ENVIRONMENTAL REQUIREMENTS ASSESSMENT OF THE BAY SCALLOP *ARGOPECTEN IRRADIANS CONCENTRICUS*

Final Report

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EXECUTIVE SUMMARY

Environmental requirements for adult bay scallops *(Argopecten irradians concentricus)* in Tampa Bay were assessed from field and laboratory studies conducted from June through October 1992. These requirements were based on correlations of scallop growth, mortality and reproduction with species-relevant measurements of water quality. Differential rates of growth and mortality were observed between the two Tampa Bay sampling locations (Boca Ciega Bay and Beacon Key). Scallop growth was significantly higher at Boca Ciega Bay, while mortality was greater at Beacon Key. Chlorophyll *a* levels were consistently higher at Beacon Key throughout the study. Turbidity and total suspended solids were higher at Beacon Key during September and October. Growth and survival were not strongly correlated with any measured water quality parameter. Scallops at both locations showed normal reproductive development and successful spawning. Under laboratory conditions, bay scallops were able to survive low dissolved oxygen (2 mg/L) for six hours at 25°C. As water temperature increased (30°C), bay scallops were less tolerant of low dissolved oxygen.

General water quality in Tampa Bay, with respect to chlorophyll *a*, turbidity and nutrients, has been steadily improving since 1980. The ability of bay scallops to grow and spawn in the waters of lower and middle Tampa Bay reflects the improvements in water quality observed over this period. Species specific water quality targets developed from this study take into consideration: 1) these recent water quality improvements, 2) comparisons between the biological and abiotic responses of bay scallops from this study, and 3) literature based values for particular parameters proven to be optimum for the growth and development of bay scallops. The following targets represent the range of a particular parameter that will allow growth and reproduction of adult bay scallops. Specific targets for larval and juvenile scallops may have a narrower range.

WATER QUALITY PARAMETER	TARGET
Bottom Temperature	25-30°C ideal (for all stages), not to exceed 32°C for prolonged periods.
Bottom Salinity	Greater than 20 ppt (24-30 ppt optimal).
Bottom Dissolved Oxygen	Not less than 2 mg/L, for less than 2 hours.
Turbidity	5-10 NTU's.
Total Suspended Solids	Less than 40 mg/L.
TSS/VSS Ratio	Greater than 1.282 (inorganic % of seston <78%).

Chlorophyll *a*	**5-10 µg/L (= mg/m^3).**
Phytoplankton	**Density: Less than 5 x 10^6 cells/L; Species: Blooms harmful;** *Ptychodiscus* **and** *Chroococcus* **fatal.**
Seagrass	*Thalassia/Syringodium* **mix ideal. Density: >75 shoots/m^2** *(Thalassia).* **Beds continuous (not patchy).**

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I. INTRODUCTION

The Environmental Requirements Assessment Project (#T-91-15) of the Tampa Bay National Estuary Program was intended to establish the water quality and habitat requirements of bay scallops *(Argopecten irradians concentricus)* in Tampa Bay. These organisms offer the potential to serve as indicators of the overall ecological condition of the bay. The specific question to be answered through this project is "What environmental conditions including water quality are required to achieve the survivability, propagation, and enhancement of beneficial living resources (e.g., bay scallops) of Tampa Bay?"

A comprehensive literature review and data synthesis was completed prior to developing and implementing the current study. (Technical report submitted to the Tampa Bay National Estuary Program entitled "Literature Search and Data Synthesis on the Bay Scallop with Emphasis on Florida Populations of the Southern Bay Scallop *Argopecten irradians concentricus").* A summary of the literature review is presented in Section II. The objectives of the literature review and synthesis were to identify and delineate the environmental factors (physical, chemical or biological) that affect the survival and distribution of bay scallops within the Tampa Bay estuary. By obtaining the most current scientific information on water quality and habitat requirements of the bay scallop, we were better prepared to develop a more efficiently designed study and prevent the duplication of efforts by other researchers. The direction of the overall study plan and design was guided by findings and recommendations detailed in the literature search and technical synthesis.

This report provides a detailed description of all activities and findings associated with the Environmental Requirements Assessment Project Scope of Work. These activities include the performance of all field and laboratory activities, including station locations and sampling methods, statistical analyses, results and findings of all activities, a discussion of findings, and suggested resource based water quality targets specific for the bay scallop in Tampa Bay.

II. LITERATURE REVIEW

A. Bay Scallop Abundance and Distribution in Florida

Even today, information on the abundance and distribution of Florida populations of bay scallop *(Argopecten irradians concentricus)* comes almost exclusively from reported commercial landings. As a result, a reliable evaluation of bay scallop stocks is difficult. A rough assessment of stocks on the west coast of Florida was recently complied, using 1) recent and historic commercial landings, 2) interviews with sources along the coast and 3) a scientific survey of scallop distribution between the Homosassa and Crystal Rivers (Arnold and Marelli, 1991; Blake et al., 1991).

Commercial landings of bay scallops are consistently highest in northwest Florida (Escambia, Santa Rosa, Okaloosa, Bay, Gulf, Franklin and Wakulla Counties). Recreational data from this region, based on telephone interviews, show that scallop densities are consistently highest in St. Joseph Bay. Overall, the northwest region has experienced a downward trend in both commercial and recreational landings in recent years.

The central west coast region runs from Taylor to Pasco Counties. This area has produced relatively consistent commercial landings in recent years. Total harvest, however, is much lower than that from the northwest region. Recreational interviews suggest that stocks in 1991 were down from previous years. No information was available for the area between the Homosassa River and Anclote Keys. The only <u>scientifi</u>c survey of bay scallop populations in Florida was conducted within this region (Blake et al., 1991). Scallop abundance was low and distribution patchy between Homosassa and Crystal Rivers during the summer of 1991. These findings are consistent with results from recreational interviews.

Commercial landings from the southwest region (Hillsborough County south to Monroe County) have been practically nonexistent since 1963. A notable exception was the relatively large number of scallops landed in Monroe County during 1990. That same year, recreational catches were unusually high in Pine Island Sound, Charlotte Harbor. Otherwise, bay scallops are essentially absent from southwest Florida waters. Anecdotal accounts suggest that bay scallops were once abundant in Tampa Bay, but they are now a rare find in the estuary. No quantitative data are available to support these accounts.

B. Life History Data Unique to the Southern Bay Scallop, *Argopecten irradians concentricus*

The life expectancy of bay scallops appears to be associated with a latitudinal gradient. Florida populations of *Argopecten irradians concentricus* have a shorter life span than North Carolina populations. Bay scallops in Alligator Harbor, Florida, apparently do not live longer than 19 months (Sastry, 1961), and animals from farther south may have even shorter life spans (12-14 months).

Shell growth is continuous throughout the year (Sastry, 1961), although it does not occur at a steady rate. Growth variation in young (<2 cm) scallops is controlled by temperature (Tettelbach and Rhodes, 1981), while larger scallops are affected by both temperature and food supply (Kirby-Smith, 1970). Populations from Anclote estuary exhibited highest growth rates (expressed as mean shell height) from May through August, a time of increasing water temperature (Barber and Blake, 1983). During this growth period, there was an increase in the mean dry weight of mantle, digestive gland and adductor muscle. After August, growth rates slowed dramatically. The relative weight of the major organs either remained constant (mantle and digestive gland) or decreased (adductor muscle). Approximately twenty percent of realized growth rate is thought to be inherited (Crenshaw et al., 1991). The presence of commensal pea crabs *(Pinnotheres maculatus)* can reduce scallop growth relative to non-infected animals (Sastry, 1961; Kruczynski, 1972).

Bay scallops are functionally hermaphroditic bivalves having one complete, synchronous gametogenic cycle during its life span. The reproductive cycle for Florida populations occurs later in the year in relation to northern populations (Barber and Blake, 1983), although the sequence of events comprising reproductive development is similar. Maximum gonad weight, gonad index and oocyte diameter are found in late September and early October. Reproductive development is correlated with the above mentioned decline in adductor muscle weight. Spawning generally occurs at this time, which coincides with a decrease in water temperature.

Variations in fecundity are also evident among bay scallop populations. A population from New York averaged 12-18 x 10^6 eggs per scallop (Palmer and Williams, 1980), a value roughly seven times higher than a population from the Anclote estuary, Florida (Barber and Blake, 1981). A latitudinal effect also correlates with egg size. Mean oocyte diameter decreases with decreasing latitude (Sastry, 1970; Barber and Blake, 1983).

The energetics of gametogenesis and reproduction have been extensively detailed for the northern bay scallop from New York (Epp et al., 1988; Bricelj et al., 1987a, 1987b) and the southern bay scallop from the Anclote estuary (Barber and Blake, 1981, 1983, 1986). The seasonal partitioning and utilization of energy reserves is similar between the two subspecies. In the Anclote Anchorage, where metabolic energy demands are high relative to available food supply, the adductor muscle is the primary energy storage organ (Barber and Blake, 1981). Lipid functions to initiate the gametogenic cycle, adductor muscle glycogen powers the oogenic development phase, and protein reserves stored in the adductor muscle provide maintenance energy for the transfer of recently absorbed food during the later stages of the spawning cycle (Barber and Blake, 1985). The energetic cost of reproduction is high for *Argopecten irradians concentricus.* Nevertheless, the relatively high reproductive effort expended by these animals helps to maintain a stable population from one year to the next in spite of the high cost of reproduction. There may, however, be consequences for this 'choice" in disbursing metabolic energy into reproductive effort. Bay scallops from the west coast of Florida already experience higher metabolic rates associated with higher environmental temperatures as well as decreased food supplies. The high cost of reproduction coupled with these environmental factors may not only be responsible for limiting the southern distribution of bay scallops, but may also accelerate the senescence of individuals within the population (Barber and Blake, 1983, 1986; Epp et al., 1988).

C. Ecological Role

The primary foods of bay scallops are benthic and tychopelagic diatoms, although a variety of algal species are efficiently utilized. Naturally occurring supplies of algae generally do not limit the growth of small scallops (<2 cm shell depth). However, as has already been mentioned, because of the increase in metabolic rate associated with higher temperatures in Florida waters, a decrease in food supply would result in less energy available for reproduction, which may limit the southern distribution of bay scallops in Florida (Barber and Blake, 1983).

Bay scallops are filter-feeders, pumping water through the mantle cavity and straining food particles on the gill cilia. Pumping and filtration effectively supports a constant level of intracellular digestion is spite of varying ambient food concentration (Palmer, 1980). Particle flux, however, is not a good predictor of bay scallop growth. Rather, it is the combination of the effects due to food concentration and flow velocity which determine the response of the individual bay scallop (Cahalan et al., 1989). In adult *Argopecten irradians concentricus,* there was an inverse relationship between suspended algal concentration and filtration rate, so that the average amount of algae cleared was steady (Palmer, 1980). Under conditions of high algal concentrations, scallops become more efficient in retaining small particles (Palmer and Williams, 1980). However, particle selection by juvenile scallops does not appear to be based upon size alone and is apparently based on other characteristics of the algae as well (Shumway and Sandifer, 1991). Scallops can collect food continuously, and, in the range of concentrations of suspended material typical of coastal environments, can respond to environmental variations quickly enough to collect a relatively constant supply of food over time.

Common benthic predators on bay scallops include various crab species, starfish, sea urchins, oyster drills, whelks, and cownose rays. In 1983, heavy predation by ring-billed and herring gulls was at least partially responsible for late fall declines in adult bay scallops at Cape Lookout, North Carolina (Peterson et al., 1989). Gulls are effective predators on adult scallops aerially exposed on intertidal flats, but become ineffective when scallops are covered by as little as 1-3 cm of water (Peterson et al., 1989). Eelgrass beds offer partial refuge from whelk predation as compared to unvegetated bottoms, which may help explain the marked habitat preference of scallops (Prescott, 1990). Epibiotic coverage on the shell does not confer any protection from predation. Vertical attachment on eelgrass functions as an effective predator-avoidance mechanism for juvenile bay scallops by placing them out of reach of many benthic predators (Pohle et al., 1991). Predator risk decreases with scallop size (Tettlebach, 1986), which suggests they undergo an ontogenetic shift from a spatial to a size refuge from predators as they move from the seagrass canopy to the sediment surface over the course of their post-settlement life history (Pohle et al., 1991).

Recruitment of bay scallops in productive beds in North Carolina was virtually wiped out during a red tide *(Ptychodiscus brevis)* outbreak in 1987 (Summerson and Peterson, 1990). However, when exposed to bloom concentrations of the toxic dinoflagellate *Protogonyaulax tamarensis* in combination with natural seston, juvenile *Argopecten irradians* fed actively and showed no mortality (Lesser et al., 1989).

The preference of settling bay scallops for seagrass beds is well documented. Even with artificial substrates, settling larvae still show a preference for turf (Ambrose, 1989). Spatial patterns in settlement showed significantly more spat in collectors near the bottom than those located one meter higher in the water column over grass beds. Recruitment was also higher in areas nearest the highest concentrations of adult scallops.

