-1.3 m
delsl	main	2-20%	>20% harvested/developed	>50% developed	sand loam	0.5-1.3 m
mulb6	main	<2%	no harvested/developed land	>50% vegetation	sand loam	0.5-1.3 m
mulBA	large	<2%	<20% harvested/developed	>50% vegetation	sand loam	0.5-1.3 m
acebb	small	<2%	<20% harvested/developed	>50% developed	mud	0.5-1.3 m
acesp	small	<2%	no harvested/developed land	>50% vegetation	mud	0.5-1.3 m
niwol	large	<2%	no harvested/developed land	>50% vegetation	fine sediment/detritus/shell hash	0.5-1.3 m
niwta	small	<2%	no harvested/developed land	>50% vegetation	fine sediment/detritus	0.5-1.3 m
nocms	small	<2%	no harvested/developed land	>50% vegetation	sand loam	0.5-1.3 m
noczi	small	<2%	no harvested/developed land	>50% vegetation	sand loam	0.5-1.3 m
sapfd	small	< 2%	<20% harvested/developed	>50% vegetation	sand loam	0.5-1.3 m
sapml	main	< 2%	<20% harvested/developed	>50% vegetation	sand loam	0.5-1.3 m
apaeb	main	<2%	>20% harvested/developed	>50% vegetation	sand loam	> 1.3 m
apaes	main	<2%	>20% harvested/developed	>50% vegetation	sand loam	> 1.3 m
job09	main	2-20%	>20% harvested/developed	>50% veg/harvested	clay and organic matter	< 0.5 m
job10	main	2-20%	>20% harvested/developed	>50% vegetation	sand with fragmented shell	< 0.5 m
rkbbr	large	2-20%	<20% harvested/developed	>50% veg/harvested	sand/organic matter	> 1.3 m
rkbuh	large	2-20%	<20% harvested/developed	>50% veg/harvested	sand/organic matter	> 1.3 m
wkbfr	main	>20%	<20% harvested/developed	>50% veg/harvested	sand loam	> 1.3 m
wkbwb	main	>20%	>20% harvested/developed	>50% developed	sand loam	> 1.3 m

Table 45. Filtration capabilities and water quality attributes for NERR sites. Mean depth denotes mean depth of instrument deployment. At most sites, instruments were deployed at 0.3 m above the bottom sediment (range 0.1 – 1.5 m). Percent of first 48 hours with hypoxia and supersaturation data are mean values for Jul-Aug 1997 and 1998; if data were not available for Jul-Aug in both years (*), the mean occurrence (percent of first 48 hours post-deployment) of hypoxia and supersaturation when these events were observed (listed in site summaries) were used.

Site	Shellfish Beds	SAV Beds	Emergent Vegetation	Forest Cover	Tidal Range	% 48 hrs ≤ 28% sat	% 48 hrs ≥ 120% sat	% year ≤ 10C	% year ≥ 25C	Mean Sal (ppt)	Mean Depth (m)
elkap	sparse	sparse	abundant	< 25%	2-4 m	23.54	30.76	4.41	8.49	29.3	0.28
elksm	sparse	sparse	abundant	< 25%	2-4 m	0.00	0.00	1.37	0	29.5	1.43
pdbby	sparse	abundant	sparse	< 25%	2-4 m	0.00	9.28	39.3	0	28.1	2.34
pdbjl	absent	absent	sparse	< 25%	< 2 m	2.95	4.86	37.68	0.75	8.9	0.68
sosse	absent	sparse	abundant	>50%	2-4 m	2.00*	8.40*	42.73	0.05	9.3	0.62
soswi	absent	abundant	abundant	>50%	2-4 m	1.00*	14.20*	39.91	0	8.7	1.05
tjros	sparse	sparse	abundant	< 25%	2-4 m	28.26	3.01	0.29	6.66	30.1	0.78
tjrtl	sparse	sparse	abundant	< 25%	2-4 m	34.96	16.96	0.48	16.21	26.6	0.39
grbgb	abundant	abundant	sparse	> 50%	2-4 m	0.00	0.00	20.65	0.02	22.2	6.5
grbsq	sparse	sparse	abundant	> 50%	2-4 m	0.00	0.00	17.38	1.82	17.1	3.5
hudsk	sparse	sparse	sparse	25-50%	< 2 m	0.00*	0.00*	19.32	0	0.2	0.67
hudts	abundant	abundant	abundant	25-50%	2-4 m	1.29	0.77	19.6	12.68	0.1	0.92
narpc	sparse	sparse	sparse	> 50%	< 2m	1.85	3.24	43.92	0.11	27.7	2.46
nartw	sparse	sparse	sparse	> 50%	< 2m	2.06*	5.40*	45.4	0	29.1	3.83
owcsu	absent	absent	absent	> 50%	< 2 m	11.68	3.09	6.48	4.97	0.3	0.58
owcwm	absent	sparse	abundant	> 50%	< 2 m	3.06	5.77	6.02	14.22	0.2	0.59
wqbcb	abundant	sparse	absent	> 50%	< 2m	0.00	26.27	18.92	3.46	29.6	1.14
wqbmp	abundant	sparse	absent	> 50%	< 2m	0.00*	2.10*	97.09	0	29.8	1.42
welht	absent	sparse	abundant	>50%	<2 m	0.00	2.58	36.63	0.08	3.1	0.4
welin	abundant	abundant	abundant	<25%	2-4 m	13.19	5.21	59.42	0	30.7	2.58
cbmjb	absent	sparse	abundant	> 50%	2-4 m	22.10*	8.30*	2.61	45.98	0.1	0.63
cbmpr	absent	sparse	abundant	> 50%	2-4 m	10.60*	19.97*	3.2	42.08	0.2	2.31
cbvgi	abundant	abundant	abundant	> 50%	< 2 m	1.00*	19.60*	38.59	12.86	19.3	0.57
cbvtc	abundant	sparse	abundant	> 50%	< 2 m	1.09	6.84	30.48	23.66	9	0.92
delbl	absent	absent	abundant	< 25%	< 2 m	26.55	0.90	34.57	23.96	2	1.46
delsl	absent	absent	abundant	< 25%	< 2 m	0.90	2.45	33.73	19.65	8.4	1.48
mulb6	abundant	absent	abundant	< 25%	< 2 m	0.00	6.75	39.96	3.37	28.7	2.78
mulBA	absent	absent	abundant	> 50%	< 2 m	0.00	2.75	43.97	11.3	2.6	1.75
acebb	sparse	absent	abundant	< 25%	2-4 m	1.25	8.77	6.14	32.95	28.9	1.25
acesp	sparse	absent	abundant	> 50%	2-4 m	3.75	0.52	6.82	27.38	26.2	1.74
niwol	abundant	absent	abundant	> 50%	2-4 m	14.46	4.13	8.44	32.68	29.1	1.46
niwta	abundant	absent	abundant	> 50%	2-4 m	11.06	7.82	13.01	29.45	5.3	1.23
nocms	abundant	absent	sparse	< 25%	< 2 m	0.00	24.50	9.5	26.57	28.4	1.35
noczi	abundant	absent	sparse	< 25%	< 2 m	4.40	5.80	10.49	30.28	21.7	1.45
sapfd	abundant	absent	abundant	>50%	2-4 m	0.90	1.55	2.01	40.04	21.6	1.84
sapml	abundant	absent	abundant	>50%	2-4 m	0.00	0.00	2.23	38.31	24	1.69
apaeb	absent	absent	absent	> 50%	< 2 m	5.33	19.59	1.32	46.58	7.4	1.8
apaes	absent	absent	absent	> 50%	< 2 m	12.70	4.23	2.12	42.49	5.6	0.61
job09	abundant	sparse	abundant	25-50%	< 2 m	31.40*	28.10*	0	98.11	38.6	0.7
job10	abundant	abundant	abundant	> 50%	< 2 m	19.60*	16.20*	0	99.59	36.2	0.45
rkbbr	absent	sparse	abundant	> 50%	< 2 m	45.80*	2.10*	0	70.18	19.6	1.73
rkbuh	absent	absent	abundant	> 50%	< 2 m	21.80*	15.80*	0	51.54	17.3	1.02
wkbfr	absent	sparse	sparse	> 50%	< 2 m	20.40*	14.10*	1.19	40.87	4.6	1.92
wkbwb	sparse	absent	absent	> 50%	< 2 m	0.00	34.90	3.44	43.33	7.7	0.59

Figure 207. Dendrogram of Reserve sites based on site characteristics.

Figure 208. Dendrogram of site scharacteristics for Reserve sites.

Periodicity (Harmonic regression analysis)
First stage regression analyses fit most individual deployment series well and typically gave a good fit within the range of the data. The time series for most variables at most sites were strongly periodic. Spectral (Fourier) time series analyses performed previously by Wenner et al. (1998) and by ourselves as preliminaries to harmonic analyses, repeatedly showed periods related to 12.42 hour, 24 hour, 29.5 day, and 365.24 day cycles. These cycles were also visually evident in most of the series through inspection using *microscope* and *plot.week*. Further visual inspection revealed a number of other complicating factors in the data such as (1) shifts in mean response at new meter deployments, (2) shifts in cycle amplitude at deployments, (3) meter decay, and (4) unusual events (presumably weather-related) on the order of 1-2 days in duration.

R-square (R^2) values and Root-Mean Square (RMSE) values for each of the five water quality variables are summarized in Figures 209-218. Sites within each Reserve whose mean levels were significantly different from each other using the Sidák method are noted with a double asterisk (**). In each figure, the mean R^2 or RMSE value across all deployments is displayed with standard error bars. Mean R^2 for depth typically exceeded 0.90, except for four sites (Head of Tide-Wells, Saw Kill-Hudson River, and both Old Woman Creek sites) with R^2 around 0.75 (Figure 209). Mean R^2 for water temperature (Figure 210) and salinity (Figure 211) were typically greater than 0.80, although for a few sites (Sawkill-Hudson River and State Route 6-Old Woman Creek) R^2 for salinity was less than 0.40. Mean R^2 for dissolved oxygen was typically 0.70 to 0.90 for most sites (Figure 212-213).

Root mean square for error (RMSE) values were an important complement to the R^2 values. The RMSE values demonstrate the predictive capabilities of the regression; about 95% of the actual data values fit the regression curves within a distance of less than twice the RMSE. RMSE values for depth were typically less than 0.10 m (Figure 214). RMSE for water temperature was usually less than 0.75°C, i.e., temperature was generally predictable to within 1.5°C (Figure 215). RMSE for salinity was less than 1.25 ppt, except for 4 sites (both South Slough sites, Joe Leary Slough-Padilla Bay, and Head of Tide-Wells) with RMSE around 2.5 ppt (Figure 216). It is interesting to note that the sites having low R^2 values for salinity (Hudson River, State Route 2-Old Woman Creek) also have small RMSE. This agreement suggests that the models predict salinity well, even though they may have low R^2 values (e.g., low R^2 values reflect little explainable variability at these freshwater sites). For dissolved oxygen, RMSE was typically less than 1 mg/l (Figure 217) or less than 10% saturation (Figure 218).

Variance in water quality variables was expressed as a function of the partial sums of squares for the deployment level regressions due to a 12.42 hour component (SST), a 24 hour component (SSD), and interaction between these components (SSTD). The interaction component (i.e., cross-product terms) allows the signature of one component to change with the signature of the other component for each water quality variable.

Overall, the 12.42 hour component accounted for more than 50% of variance in water depth, with less than 20% of variance attributed to the 24 hour component (Figures 219-220). The 12.42 hour component accounted for more depth variance than the 24 hour component at 75% (*n*=33) of the NERR sites, except for a few sites which experienced minimal depth variance (i.e., Saw Kill-Hudson River; Azevedo Pond-Elkhorn Slough; Jobos Bay; Old Woman Creek; Padilla Bay; and Weeks Bay).

For water temperature, 24 hour cycles tended to dominate most sites and, on average, accounted for approximately 30- 50% of variance (Figure 221). At most sites, 12.42 hour cycles accounted for less than 20% of water temperature variance (Figure 222). Sites that constituted exceptions to this rule included the Inlet Site-Wells site and the Great Bay-Great Bay site, where the 12.42 hour cycle accounted for 40-60% of temperature variance and 24 hour cycle accounted for less than 20% of temperature variance. Other sites where the variance of the 12.42 cycle accounted for more temperature variance than 24 hour cycle included South Marsh-Elkhorn Slough, T-wharf-Narragansett Bay, and Bouy 126-Mullica River.

Surprisingly, salinity was only strongly influenced (40-80% of salinity variance) by the 12.42 hour cycle at half of the sites (Figure 223). At sites where salinity was not strongly influenced (10-20% of salinity variance) by the 12.42 hour cycle, 24 hour cycles only accounted for 5-35% of salinity variance (Figure 224); thus, interaction between these cycles accounted for the majority of salinity variance. Twenty-four hour cycles accounted for slightly more salinity variance (>5%) than 12.42 hour cycles at sites that experienced only slight variations in annual salinity. These sites included low-salinity sites (Hudson River, Old Woman Creek, Jug Bay-Chesapeake Bay MD, and Joe Leary Slough-Padilla Bay), high-salinity sites (Potters Cove-Narragansett Bay and Jobos Bay), and sites that experienced minimal tidal effects (Weeks Bay, Apalachicola, Azvedo Pond-Elkhorn Slough, and South Marsh-Padilla Bay).

Harmonic regression results for dissolved oxygen were highly diverse across sites, and very similar for both percent saturation and mg/L units (Figures 225-228). Dissolved oxygen variance due to 24 hour cycles was usually between 15 and 40%; however, there were some notable exceptions. Twenty-four hour cycles accounted for 50-70% of dissolved oxygen variance at the following sites: Azevedo Pond-Elkhorn Slough; Central Basin-Waquoit Bay; Potters Cove-Narragansett Bay; Saw Kill-Hudson River; and both Jobos Bay sites. Variance in dissolved oxygen due to 12.42 hour cycles was also quite diverse at the 40 sites analyzed. These cycles (12.42 hours) typically accounted for 5-30% of dissolved oxygen variance; however at 7 sites (Inlet Site-Wells Bay; Squamscott River-Great Bay; T-wharf-Narragansett Bay; Tivoli South Bay-Hudson River; Scotton Landing-Delaware Bay; Taskinas Creek-Chesapeake Bay VA; and Marsh Landing-Sapelo Island), 12.42 hour cycles accounted for 40-60% of dissolved oxygen variance.

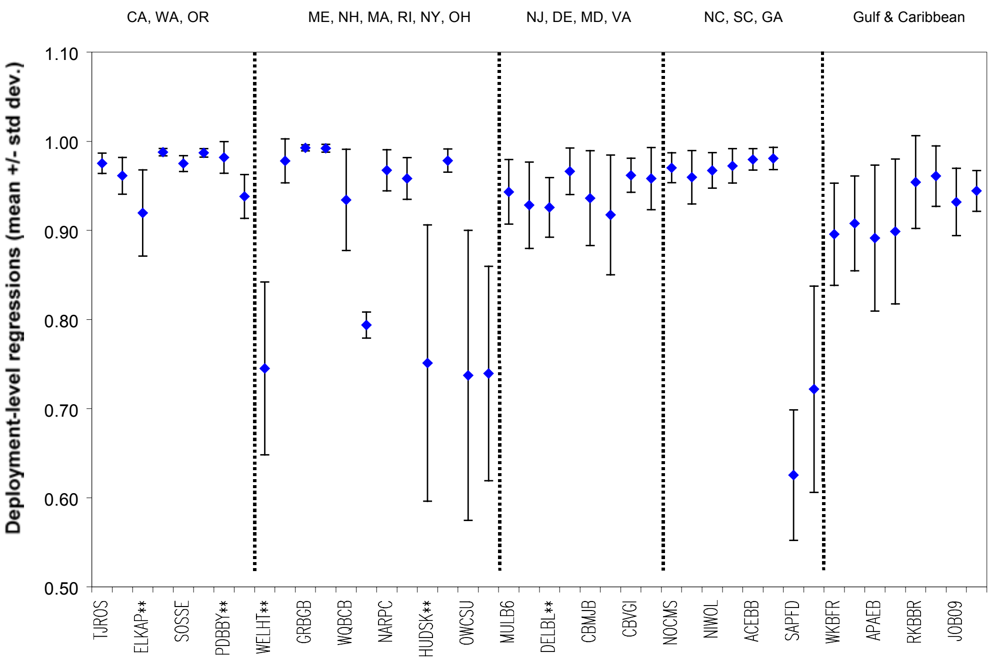


Figure 209. R-square (mean ± standard error) values for water depth. Sites within a Reserve that were significantly different from each (Sidák method) are indicated with **
Note: For each Reserve, the first site is labeled and the second site is not labeled.

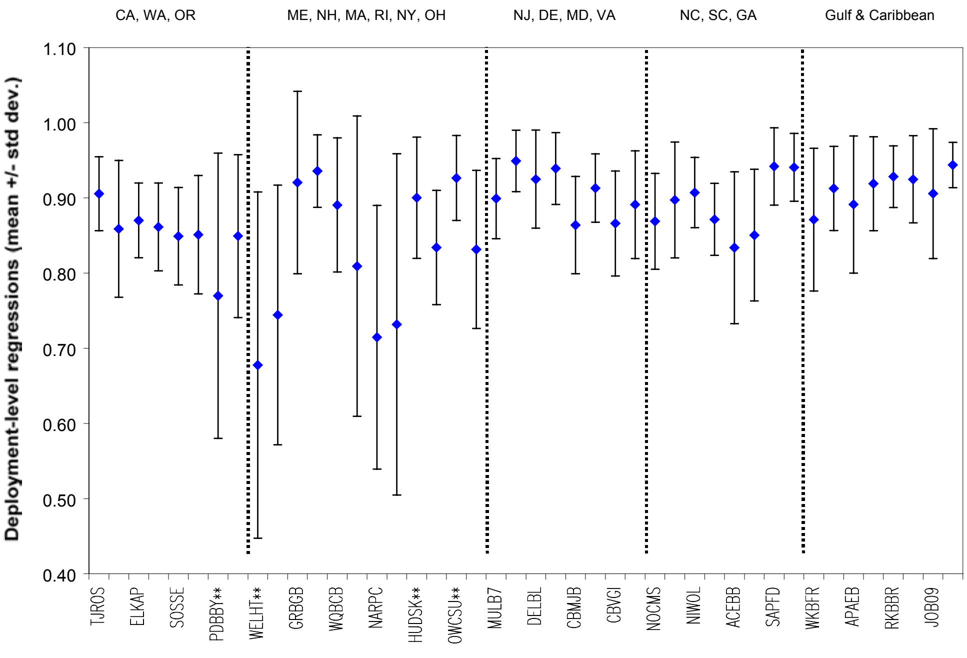


Figure 210. R-square (mean ± standard error) values for water temperature. Sites within a Reserve

that were significantly different from each (Sidák method) are indicated with **
Note: For each Reserve, the first site is labeled and the second site is not labeled.