The pea crab, *Pinnotheres maculatus,* is an internal commensal parasite of the bay scallop. Bay scallops infected with pea crabs grew slower and were consistently lower in mean dry weight than uninfected scallops (Kruczynski, 1972). The percentage of infected bay scallops in Alligator Harbor, Florida, ranged from 13 percent to 36 percent seasonally (Sastry and Menzel, 1962).

A small portion of bay scallop mortality has been attributable to parasites and disease, although the occurrence of these agents in natural populations of scallops is remarkably low. While these infestations are typically nonfatal, they may affect the marketability of scallops (Otwell et al., 1984). Under hatchery conditions, however, a serious disease called chlamydiosis can cause high mortalities in larval and postmetamorphic bay scallops (Leibovitz, 1989).

D. Environmental Requirements

Both salinity and temperature exert significant effects on development and survival of bay scallops, but temperature is clearly the dominant factor influencing growth. Temperature tolerance ranges and optima are dependent on the specific life stage. Eggs and larvae generally have a narrower range than juveniles and adults. Temperatures of 35°C or higher and/or salinities of 10 ppt (parts per thousand) or less are lethal for all life stages of *Argopecten irradians irradians* (Tettelbach and Rhodes, 1981). Temperature ranges reported for Florida populations are 9-32°C from Alligator Harbor (Sastry, 1965) and 21.5-32°C from Anclote estuary (Barber and Blake, 1985). Bay scallops transplanted to the vicinities of two Florida power plants had higher incidences of mortality at thermally altered stations than at ambient stations (Studt and Blake 1976). Sublethal effects, including disruption of the reproductive cycle, were found at all thermally affected stations

Bay scallops may survive salinities as low as 7 ppt by closing their valves and isolating themselves from the environment, but only for time periods of less than two hours (Sastry, 1961). While it has been suggested that short exposures to low salinities (resulting from heavy runoff) probably does not affect bay scallop survival (Fay et al., 1983), such events in a shallow estuary like Tampa Bay often result in prolonged salinity reductions which would ultimately and severely affect bay scallop survival. In fact, such evidence was provided by a severe spring rainstorm in Groton, Connecticut, in 1982, that resulted in mortality levels approaching 100 percent (Tettlebach et al., 1985). All lines of evidence support the conclusion that the bay scallop mass mortality resulted directly from low salinities incurred by the storm.

Resting requirements of oxygen for adult bay scallops is comparable to other bivalves capable of burst swimming responses. Rate of oxygen uptake has been shown to be independent of dissolved oxygen concentration down to 1.5 ppm, indicating that scallops are not limited by low dissolved oxygen (Van Dam, 1954). Seasonal variation in oxygen consumption is related to ambient water temperature. Northern bay scallops show a limited ability to acclimatize oxygen consumption to seasonal temperature changes over the range of 1-23°C (Shumway and Sandifer, 1991). A significant increase in oxygen uptake accompanies increased gametogenic activity in young scallops. Weight-normalized oxygen uptake rate of senescent scallops is significantly lower than that of young scallops (Shumway and Sandifer, 1991).

High turbidity levels interfere with normal growth and reproductive processes in bay scallops. Additionally, soft mud and silt substrates are harmful to the survival of settling juveniles. High current velocities negatively affect scallop growth, with adults being more sensitive to current speed than juveniles (Eckman et al., 1989). However, the extent of current effects on growth vary significantly depending on the animal's orientation to the flow. Hydrodynamics also play a significant role in scallop recruitment. In fact, hydrodynamics in eelgrass meadows may exert a stronger influence on recruitment than characteristics of the seagrass beds, including blade densities and interblade abrasion (Eckman, 1987).

Survival of juvenile *Argopecten irradians irradians* is significantly affected by mercury (Nelson et al., 1977). Toxicity of mercury at low concentrations is enhanced by high temperature and low salinity, whereas at high mercury concentrations this effect is diminished. The growth rate of larval bay scallops is negatively affected by low concentrations of zinc (Yantian, 1988). A progressive decrease in growth and increase in larval deformity and mortality was observed with increasing zinc concentrations. Juvenile bay scallops exposed to heavy metal showed the following order of toxicity: Cu > Se > Zn > Pb (Nelson et al., 1988).

E. Research Needs

The scientific literature on the bay scallop is extensive. However, as researchers in Florida have pointed out, the available information is not directly applicable to local populations (Arnold, 1990). Most of the knowledge on Florida bay scallops comes from the excellent work of Sastry, Barber and Blake. These authors have provided data which clarify the similarities and differences between Florida bay scallops and northern conspecifics. Differences include egg size, spawning signals (notably temperature), and spawning seasons.

From this literature review and discussions with contemporary investigators, several areas. of critical research have been identified. From a fisheries management and enhancement perspective, the following priorities have been identified by Florida Marine Research Institute personnel:

1) recreational fishery assessments;
2) settlement and recruitment monitoring;
3) habitat and population enhancement.

Areas of critical research that have been identified and are currently receiving the attention of Norm Blake focus on the bay scallop larval cycle. By being "catastrophic spawners", successful recruitment is dependent upon favorable environmental conditions during this important stage in their life cycle. The effects of temperature, salinity, and food as well as their interactions are being evaluated for larval scallops.

Water quality parameters are thought to be important in limiting the distribution of scallops in this area, although these factors and their effects have never been investigated. Turbidity levels, which are potentially manageable, need to be established for normal growth and reproduction in bay scallops. The effects of heavy metals, hydrocarbons and other contaminants on bay scallops need to be investigated. No work has been conducted on temperature:salinity combinations for adult *Argopecten irradians concentricus.* Ranges and limits for these and other parameters need to be established as well.

The subsequent study design for the assessment of the environmental requirements of the bay scallop reflects some of these research needs.

III. STUDY DESIGN

Certain environmental characteristics are more pertinent than others to the maintenance and perpetuation of bay scallop populations. Temperature and salinity are two important physical parameters which synergistically influence survival and growth of both larval and adult scallops. Temperature influences gametogenesis and spawning (Barber and Blake, 1983; Bricelj et al., 1987) as well as affecting the organism's sensitivity to low salinity (Mercaldo and Rhodes, 1982). Although oxygen uptake rates have been shown to be independent of oxygen concentrations down to 1.5 milligrams/liter, critical levels of dissolved oxygen for bay scallops have not yet been determined (Van Dam, 1954). Scallop growth is influenced by water currents (Marshall, 1960; Cooper and Marshall, 1963; Kirby-Smith, 1972). Seagrasses are important as sites of attachment for recently metamorphosed young (Kirby-Smith, 1970; Thayer and Stuart, 1974), and indirectly provide food and protection for the adult (Peterson, 1982; Peterson et al., 1984). Turbidity may affect the survival of eggs and larvae, and adult feeding rates and filtering efficiencies. The deleterious effects of suspended solids include lower assimilation (Dyer, 1975) and higher mortality rates (Duggan, 1973). Chlorophyll *a* levels reflect the total amount of available food resources, while phytoplankton composition provides data on the availability and quality of potential food items.

Objectives

This study was designed to address the environmental requirements of adult populations of the bay scallop *(Argopecten irradians concentricus)* in Tampa Bay. As such, investigations center on those parameters which may affect the growth, survival and development of the adult bay scallop through the reproductive cycle. Complementary studies on scallop spawning, larval settlement and juvenile growth were conducted by Blake under contract to the Tampa Bay National Estuary Program. Results from those studies have been incorporated into this report to provide information on the entire life cycle of the bay scallop in Tampa Bay waters.

This study consists of two complementary components: field studies and laboratory experiments. The field studies were intended to collect data on specific water quality and habitat parameters relevant to the bay scallop at different sites within the Tampa Bay estuary. Laboratory experiments investigated organismal responses to changes in, and absolute levels of, temperature, salinity and dissolved oxygen during the late, pre-spawning period of the adult life cycle.

IV. MATERIALS AND METHODS

A. Field Collections

1. Strategy

The strategy for field efforts was to maintain scallops at two locations within Tampa Bay and collect data on a suite of relevant parameters at each location on a regular or continuous basis. Coupled with these measurements were determinations of adult scallop mortality, growth and reproductive stage. Comparisons in scallop development between locations were made with respect to differences in observed water quality and habitat specifications. These studies were conducted during those months of the year (June-November) when bay scallops from this area are in the adult stage of their life cycle.

Specific water quality and environmental parameters considered important to the bay scallops and which were measured during field investigations included temperature, salinity, dissolved oxygen, turbidity, suspended solids, chlorophyll *a*, phytoplankton composition and habitat structure (Table 1). These parameters have been identified through the literature search and discussions with local experts as critical to the successful reestablishment of bay scallops in Tampa Bay. Biological responses monitored in relationship to water quality parameters involved growth, mortality, reproductive development and potential for fouling.

It is important to mention that efforts were made to coordinate field studies with ongoing studies being conducted by Norman J. Blake, University of South Florida Department of Marine Science. These efforts have the potential to greatly enhance the findings of the current project and provide the program with additional information regarding the management of the bay's living resources. Those activities or schedules which reflect these cooperative efforts are noted below.

2. Station Selection

Station selection was contingent upon prospective areas having sufficient seagrass habitat to enable potential scallop populations to become established. Two sites were selected for conducting field studies (Figure 1). The location of both sites, along with the rationale for their selection, are discussed below.

Site 1. BOCA CIEGA BAY (27°40.45'N: 82°40.20'W). Grassflats near Mullet Key Bayou/Tierra Verde/Sunshine Skyway Causeway. This station was situated immediately east of the Sunshine Skyway Causeway between Bunces and Maximo Passes in lower Tampa Bay. This location is an area that probably sustained the last standing scallop population within Tampa Bay proper, and may therefore need the least remedial action to restore viable populations. Bay scallops were collected

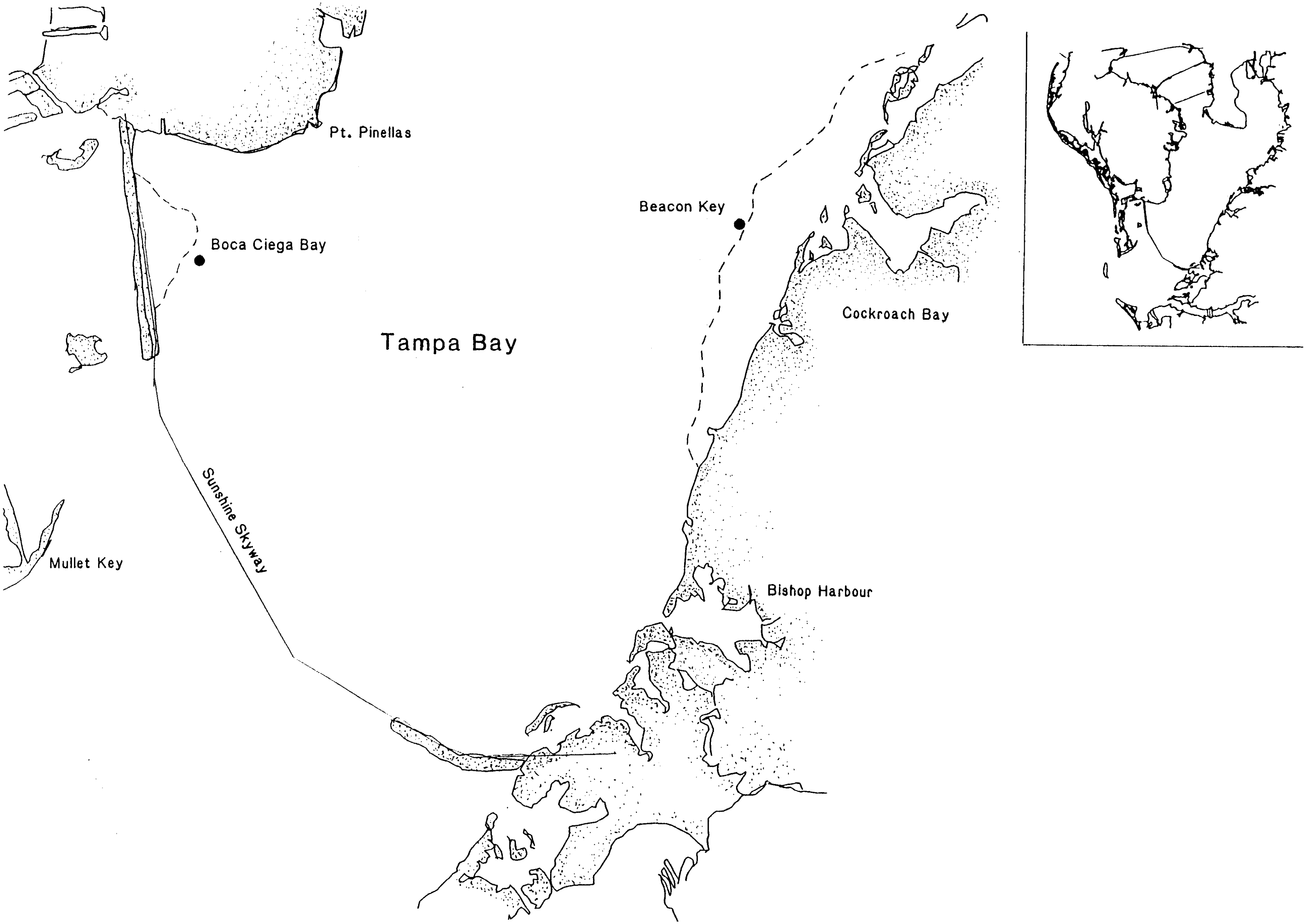

Figure 1. Station locations.