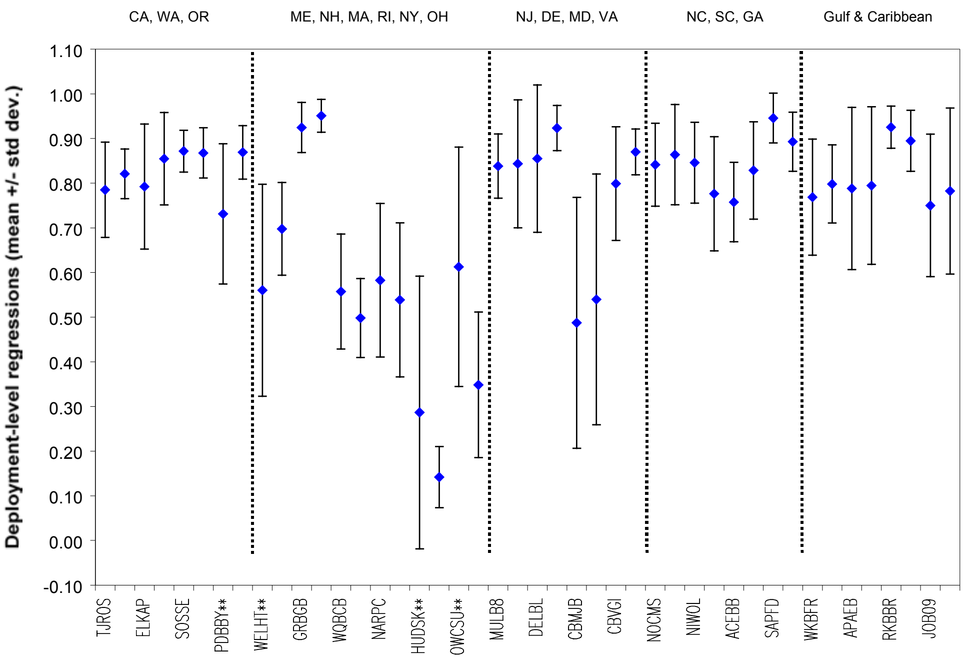


Figure 211. R-square (mean ± standard error) values for salinity. Sites within a Reserve that were significantly different from each (Sidák method) are indicated with ** Note: For each Reserve, the first site is labeled and the second site is not labeled.

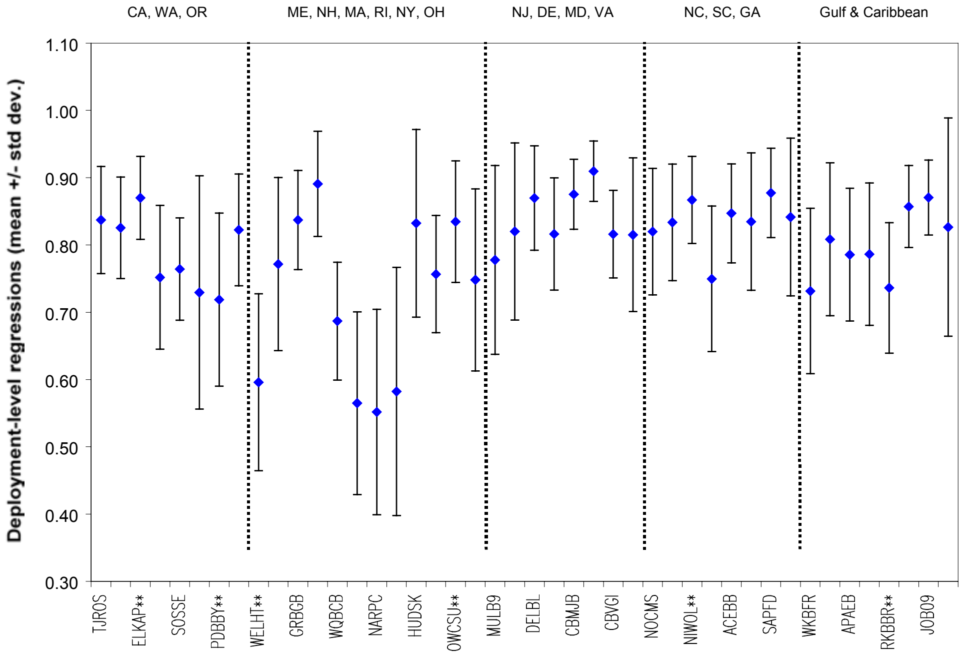


Figure 212. R-square (mean ± standard error) values for DO (% saturation). Sites within a Reserve that were significantly different from each (Sidák method) are indicated with ** Note: For each Reserve, the first site is labeled and the second site is not labeled.

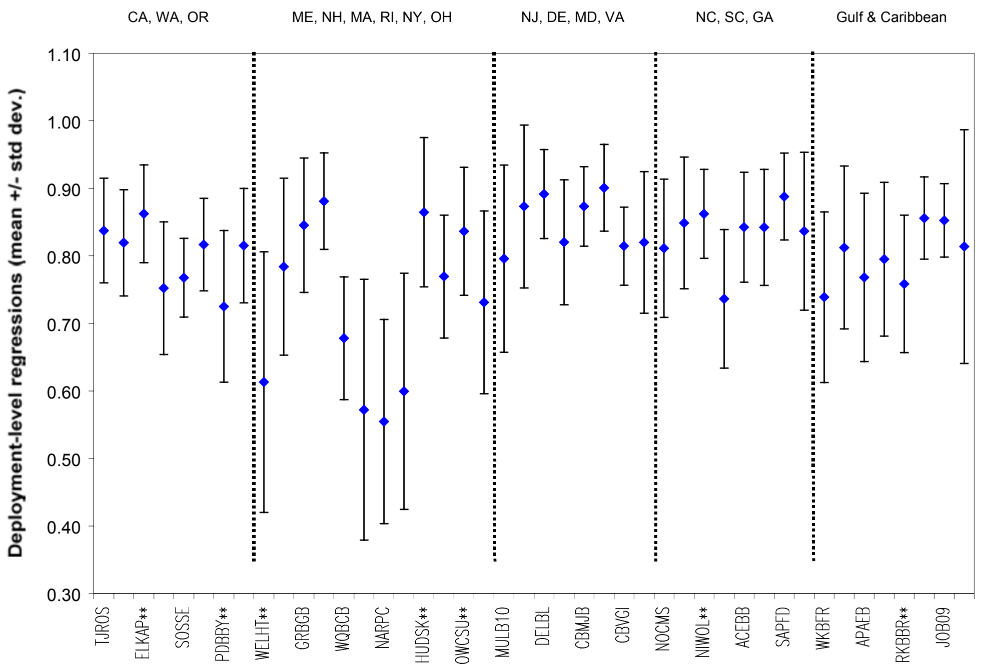


Figure 213. R-square (mean ± standard error) values for DO (mg/L)._Sites within a Reserve that were significantly different from each (Sidák method) are indicated with ** Note: For each Reserve, the first site is labeled and the second site is not labeled.

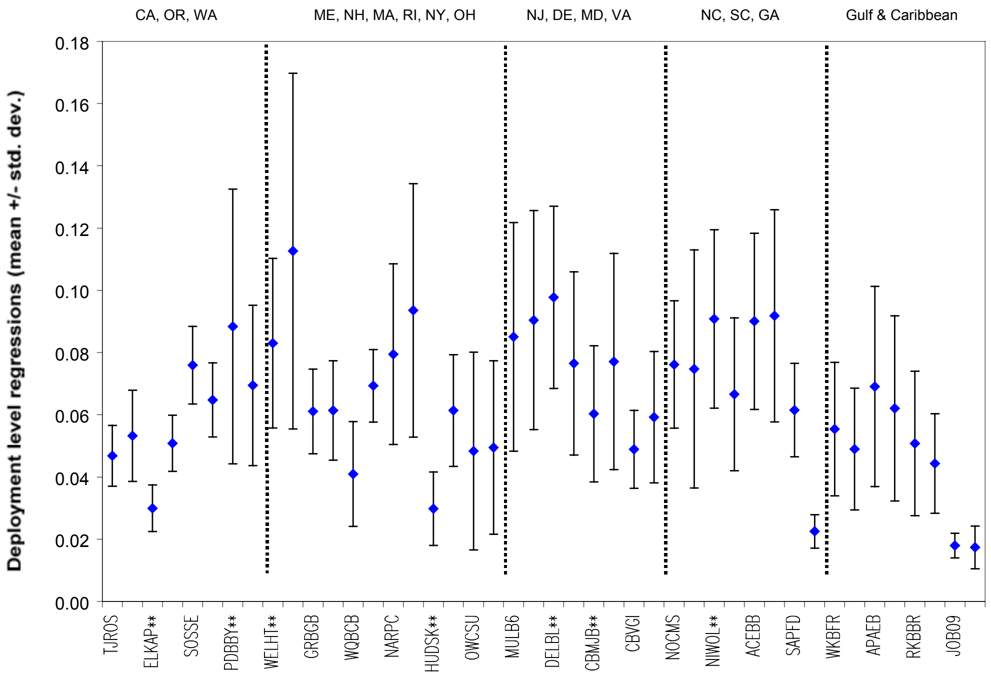


Figure 214. RMSE (mean ± standard error) values for water depth. Sites within a Reserve that were significantly different from each (Sidák method) are indicated with ** Note: For each Reserve, the first site is labeled and the second site is not labeled.

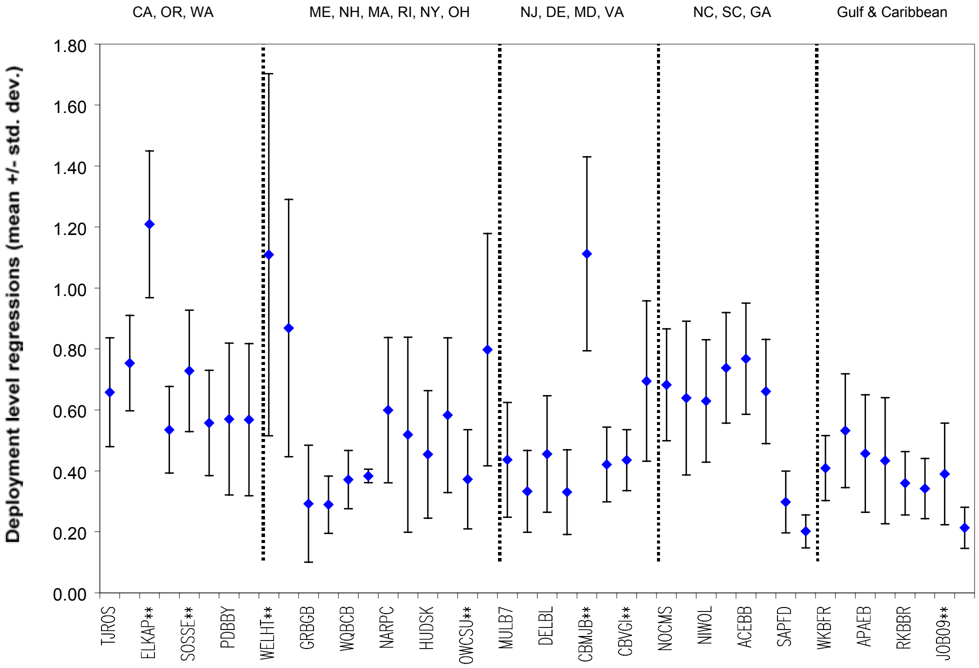


Figure 215. RMSE (mean ± standard error) values for water temperature. Sites within a Reserve that were significantly different from each (Sidák method) are indicated with ** Note: For each Reserve, the first site is labeled and the second site is not labeled.

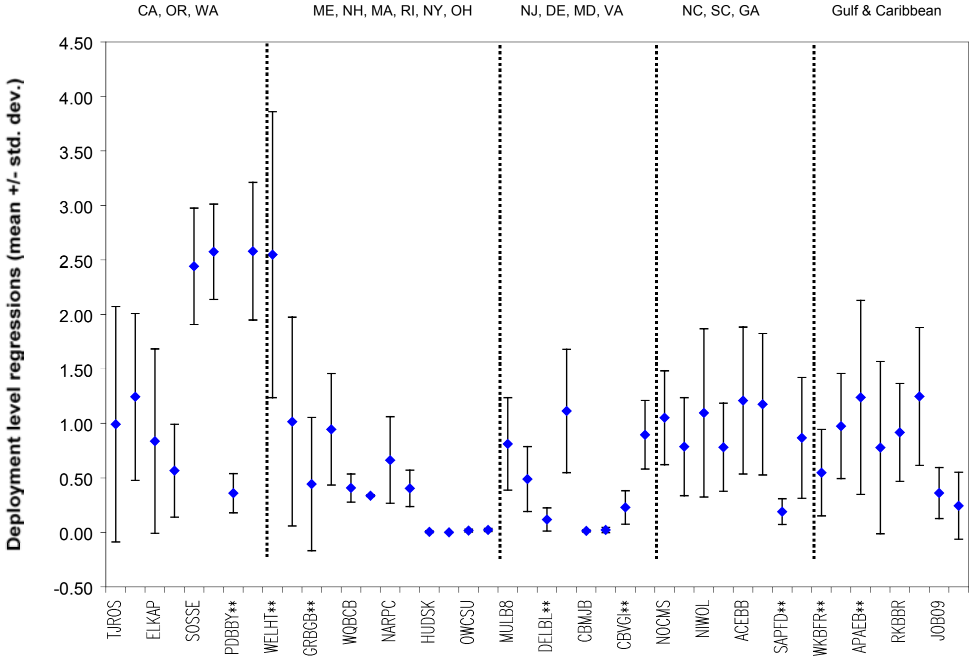


Figure 216. RMSE (mean ± standard error) values for salinity. Sites within a Reserve that were significantly different from each (Sidák method) are indicated with ** Note: For each Reserve, the first site is labeled and the second site is not labeled.

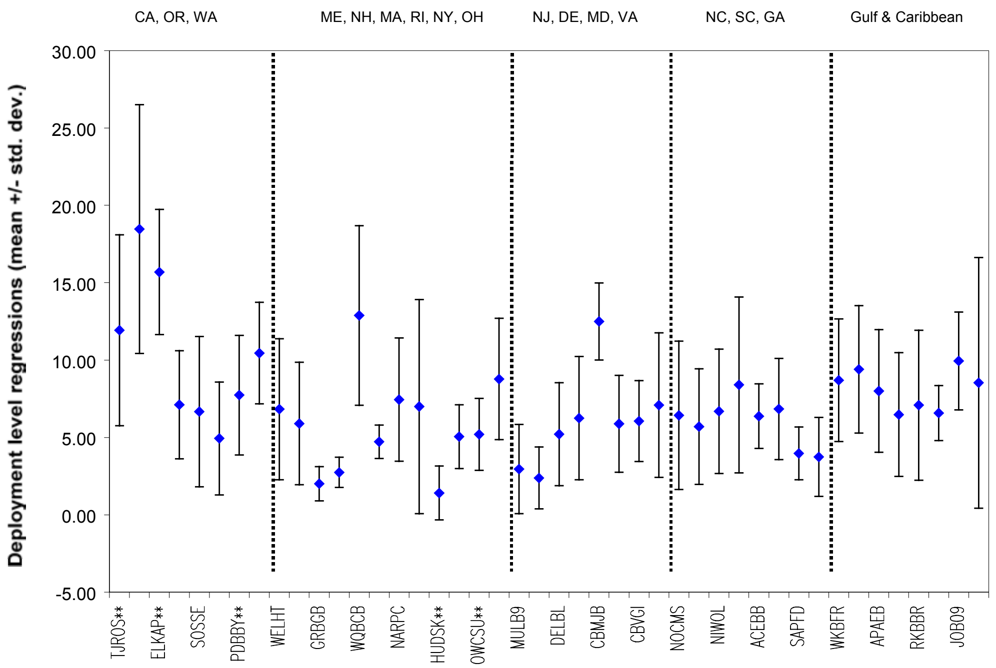


Figure 217. RMSE (mean ± standard error) for DO (% saturation). Sites within a Reserve that were significantly different from each (Sidák method) are indicated with ** Note: For each Reserve, the first site is labeled and the second site is not labeled.

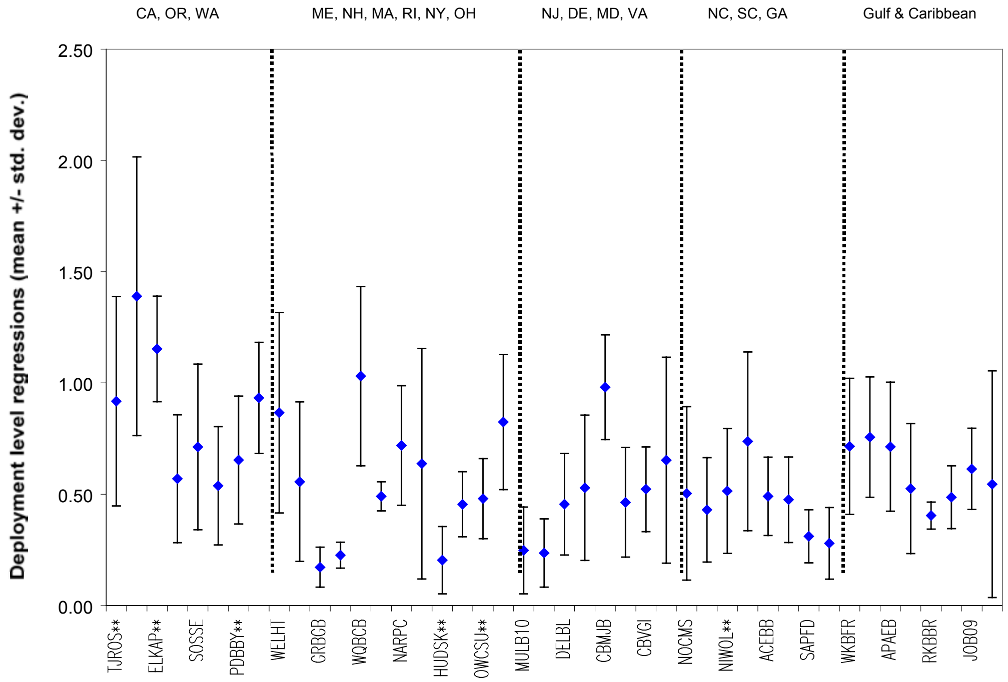


Figure 218. RMSE (mean ± standard error) for DO (mg/L). Sites within a Reserve that were significantly different from each (Sidák method) are indicated with ** Note: For each Reserve, the first site is labeled and the second site is not labeled.