Table 1. **Specific water quality and environmental parameters considered most relevant to adult southern bay scallops** *(Argopecten irradians concentricus).* **Parameters measured during field investigations are marked with an asterisk (*).**

PARAMETER	REFERENCE
Temperature*	Tettlebach & Rhodes, 1981
Dissolved Oxygen*	Van Dam, 1954; Shumway & Sandifer, 1991
Salinity*	Tettlebach & Rhodes, 1981
Food Supply*	Fegley et al., 1992; Calahan et al., 1989
Macrophyte Abundance*	Ambrose, 1989; Prescott, 1990; Eckman, 1987
Current Speed	Eckman et al., 1989
Turbidity*	Stone & Palmer, 1975
Suspended Solids*	Dyer, 1975
Predators	Peterson et al., 1989

routinely for research purposes from this area in 1973 (Dyer, 1975), and they have also been reported as recently as 1982 (U.S. Fish and Wildlife Service, 1982). Currently, research on juvenile scallop development is being conducted in these waters (Blake, personal communication). Finally, several studies relating to seagrass productivity have also taken place in this locale (Hall, personal communication).

Site 2. BEACON KEY (27°40.62'N: 82°32.58'W). South of Cockroach Bay off Beacon Key in middle Tampa Bay. This location represents an area further up the estuary possessing sufficient habitat, but which has not supported documented populations of bay scallops for decades. Juvenile scallop "seeding" demonstration projects (also sponsored by the TBNEP) are being conducted in these waters as well. These "seeding" demonstrations are intended to complement efforts from the current study.

Monitoring stations were positioned at the deep, outer edge of seagrass beds at each site in approximately six feet of water. At each location, one station was located within the seagrass bed while the other station was situated on the unvegetated sand bottom adjacent to the grassbed. In this way, possible differences in scallop development with respect to habitat structure and quality could be ascertained.

3. Data Collection and Analysis -- Biological Components

Two separate scallop deployments were made during this study. The first deployment, which took place on June 30, consisted of scallops spawned in the St. Petersburg laboratory of Blake. These scallops remained in the field until September 29. The second deployment occurred on August 17, and involved scallops collected from shallow grassflats near Steinhatchee, Florida. Monitoring of the second deployment continued through October 27, 1992.

Scallops were maintained in cages at each station. Each cage was constructed from high density polyethylene with half-inch mesh openings. Cage dimensions were 1’ x 1’ x 2 1/2’. Cages were attached to chains and weighted to secure them and prevent them from drifting.

For the first deployment, an array of six cages was positioned at each station. Duplicate cages, each containing fifty young adult scallops, were placed over both seagrass and sand bottom to monitor growth and mortality. A third cage containing 100 scallops was deployed over each habitat type to monitor reproductive development. During the second deployment, a single cage containing fifty adult scallops, was placed over each habitat type at each station. A single cage housing 100 individuals for reproductive monitoring was maintained at each sampling station.

Growth was determined biweekly by measuring shell height to the nearest 0.1 millimeter. Mortality was also determined biweekly and empty shell s removed from the cages. Qualitative estimates were made of the amount of fouling on the scallop shells by visual observations and recorded as a percentage of available shell area.

Reproductive development and spawning were monitored histologically. Five to ten organisms were removed biweekly from each reproductive cage, placed on ice, and returned to the laboratory for histological determinations of gonadal development. Scallops were removed from their shells, bisected sagittally, and fixed in Helly's fixative made with zinc chloride (Barber and Blake, 1983). Scallop halves were processed through six changes of S-29 dehydrant and three changes of UC-670 clearing agent before being embedded in Paraplast. Sections (6 µm) were stained with Hematoxylin and Eosin. Mean oocyte diameter was determined by measuring the average diameter of ten oocytes from each scallop using a compound microscope with an ocular micrometer. Gametogenic stage was determined by visually estimating the percent of acinal spaces which were occupied by mature eggs. (Acini are bulb-shaped structures composed of a layer of germ cells. The lumina are variably filled with the developing gametes depending on the stage of gametogenesis.)

4. Data Collection and Analysis -- Water Quality

Water samples (from the bottom of the water column) were collected biweekly at each station for the determination of total and volatile suspended solids, turbidity and chlorophyll *a* content. Three replicates were collected for each parameter over both grass and sand habitats at each station. Biweekly samples were also collected at each site for analysis of phytoplankton species composition.

A Hydrolab Corporation Model Datasonde IIH water quality data logger, equipped with a recessed cathode DO sensor, was deployed in the seagrass habitat at both sites on August 27, 1992. Each instrument was programmed to record temperature, salinity and dissolved oxygen at twenty minute intervals. Each instrument was left in the field for periods of up to ten days, after which time they were retrieved, cleaned, recalibrated and redeployed.

Five separate Hydrolab deployments were made from August 27 through October 27, 1992. Correction factors were developed for each deployment based on regression equations (derived from laboratory calibrations) to account for membrane fouling and sensor drift.

Laboratory analyses for turbidity, suspended solids and chlorophyll *a* were performed by Mote Marine Laboratory. Phytoplankton samples were analyzed by Dr. Susan Jensen, Environmental Quality Laboratory, Port Charlotte, Florida (Dr. Ralph Montgomery, Director). Phytoplankton analyses included size analysis in addition to species composition to determine which size classes are useful as food for bay scallops.

B. Laboratory Experiments

1. Strategy

There is currently no information regarding the ranges of temperature, salinity and dissolved oxygen tolerated by adult or juvenile bay scallops. Information on these tolerances are essential to interpreting responses of animals in the field to other measured variables. The following laboratory experiments are designed to determine organismal responses to changes in these parameters.

Laboratory experiments focused on organismal responses to low dissolved oxygen at several temperature and salinity combinations. Selected levels of these parameters reflected conditions that occurred during the summer and early fall when adults would be found in the bay. Based on these considerations, the following ranges in each parameter were investigated:

Dissolved oxygen: 1-5 mg/L
Temperature: 25-35°C
Salinity: 15-35 ppt

2. Collection and Maintenance

Adult bay scallops (mean shell height = 57.65 ± 2.45 mm) were collected from Steinhatchee, Florida, on September 3 and kept in indoor holding tanks at Mote Marine Laboratory for two weeks prior to experiments. Holding tanks were maintained at a temperature of 25 ± 0.5°C, a salinity of 33 ± 1 ppt, and at saturated oxygen conditions. Prior to each trial, scallops (three per aquarium) were transferred to the control and both test tanks, and acclimated to test temperatures and salinities over 24 hours. Temperature was regulated by aquarium heaters and the salinity was adjusted with deionized water. Scallops were fed a continuous supply (4×10^6 cells/ml @ 10 mL/hr) of the green alga, *Tetraselmis* sp. before, during and after each tolerance test. A drip method of feeding was employed. Desired DO levels were achieved by bubbling a mixture of air and N_2 to the test aquaria through a gang valve.

DO was lowered to the desired level over a four hour period. This was accomplished by connecting a N_2 and an air source to a gang valve on each aquarium, and adjusting the component flows until the delivery of oxygen was reduced to achieve the appropriate reduction in oxygen level. DO levels were checked every 15 minutes with a YSI Model 57-oxygen meter calibrated using the Winkler method. Water quality (ammonia and nitrite) was monitored hourly.

Seven exposure trials were conducted between September 18 and October 9, 1992. During each trial, observations were made on "escape response," valve gaping (whether open or closed) and response to tactile stimuli (touching the tentacles of the mantle margin). After the conclusion of each trial (including a return to normoxic conditions), scallops were returned to the holding tank and observed for latent mortality for up to three days.

C. Statistical Analysis

All data sets from field collections were tested for normality and homogeneity of variance prior to any single or multiple comparison of means. No data transformations were necessary for either the biological or water quality data sets. Comparisons of growth, which followed the methods of Andersen and Nass (1993), consisted of both within and between site comparisons. (Analyses of variance with repeated measures were not appropriate because growth and survival was not followed for each individual but rather for each treatment as a whole.) Pearson product moment correlations were employed to determine the strength of association between measured water quality characteristics and biological responses (i.e, growth and mortality). Faunal abundance, diversity, richness, evenness and equitability were calculated for the phytoplankton data. Phytoplankton data were also subjected to hierarchical cluster analysis (Biostat II) which generated Bray-Curtis trellis diagrams of similarity.

Laboratory experiments were intended to provide qualitative information on organismal responses to different regimes of physical water conditions. Observations are discussed with respect to the organism's ability to survive these conditions and the implications they may have for survival in the field. No statistical treatment of these results was made.

V. RESULTS

A. Field Studies

1. Biological Components

Growth

During the initial deployment, several cages at each site were either tampered with or lost. One grass habitat cage was missing at Beacon Key on July 16; one growth cage (sand) and the sand reproduction cage were both missing on August 3. One growth cage (sand) at Boca Ciega Bay was missing on August 19. Because of these problems, no within habitat variability could be determined, and statistical comparisons within and between sites were made on the total number of live organisms within each habitat, regardless of the number of cages (or individuals) present. Growth was calculated as the mean of all live organisms from each habitat type for that time period. Consequently, the number of individuals was not constant over time and space.

Scallop growth at both sites followed an asymptotic pattern. This pattern was similar to the growth curve of a natural population from the Anclote Anchorage monitored by Barber and Blake in 1983 (Figure 2). Fastest growth (expressed as a change in mean shell height) occurred during the initial stages of the study (June through August) when water temperatures were highest. After August, growth rates slowed dramatically. Scallops reached a maximum mean shell height of 58.60 ± 3.18 mm by October 27.

Growth comparisons followed the methods of Andersen and Nass (1993). There were no significant differences (t test; $p > 0.05$) in growth between grass and sand at either Boca Ciega Bay (Figure 2) or Beacon Key (Figure 3). Consequently, growth data were averaged for all cages at each site to compare scallop growth between Boca Ciega Bay and Beacon Key (Figure 4). There was not a statistically significant difference ($p = 0.058$) between sites at the beginning of the first deployment (June 30). However, for each subsequent sampling period through September 15, there was a statistically significant difference in growth between Boca Ciega Bay and Beacon Key ($p < 0.001$). Similarly, there was not a statistically significant difference ($p = 0.287$) between sites at the beginning of the second deployment (August 19). However, there was a statistically significant difference ($p = 0.038$) in mean shell height between Boca Ciega Bay and Beacon Key on September 29 and October 27.

Mortality

Combined (both sites) initial mortality rates were low during the two week period following each deployment (12% for June 30 deployment and 0% for August 18 deployment), indicating that stresses involved with maintenance, transport and deployment were minimal. Overall mortality