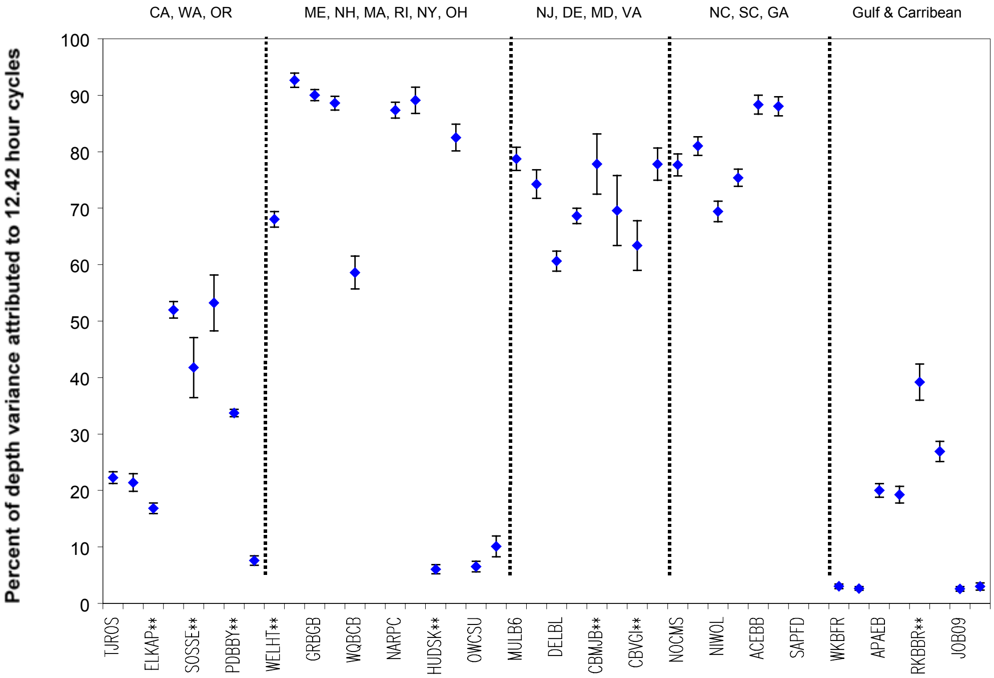


Figure 219. Percent of depth variance (mean ± standard error) due to 12.42 hour cycles. Sites within
Reserves that were significantly different from each (Sidák method) are indicated by **
Note: For each Reserve, the first site is labeled and the second site is not labeled.

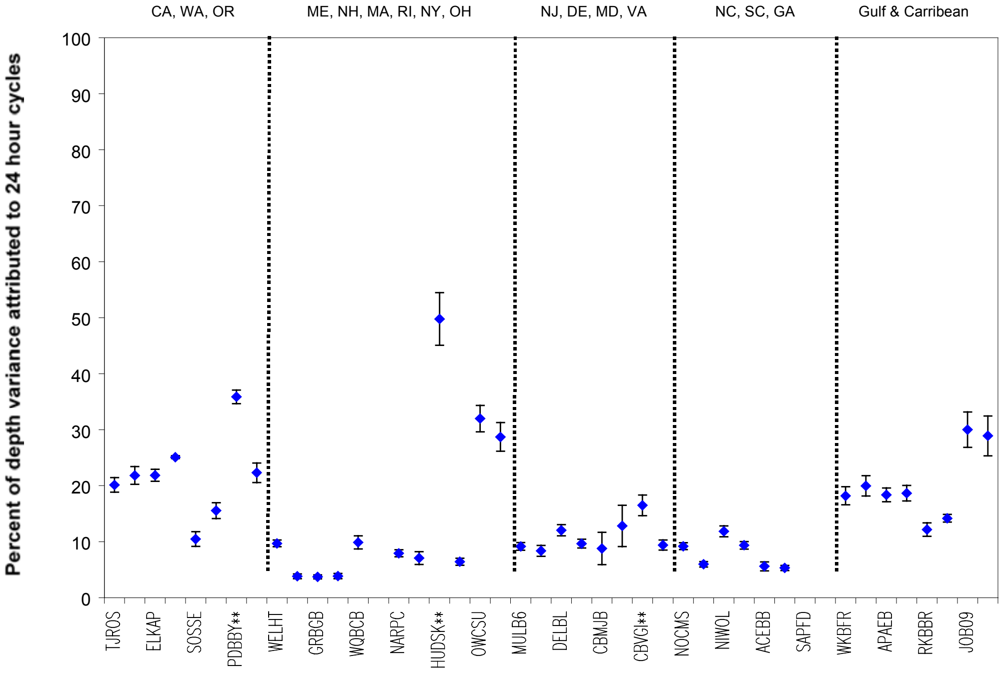


Figure 220. Percent of depth variance (mean ± standard error) due to 24 hour cycles. Sites within
Reserves that were significantly different from each (Sidák method) are indicated by **
Note: For each Reserve, the first site is labeled and the second site is not labeled.

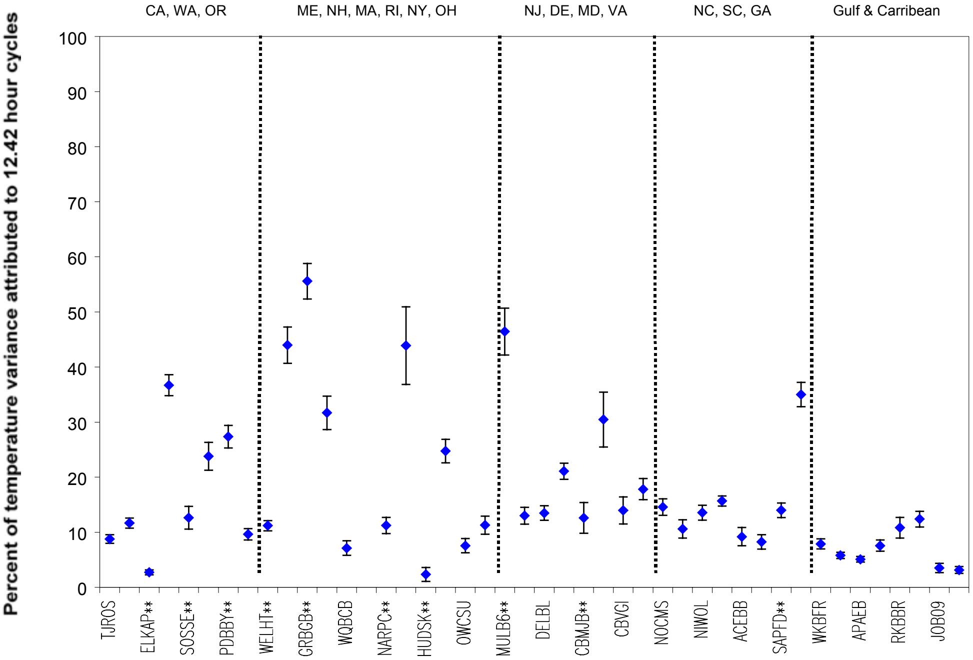


Figure 221. Percent of temperature variance (mean ± standard error) due to 12.42 hour cycles. Sites within Reserves that were significantly different from each (Sidák method) are indicated with ** Note: For each Reserve, the first site is labeled and the second site is not labeled.

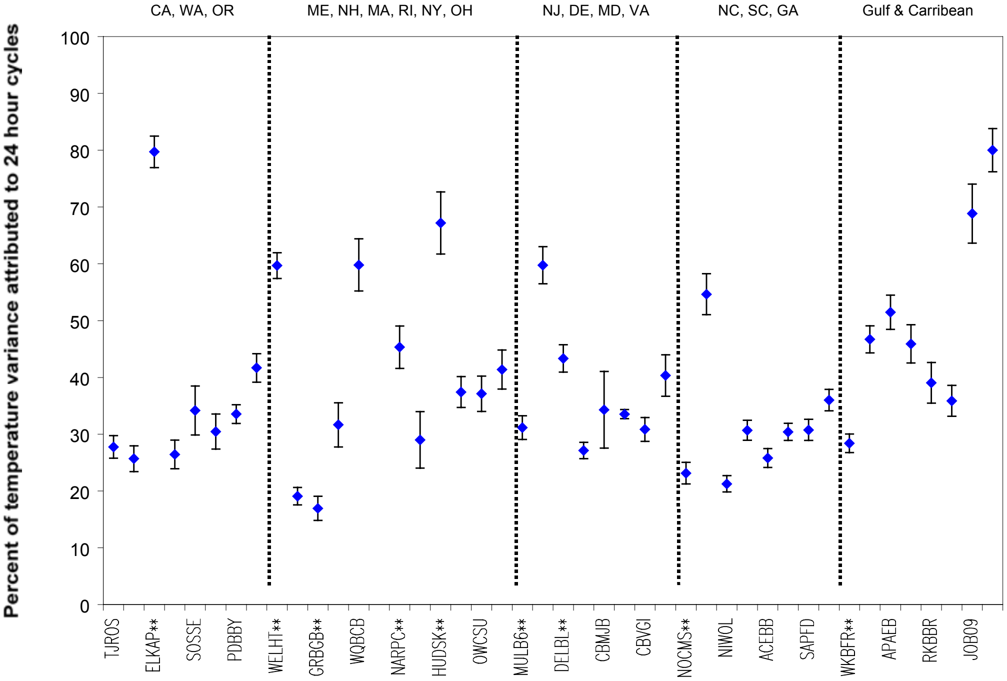


Figure 222. Percent of temperature variance (mean ± standard error) due to 24 hour cycles. Sites within Reserves that were significantly different from each (Sidák method) are indicated with ** Note: For each Reserve, the first site is labeled and the second site is not labeled.

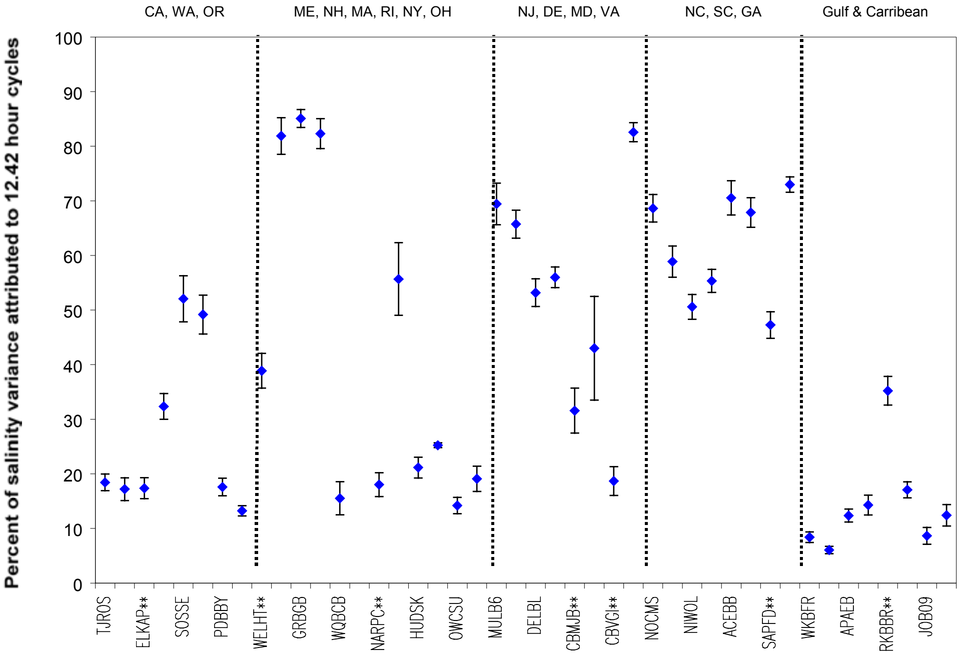


Figure 223. Percent of salinity variance (mean ± standard error) due to 12.42 hour cycles. Sites within Reserves that were significantly different from each (Sidák method) are indicated with ** Note: For each Reserve, the first site is labeled and the second site is not labeled.

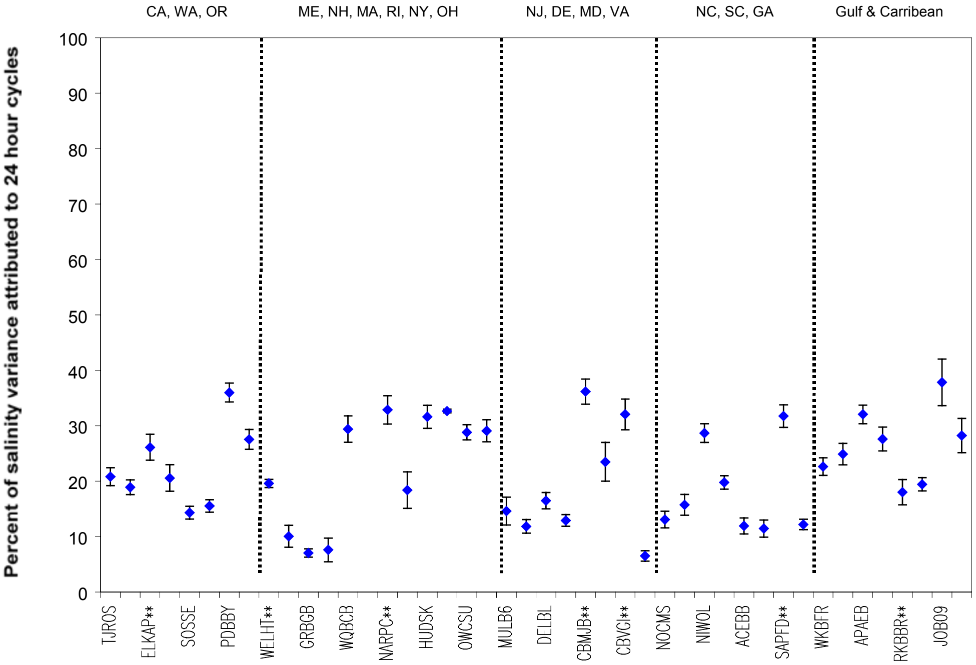


Figure 224. Percent of salinity variance (mean ± standard error) due to 24 hour cycles. Sites within Reserves that were significantly different from each (Sidák method) are indicated with **

Note: For each Reserve, the first site is labeled and the second site is not labeled.

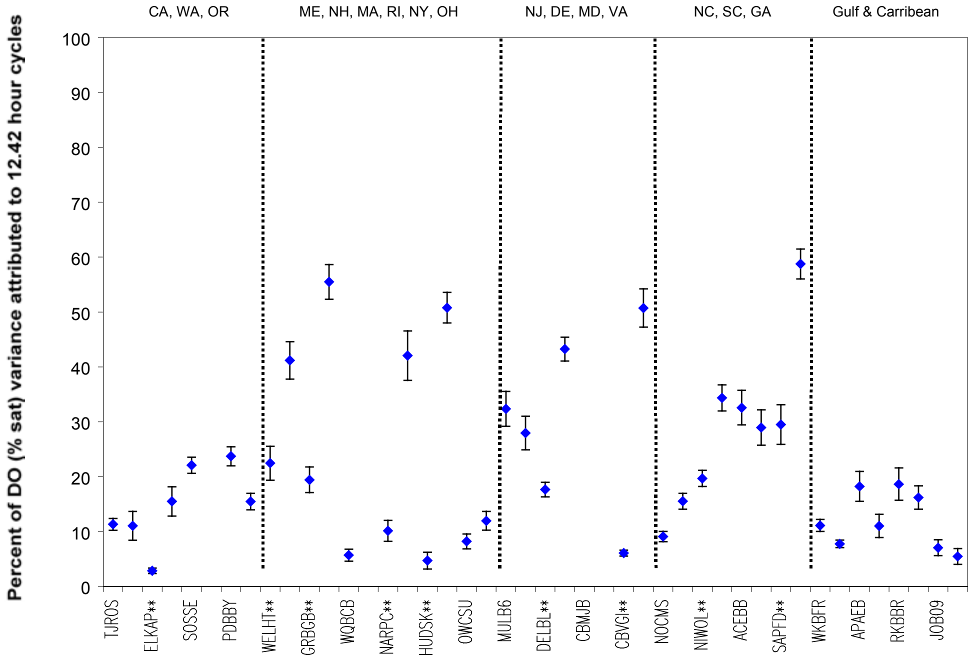


Figure 225. Percent of DO (% saturation) variance (mean ± std. error) due to 12.42 hour cycles. Sites within Reserves that were significantly different from each (Sidák method) are indicated by ** Note: For each Reserve, the first site is labeled and the second site is not labeled.

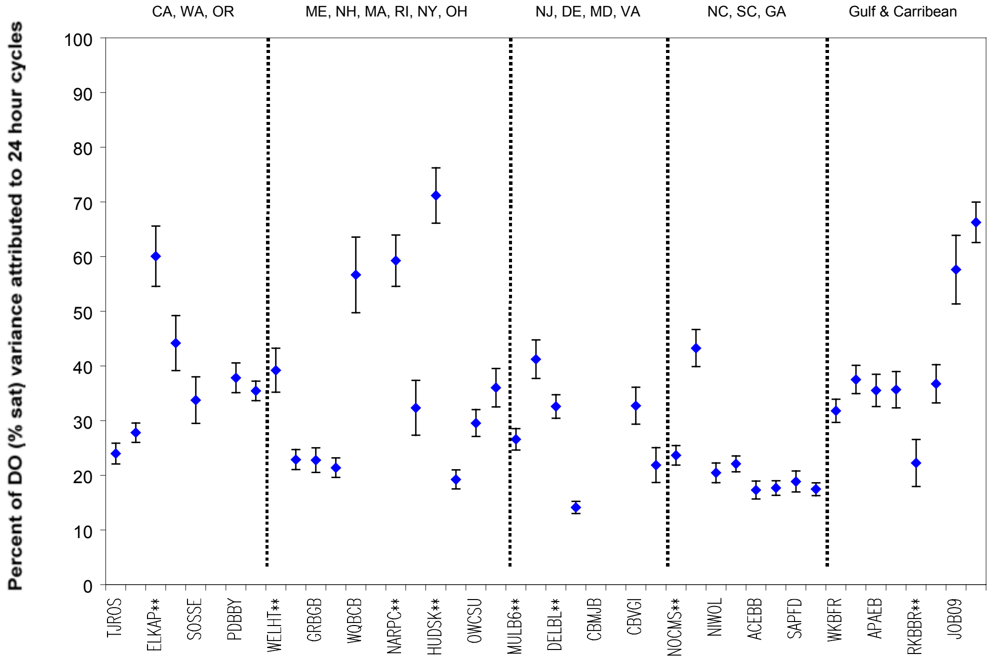


Figure 226. Percent of DO (% saturation) variance (mean ± std. error) due to 24 hour cycles. Sites within Reserves that were significantly different from each (Sidák method) are indicated with ** Note: For each Reserve, the first site is labeled and the second site is not labeled.

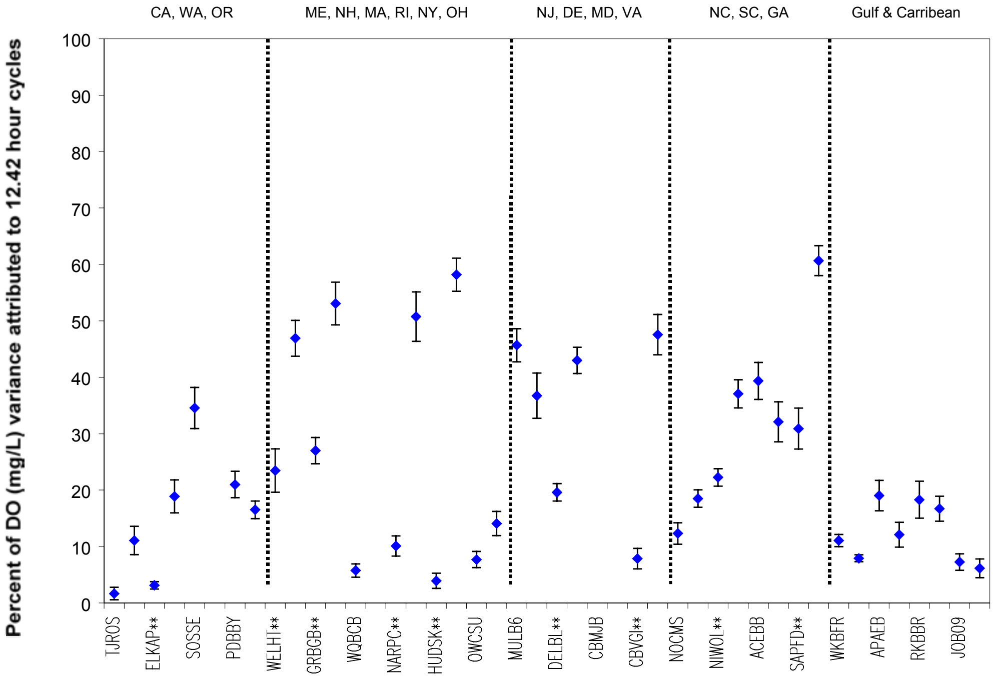


Figure 227. Percent of DO (mg/L) variance (mean ± std. error) due to 12.42 hour cycles. Sites within Reserves that were significantly different from each (Sidák method) are indicated with ** Note: For each Reserve, the first site is labeled and the second site is not labeled.

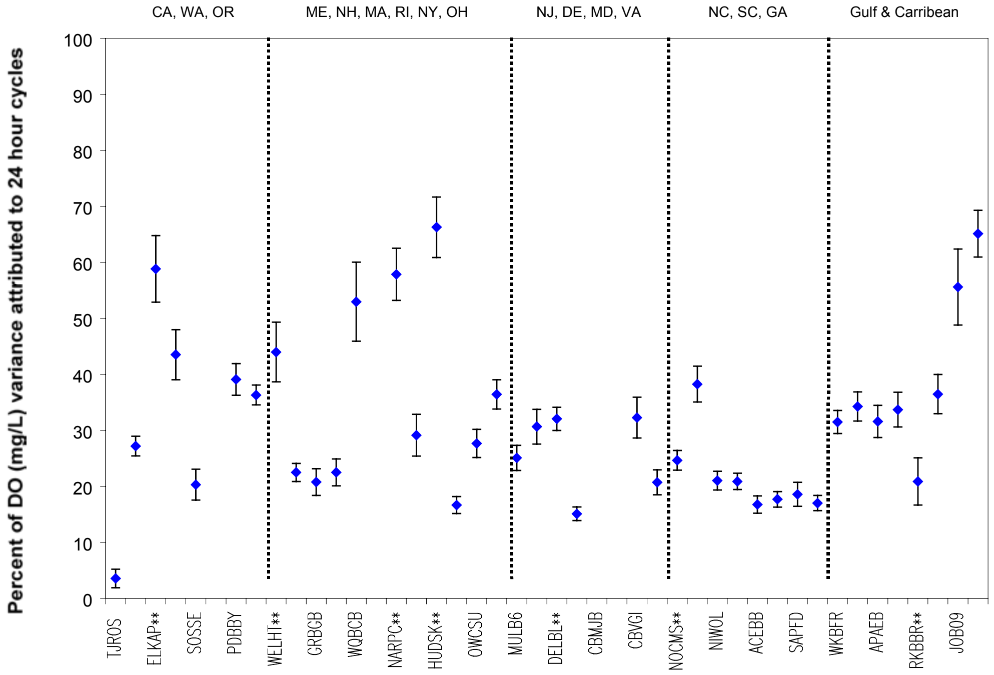


Figure 228. Percent of DO (mg/L) variance (mean ± std. error) due to 24 hour cycles. Sites within Reserves that were significantly different from each (Sidák method) are indicated with **
Note: For each Reserve, the first site is labeled and the second site is not labeled.

Photosynthesis and respiration

Approximately 75% of the data calculated from the SWMP between 1996-1998 were consistent with the assumption that the water masses moving past the sensors were homogeneous. Two major exceptions to this pattern occurred at the Sawkill Creek site (Hudson River) and at Joe Leary Slough (Padilla Bay). At Sawkill Creek, only 31% of the data were included in metabolic rate calculations. At this site, the data sonde was deployed just upstream of a dam in the creek. Physical processes (e.g., advection of different water masses when stream flow was greater than 0.4 m^3/s), rather than biological processes, probably enhanced oxygen exchange across the air-water interface and controlled the oxygen dynamics at this site. At Joe Leary Slough, 57% of the observations were used to calculate metabolic rates. This small, intermittently flushed slough drains agricultural fields and pastures. Restricted water flow and intermittent tidal flushing between the Joe Leary Slough and Padilla Bay, due to a dam and one-way tide gates, led to some questionable results. When high tides occurred during the middle of the day, the calculations led to an erroneous estimate of production or respiration. In this case, physical processes, rather than biological processes, controlled oxygen concentrations. Instrument drift was a significant problem at three sampling sites: Apalachicola Bay-Bottom, Rookery Bay-Upper Henderson, and Weeks Bay-Fish River. At these sites, only the first 2 days of each deployment were used to estimate metabolic rates.

Respiration generally was greater than gross production (Figure 229), except at two sites (Goodwin Islands-Chesapeake Bay VA and Central Basin-Waquoit Bay) where gross production exceeded respiration and one site (Hudson River Sawkill) were production and respiration were equal. Average metabolic rates among Reserves were variable: 0.6-15.6 $gO_2\ m^{-3}\ d^{-1}$ gross production, 0.7 – 19.3 $gO_2\ m^{-3}\ d^{-1}$ total respiration, and 0.3 to – 9.1 $gO_2\ m^{-3}\ d^{-1}$ net ecosystem metabolism. The highest rates occurred at the Elkhorn Slough-Azevedo Pond and Chesapeake Bay Maryland-Jug Bay sites. Metabolic rates at these sites were nearly double the rates at the other sites (Figure 229). The lowest gross production and total respiration rates occurred at the Hudson River-Sawkill site, a small freshwater creek. Rates were also generally low at the Great Bay sites, Narragansett Bay-T-wharf and Weeks Bay-Fish River (Figure 229).

Temperature and metabolic rates were significantly correlated at most of the 27 sites evaluated (Waquoit Bay Metoxit Point was not included in the analyses due to the small amount of data available for this site). Gross production and temperature were positively correlated ($p=0.05$) at all but six sites (and negatively correlated at two sites), respiration and temperature were positively correlated ($p=0.05$) at all but three sites, and net ecosystem metabolism and temperature were correlated at all but six sites. These findings suggest that biological processes controlled metabolic rates at these sites, with warmer temperatures associated with higher metabolic rates.

In contrast, salinity and metabolic rates were significantly correlated at only about half of the sites. On these occasions, metabolic rates were higher during periods of high salinity. Higher gross production values generally occurred at euhaline sites (25- 30 ppt) that experienced a moderate variation (10 ppt) in salinity range over annual cycles. These sites include Padilla Bay- Bay View Channel, Waquoit Bay-Central Basin, and Narragansett Bay-Potters Cove). High gross production was also observed at the tidal freshwater sites sampled in Chesapeake Bay Maryland (Figure 230). Metabolic rates were not associated with tidal range or DO (% sat) concentration.

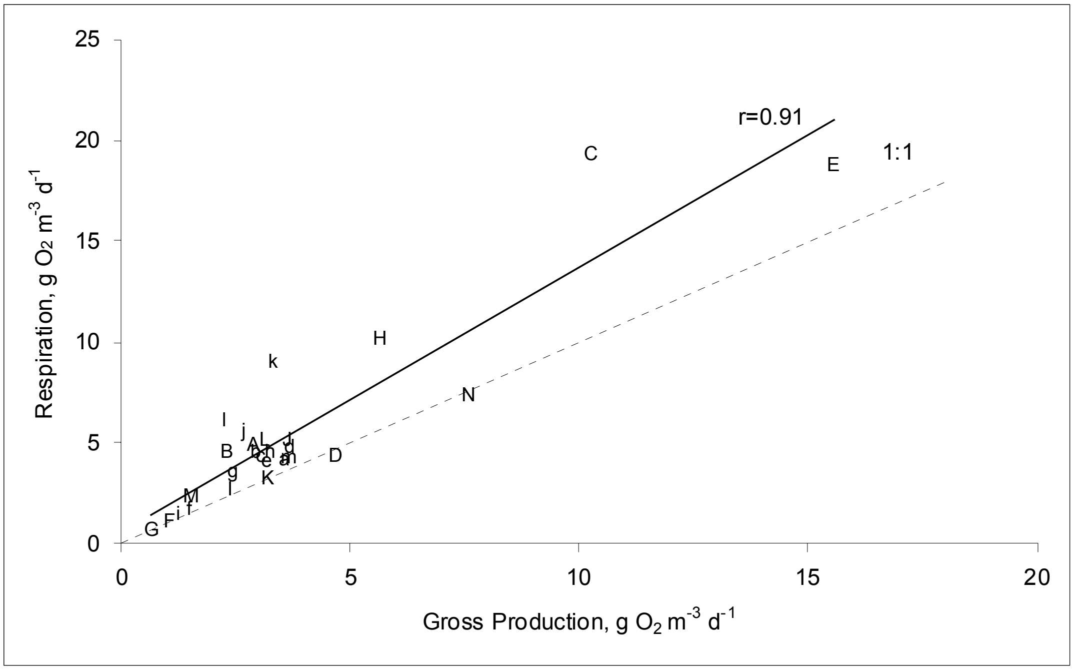


Figure 229. Mean volumetric rates of production and respiration among NERR sites. Legend used for all graphs: A-ACEBB, a – ACESP, B – APAES, b - APAEB, C – CBMJB, c - CBMPR, D – CBVGI, d - CBVTC, E – ELKAP, e - ELKSM, F – GRBGB, f - GRBSQ, G – HUDSK, g - HUDTS, H – JOB09, h – JOB10, I – NARPC, i - NARTW, J – NIWOL, j - NIWTA, K – PADBY, k - PADJL, L – RKBBR, l - RKBUH, M – WKBFR, m - WKBWB, N – WQBCB, n - WQBMP.

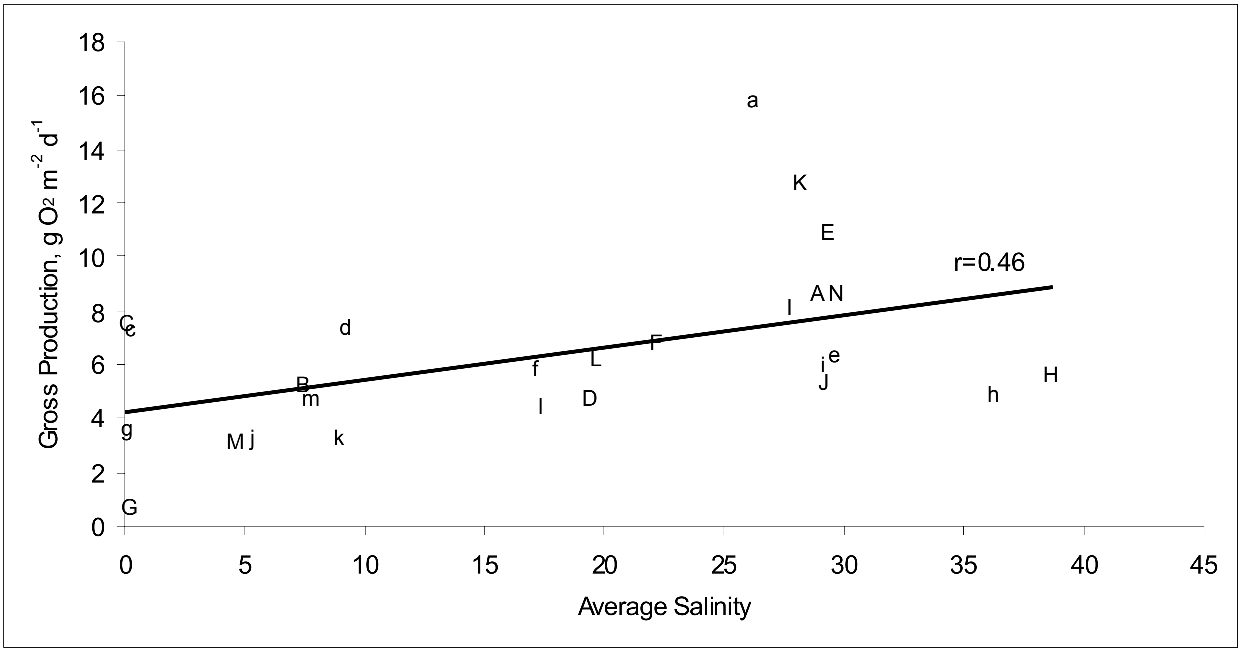


Figure 230. Gross production vs. average salinity among NERR sites.

Shallow sites (≤ 1 m) were more productive and had higher respiration rates than deep sites (> 2 m), with the exception of Padilla Bay-Bay View. At the Bay View site, the data sonde was deployed in a 4 m deep channel. The inter-tidal eelgrass beds surrounding the site are exposed at low tide; thus, the average water depth where the data sonde was located was likely deeper than the average water depth of the waterbody. Similarly, water depths were highly variable (0.7-6.5 m) between deployments among all sites. Because of this variation, volumetric metabolic rates were converted to areal metabolic rates by multiplying volumetric rates by average water depth in the area where the data sonde was located. Comparing production or respiration among the Reserves on a per m^2 basis also provides useful information, particularly at the sites with submersed macrophytes such as eelgrass or macroalgae. Thus, the deeper sites in ACE basin (St Pierre) and Padilla Bay (Bayview Channel) had the highest rates of production and respiration (Figure 231).

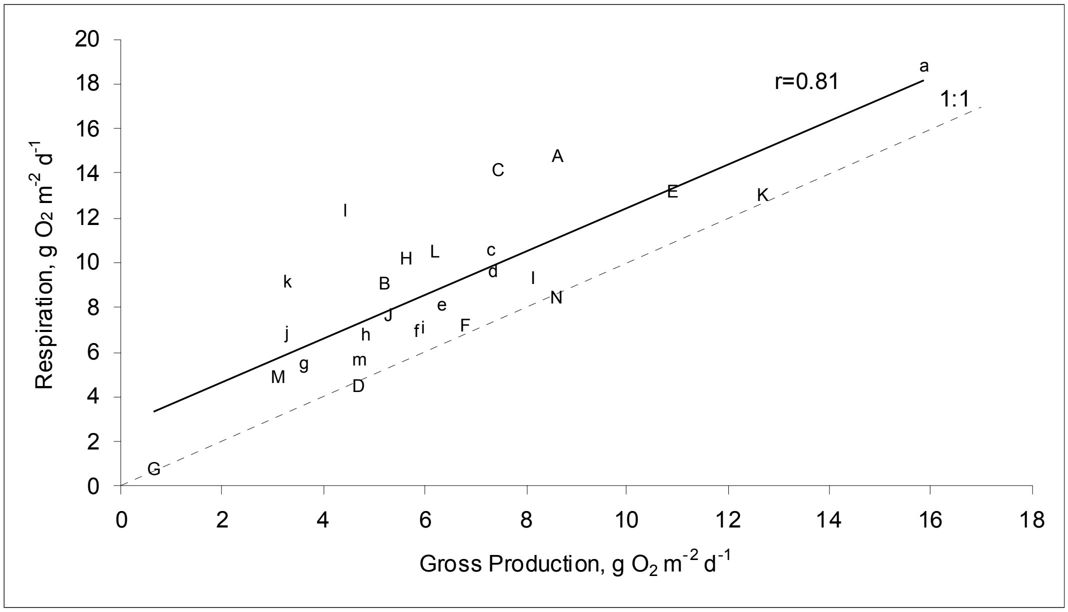


Figure 231. Areal metabolic rates among NERR sites.