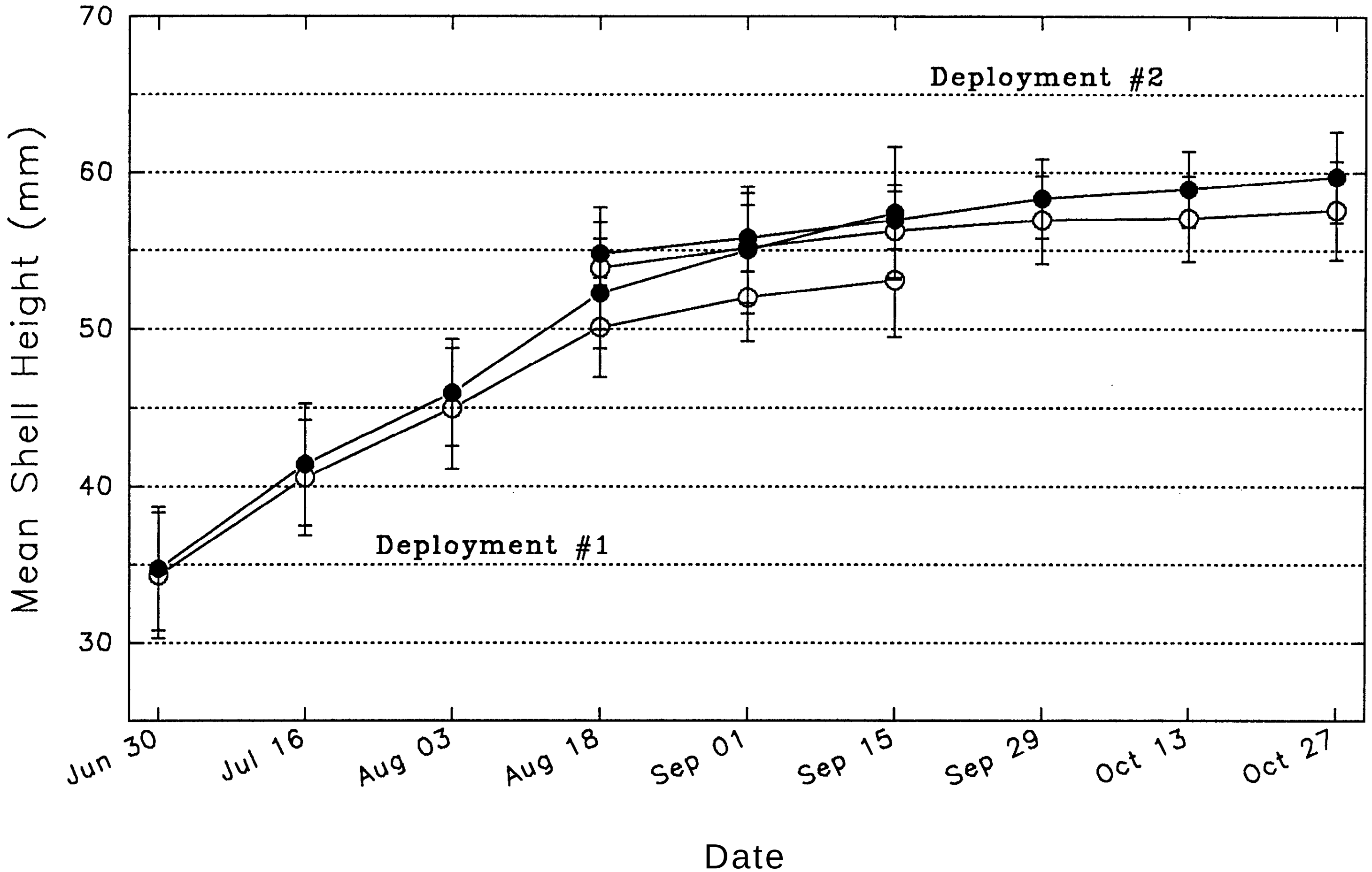

Figure 2. Shell height (mean ± 1 S.D.) of surviving bay scallops from sand (•) and grass (o) stations at Boca Ciega Bay from June 30 through October 27, 1992.

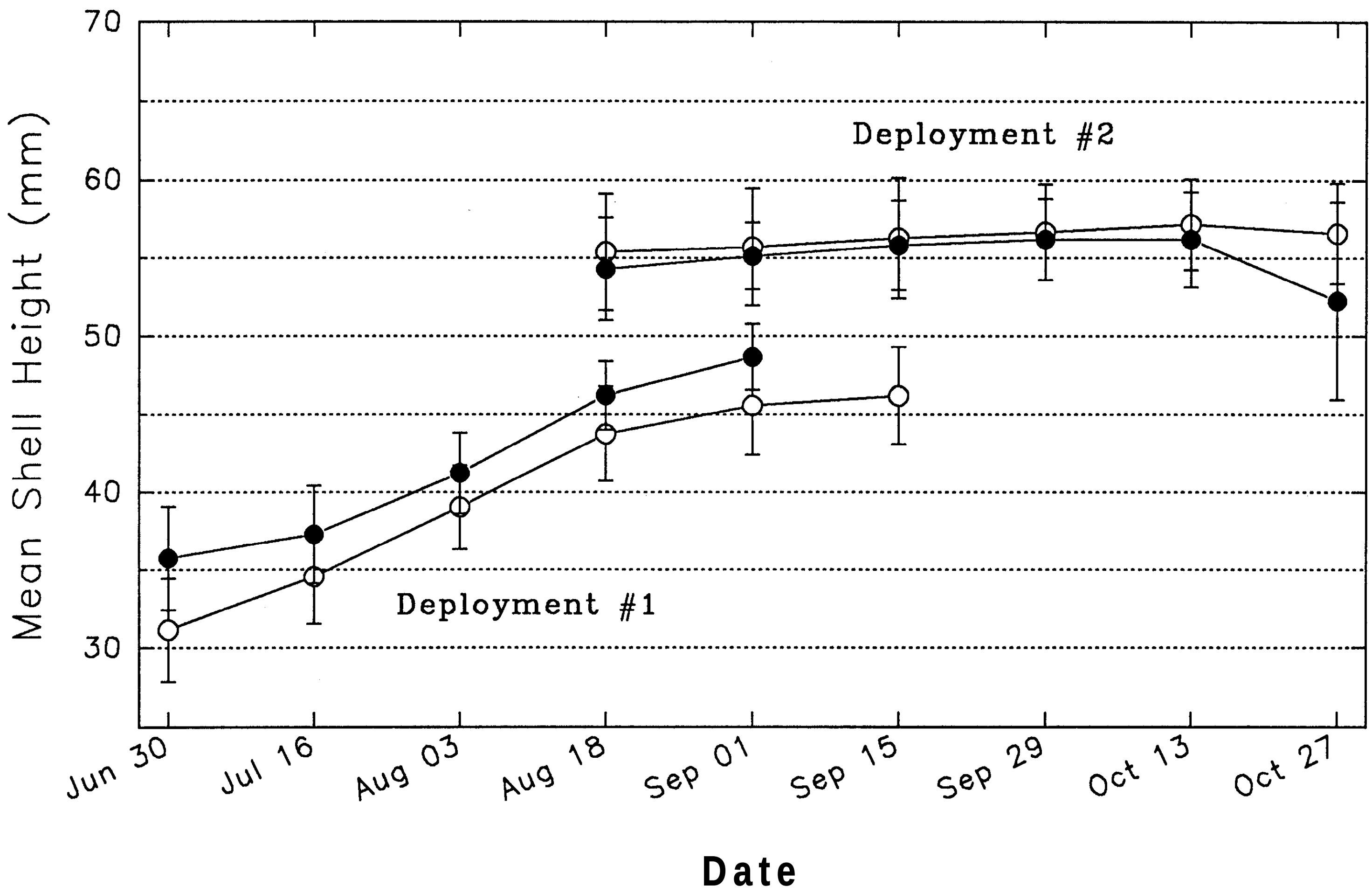

Figure 3. Shell height (mean ± 1 S.D.) of surviving bay scallops from sand (•) and grass (o) stations at Beacon Key from June 30 through October 27, 1992.

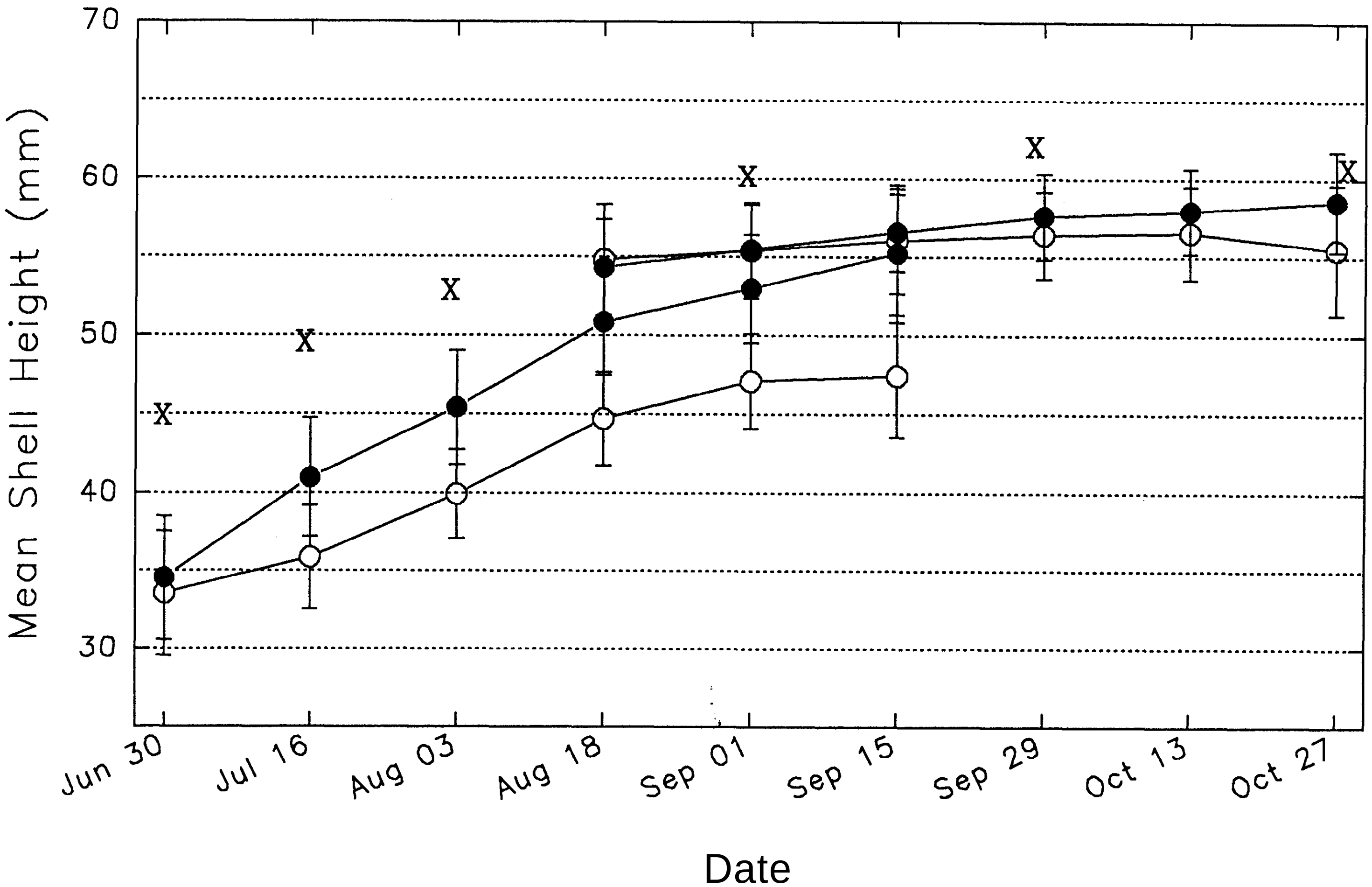

Figure 4. Shell height (mean ± 1 S.D.) of surviving bay scallops from Boca Ciega Bay (•) and Beacon Bay (o) from June 30 through October 27, 1992. "X" represents growth data for natural populations of bay scallop from Anclote Anchorage, 1979-1981 (Barber and Blake, 1983)

rates from the first deployment (= laboratory spawned scallops) were similar between sites (Figure 5). Eighty-five percent of all organisms at each site were dead after 2½ months. A substantial percentage of this mortality (28% at Beacon Key; 25% at Boca Ciega Bay) was preceded by a condition tentatively referred to as "hinge disease", whereby the two valves became separated at the hinge. Overall mean cumulative percent mortality during the second deployment was 84 percent at Beacon Key and 53 percent at Boca Ciega Bay by October 27. The greatest differences in cumulative mortality between sites were observed from September 29 through October 27.

Reproductive Development

Scallops from the first deployment were sexually mature with full gonads on July 16, two weeks after deployment (Table 2). One organism from Boca Ciega Bay and three from Beacon Key showed signs of having partially spawned. (Gonads that are partially full of mature ova usually indicate some relative degree of spawning). Three weeks later (August 3), reproductive conditions at both sites had changed only slightly. The gonadal acini (= follicle lumen) were slightly less than full at Boca Ciega Bay and between 50 and 100 percent full at Beacon Key. By September 15, gonadal acini from Boca Ciega Bay scallops were 50 to 90 percent full of mature ova, while Beacon Key scallops had gonadal acini which ranged from 90 percent to less than 25 percent full. By September 29, remaining scallops from Boca Ciega Bay had gonadal acini that were 25-90 percent full.

Scallops from the second deployment (August 19) were sexually mature with gonadal acini 75-100 percent full on September 1 (Table 3). No differences in reproductive state were noted between sites. By September 15, gonads had been reduced to 50 percent at both sites and partial spawning was observed in two scallops from Beacon Key. Major spawning activity occurred from September 24 through the end of October. On September 29, approximately half of the scallops examined at both sites had spawned. All scallops from Beacon Key had spawned by October 13, while less than half at Boca Ciega Bay had still retained their gametes. Overall, spawning occurred slightly earlier and more completely at Beacon Key compared to Boca Ciega Bay during this study.

Mean oocyte diameter from the first deployment ranged from 29.79 to 45.63 µm (Table 2). There were no observable differences in mean oocyte diameter between Boca Ciega Bay and Beacon Key. Organisms that showed signs of spawning (gonads 50% or less) had a lower mean oocyte diameter than organisms that had gonadal acini full of oocytes.

Mean oocyte diameter from the second deployment varied from 25.16 to 46.25 µm (Table 3). No observable differences in mean oocyte diameter were found between Boca Ciega Bay and Beacon Key. Organisms that showed signs of spawning (gonads 50% or less) had a lower mean oocyte diameter than organisms that had gonadal acini full of oocytes.