Metabolic rates were not noticeably different among five geographic regions (Northeast, Mid-Atlantic, Southeast, Gulf and Caribbean, West Coast); however, there were consistent trends among different habitat types. Two sites with extensive beds of either eelgrass (Goodwin Island, Chesapeake Bay VA) or macroalgae (Central Basin, Waquoit Bay) were all autotrophic. The other eelgrass site (Bayview Channel, Padilla Bay) was balanced probably because the data sonde was deployed in a deep channel, not in the inter-tidal eelgrass bed. Four sites (Jobos Bay and Rookery Bay sites) surrounded by mangrove swamps were all strongly heterotrophic, particularly the Rookery Bay sites. Three tidal freshwater marsh creeks and six salt marsh creeks were all heterotrophic (Figure 232). Seven sites were located in open water bays or small rivers and were also heterotrophic, although the extent of this condition varied from extremely heterotrophic (i.e., Apalachicola East Bay) to moderately heterotrophic (i.e., Narragansett Bay and Great Bay-Buoy 126). Three sites located in small creeks or ponds completely surrounded by uplands were either heterotrophic (Elkhorn Slough-Azevedo Pond, Padilla Bay-Joe Leary Slough) or balanced (Hudson River-Sawkill).

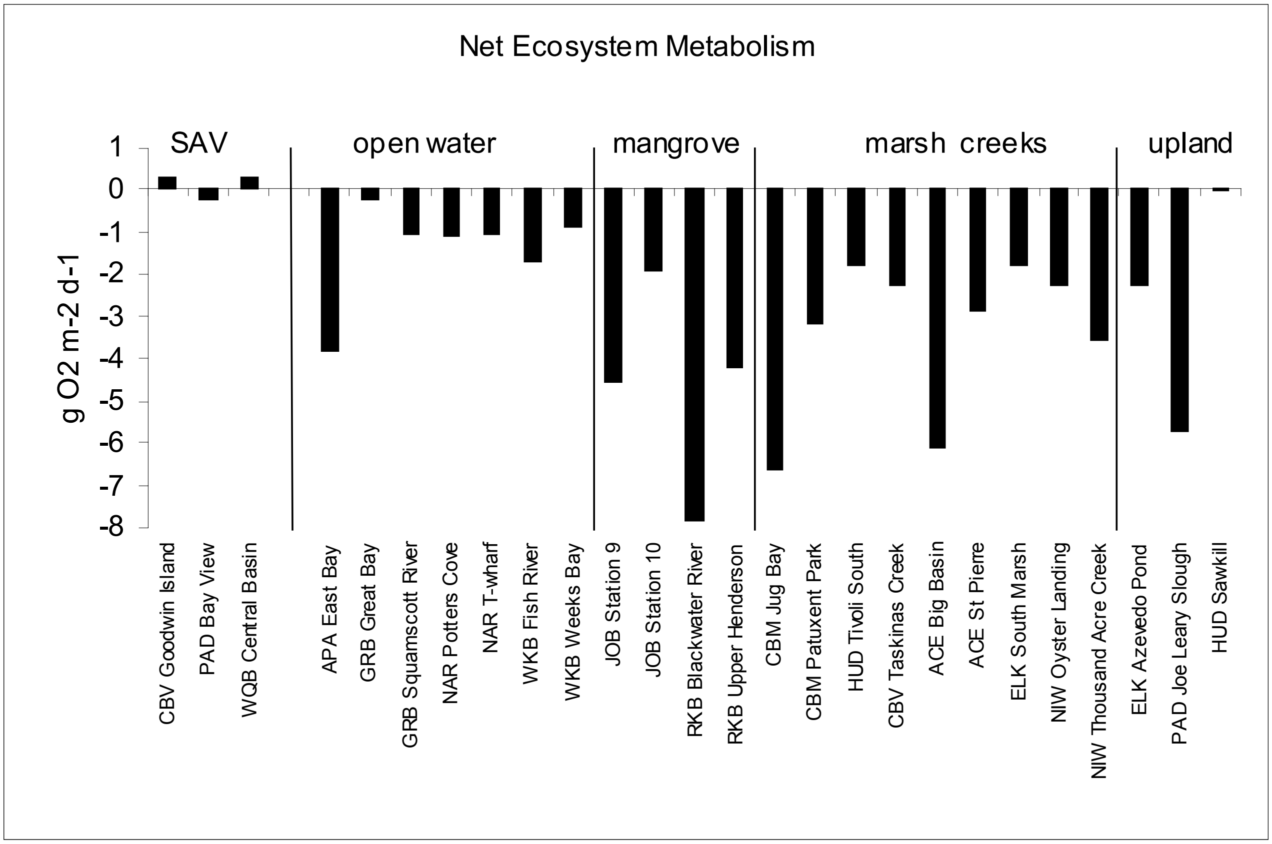


Figure 232. Relationship between net ecosystem metabolism (NEM) and habitat types.

Mean annual freshwater flow varied by over three orders of magnitude; however, the metabolic rates were not related to freshwater flow (Figure 233). Sites at reserves with intermediate flows (Chesapeake Bay-MD and ACE Basin) were generally more heterotrophic than sites with either higher or lower flows, except for Upper Henderson (Rookery Bay) and Joe Leary Slough (Padilla Bay), which had a low flow and was extremely heterotrophic.

In general, respiration was higher at the sites with intermediate freshwater fill times, which was calculated from estimates of freshwater flow and estuarine volume (Figure 234). This trend was not significant for gross production and freshwater fill time, although sites with greater freshwater fill times generally had higher gross production rates. As freshwater fill time increased, sites generally became more heterotrophic, except at Waquoit Bay-Central Basin and Padilla Bay-Bay View (Figure 235). Freshwater fill times provide a simple way to estimate residence time without including the complexities associated with estuarine circulation. Literature values of residence time were available for nine sites: Apalachicola Bay (Mortazavi et al. 2000), Chesapeake Bay Md (Jug Bay and Patuxent River Park, Hagy et al. 2000), Elkhorn Slough (South Marsh, Largier et al. 1997), Great Bay (Buoy, GBNERR homepage), Hudson (Tivoli South, Howarth et al. 1996), Narragansett Bay (Potter Cove, T-wharf, Nixon et al. 1995), and Waquoit Bay (Central Basin, Jay et al. 1997). No trend between residence time and gross production was evident; however, as residence time increased, respiration increased and sites became more heterotrophic ($p=0.06$, $r^2=0.40$, Figure 236).

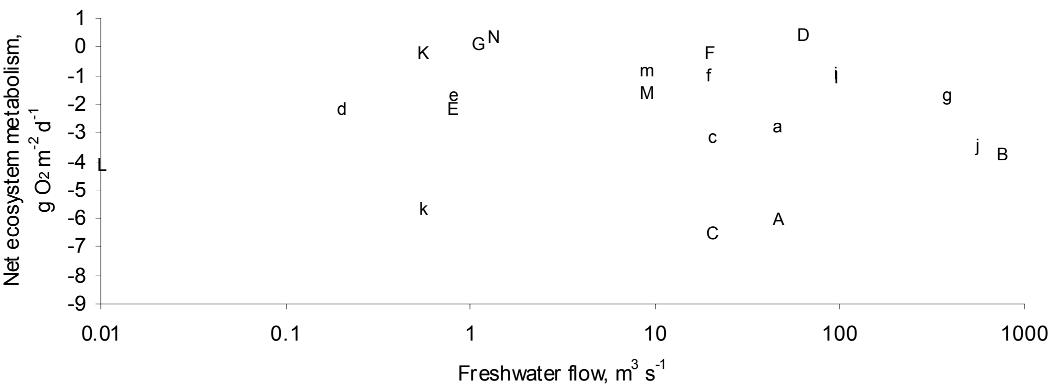


Figure 233. Net ecosystem metabolism vs. freshwater flow among NERR sites.

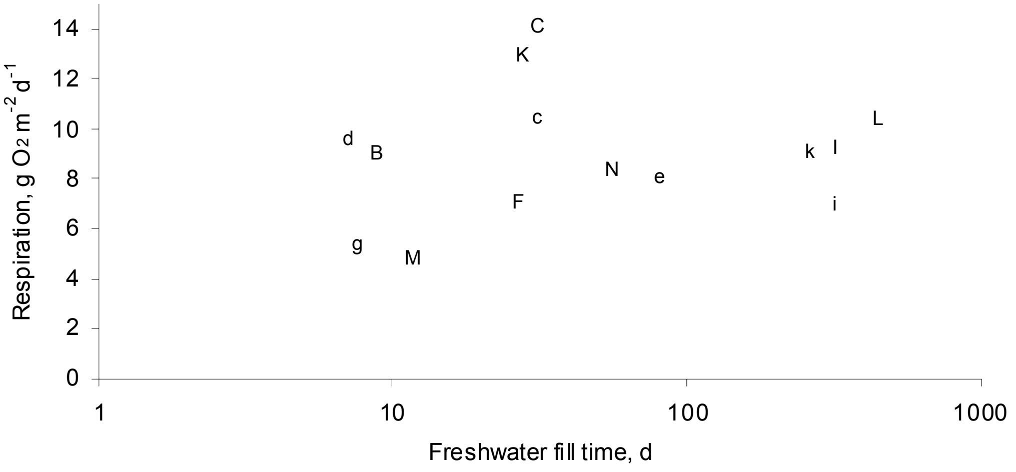


Figure 234. Respiration vs. freshwater fill time among NERR sites.

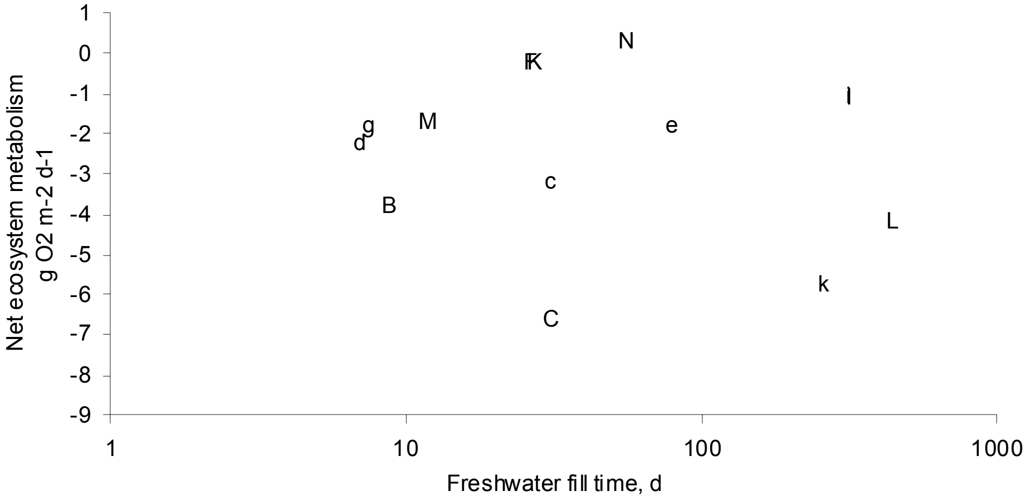


Figure 235. Net ecosystem metabolism vs. freshwater fill times among NERR sites.

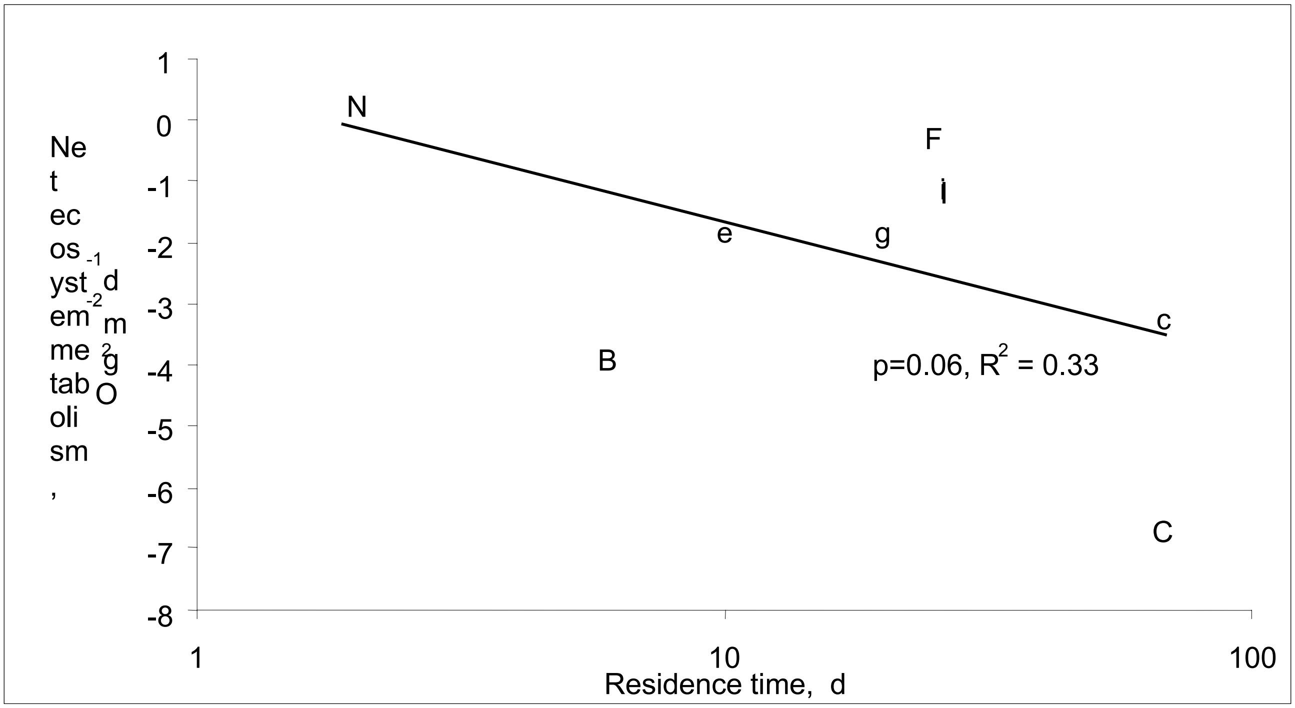


Figure 236. Net ecosystem metabolism vs. residence time among selected NERR sites.

No consistent trends were observed between metabolic measurements and either nutrient or chlorophyll *a* concentrations at the 13 sites with available nutrient data (ACE Basin-both sites, Chesapeake Bay- Goodwin Island, Elkhorn Slough-both sites, Great Bay-both sites, Hudson River-both sites, Jobos Bay-both sites, North Inlet/Winyah Bay-both sites). The range in average chlorophyll *a* concentrations was between 2-13 µg/l. Average nutrient concentrations ranged between 2-300 µM DIN and 0.1-3.5 µM DIP.

Although correlation analysis found no association between nutrient concentrations and metabolic processes, visual examination of DIN:DIP versus P:R ratios suggested increased metabolism when N and P concentrations were less than the 16:1 Redfield ratio (Figure 237). The ratio of DIN:DIP is frequently used to determine whether phytoplankton are nitrogen or phosphorus limited. Less than a ratio of 16:1 indicates nitrogen limitation. Ratios greater than 16:1 indicate phosphorus limitation. The DIN:DIP ratio by itself is not always a good predictor of trophic conditions because water column nutrient concentrations represent a balance between input and removal processes which involve both physical (advection and burial) and biological (uptake, regeneration and denitrification) processes. These data suggest that Reserve sites are unlikely to be autotrophic under nitrogen-limited conditions; however, greater heterotrophy with increasing phosphorus limitation did not necessarily occur. Phosphorus limitation of primary production, common in freshwater systems, may have occurred at the two freshwater Hudson River sites which had extremely high DIN:DIP ratios, but very different P:R ratios. All the other sites for which nutrient data were available were either mesohaline or euryhaline in character. Sites with DIN:DIP ratios between 16:1 and 20:1 were either strongly heterotrophic (e.g., both ACE Basin sites) or autotrophic (e.g., Chesapeake Bay VA-Goodwin

Islands).

Nutrient (N & P) loading rates were available from the literature or could be calculated for 9 of the sites: Apalachicola (Mortazavi et al. 2000), Chesapeake Bay MD (both sites, Boynton et al. 1995), Elkhorn Slough (both sites, Caffrey unpublished data), Narragansett Bay (both sites, Nixon et al. 1995), Weeks Bay (Fish River, Pennock 1996), and Waquoit Bay (Central Basin, D'Avanzo et al. 1996). The only association found between nutrient loading and metabolic rates was between nitrogen loading and net ecosystem metabolism (Figure 238). Sites with higher nitrogen loads were more autotrophic than sites having low nitrogen loads (Figure 238). Several researchers have reported a similar pattern (Smith and Hollibaugh 1993, 1997, D'Avanzo et al. 1996, Kemp et al. 1997). The balance between organic loading and inorganic loading seems to be particularly critical in determining whether sites are autotrophic or heterotrophic (Kemp et al. 1997). All sites receive organic inputs from surrounding uplands, marshes, or mangrove forests. As bacteria break down that organic material, oxygen is consumed by bacterial respiration and nutrients are released or regenerated. Although those nutrients are then used to support primary production that produces oxygen, there are lags between input of organic matter, nutrient regeneration and subsequent production. However, when inorganic nutrients directly enter the system from upstream or land runoff, there is no lag in their use by phytoplankton.

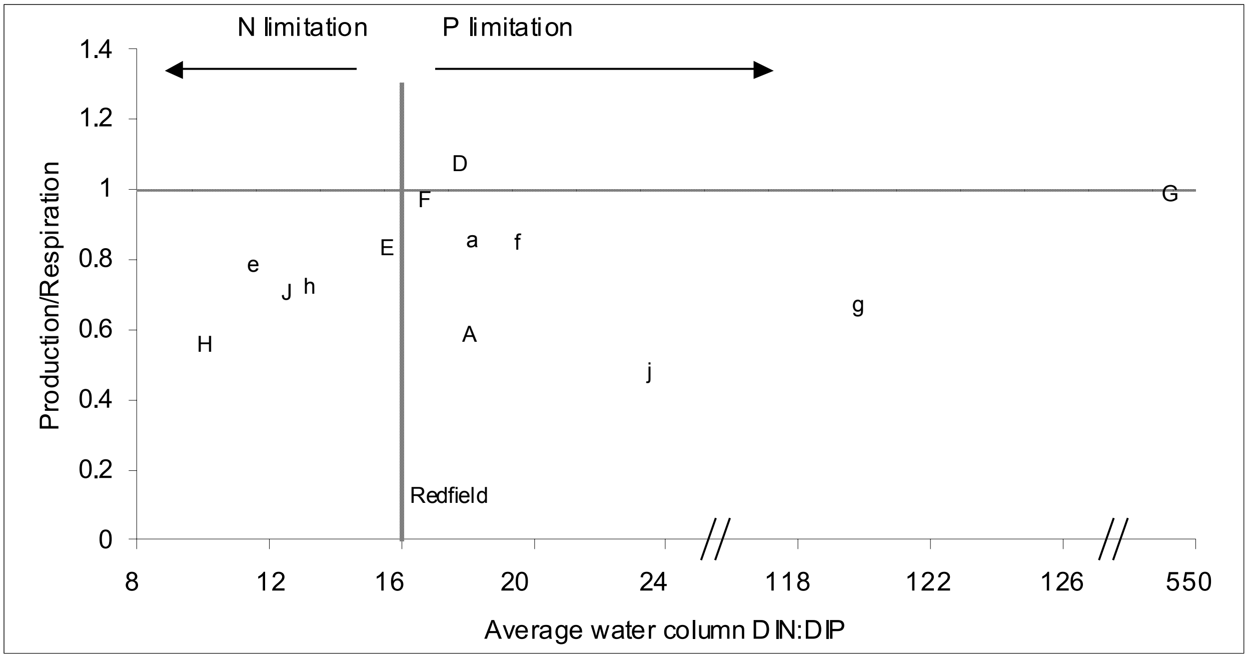


Figure 237. Ratios of dissolved inorganic nitrogen (DIN) to phosphate (DIP) vs. production to respiration.