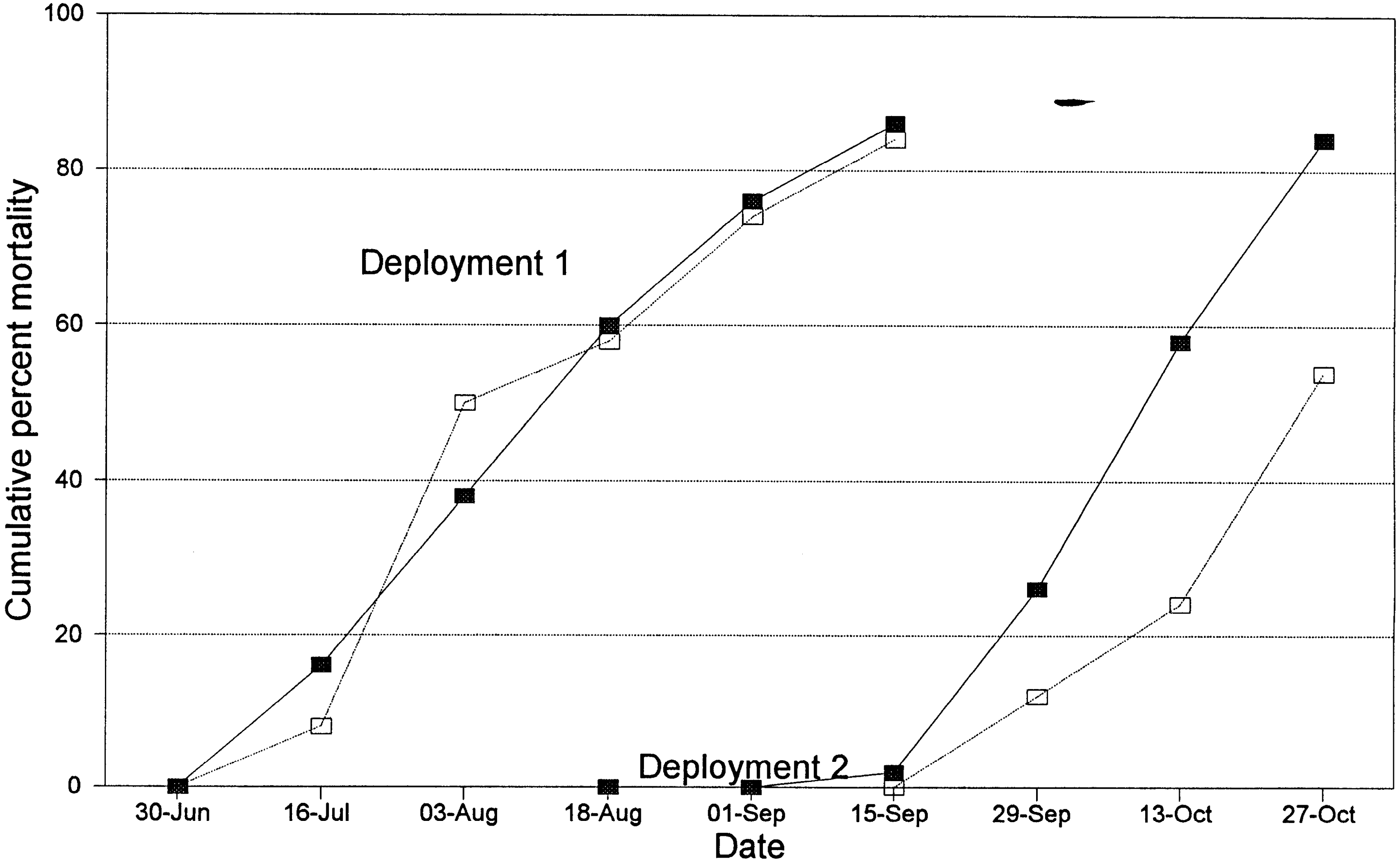

Figure 5. Cumulative percent mortality for laboratory spawned (Deployment 1) and wild (Deployment 2) bay scallops from Boca Ciega Bay (ž) and Beacon Key (■) from June 30 through October 30, 1992.

Table 2. Scallop reproductive condition for individuals from the first deployment (July 16 to September 24). Conditions include gonad size, spawning status and mean oocyte diameter (µm). (BCB = Boca Ciega Bay; BK = Beacon Key; G = Grass; S = Sand)

STATION	DATE	GONAD SIZE	SPAWNING STATUS	MEAN OOCYTE DIAMETER(µm)
BCB-G	16-Jul	FULL		41.75
BCB-G	16-Jul	FULL		40.25
BCB-G	16-Jul	FULL		39.17
BCB-G	16-Jul	FULL		
BCB-G	16-Jul	FULL		
BCB-S	16-Jul	FULL		
BCB-S	16-Jul	FULL		
BCB-S	16-Jul	FULL		42.50
BCB-S	16-Jul	50%	SPAWNED	
BCB-S	16-Jul	FULL		
BK-G	16-Jul	75-50%	PARTIAL SPAWN	38.61
BK-G	16-Jul	75-50%	PARTIAL SPAWN	40.68
BK-G	16-Jul	75-50%	PARTIAL SPAWN	39.17
BK-G	16-Jul	90%		38.93
BK-G	16-Jul	FULL		
BK-S	16-Jul	90%		
BK-S	16-Jul	90%		37.67
BK-S	16-Jul	FULL-90%		
BK-S	16-Jul	FULL-75%		
BK-S	16-Jul	90%		40.00
BCB-G	03-Aug	FULL		39.17
BCB-G	03-Aug	FULL		
BCB-G	03-Aug	FULL		
BCB-G	03-Aug	90%		
BCB-G	03-Aug	90%		
BCB-S	03-Aug	90%		
BCB-S	03-Aug	90%		
BCB-S	03-Aug	75%		44.17
BCB-S	03-Aug	FULL		
BCB-S	03-Aug	50%		
BK-G	03-Aug	50-75%		
BK-G	03-Aug	50%		40.25
BK-G	03-Aug	FULL		
BK-G	03-Aug	75%		45.00
BK-G	03-Aug	75%		
BCB	15-Sep	75%		
BCB	15-Sep	50-75%		
BCB	15-Sep	50%		35.50
BCB	15-Sep	90%		45.63
BCB	15-Sep	50%		37.88
BCB	15-Sep	50%		43.21
BK	15-Sep	<25%	SPAWNED	29.79
BK	15-Sep	<25%	SPAWNED	32.12

Table 2. Continued.

BK	15-Sep	<25%	SPAWNED	34.67
BK	15-Sep	50%		
BK	15-Sep	75-90%		
BCB	24-Sep	90%		36.46
BCB	24-Sep	25%		38.93
BCB	24-Sep	50%		35.96

Table 3. Scallop reproductive condition for individuals from the second deployment (September 1 to October 27). Conditions include gonad size, spawning status and mean oocyte diameter (µm) (BCB = Boca Ciega Bay; BK = Beacon Key).

STATION	DATE	GONAD SIZE	SPAWNING STATUS	MEAN OOCYTE DIAMETER(µm)
BCB	01-Sep	>75%		44.38
BCB	01-Sep	FULL		
BCB	01-Sep	>75%		38.61
BCB	01-Sep	90%		46.25
BCB	01-Sep	FULL		
BCB	01-Sep	FULL-90%		
BCB	01-Sep	75%		
BK	01-Sep	75%		
BK	01-Sep	FULL		35.54
BK	01-Sep	75%		
BK	01-Sep	75%		41.43
BK	01-Sep	FULL		41.79
BK	01-Sep	75%		
BK	01-Sep	75-90%		
BCB	15-Sep	75%		
BCB	15-Sep	75%		41.79
BCB	15-Sep	FULL-90%		
BCB	15-Sep	75%		38.75
BCB	15-Sep	50-75%		
BCB	15-Sep	90%		33.57
BCB	15-Sep	50%		
BK	15-Sep	FULL-75%		38.13
BK	15-Sep	50%		
BK	15-Sep	FULL		39.26
BK	15-Sep	50-75%		
BK	15-Sep	90%		37.50
BK	15-Sep	50%	PARTIAL SPAWN	
BK	15-Sep	25-50%	PARTIAL SPAWN	26.41
BCB	24-Sep	25%	MOSTLY SPAWNED	
BCB	24-Sep	<25%	MOSTLY SPAWNED	
BCB	24-Sep	50%	SPERM INTACT	
BCB	24-Sep	<25%	MOSTLY SPAWNED	25.95
BCB	24-Sep	50%		32.37
BCB	24-Sep	50-75%		
BK	24-Sep	50-75%		
BK	24-Sep	10%	SPAWNED	29.12
BK	24-Sep	10%	SPAWNED	30.83
BK	24-Sep	75%		41.39
BK	24-Sep	50%		32.64
BK	24-Sep	90%		
BK	24-Sep	50%		33.39
BCB	13-Oct	10%	SPAWNED	32.97
BCB	13-Oct	50%	PARTIAL SPAWN	

Table 3. Continued.

STATION	DATE	GONAD SIZE	SPAWNING STATUS	MEAN OOCYTE DIAMETER(µm)
BCB	13-Oct	25%	SPAWNED	30.14
BCB	13-Oct	75%		
BCB	13-Oct	FULL		
BCB	13-Oct	25%	SPAWNED	
BCB	13-Oct	25%	SPAWNED	
BK	13-Oct	25%	SPAWNED	
BK	13-Oct	10%	SPAWNED	35.47
BK	13-Oct	50%	PARTIAL SPAWN	
BK	13-Oct	50%	PARTIAL SPAWN	
BK	13-Oct	25%	SPAWNED	27.50
BK	13-Oct	25%	SPAWNED	
BK	13-Oct	10%	SPAWNED	
BK	13-Oct	10%	SPAWNED	25.16
BK	13-Oct	10%	SPAWNED	29.50
BK	13-Oct	50%	PARTIAL SPAWN	
BK	13-Oct	<10%	SPAWNED	
BK	13-Oct	0%	SPAWNED	
BK	13-Oct	25%	SPAWNED	30.17
BCB	27-Oct	FULL		39.17
BCB	27-Oct	50%		39.44
BCB	27-Oct	25%	SPAWNED	40.00
BCB	27-Oct	25-50%	PARTIAL SPAWN	42.14
BCB	27-Oct	50%		42.50
BCB	27-Oct	10%	SPAWNED	29.06
BCB	27-Oct	10-25%	SPAWNED	31.07
BCB	27-Oct	25-50%	PARTIAL SPAWN	43.50
BK	27-Oct	50%	PARTIAL SPAWN	
BK	27-Oct	0%	SPAWNED	
BK	27-Oct	10%	SPAWNED	29.41
BK	27-Oct	75%		44.44
BK	27-Oct	25%	SPAWNED	
BK	27-Oct	10%	SPAWNED	29.84
BK	27-Oct	50%	PARTIAL SPAWN	41.43
BK	27-Oct	50%	PARTIAL SPAWN	

A photomicrographic display of the various stages of scallop gonadal condition is presented in Appendix D.

2. Water Quality Parameters

Continuous *in situ* Parameters

Over a two month period, each Hydrolab unit recorded temperature, salinity and dissolved oxygen every twenty minutes for a total of 3,225 individual measurements. A complete listing of corrected dissolved oxygen, temperature and salinity readings has been submitted to the TBNEP office.

Very little difference in temperature was observed between Boca Ciega Bay and Beacon Key (Figure 6). Mean daily temperature at both sites fluctuated between 29 and 31°C through late September, when the daily mean temperature fell to a range between 23 and 26°C.

Salinity ranged from 26 to 30 parts per thousand (ppt) at Boca Ciega Bay and from 22 to 28 ppt at Beacon Key (Figure 6). Mean daily salinity was consistently lower by one to five ppt at Beacon Key.

Daily maximum dissolved oxygen (DO) at Boca Ciega Bay varied between 6 and 10 mg/L (most often around 8 mg/L), while the daily minimum DO ranged between 3 and 6 mg/L (Figure 7). Daily maximum DO at Beacon Key varied between 8 and 12 mg/L, while the daily minimum DO varied between 2 and 4 mg/L (Figure 8). Both daily maxima and minima DO fluctuated more widely over time at Beacon Key. In addition, over the course of a single day, DO at Beacon Key often fluctuated between 3 and 9 mg/L. On September 9, the greatest daily fluctuation in DO occurred at Beacon Key, varying between 1.63 and 12.23 mg/L.

Dissolved oxygen data were averaged for each twenty minute time period over a 24 hour cycle for each site (Figure 9). Lowest mean DO levels occurred at 0840, while the highest mean levels occurred at 1720. Greater mean daily fluctuations in DO were observed at Beacon Key.