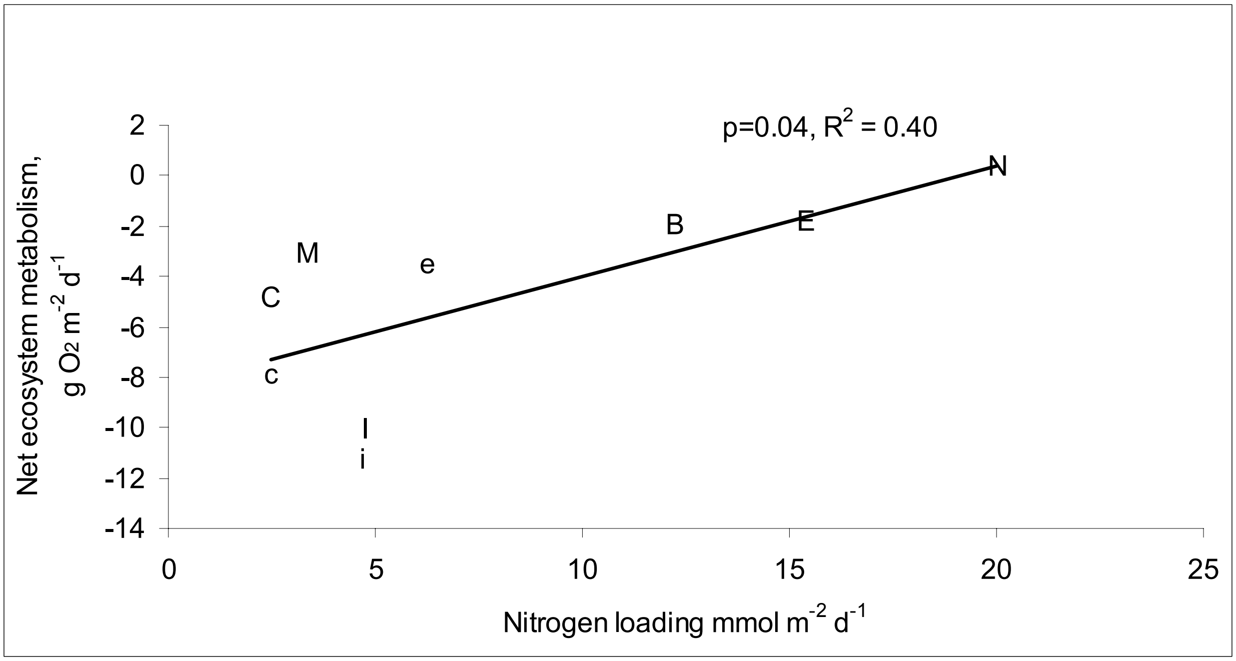


Figure 238. Net ecosystem metabolism versus nitrogen loading among selected NERR sites.

DISCUSSION

Water Quality Synthesis

The 44 water quality sites of the NERR SWMP represent multiple geographic regions, climates and salinity regimes. These sites also have varying levels of anthropogenic influence, ranging from no developed land in the immediate watershed of the site to having >20% of the watershed either developed or utilized for agriculture or silviculture. Most of the sites are located in shallow water (<2 m) and the daily fluctuations in temperature, salinity and dissolved oxygen are representative of conditions that occur in shallow water estuarine environments throughout the nation's estuaries. Location of water quality monitoring sites may have a profound impact on the magnitude and variability of water quality variables; hence data from only a couple of sites may not provide adequate representation of conditions that occur throughout the estuary, particularly with respect to deep areas.

Dissolved Oxygen

Dissolved oxygen (DO) is a fundamental requirement for maintaining a diverse estuarine ecosystem. Oxygen content of estuarine waters varies with temperature, salinity, turbulence, photosynthetic activity of algae and plants, and atmospheric pressure. Temperature and biological activity can greatly influence variability in DO at daily and seasonal time scales. Biological respiration, including that associated with decomposition, reduces DO. Spatial variability in DO concentrations can occur within estuaries as a result of differing biological and physical processes. Increased loads of organic matter and nutrients can decrease DO concentration as a result of increased microbial respiration that occurs during organic degradation processes (Chapman 1992).

In addition to biological and chemical processes, dissolved oxygen concentration is also affected by land use patterns. Among watershed types (forested, industrial, urban and suburban) in the Charleston Harbor estuary, Lerberg et al. (2000) noted that hypoxia was regularly observed in both developed and undeveloped creeks. Wenner et al. (1998) noted that the frequency and duration of low DO events tended to be greater for creeks with developed watersheds, suggesting a relationship between land use and dissolved oxygen concentration. Because low DO concentrations regularly occur in shallow tidal creeks, frequency and duration of these events may be a better indication of degraded water quality in tidal creeks rather than just occurrence of low DO.

Increases in the extent and volume of hypoxic and anoxic water in the marine environment have occurred globally over the last several decades and are an important environmental issue that coastal resource managers must address (Diaz and Rosenberg 1995). According to the Environmental Protection Agency (EPA), low dissolved oxygen is one of the most common causes of not achieving designated uses in the Nation's estuaries (EPA 1990). The EPA found that about 19-25% of the bottom water area in the Virginian Province had DO concentrations <5 ppm and 4-8% had concentrations <2 ppm. These hypoxic conditions occur primarily in the upper portion of Chesapeake Bay where areas continuously experience low dissolved oxygen, rather than just at night, during the summer months (Whitledge 1985).

Determination of DO concentrations is an important part of water quality monitoring because oxygen influences nearly all chemical and biological processes within water bodies. A threshold concentration of 4-5 ppm is used by the EPA and by some states (e.g., South Carolina) to set water quality standards (EPA 1990, DHEC 1993). When DO concentrations decline below 2 ppm, generally accepted as the minimum oxygen level necessary for sustaining animal life and reproduction, hypoxia results. It has been suggested that exposure to anoxic and hypoxic DO conditions is a controlling factor in the distribution of aquatic organisms (Diaz and Rosenberg 1995, Lerberg 1997). Subtle effects on physiology, reproduction, and behavior may occur from lowered DO, while severe hypoxia can cause shifts in distribution or abundance of populations (Fry 1971, Summers et al. 1997).

Conversely, excessively high levels of dissolved oxygen (supersaturation) may also be indicative of high primary production. Thus, DO concentration provides an index of the balance between production and oxygen consumption. In areas with elevated primary production, supersaturation values > 120% are not uncommon during daylight periods and may reach 500 % in shallow estuarine waters (Kalle 1972). While there is little information available on supersaturation effects on biota, high oxygen concentrations may have a toxic effect on plants and animals through the formation of reactive oxygen species (Turner and Brittain 1962, Dalton 1995). In water that is over-saturated with oxygen, respiration of plants is markedly increased (Gessner 1959). Supersaturation was most prevalent in spring at NERR sites and may be related to increased algal production as temperatures rise during daylight hours. Lentic conditions, in combination with lower suspended solids and increased water clarity, have resulted in high algal biomass, higher pH readings, and frequent dissolved oxygen supersaturation as well as nutrient depletion in slack-water areas of the lower Mississippi River (Beckett and Pennington 1986). A relationship between high levels of chlorophyll a, oxygen supersaturation (>120%) and non-conservative nutrient concentrations have been noted for other estuaries during low-flow conditions in spring and summer (Rendell et al. 1997).

Our synthesis of water quality data from the NERR SWMP indicates that water quality in the Reserves has not experienced many of the problems found in other more populated areas of the country. Although hypoxic events occur frequently in the NERRs, these events are generally of short duration. Short periods of hypoxia are generally within the tolerance range of many aquatic animals that take up more oxygen and transport it more effectively to cells. A few sites experienced hypoxic events that lasted for >24 h, a duration which can affect growth and survival. The longer the duration of hypoxia, the greater the impact to juvenile and larval growth and survival (USEPA 2000).

While the percent of time that DO was less than 28% saturation (~2 mg/l) varied substantially among reserves and between years, most of the hypoxic events occurred in summer when water temperatures were highest. Seasonal hypoxia, as experienced by many of the Reserve sites, develops at bottom depths when respiration in the water and sediment depletes oxygen faster than it can be replenished. Reserves in the Gulf of Mexico and Caribbean Sea had the highest occurrence of hypoxia events > 24 h duration, which was associated with the high temperatures observed at these Reserves. Hypoxia may also be related to estuarine circulation patterns and whether circulation is adequate to promote flushing of water over one or several tidal cycles. Daily cycles of hypoxia are related to lack of stratification in shallow estuarine habitats where nighttime respiration depletes DO. Although it is clear that both natural factors (i.e., degree of stratification, water temperature and circulation patterns) and anthropogenic factors (i.e., nutrient loading) can contribute to low DO events, further investigation is needed to evaluate long-term trends and inter-annual variability in low DO events recorded from the NERR SWMP. Incorporation of additional information such as weather patterns, rainfall, sea level rise, nutrient loading, habitat differences, and land cover are required to better

understand such trends.
The large fluctuations in dissolved oxygen which occur over short-time periods in the NERRs demonstrate the need for long-term continuous measurements to estimate the frequency and duration of exposure to low DO. For example, hypoxia events occasionally lasted for greater than 24 hours during the first 48 hours post-deployment; thus, less frequent sampling would underestimate the extent to which natural and anthropogenic hypoxia occur. Similarly, harmonic regression models required enormous amounts of input data in order to fit these models to the observed water quality data. The vast amount of data collected by the NERRs may also prove useful in developing models that coastal zone managers could use to predict oxygen conditions in shallow estuarine systems. The inability to correctly characterize dissolved oxygen conditions in estuarine systems impairs conclusions from waste load allocation models and other water quality evaluations that are used to develop wastewater treatment strategies and requirements (Summers et al. 1997).

Salinity

Salinity among sites in the NERR SWMP ranged from limnetic to euhaline. Few sites within reserves were statistically similar in mean salinity or salinity range; however, these differences were typically small and may not be biologically significant. Large differences in salinity conditions between sites within a Reserve were observed at several reserves. Seasonal differences in salinity occurred at most reserve sites and were probably a reflection of seasonal changes in precipitation and evaporation. Tidal and diel cycles also appeared to strongly influence salinity at reserves.

Salinity may be the most important factor affecting the distribution of estuarine organisms. It is an essential element in determining estuarine habitat and directly affects the distribution, abundance and composition of biological resources. Although variability in salinity influences distributions of organisms, most of the nation's estuaries experience significant salinity variability both daily and seasonally. The frequency and magnitude of this variability differs in each estuary, largely as a result of fresh water inflow, tides, winds, and coastal shelf processes (Orlando et al. 1994).

Depending upon the time scale, variability in salinity can be predictable or highly episodic. Fluctuation in salinity at hourly intervals is most often attributed to the tidal cycles. With a few exceptions (i.e., Weeks Bay, Old Woman Creek, Padilla Bay-Joe Leary Slough), NERR sites experience semi-diurnal tides in which high salinity oceanic waters enter the estuary during the flood tide stage. At the time scale of days to weeks, variability is most often attributable to short-duration fresh water pulses, the spring-neap cycle, and frontal passages. Seasonal effects are responsible for most of the net changes in annual salinity, due to differences in fresh water discharge and prevailing wind speed/direction. Intense, episodic events such as floods also have a dramatic effect on salinity, as indicated by examination of salinity conditions following hurricanes that occurred in the North Carolina and Virginia NERRs during 1998. Tropical storms and high volume releases from control structures can eliminate vertical stratification and suppress tidal influences (Orlando et al. 1994).

Anthropogenic factors can affect salinity variability at a range of spatial scales. Changes in salinity at the watershed level have occurred due to alterations of flow regime. Within individual tidal creeks, salinity fluctuates in response to runoff events. In the Charleston Harbor estuary, salinity varies within creeks, among creeks, and among watershed classes (Lerberg et al. 2000). Within this estuary, tidal creeks are much more dynamic than most large estuaries and typically experience salinity fluctuations

> 6 ppt over tidal cycles (Lerberg et al. 2000). Variance in salinity, as represented by the salinity range, is greater in creeks surrounding suburban, urban and industrial land uses, than in forested upland creeks, which was attributed to increased amounts of impervious surface at the anthropogenically impacted sites (Lerberg et al. 2000). Increased amount of impervious surface alters hydrodynamic processes, especially the rate at which precipitation runoff reaches receiving waters. As additional data are collected from the NERR SWMP, it would be informative to examine whether extreme and highly variable fluctuations in the salinity pattern are an indicator of hydrodynamic changes to monitoring sites resulting from watershed development or land use changes.

Periodicity (Harmonic Regression Analysis)

It was abundantly clear, even after only a cursory inspection of only a few of the raw data series, that the periodicity in these data was strong and very complicated. It was also clear that there were many complicating factors present including meter probe accuracy, deployment effects, and weather anomalies. Isolation of periodicity from this diverse web of signals, and subsequent interpretation of the results without oversimplification of the patterns presented, proved challenging. Comprehensive interpretation of these diverse results, especially for salinity and dissolved oxygen, will require active participation of individuals more familiar with the sites and with the physical phenomena driving these measured water quality variables.

The standard errors of the estimates in the harmonics figures are relatively small, indicating that estimated annual averages based on these harmonic regressions are fairly accurate; however, many of the sites within reserves are significantly different from each other. Sites within reserves are often as different, or more different, than sites between reserves. It is clear that enough data are being collected (i.e., every 30 minutes) to obtain accurate estimates. Results would be improved greatly if meters delivered more reliable results for longer periods of time, deployment effects were reduced (i.e., carefully deploying new meters to obtain a more continuous signal), and annual sampling regimes were more complete and uniform across sites.

In some cases, seemingly anomalous site results may be due to incomplete or non-uniform sampling regimes. Several sites did not collect data at certain seasons of the year (i.e., winter for reserves in the northeast) or contained gaps of more than 45 days between deployments. In these cases, fitted seasonality curves were truncated to correspond only to periods of the year where gaps were less than 45 days. Non-uniformity in seasonal sampling confounded the predicted values for water quality variables. For example, mean predicted water temperatures for East Coast sites increased from north (New England) to south (Mid-Atlantic, Southeast Coast, and Gulf of Mexico/Caribbean). An exception to this trend was the Chesapeake Bay MD NERR, which had an unusually high mean temperature relative to other sites in its region; however, the anomalous mean predicted water temperature for this site was due to the fact that sampling was primarily conducted in summer.

The approach taken here, to separately model each deployment's series with a harmonic regression and then analyze summary measures for each deployment across years and sites, is statistically valid and has been to some extent successful. In particular, the 37-term deployment-level harmonic regression model has fit surprisingly well across about 10,000 deployments having a great diversity of patterns. A number of the descriptives calculated from these fitted regressions have not been as useful as hoped; however, descriptives based on first-full 12.42 hour and 24 hour signatures in each deployment tended to have large standard errors, and for some sites showed anomalous results.

If similar analyses are to be performed in the future, dropping cross-product terms from the deployment level regressions should be seriously considered. Though the inclusion of cross-product terms led to better-fitting models, especially at extreme values in the data, they also complicated the fitted models substantially, making it difficult to separate the patterns due to 12.42 hour and 24 hour cycles. Omission of cross-product terms would produce 12.42 hour and 24 hour "average" signatures for each deployment, which could then be more easily viewed and described, and which would be more accurately estimated than first-full-cycle profiles. Whether these "average profiles" would be a fair representation of the 12.42 hour and 24 hour cycles for a given deployment should be resolved.

Metabolic Properties

Production, respiration and net ecosystem metabolism were calculated using dissolved oxygen data (% saturation, mg/L), water temperature (°C) and salinity (ppt) data from 27 sites (14 reserves) encompassing a wide range of estuarine conditions (i.e., freshwater, salt marsh, and mangrove swamp). All sites were subjected to upland runoff and several sites were located on large bodies of water that were well flushed by tidal cycles. In general, results were consistent with our understanding of how estuaries function. At individual sites, an autotrophic versus heterotrophic status appeared to be related to the habitat type, specifically whether it was dominated by submersed aquatic vegetation or not. Where primary producers such as SAV dominated, systems were autotrophic. In marsh-dominated systems, organic material produced in the marshes is exported to tidal creeks and bays where decomposition occurs leading to heterotrophic conditions in the water column. Similarly, in the open water of estuarine bays and rivers, allothchonous inputs of organic carbon can also lead to heterotrophic conditions. Smith and Hollibaugh (1993) found that 17 of 27 marsh, estuarine or coastal ocean locations were net-heterotrophic. This review along with the results of this study suggests that aquatic heterotrophic conditions are a common feature among many estuarine systems.

The results from this study suggest that freshwater flow and residence times are critical variables controlling metabolic rates. In order to provide a comprehensive evaluation of production and respiration at the ecosystem level throughout the entire NERR system, metabolic rates should be calculated for the eight Reserve sites not included in this synthesis. Furthermore, additional metabolic calculations should be made for all Reserve sites for the years not included in this study (1995, 1999, and 2000) to better assess inter-annual variation at NERR sites. Analysis of this longer data record would also permit examination of how inter-annual changes in the timing and amounts of freshwater (e.g., El Niño and La Niña climates) affect metabolic rates at each Reserve.