Histograms were generated to show the amount of time per day that DO values fell below potentially stressful or lethal limits (4 mg/L and 2 mg/L, respectively). On only four occasions did the DO at Boca Ciega Bay drop below 4 mg/L, with each episode lasting less than three hours (Figure 10). Dissolved oxygen at Beacon Key, however, frequently dropped below 4 mg/L, at least through late September (Figure 10). These occurrences were mostly continuous and typically lasted up to six hours, with some days experiencing more than eight hours of DO at levels less than 4 mg/L. On one occasion (September 9) the DO dropped below 2 mg/L (for 2 hours).

Other Water Quality Parameters

Very little within-site differences (sand vs. grass) were observed in any water quality parameter at either site, with the exception of

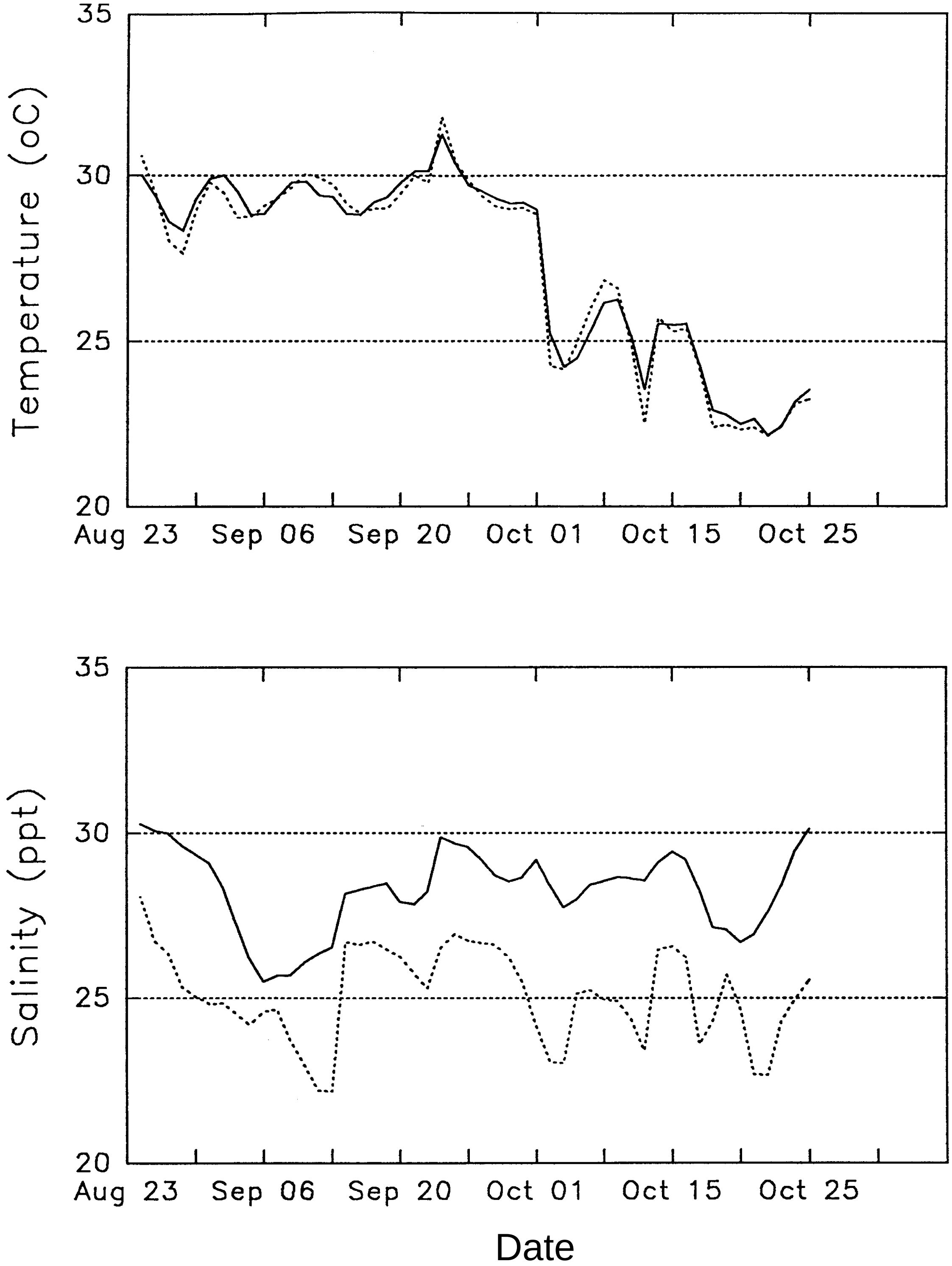

Figure 6. **Mean daily bottom temperature (°C) and salinity (ppt) at Boca Ciega Bay (-) and Beacon Key (---------) from August 27 through October 27, 1992. Mean obtained from seventy-two daily readings at 20 minute intervals.**

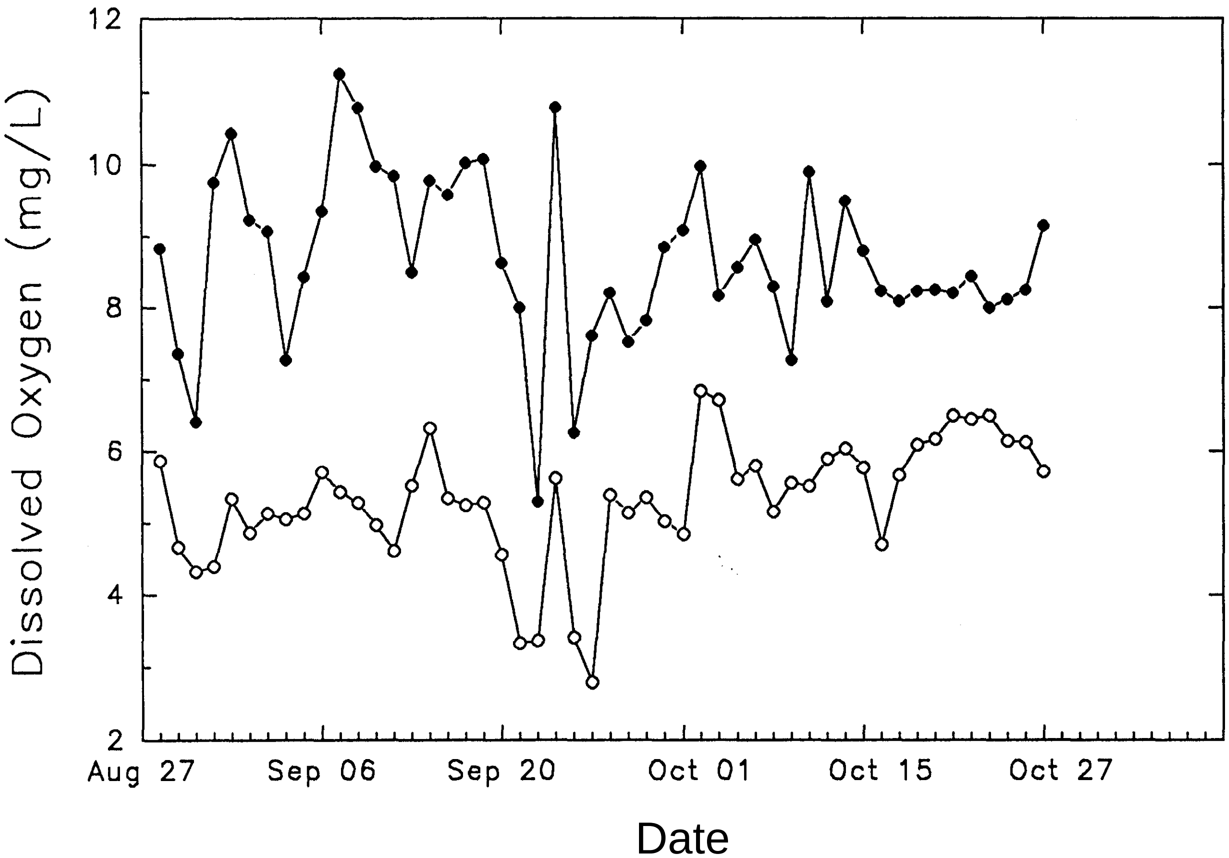

Figure 7. **Daily maximum (•) and minimum (o) dissolved oxygen (mg/L) at Boca Ciega Bay from August 27 through October 27, 1992.**

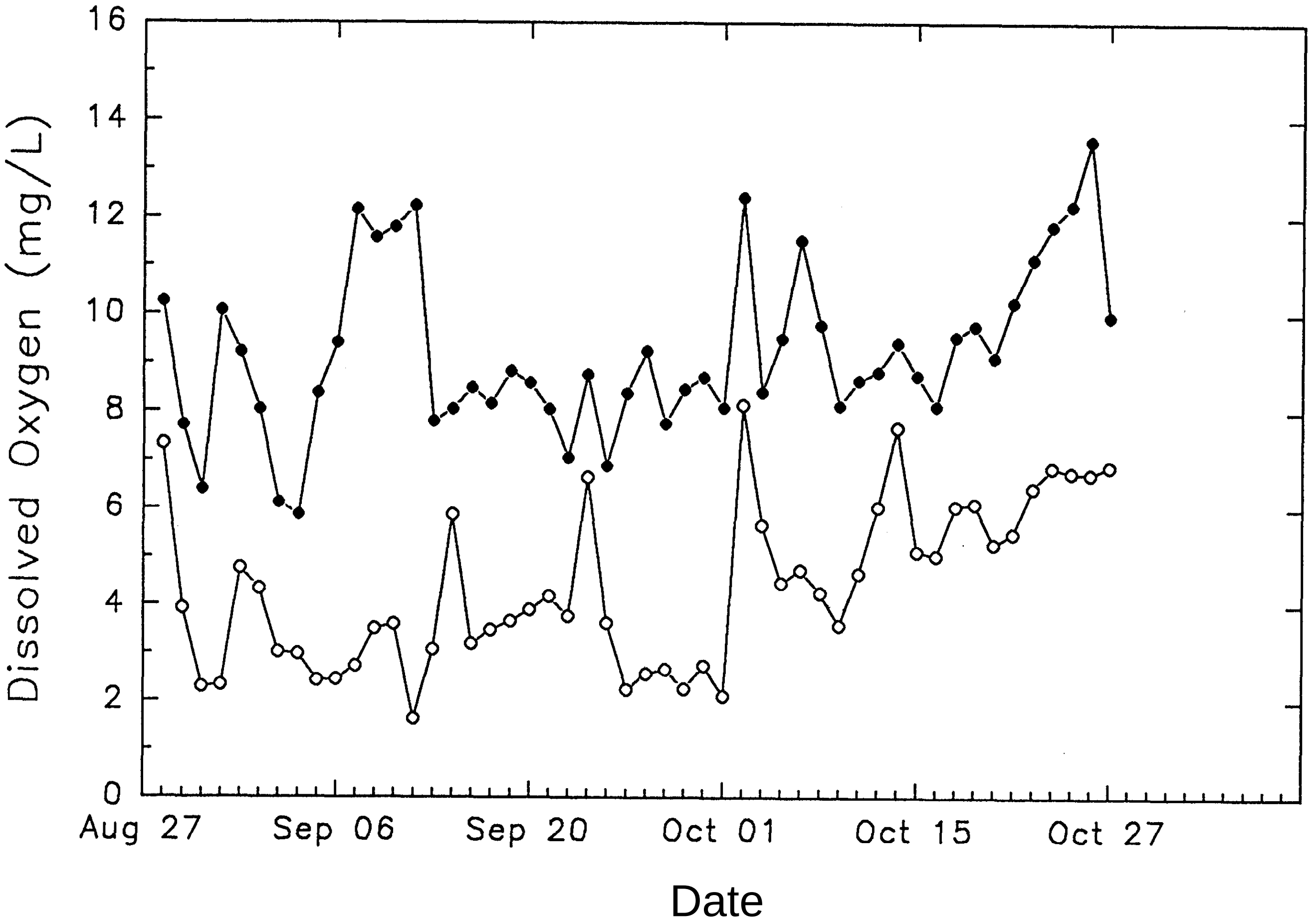

Figure 8. **Daily maximum (•) and minimum (o) dissolved oxygen (mg/L) at Beacon Key from August 27 through October 27, 1992.**

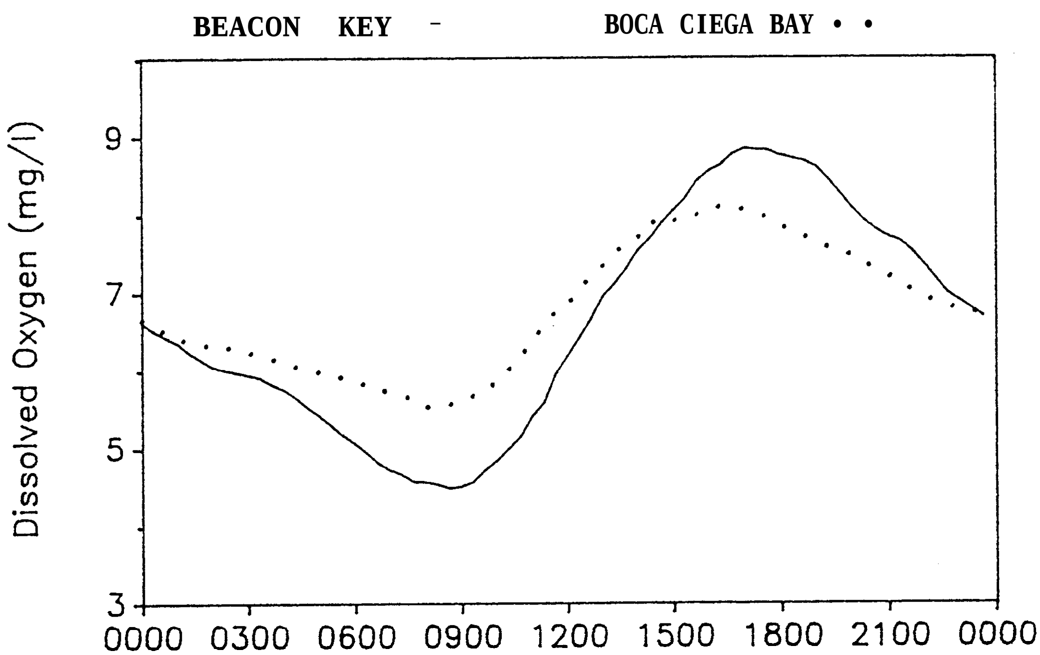

Figure 9. Diurnal dissolved oxygen (mg/L) at Beacon Key (—) and Boca Ciega Bay (····). Values represent mean DO from each twenty minute interval for every day between August 27 and October 27, 1992.