Metabolism results suggest that nutrient (mainly nitrogen) loading to these systems may be a critical factor in determining whether systems are autotrophic or heterotrophic. While nutrient concentration data can be helpful, many factors (i.e., uptake, regeneration, burial, advection) affect concentrations making it difficult to interpret the results. Thus, annual estimates of nitrogen and phosphorus loadings to the systems would be the most useful data for interpreting metabolism results. Additional ancillary data such as watershed area, detailed bathymetry and hypsography (i.e., mean depth, estuarine area at different depths, estuarine volume), freshwater flow, and residence time (including seasonal and spatial variability) are also needed for each Reserve to better interpret metabolic data.

We believe that estimating metabolic rates provides valuable information for the individual Reserves and the Reserve system as a whole. Additional deployment sites should be selected to ensure good estimates of metabolic rates. Sites should be chosen so that biological processes dominate over physical processes. Two of the sites examined, Saw Kill Creek (Hudson River NERR) and Joe Leary Slough (Padilla Bay NERR), are good examples of sites where physical processes, rather than biological processes, dominated oxygen exchange; thus, the methods for calculating metabolic measurements were not appropriate at these sites.

Program Overview and Recommendations

Instruments and Approach

With the exception of dissolved oxygen drift due to instrument fouling (pp. 18-19), data sondes provided reliable and comparable water quality data for the range of geographical areas and environmental settings sampled. This instrumentation was well suited for collecting the data needed by a national program that has the objective of characterizing short-term variability and long term changes in aquatic environments. The instruments were relatively easy to calibrate and maintain and generally hold calibration for the parameters measured for the 10-14 day deployment periods. The only problem noted was that at some sites, mainly those located at southern latitudes, the dissolved oxygen probe frequently showed evidence of fouling after about 48 hours. Fouled probes resulted in an underestimate of the degree of supersaturation and an overestimate in the severity of hypoxia that occurred at a site. The Research Coordinators estimate that approximately one full time technician is required to collect the water quality data for two deployment sites using the data sonde technology. Technician responsibilities include maintaining and deploying the instruments, conducting a quality assurance program to ensure high quality data are collected, downloading the data, and transfer of data and metadata to the Centralized Data Management Office (CDMO).

All of the parameters evaluated by this study (depth, conductivity/salinity, temperature, dissolved oxygen as % saturation, and dissolved oxygen concentration as mg/l) provide valuable information about estuarine system dynamics. The depth data were particularly important for evaluation and interpretation of the temporal variability in parameters associated with tides. We did not evaluate the pH data based on a recommendation from the expert panel. The panel noted that at this time they did not know how to interpret the results of these analyses and several panel members expressed concerns about the reliability of the data over the several week deployment periods that were used. We recommend that the pH data be evaluated in the future to assess its usefulness and to determine its reliability. Recent data suggest this information may be related to the growth and productivity of some bivalve species (A. Ringwood, personal communication).

The procedures used to select and establish deployment sites were not standardized across NERR sites. Many of the reserve programs selected sites that their scientists and managers felt represented either: (1) typical relatively pristine; and (2) typical “disturbed” habitat. Other reserve programs, however, selected sites that represented conditions or habitats that they felt were typical of the ecological conditions in the reserve or provided information that addressed questions of interest to the reserve. In many cases, site selections were made without detailed knowledge of the factors associated with the site that affect water quality (i.e., estuarine circulation, size of drainage basin, land cover in the drainage basin). Hydrographic processes and factors affecting water quality at some of the deployment sites are too complex to characterize using the limited data collected by the SWMP. At almost all reserves, ancillary data such as bathymetry, residence time of water at the sample site, freshwater inflow, pollutant loadings, watershed size, and land cover within the drainage area were not available or only partially available to assist with interpretation and synthesis of the SWMP data.

Although general protocols for instrument deployment were developed by SWMP, differences in deployment methods affected the comparability of the data across sites and regions. Depth of deployment of instruments above the bottom sediment was not uniform for all sites. At most sites (n=24), instruments were moored 0.1 to 0.6 m (mean = 0.3 m) above the bottom sediment, a variation approximately equivalent to the length of the instrument itself. Assuming that the definition of the mooring depth was consistently used by these sites (i.e., depth always refers to the depth of some point on the instrument such as the probe), this is not a troublesome difference. At three Reserves (Padilla Bay, Narragansett Bay, and Wells Bay), depth of deployment above the bottom sediment differed between sites within the same Reserve by 0.5 to 1.0 m. At these sites the mean depth of deployment of the instrument above the bottom sediment was 0.9 m (range = 0.3 to 1.5m), similar to the mean depth of deployment of instruments above the bottom sediment at Waquoit Bay (0.8 m). Mean depth of deployment of instruments at these sites is almost three times the mean depth of deployment for all other sites. Instrument depth above the bottom sediment was not provided for 10 sites.

In addition to deployment depth, standardization of the actual location (i.e., mid-channel, adjacent to the shoreline) of sampling sites needs to be considered. Although logistical considerations often determine where and how instruments are deployed, subtle differences between sites can result in pronounced differences that preclude comparison between sites. For example, at both monitoring sites used by the Sapelo Island NERR and at the Great Bay Buoy, instruments were deployed from a floating platform rather than a fixed platform; thus, depth data could not be compared to other sites. These differences frequently have major influence on the values of the parameters measured as well as analysis results (e.g., comparisons within and among reserves). Most importantly, however, they affect the value of the collected information for addressing regional and national issues (e.g., status and trends in the extent and severity of hypoxia). In order to reduce discrepancies in measurements of water quality variables due to sampling design, we recommend that Reserves collectively develop a protocol, and provide the appropriate training, to standardize instrument deployment practices.

Data Management

A number of problems were encountered in the process of incorporating the water quality data into a central database (MS Access) to obtain a continuous time series of data for all sites. A summary of the problems encountered with the data were first presented at the March 2000 Research Coordinators Meeting in Williamsburg, VA, but will be briefly revisited here. First and foremost, the quantity of data was highly variable among sites. Data gaps were due to numerous factors including equipment failure, staffing problems, or weather (particularly freezing water temperatures that precluded winter observations at NERRs located in the Northeast and Lake Erie). Second, the quality of data was also highly variable, largely due to the utilization or under-utilization of the “anomalous data” and “missing data” sections of the metadata report. The “anomalous data” section is included to allow each Reserve to document and explain what constitutes suspect data and why these data were removed; however, this is frequently not performed. It often appeared that some Reserves only assessed the quality of data to determine if values were within the instrument range, but not whether the data were abnormally high or low. In contrast, some Reserves reported that data were retained due to a lack of justification to remove the data; however, they felt the data were suspect. Regarding the "missing data" section, many Reserves felt that this section should only reflect data that were missing due to instruments not being deployed. As a result of this perceived redundancy, the comments in the "missing data" section often only provided a reference to the "anomalous data" section. To address this issue, the CDMO decided in August 2000 to modify the wording of the protocols for both the "anomalous data" and "missing data" sections. Lastly, we suggest that Research Coordinators include a justification of sample site selection along with the metadata.

Deployment and retrieval data need to be included with the metadata, and the CDMO has taken necessary action to implement this recommendation. Deployment and retrieval data were necessary to determine deployment duration and, subsequently, the effect of dissolved oxygen drift at 1, 2, 4, 7, and 14-day intervals post-deployment due to bio-fouling (See DO discussion). Deployment-retrieval information was also necessary to explain abrupt shifts in observed water quality data, which often resulted when even slight differences in deployment of meters occurred with respect to water depth, tide stage, or time of day (See Discussion section on Instruments and Approach). Inclusion of deployment and retrieval data was also particularly helpful when Reserves simply switched out YSI meters and no gap (i.e., no "missing data") was observed. Identification of abrupt shifts in water quality parameters due to new deployments was easily accomplished by incorporating deployment data into scatter plots of raw data. As a result of the ease and benefits of these procedures, we strongly recommend that all Reserves visually examine their data using scatter plots containing deployment information before completing the "anomalous data" section.

Standardization of the NERR SWMP with a readily available, relational database such as MS Access is highly recommended for managing data at the Reserve level. The major benefit of managing data in MS Access is the large storage capability of this program, which enables data from multiple sites to be stored in a single database. Because all of the data are contained within a single database, representing a semi-continuous time series, simple queries can be used to extract facets of the data that can then be exported into MS Excel for graphing. Furthermore, use of a standard database format would save a tremendous amount of time when preparing data from the NERR SWMP for synthesis reports and projects such as this one.

Synthesis Approach

Our approach to analysis of the water quality data collected by the SWMP worked well for this synthesis, given the large amount of data and the complexity of the analyses. A particularly useful element of the process was convening an expert panel. The panel, consisting of scientists, NERR staff and statisticians experienced in the collection, analysis and interpretation of water quality data, assisted in developing the following analytical approach for the project:

- Acquire and conduct QA/QC on data sets.
- Evaluate sampling methods (i.e., deployment duration and data quality).
- Develop site descriptions (i.e., climate, land use, site characteristics).
- Provide descriptive statistics and characterize spatial and temporal variation for sites.
- Compare parameters across sites and across reserves, with emphasis on dissolved oxygen extremes and salinity and their association with other variables.
- Assess the contribution of diel and tidal cycles with respect to variance in parameters among sites within the same reserve and among reserves.

The expert panel was especially valuable in identifying key parameters on which to base analyses and key indicators and measures for defining the extent and severity of hypoxia; discussions about stratification, summarization and evaluation of the data; and providing input on alternative sampling approaches and trends assessment. It was also helpful to have the expert panel available for guidance and advice throughout the project. We recommend a group of experts to participate in all aspects of future synthesis efforts.

Analysis of data took a bottom up approach in which analyses were first produced for each site within a reserve, then were integrated within reserves, and finally were used to determine similarities among reserves. This approach provided much of the information needed to determine the range of water quality conditions represented by the NERR system (i.e., duration and frequency of hypoxia, salinity ranges, depth, and temperature extremes). In combination with other attribute variables, we were able to identify groups of reserves that have similar characteristics and water quality conditions.

Ancillary Data

In November 1999, a working group of scientists familiar with water quality data (i.e., the expert panel) convened in Charleston, SC, to develop a detailed analytical plan for the Synthesis of Water Quality project. During this meeting, this panel determined that in order to conduct classification analyses, a data matrix, consisting of ecological attribute data for each site, must be developed and used as input data for these analyses. Following this recommendation, a 14-question site attributes survey was developed and sent to Research Coordinators in November 2000. This survey was divided into three sections: measurements, source input attributes, and filtering attributes (Appendix A). The measurements section sought specific values regarding the surface areas of the drainage basin and the water body where sampling sites were located, as well as the approximate freshwater discharge into the water body where sampling sites were located. The source input attributes section consisted of six questions which sought qualitative, scored responses intended to characterize sites based on the extent to which water quality at sampling sites was affected by upstream processes. The filtering attributes section consisted of five questions that also sought qualitative responses intended to characterize sites based on their ability to regulate inputs derived from outside sources.

Reception to and perception of the site attributes survey was generally favorable, and all Reserves completed the surveys in a relatively timely fashion. With a few exceptions, the response choices for both of the qualitative sections were applicable to almost all sites. The quantitative section, however, was much more difficult to complete. Estimates of the approximate drainage basin area from which water and nutrients could enter the water body where sites were located were obtained for 84% (*n*=37) of the sites. On several occasions, disclaimers indicated that estimates either represented areas much larger than the actual drainage basin for the water body of interest, or conversely, that estimates only pertained to a portion of the actual drainage basin, such as the tidal wetland component. Estimates of water body size was only provided for 68% (*n*=30) of the sites. On several occasions, creek width or length was provided, but an actual area was not provided. Estimates of freshwater flow were only provided for 45% (*n*=20) of the sites. Freshwater flow was not applicable at three marine sites (Mullica River-Bouy 126 and Jobos Bay-both sites) and both freshwater sites at Old Woman Creek. In addition to providing input data for characterizing and classifying sites in the NERR SWMP, the attributes survey also identified deficiencies in ancillary data collection which would have been helpful to explain observed water quality measurements and to better understand the ecological processes at the estuaries in the NERR SWMP. For example, from limited estimates of freshwater flow, it was observed that sites with intermediate flow rates were most commonly heterotrophic. The strength of this relationship is weak, however, because estimates of flow rates, which varied by over three orders of magnitude, were available for less than half of the sites with metabolism data. Furthermore, nutrient data were only available for 27 of the 44 sites in this study. Better documentation of flow rates and collection of nutrient data at all sites in this study may have resulted in better understanding of the relationship between flow rate and production, respiration, and net ecosystem metabolism.

Future ancillary data collection should also build upon the qualitative and quantitative data obtained from the site attributes survey. At many of the sites in the NERR SWMP, precipitation and flow rate vary dramatically on a seasonal basis. Regarding these two parameters, efforts should be made to record semi-continuous observations, rather than annual averages, which could then be directly compared to simultaneously collected water quality data. Implementation of weather monitoring at sampling stations may provide an opportunity to collect these data. Regarding habitat quality, impervious surface, and land use patterns within the drainage basin and adjacent to sampling stations, efforts should be made to collect quantitative data using GIS technology. GIS technology would be useful to calculate drainage basin areas for water bodies where sampling stations are located; however, the real challenge is defining the boundaries of sub-drainage basins that feed into tidal creeks.

Future Sampling

At six reserves (Padilla Bay, Chesapeake Bay-VA, Jacques Cousteau, ACE Basin, North Inlet-Winyah Bay, and Rookery Bay), one instrument was deployed at a clear reference location and served as a long-term control and additional instruments were deployed at other locations to monitor specific, non-point source pollution concerns within the Reserve (Trueblood et al. 1996, Wenner and Geist 2001). At most reserves, however, it was not possible to clearly differentiate between sites in terms of anthropogenic impacts. Due to the inconclusive determination of impacted and reference sites between and among reserves participating in the SWMP, analyses comparing daily salinity range and percent of time variables at impacted and reference sites were not performed. Once data are available on land cover and estimates of the watershed surrounding sampling sites, it will be possible to identify impacted and reference sites and to make statistical comparisons of water quality variables between these site categories.

Given the diversity of habitats within each Reserve, particularly with respect to water depths and flow regimes, we recommend that Research Coordinators submit a justification of how and why reference sites were selected and what habitat each deployment site represents. Incomplete data on habitat made it difficult to interpret the results for some of the sites. For example, oxygen dynamics at Tivoli South Bay (Hudson River) are affected both by processes going on in both Tivoli South Bay, colonized by Eurasian water chestnut, and the upper Hudson River, which has extensive beds of *Valisneria* sp. in shallow areas. A rather complex modeling effort would be required to tease apart the effects of these two different plant species on the observed oxygen dynamics. Similar difficulty in interpreting some of the results existed at sites such as Azevedo Pond (Elkhorn Slough), Bay View Channel (Padilla Bay), and Taskinas Creek (Chesapeake Bay-VA).

Standardization of the selection of reference locations should also be considered so that the reference locations provide a reference for the entire NERR SWMP, rather than just a reference for a particular Reserve. Developing a clear understanding of what sampling sites represent is critical. For example, mean water depth for all but 8 sites included in this synthesis was less than 2 m; thus, the results of this synthesis would likely have been different had instruments been deployed in deeper portions of Reserves. Knowledge of circulation patterns within each Reserve, as well as the ancillary data items mentioned above, would greatly enhance the selection of appropriate sampling sites. This is particularly true with respect to production and respiration analyses. We therefore recommend that Reserves consult with physical oceanographers familiar with estuarine and marsh circulation patterns in order to improve site selection at both the Reserve and the system-wide levels.

Future Analyses

The NERR SWMP provides water quality data over a broad range of spatial (local, regional, national) and temporal (minutes, hours, days, seasons, years) scales and constitutes a unique database at scales not previously or currently measured by other national programs. It seems appropriate that a regular synthesis be provided in order to analyze and synthesize the enormous amount of data being collected by the SWMP. Such synthesis should determine the similarities/dissimilarities among reserves, as well as provide much of the information needed to determine the range of water quality conditions represented by the NERR system (i.e., severity and frequency of hypoxia, salinity ranges, tidal periods, and other habitat attributes). An annual or bi-annual synthesis would provide information on the status of the NERRS and any trends occurring by comparing the frequency, duration, severity, periodicity, and explanatory environmental factors for hypoxia and other "key" water quality indicators among reserves, regionally, and nationally. To collaborate more effectively with Research Coordinators on water quality synthesis, we suggest that Research Coordinators perform site-level syntheses as part of an annual report, with assistance and review by a synthesis team.

Thirty-minute intervals appeared to provide better assessment of the minimum and maximum dissolved oxygen conditions than measuring at longer time intervals. Comparing the data from 30-minute intervals versus 4-hour intervals, we found that mean values were not significantly different between these intervals. The mean value of dissolved oxygen has been found to be least relevant for predicting the effects of hypoxic exposure to aquatic resources (Summers et al. 1997). For NERR sites in which there is considerable dissolved oxygen variability over tidal and diel cycles, low dissolved oxygen conditions may be underestimated if a four-hour interval is used.

Instrument drift when measuring dissolved oxygen appears to be a major consideration in future sampling strategy and data analysis. Although the percent of time that hypoxia and supersaturation occurred was found to vary annually and among sites, regression analyses suggests that a bias occurs when instruments are deployed for up to two weeks. By only utilizing data within 48 hours of deployment, we were able to minimize the bias due to instrument drift. Although longer deployment duration is logistically desirable and provides a better data set for assessing periodicity, we recommend that the data be carefully examined by each site before conducting DO analyses in order to determine whether only a subset or the entire data set should be used.

This synthesis of water quality has demonstrated that multivariate analysis is a useful tool for analyzing relationships between complex data matrices. We used cluster analysis to identify groups of sampling sites based on their water quality, land use and biological characteristics. Further refinement of these attributes and the addition of others that are based on actual water quality observations (i.e., temperature extremes, mean salinity, mean depth, duration and frequency of hypoxia and supersaturation) will help to further refine comparisons among Reserve sites. Future analyses should also explore the use of principal component analysis to relate variables and allow for classification of sites. If available, actual values, rather than ordinal scale data, should be used in future analyses. As a compromise, the use of innovative multivariate analyses (e.g., CART) that combine quantitative and ordinal scale data should also be explored.