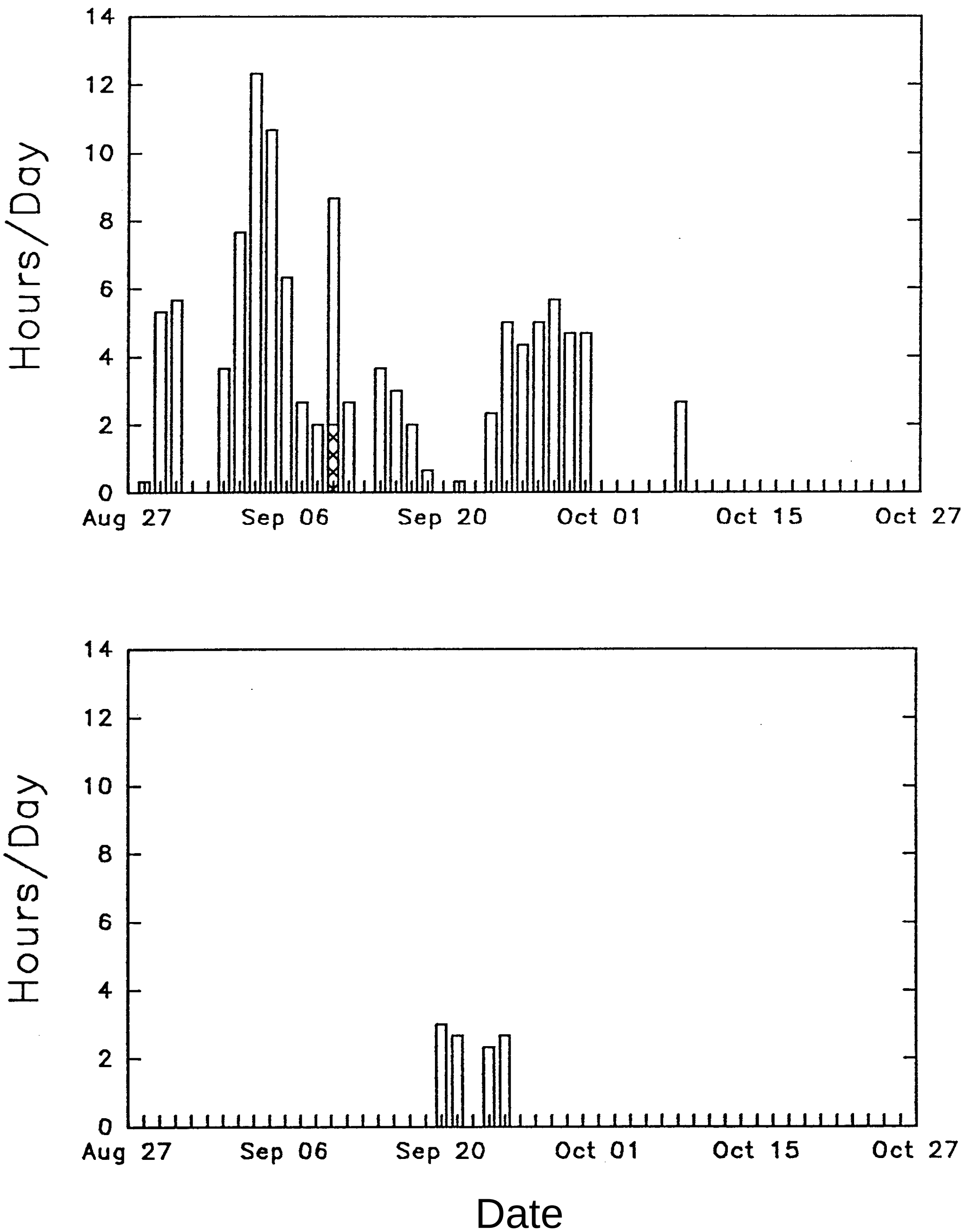

Figure 10. Histogram showing hours per day that dissolved oxygen fell below 4 mg/L (•) and 2 mg/L (⊠) at Beacon Key (top) and Boca Ciega Bay (bottom) between August 27 and October 27, 1992.

Beacon Key on September 15 (Table 4). (On two occasions, there were significant differences [$p < 0.05$] in suspended solids; another time chlorophyll a levels were significantly different between grass and sand at Beacon Key). Therefore, replicates from each site were pooled to compare water quality differences between Boca Ciega Bay and Beacon Key.

Turbidity levels most often ranged between 4 and 6 NTU's at both sites and remained fairly constant throughout the study (Figure 11). However, mean turbidity levels of 14.85 ± 0.95 and 20.62 ± 13.26 were observed at Beacon Key on September 15 and October 13, respectively. Similar high turbidity levels were not found at Boca Ciega Bay on these sampling dates.

Chlorophyll *a* levels were significantly higher (t test; $p = 0.05$) at Beacon Key throughout the study (Figure 11). Chlorophyll *a* levels ranged from 3.69-9.75 and 10.78-26.14 mg/m^3 at Boca Ciega Bay and Beacon Key, respectively. Temporal trends in chlorophyll *a* showed similarities to trends in turbidity throughout the study.

Levels of Total Suspended Solids (TSS) consistently ranged between 15 and 25 mg/L (Figure 12). Temporal trends in TSS were similar between Boca Ciega Bay and Beacon Key, although TSS levels were slightly higher at Beacon Key from September through the end of October. Highest levels of TSS at both sites occurred on October 13.

Temporal trends in Volatile Suspended Solids (VSS) were similar to trends in turbidity (Figure 12). While VSS levels remained very constant at Boca Ciega Bay throughout the study (6.56-8.34 mg/L), VSS levels at Beacon Key varied from 6.72 to 13.53 mg/L. VSS levels at Beacon Key experienced the greatest fluctuations between September 1 and October 27.

Water Quality and Biological Correlation Analysis

Relationships among the various water quality measurements and biological parameters were explored using Pearson product moment correlation analysis. Table 5 summarizes correlations among variables from deployment 1, and Table 6 summarizes correlations from deployment 2. Pairs of variables with positive correlation coefficients and p values below 0.05 tend to increase together. For pairs of variables with negative correlation coefficients and p values below 0.05, one variable tends to decrease while the other increases. There is no significant relationship between two variables with p values greater than 0.05.

Chlorophyll *a* and turbidity were positively correlated ($p > 0.909$) at both stations for the first deployment (Table 5). At Beacon Key, volatile suspended solids were positively correlated with chlorophyll *a* ($p = 0.932$) and turbidity ($p = 0.987$). All combinations of growth and mortality within and between stations were also positively correlated.

The majority of correlations for deployment 2 were between stations, mostly between suspended solids fractions and turbidity. At Boca Ciega Bay, positive correlations were found between total and volatile suspended

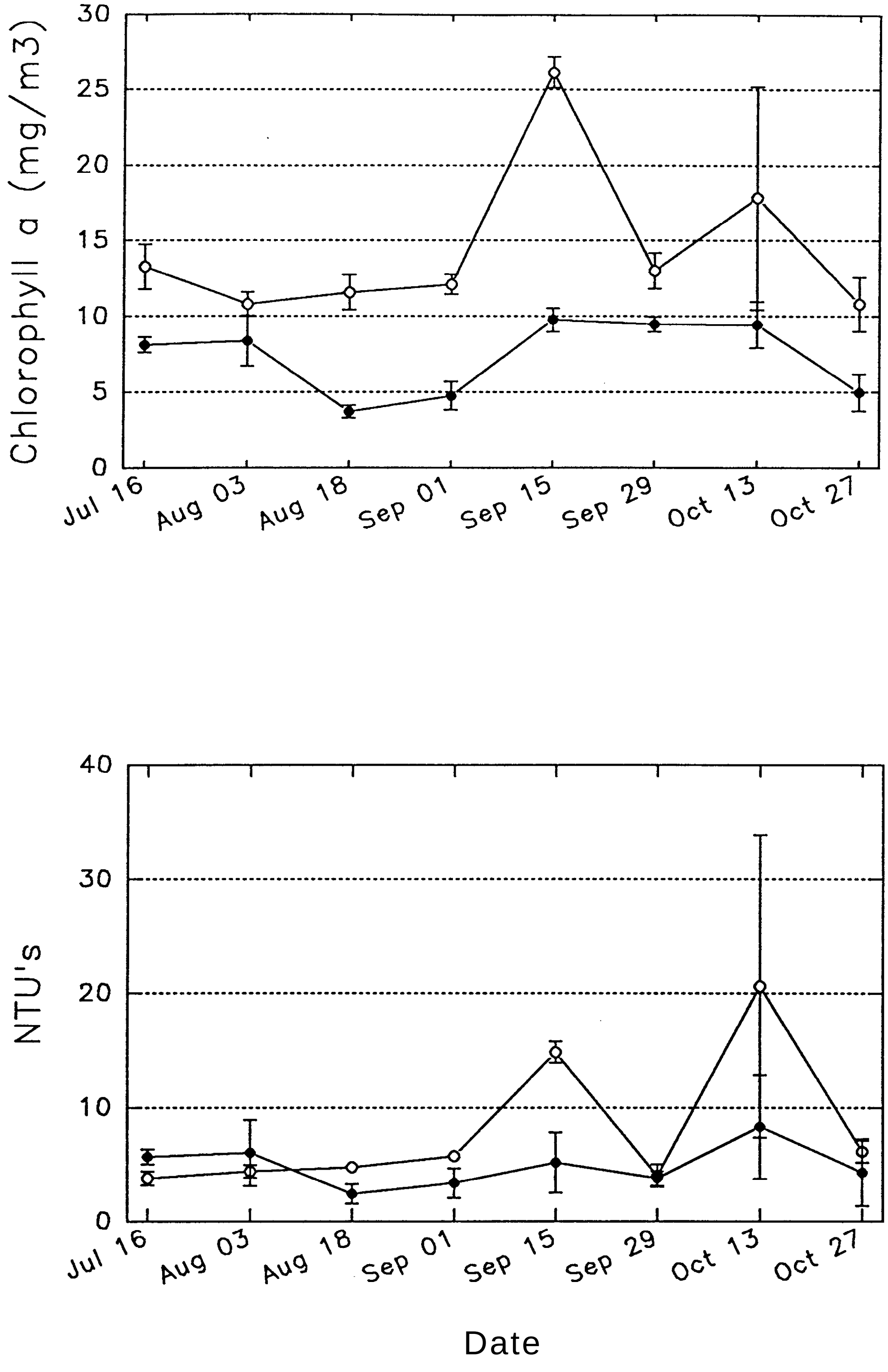

Figure 11. **Chlorophyll a (top) and turbidity (bottom) (mean ± 1 S.D.) at Boca Ciega Bay (•) and Beacon Bay (o) from July 16 through October 27, 1992.**