In addition to multivariate techniques, the application of NERR SWMP data as a component in models should be determined. A number of water quality models are available which could be evaluated for compatibility with the NERR water quality data. A comprehensive watershed assessment tool, Better Assessment Science Integrating Point and Non-point Sources (BASINS) is a GIS-based software for evaluating watersheds both qualitatively and quantitatively (Lahlou et al. 1998). The BASINS model can be used to: 1) determine the cumulative effect of point and point sources, as well as non-point sources of pollution and the watersheds ability to attenuate them; 2) consider the water quality impacts of hypothetical patterns of landuse/landcover change; and 3) explore how loadings change with the meteorologic extremes of storm events and drought. Another model in which NERR water quality may be valuable as an input component is the SWAMP (Spatial Wetland Assessment for Management and Planning) model. This GIS based model evaluates the functional contribution of wetlands to the watershed in which it exists by evaluating water quality, hydrology and habitat functions (Sutter and Cowen 2000). Incorporating NERR SWMP data into models may enable broader application of the data by coastal managers in their decision process.

Benefits of the NERR SWMP

Most coastal water-quality problems result from waste associated with concentration of the human population along the coasts and from land-use practices in coastal watersheds. At present, at least 37% of the population in the US is located within 100 km of major estuaries or the oceans (Cohen et al. 1997) and the upward trend in population growth within coastal areas is expected to continue well into the future (National Research Council 1993). Although water quality has improved nationwide since passage of the Clean Water Act, it is important that all levels of government, and public and private groups work together to maintain or improve water quality in coastal areas. Gathering and reporting of monitoring data is an important step in a process aimed at addressing concerns of society about water quality problems. By identifying water quality problems, the resulting risks to both ecosystem health and human health can be better addressed.

The NERR SWMP represents a diverse and intensive (spatially and temporally) monitoring program that provides important water quality reference database for both annual trends and the impacts of episodic events. The 22 Reserves included in this report represent the five major coastal/estuarine regions in the United States (West Coast, Northeast and Great Lakes, Mid-Atlantic Coast, Southeast Coast, and the Gulf of Mexico and Caribbean Sea) with 4-6 replicate estuaries per region. The difference in latitude between the southern most Reserve (Jobos Bay, PR) and the northernmost reserve (Padilla Bay, WA) is approximately 31 degrees of latitude (~ 2,000 miles). With the exception of these two Reserves, the NERR SWMP covers estuaries between 26°N (Rookery Bay, FL) and 43°N (Wells, ME), representing approximately 1,000 miles north to south with Reserves located at every latitude except for 27°N, 28°N, 35°N, and 40°N. The most compelling indication of the diversity of estuaries in the NERR SWMP, however, is the realization that the NERR SWMP represents five Köppen classification climatic zones (Savannah, Steppe, Mediterranean, Humid sub-tropical, and Cold temperate) and 14 biogeographic zones within these major climatic zones. The recent addition of Kachemak Bay, Alaska NERR subsequently extends the climatic and biogeographic coverage of the NERR SWMP to include Polar tundra climate and biogeography.

In addition to large-scale geographic diversity, the sampling sites within the NERR SWMP also represent a good mix of degraded versus relatively undisturbed habitats. Deployment of at least one YSI at a reference/long-term control sites and deployment of additional data YSI data sondes at degraded sites has allowed some reserves to investigate differences in water quality dynamics between degraded and undisturbed habitats. Since the inception of the program in 1995, data from the NERR SWMP has been used as a basis for making management decisions. At Joe Leary Slough (Padilla Bay NERR), documented differences in the frequency and duration of hypoxia due to spreading dairy wastes on fields the waterbody resulted in management agencies taking action to cleanup this practice. Salinity data has also proved useful in making management decisions. Salinity data from Rookery Bay revealed differences in crustacean recruitment and abundance due to altered salinity regimes in Henderson Creek and this finding was ultimately used to secure funding to retrofit a weir to restore more natural pulsing of freshwater into the creek.

In addition to monitoring man-made disturbances, long-term, semi-continuous data collection also presents an opportunity to study acute and chronic environmental events such as excessive flooding or drought. In 1996, two major hurricanes (Bertha and Fran) made landfall in coastal North Carolina and the water quality effects of both were recorded by three Reserves (North Carolina, North Inlet-Winyah Bay, and Chesapeake Bay, VA). Temperature, salinity, and dissolved oxygen were altered tremendously as a result of these two hurricanes, but the recovery time to pre-storm conditions took much longer following Hurricane Fran. Because YSIs were deployed prior to these storms, the differential magnitude and duration of affected water quality due to these storms could be determined. Similarly, because YSIs were deployed on a long-term, semi-continuous basis at the Great Bay, NH, NERR in 1998, the effects of drought on water quality at these sites were documented.

The NERR SWMP represents tremendous progress in the establishment of a water quality-monitoring program to monitor the health and functionality of this nation's estuaries. Good water quality is critical for the health and survival of most plant and animal species, including humans. Poor water quality limits the extent to which we use surface waters for drinking, the harvesting of fish and shellfish, and can impair aquatic habitats, causing a decline or even extinction in local populations of many species (Wenner and Thompson 2001). Establishment of estuarine reserves and the NERR SWMP present opportunities to educate the public about water quality issues, with specific emphasis on the causes and consequences of degraded water quality. Water quality data from the National Estuarine Research Reserves' System-wide Monitoring Program also provides necessary background data from which specific, experimental hypotheses can be formulated to systematically evaluate the effects of anthropogenic influences on estuarine ecosystems and the requirements to restore the functionality of these estuaries to their undisturbed conditions.

References

Beckett, D.C. and C.H.Pennington. 1986. Water quality, macroinvertebrates, larval fishes, and fishes of the lower Mississippi River—A Synthesis. US Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS. Technical Report E-86-12. 136 pp.

Bliss, C.I. 1970. Statistics in Biology (vol.2). New York: McGraw-Hill.

Boynton, W.R., J.H. Garber, R. Summers and W.M. Kemp. 1995. Inputs, transformations and transport of nitrogen and phosphorus in Chesapeake Bay and selected tributaries. Estuaries 18:285-314.

Chapman, D. 1992. Water quality assessments. London: Chapman and Hall.

Cohen, J.E., C. Small, A. Mellinger, J. Gallup and J. Sachs. 1997. Estimates of coastal populations. Science 278: 1211:1212.

Copeland, B.J. and W.R. Duffer. 1964. Use of a clear plastic dome to measure gaseous diffusion rates in natural waters. Limnology and Oceanography. 9:494-499.

Dalton, D.A. 1995. Antioxidant defenses of plants and fungi. Ch. 9, pp. 298-355. In: Ahmad, S. (ed.). Oxidative Stress and Antioxidant Defenses in Biology. Chapman and Hall, New York.

D'Avanzo C., J.N. Kremer and S.C. Wainright . 1996. Ecosystem production and respiration in response to eutrophication in shallow temperate estuaries. Mar Ecol. Prog. Ser. 141:263-274.

Department of Health and Environmental Control (DHEC). 1993. Water Classifications and Standards and Classified Waters. State of South Carolina Regulations 61-69.

Diaz, R.J. and R. Rosenberg. 1995. Marine benthic hypoxia: A review of its ecological effects and the behavioural responses of benthic macrofauna. Oceanography and Marine Biology: An Annual Review. 33: 245-305.

Environmental Protection Agency. 1990. The quality of our nations water: a summary of the 1988 National Water Quality Inventory. EPA 440/4/90-005. Office of Water, Environmental Protection Agency, Washington, D.C.

Fry, F.E.J. 1971. The effect of environmental factors on the physiology of fish. Pp. 1-87 *In* Hoar, W.S. and D.J. Randall (*eds*). Fish Physiology, Volume XI, Environmental Relations and Behavior, Academic Press, London.

Gessner, F. 1959. Hydrobotanik, Vo. II, Deutscher Verlag der Wissenschaften, Berlin.

Great Bay NERR website; (http://inlet.geol.sc.edu/GRB/site_des.html#CLASSIFICATION)

Hagy J.D., L.P. Sanford and W.R Boynton. 2000. Estimation of net physical transport and hydraulic residence times for a coastal plain estuary using box models. Estuaries 23:328-340.

Hartman, B. and D.E. Hammond. 1984. Gas exchange rates across the sediment water and air-water interfaces in south San Francisco Bay. Journal of Geophysical Research 89:3593-3603.

Howarth, R.W., R. Schneider and D. Swaney. 1996. Metabolism and organic carbon fluxes in the tidal freshwater Hudson River. Estuaries 19:848-865.

Hsu. 1996. *Multiple Comparisons: Theory and Methods*. London: Chapman and Hall.

Jay, D.A, R.J. Uncles, J. Largier, W.R. Geyer, J. Vallino and W.R. Boynton. 1997. A review of recent developments in estuarine scalar flux estimation. Estuaries 20:262-280.

Kalle, K. 1972. Dissolved gases in oceans. In: O. Kinne, ed. Marine Ecology, Vol. 1, Part 3, Environmental Factors. Wiley-Interscience, New York.

Kemp, W.M. and W.R. Boynton. 1980. Influence of biological and physical processes on dissolved oxygen dynamics in an estuarine system: implications for measurement of community metabolism. Est. Coast. Mar. Sci. 11:407-431.

Kemp, W.M., E.M. Smith, M. Marvin-DiPasquale and W.R. Boynton. 1997. Organic carbon balance and net ecosystem metabolism in Chesapeake Bay. Mar Ecol Prog Ser 150: 229-248.

Largier, J.L., J.T. Hollibaugh and S.V. Smith. 1997. Seasonally hypersaline estuaries in Mediterranean-climate regions. Est Coast Shelf Sci 45:789-797

Lerberg, S.B., A. F. Holland and D.M. Sanger. 2000. Responses of tidal creek macrobenthic communities to the effects of watershed development. Estuaries 23(6): 838-853.

Lahlou, M., L. Shoemaker, S. Choudhury, R. Elmer, A. Hu, H. Manguerra, H. and A. Parker. 1998. Better Assessment Science Integrating Point and Non-point Sources: BASINS Version 2.0 User's Manual, EPA-823-B-98-006.

Marino, R. and R.W. Howarth. 1993. Atmospheric oxygen exchange in the Hudson River: dome measurements and comparison with other natural waters. Estuaries 16:433-445.

McDonald, J. 1996. Suggested data analysis protocol for YSI 6000 and YSI 6600 deployment studies. Protocol developed for NERRs program (confirmed April 2001). 6 p.

Mortazavi, B. R.L. Iverson, W. Huang, F.G. Lewis and J.M. Caffrey. 2000. Nitrogen budget of Apalachicola Bay, a bar-built estuary in the northeastern Gulf of Mexico. Mar Ecol Prog Ser 195:1-14.

National Resource Council. 1993. Managing Wastewater in Coastal Urban Areas. National Academy Press, Washington, DC.

Nixon, S.W. and C.A. Oviatt. 1972. Preliminary measurements of midsummer metabolism in beds of eelgrass, Zostera marina. Ecology 53:150-153.

Nixon, S.W., S.L. Granger and B.L. Nowicki. 1995. An assessment of the annual mass balance of carbon, nitrogen, and phosphorus in Narragansett Bay. Biogeochemistry 31:15-61.

Odum, H.T. 1956. Primary production in flowing waters. Limnology and Oceanography 1:102-117.

Odum, H.T. and C.M. Hoskins. 1958. Comparative studies on the metabolism of marine waters. Publications of the Institute of Marine Science, Texas 5:16-46

Orlando, S.P., Jr., D.H. Wendt, C.J. Klein, M.E. Patillo, K.C. Dennis and G.H. Ward. 1994. Salinity characteristics of South Atlantic estuaries. Silver Spring, MD: NOAA, Office of Ocean Resources Conservation and Assessment.

Oviatt C.A., A.A. Keller, P.A. Sampou and L.L. Beatty. 1986. Patterns of productivity during eutrophication: a mesocosm experiment. Mar. Ecol. Prog. Ser. 28:69-80

Pennock JR. 1996. Nutrients and aquatic primary production. pp 30-36, IN Miller-Way T, Dardeau M, and Crozier G (eds). Weeks Bay National Estuarine Research Reserve: an estuarine profile and bibliography. Dauphin Island Sea Lab Technical Report 96-01.

Rendell, A. R., T.M. Horrobin, T.D. Jickells, H. M. Edmunds, J. Brown and S.J. Malcolm. 1997. Nutrient cycling in the Great Ouse Estuary and its impact on nutrient fluxes to The Wash, England. Est. Coastal Shelf Sci. 45 (5): 653-668.

Šidák, Z. 1967. Rectangular confidence regions for the means of multivariate normal distributions. *Journal of the American Statistical Association* 62: 626-633.

Smith, S.V. and J.T. Hollibaugh. 1993. Coastal metabolism and the oceanic organic carbon balance. Rev. Geophys. 31:75-89

Smith, S.V. and J.T. Hollibaugh. 1997. Annual cycle and interannual variability of ecosystem metabolism in a temperate climate embayment. Ecol Mono 67: 509-533

Summers, J. K., S. B. Weisberg, A. F. Holland, J. Kou, V. D. Engle, D. L. Breitberg, and R. J Diaz. 1997. Characterizing dissolved oxygen conditions in estuarine environments. Environmental Monitoring and Assessment 45:319-328.

Sutter, L. and J. Cowen. 2000. Spatial Wetland Assessment for Management and Planning (SWAMP) Web site (http://www.csc.noaa.gov/lcr/swamp/text/p661.htm)

Swaney D.P., R.W. Howarth and T.J. Butler. 1999. A novel approach for estimating ecosystem production and respiration in estuaries: application to the oligohaline and mesohaline Hudson River. Limnol. Oceanogr. 44:1509-1521.
Trueblood, D.D., A. Stratton, E. Wenner, L. Edmiston, D. Nemazie, J. Shields, W. Meredith, J. Caffrey, P. Wellenberger, C. Nieder, C. Gonzalez, A. Beck, S. Ross, J. Schubauer-Berigan, D. Klarer, D. Bulthuis, T. Hopkins, S. Stevens, S. Rumrill, J. Kervavez, R. Crawford, B. McCormack and M. Dionne. 1996. A national non-point source pollution monitoring program for the National Estuarine Research Reserve System. In Watershed '96 Proceedings. Environmental Protection Agency, Office of Water, 874-876.

Turner, J. S. and E.G. Brittain. 1962. Oxygen as a factor in photosynthesis. Boil. Rev. 37: 130-170.

US Environmental Protection Agency. 2000. Ambient water quality criteria for dissolved oxygen (saltwater): Cape Cod to Cape Hatteras. Office of Water, Washington, DC.

Wenner, E.L., A.F. Holland and D.M. Sanger. 1998. Assessing short-term variability in dissolved oxygen and other water quality variables in shallow estuarine habitats. Ocean Community Conference Proceedings, November 16th-19th. 2:802-806.

Wenner, E. and M. Thompson. 2001. Water Quality Synthesis. In: South Carolina Department of Natural Resources and National Oceanic and Atmospheric Administration, Coastal Services Center. Characterization of the Ashepoo-Combahee-Editsto (ACE) Basin, South Carolina. CD-ROM. SC Marine Resources Center Special Scientific Report 17. NOAA/CSC/20010-CD. Charleston, SC: NOAA Coastal Services Center.

Wenner, E.L and M. Geist. 2001. The National Estuarine Research Reserves Program to monitor and preserve estuarine waters. Coast. Mgmt., 29:1-17.

Whitledge, T.E. 1985. Nationwide review of oxygen depletion and eutrophication in estuarine and coastal waters. Report to U.S. Dept. of Commerce, National Ocean Service, Contract DE-AC02-76CG00016 with U.S. Dept. of Energy. Washington DC: Dept. of Commerce.

APPENDIX A: National Estuarine Research Reserve Classification Survey.

Measurements

1. What is the approximate area (Ha) of the drainage basin represented by each sampling site?
   Site ___________ = ___________ Site ___________ = ___________
2. What is the approximate area (m^2) of the water body where each sampling sites is located?
   Site ___________ = ___________ Site ___________ = ___________
3. What is the approximate freshwater discharge (cm^3sec^{-1}) into the water body where sites are located?
   Site ___________ = ___________ Site ___________ = ___________

Input attributes

1. Which of the following water body descriptions best describes where your sites are located?
   Site ___________ = ___________ Site ___________ = ___________
   (a) small tributary, removed from the watershed's main water body
   (b) large tributary, but not the watershed's main water body
   (c) watershed's main water body (open estuary, bay or sound)

2. Which of the following categories best describes the percentage of impervious surface adjacent to the water bodies where your sites are located?
   Site ___________ = ___________ Site ___________ = ___________
   (a) < 2% impervious surface
   (b) 2-20% impervious surface
   (c) > 20 % impervious surface

3. Which of the following land use patterns best describes the perimeter of your sites?
   Site ___________ = ___________ Site ___________ = ___________
   (a) > 20% agriculture/silviculture and/or developed land
   (b) < 20% agriculture/silviculture and/or developed land
   (c) No agriculture/silviculture and/or developed land

4. Which of the following categories best describes the surrounding habitat at your sites?
   Site ___________ = ___________ Site ___________ = ___________
   (a) > 50% of adjacent land cover comprised of natural vegetation
   (b) > 50% of adjacent land cover comprised of a combination of natural vegetation, silviculture and/or agriculture
   (c) > 50% of adjacent land cover developed (or < 10% natural vegetation)

5. Which soil type best describes the soil type at your sites?
   Site ___________ = ___________ Site ___________ = ___________
   (a) sand loam (b) clay loam (c) other (please specify)

6. Which of the following categories best describes annual precipitation at your sites?
   Site ___________ = ___________ Site ___________ = ___________
   (a) <20 in. (b) 20-50 in. (c) > 50 in.

Filtering attributes

1. Which of the following categories best describes the abundance of shellfish beds at your sites?
   Site ___________ = ___________ Site ___________ = ___________
   (a) present and highly abundant
   (b) present and sparsely abundant
   (c) absent

2. Which of the following categories best describes the abundance of SAV at your sites?
   Site ___________ = ___________ Site ___________ = ___________
   (a) present and highly abundant
   (b) present and sparsely abundant
   (c) absent

3. Which of the following categories best describes the abundance of emergent vegetation at your sites?
   Site ___________ = ___________ Site ___________ = ___________
   (a) present and highly abundant
   (b) present and sparsely abundant
   (c) absent

4. Which of the following categories best describes the surrounding forest cover at your sites?
   Site ___________ = ___________ Site ___________ = ___________
   (a) 50% forested (b) 25-50% forested (c) < 25% forested

5. Which of the following categories best describes tidal amplitude at your sites?
   Indicate tide range if available.
   Site ___________ = ___________ Site ___________ = ___________
   (a) < 2 m (b) 2-4 m (c) > 4 m