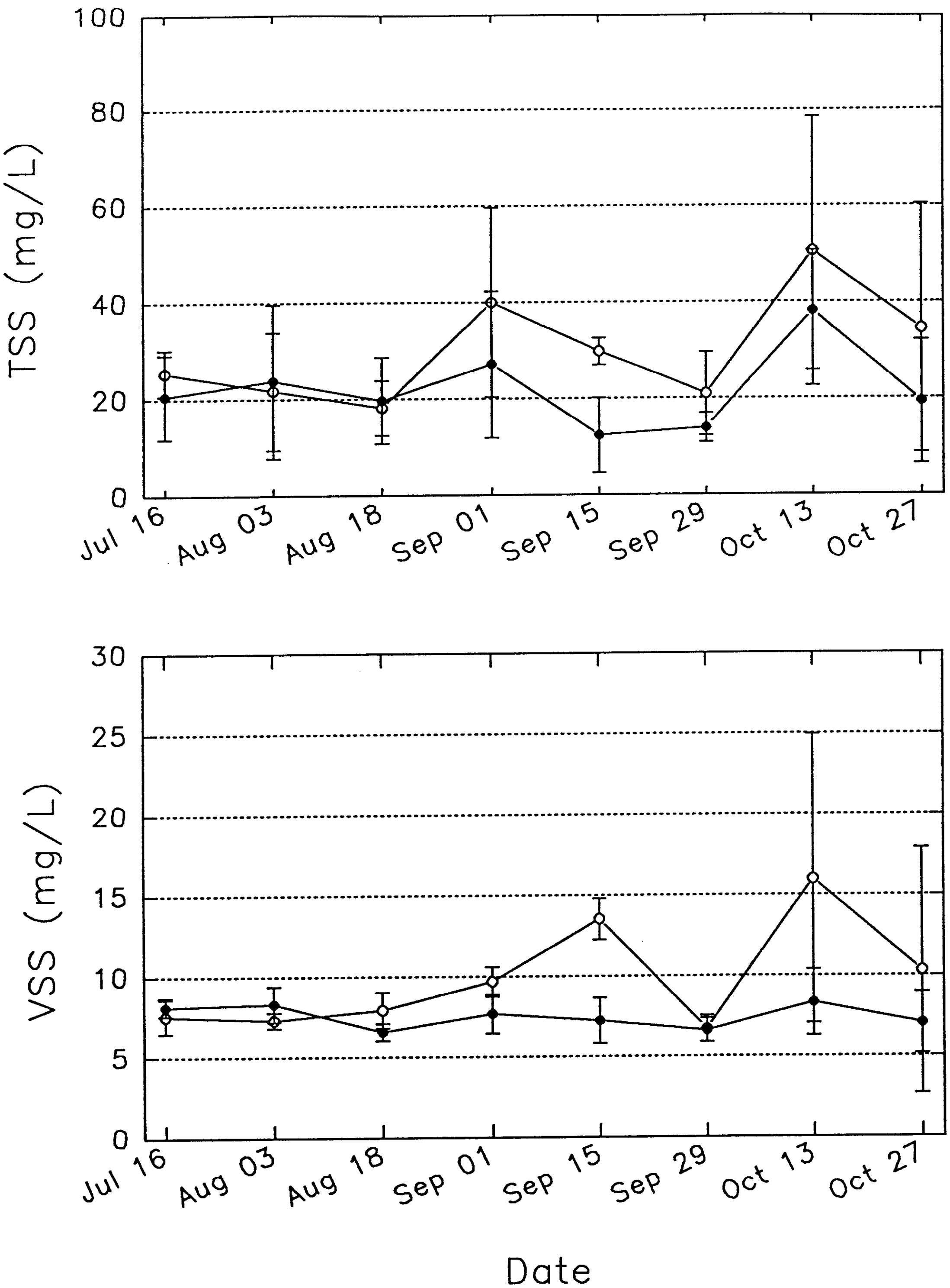

Figure 12. Total suspended solids (top) and volatile suspended solids (bottom) (mean ± 1 S.D.) at Boca Ciega Bay (•) and Beacon Bay (o) from July 16 through October 27, 1992.

Table 4. Water quality statistical summary (Student t test) for a) within site and b) between site comparisons. Where a significant difference is observed, the station with the higher value is listed.

a) WITHIN SITE COMPARISONS (α = 0.05; df = 4; n = 6)
(Sand vs. Grass)

	JUL 16	AUG 03	AUG 19	SEP 01	SEP 15	SEP 29	OCT 13	OCT 27
Turbidity							BK(S)	
VSS		BK(S)	BK(S)				BK(S)	
TSS			BK(S)				BK(S)	
CHL A					BK(S)		BK(S)	

b) BETWEEN SITE COMPARISONS (α = 0.5; df = 10; n = 12)
(BEACON KEY VS. BOCA CIEGA BAY)

	JUL 16	AUG 03	AUG 19	SEP 01	SEP 15	SEP 29	OCT 13	OCT 27
Turbidity			BK	BK	BK			
VSS					BK			
TSS					BK			
CHL A	BK		BK	BK	BK	BK		BK

Table 5. Pearson product moment correlation among water quality and biological parameters from the first scallop deployment (July 16-19 to September 15). Cell contents include the correlation coefficient (r), the P value and the number of samples (n) (BCB = Boca Ciega Bay; BK = Beacon Key; chl = chlorophyll a; tss = total suspended solids; vss = volatile suspended solids; turb = turbidity; mort = mortality).

	BK-chl	BCB-tss	BK-tss	BCB-vss
BCB-chl	0.616 0.268 5	-0.532 0.356 5	-0.017 0.978 5	0.517 0.372 5
BK-chl		-0.851 0.067 5	0.222 0.720 5	-0.257 0.676 5
BCB-tss			0.294 0.631 5	0.428 0.473 5
BK-tss				0.199 0.749 5

	BK-vss	BCB-turb	BK-turb	BCB-growth
BCB-chl	0.396 0.509 5	0.909 0.032 5	0.519 0.371 5	-0.195 0.754 5
BK-chl	0.932 0.021 5	0.236 0.702 5	0.973 0.005 5	0.539 0.349 5
BCB-tss	-0.650 0.235 5	-0.185 0.765 5	-0.775 0.124 5	-0.289 0.637 5
BK-tss	0.477 0.416 5	-0.085 0.892 5	0.279 0.650 5	0.427 0.473 5
BCB-vss	-0.335 0.581 5	0.796 0.107 5	-0.327 0.591 5	-0.651 0.234 5
BK-vss		0.010 0.987 5	0.972 0.006 5	0.771 0.127 5

Table 5. Continued.

	BK-vss	BCB-turb	BK-turb	BCB-growth
BCB-turb			0.128 0.837 5	-0.521 0.368 5
BK-turb				0.698 0.190 5

	BK-growth	BCB-mort	BK-mort
BCB-chl	-0.287 -0.640 5	-0.071 0.910 5	-0.176 0.777 5
BK-chl	0.441 0.457 5	0.592 0.293 5	0.528 0.361 5
BCB-tss	-0.180 0.772 5	-0.286 0.641 5	-0.253 0.681 5
BK-tss	0.456 0.441 5	0.498 0.393 5	0.458 0.438 5
BCB-vss	-0.642 0.243 5	-0.529 0.359 5	-0.603 0.282 5
BK-vss	0.703 0.186 5	0.821 0.088 5	0.769 0.129 5
BCB-turb	-0.581 0.304 5	-0.392 0.514 5	-0.490 0.402 5
BK-turb	0.613 0.271 5	0.750 0.144 5	0.693 0.195 5
BCB-growth	0.993 < 0.001 5	0.987 0.002 5	0.998 < 0.001 5

Table 5. Continued.

	BK-growth	BCB-mort	BK-mort
BK-growth		0.975 0.005 5	0.993 < 0.001 5
BCB-mort			0.994 < 0.001 5

The pair(s) of variables with positive correlation coefficients and P values below 0.050 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.050 one variable tends to decrease while the other increases. For pairs with P values greater than 0.050, there is no significant relationship between the two variables.

Table 6. Pearson product moment correlation among water quality and biological parameters from the second scallop deployment (August 19 to October 27). Cell contents include the correlation coefficient (r), the P value and the number of samples (n). (BCB = Boca Ciega Bay; BK = Beacon Key; chl = chlorophyll a; tss = total suspended solids; vss = volatile suspended solids; turb = turbidity; mort = mortality)

	BK-chl	BCB-tss	BK-tss	BCB-vss
BCB-chl	0.711 0.113 6	-0.040 0.940 6	0.200 0.705 6	0.286 0.583 6
BK-chl		-0.145 0.785 6	0.175 0.740 6	0.305 0.557 6
BCB-tss			0.825 0.043 6	0.842 0.035 6
BK-tss				0.971 0.001 6

	BK-vss	BCB-turb	BK-turb	BCB-growth
BCB-chl	0.471 0.346 6	0.660 0.154 6	0.619 0.190 6	0.512 0.299 6
BK-chl	0.669 0.146 6	0.509 0.302 6	0.717 0.108 6	0.086 0.872 6
BCB-tss	0.554 0.254 6	0.616 0.193 6	0.533 0.277 6	0.106 0.841 6
BK-tss	0.781 0.067 6	0.774 0.071 6	0.686 0.132 6	0.420 0.407 6
BCB-vss	0.830 0.041 6	0.803 0.054 6	0.775 0.070 6	0.278 0.594 6
BK-vss		0.893 0.017 6	0.966 0.002 6	0.347 0.501 6

Table 6. Continued.

	BK-vss	BCB-turb	BK-turb	BCB-growth
BCB-turb			0.929 0.007 6	0.600 0.208 6
BK-turb				0.327 0.527 6

	BK-growth	BCB-mort	BK-mort
BCB-chl	0.932 0.007 6	-0.045 0.932 6	0.074 0.889 6
BK-chl	0.477 0.339 6	-0.322 0.534 6	-0.249 0.634 6
BCB-tss	0.192 0.716 6	0.176 0.739 6	0.305 0.557 6
BK-tss	0.412 0.417 6	0.332 0.521 6	0.437 0.386 6
BCB-vss	0.444 0.378 6	0.124 0.815 6	0.255 0.626 6
BK-vss	0.476 0.340 6	0.161 0.761 6	0.285 0.585 6
BCB-turb	0.755 0.083 6	0.329 0.525 6	0.485 0.329 6
BK-turb	0.597 0.211 6	0.060 0.910 6	0.212 0.687 6
BCB-growth	0.696 0.125 6	0.817 0.047 6	0.856 0.030 6

Table 6. Continued.

	BK-growth	BCB-mort	BK-mort
BK-growth		0.188 0.721 6	0.319 0.538 6
BCB-mort			0.982 < 0.001 6

The pair(s) of variables with positive correlation coefficients and P values below 0.050 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.050 one variable tends to decrease while the other increases. For pairs with P values greater than 0.050, there is no significant relationship between the two variables.

solids and between growth and mortality. The only positive correlations at Beacon Key were between turbidity and volatile suspended solids.

3. Phytoplankton Composition and Data Analysis

Phytoplankton species composition consisted of sixty-three taxa belonging to five orders of algae. A composite species list may be found in Appendix Table A. The most common species included the chrysophytes *Rhizosolenia setigera* Brightwell, *Rhizosolenia calcar-avis* Schultze, *Campylosirus cymbelliformis* Grunow, and *Skelotonema costatum* (Greville). The cyanophyte *Chroococcus dispersa* Lemmermann was also occasionally dominant.

Overall phytoplankton density varied by an order of magnitude, ranging from 3×10^6 to 3×10^7 cells/liter (Figure 13). Phytoplankton density remained fairly constant at Boca Ciega Bay (except for a peak on September 1) while greater fluctuations were observed at Beacon Key. The greatest difference in phytoplankton density between the two sites occurred on October 13.

Phytoplankton species diversity (Shannon index) was greater at Beacon Key from mid-August through mid-October, while species diversity was higher at Boca Ciega Bay in late July and late October (Table 7). Diversity was lowest and dominance (Simpsons index) highest at both sites on July 16. Species diversity and richness was highest on August 3 at Boca Ciega Bay and on October 13 at Beacon Key.

Similarity groupings were equally divided between spatial and temporal associations (Figure 14). The closest associations between pairing sequences arranged by increasing distances were: Boca Ciega Bay on August 19 and October 27 (temporal); Boca Ciega Bay and Beacon Key on September 1 (spatial); Boca Ciega Bay on September 15 and 29 (temporal); Boca Ciega Bay and Beacon Key on July 16 (spatial); and Beacon Key on September 15 and October 27 (temporal). These associations showed moderate similarities in Bray-Curtis trellis diagram (Figure 15). Remaining groupings showed low to very low similarities.

B. Laboratory Experiments

Results from the laboratory exposure trials are shown in Table 8. Trial 1, conducted under ambient temperature, salinity and oxygen (no acclimation from holding conditions), resulted in positive tactile responses and no mortality. Trial 2 exposed organisms to dissolved oxygen levels of 2-4 mg/L for 2.5 hours (simulating a temporal lag in dissolved oxygen that might be experienced in the field) and also resulted in positive behavioral responses and no mortality. Test organisms were able to survive short-term exposure to low dissolved oxygen without any apparent reduction in behavior or response. Six hours of exposure to dissolved oxygen levels less than 2 mg/L at 24°C (Trial 3) showed no reduction in tactile response and no mortality. At higher temperature (30°C), exposure to less than 2 mg/L dissolved oxygen for six hours resulted in one casualty (this organism's hinge became disassociated prior

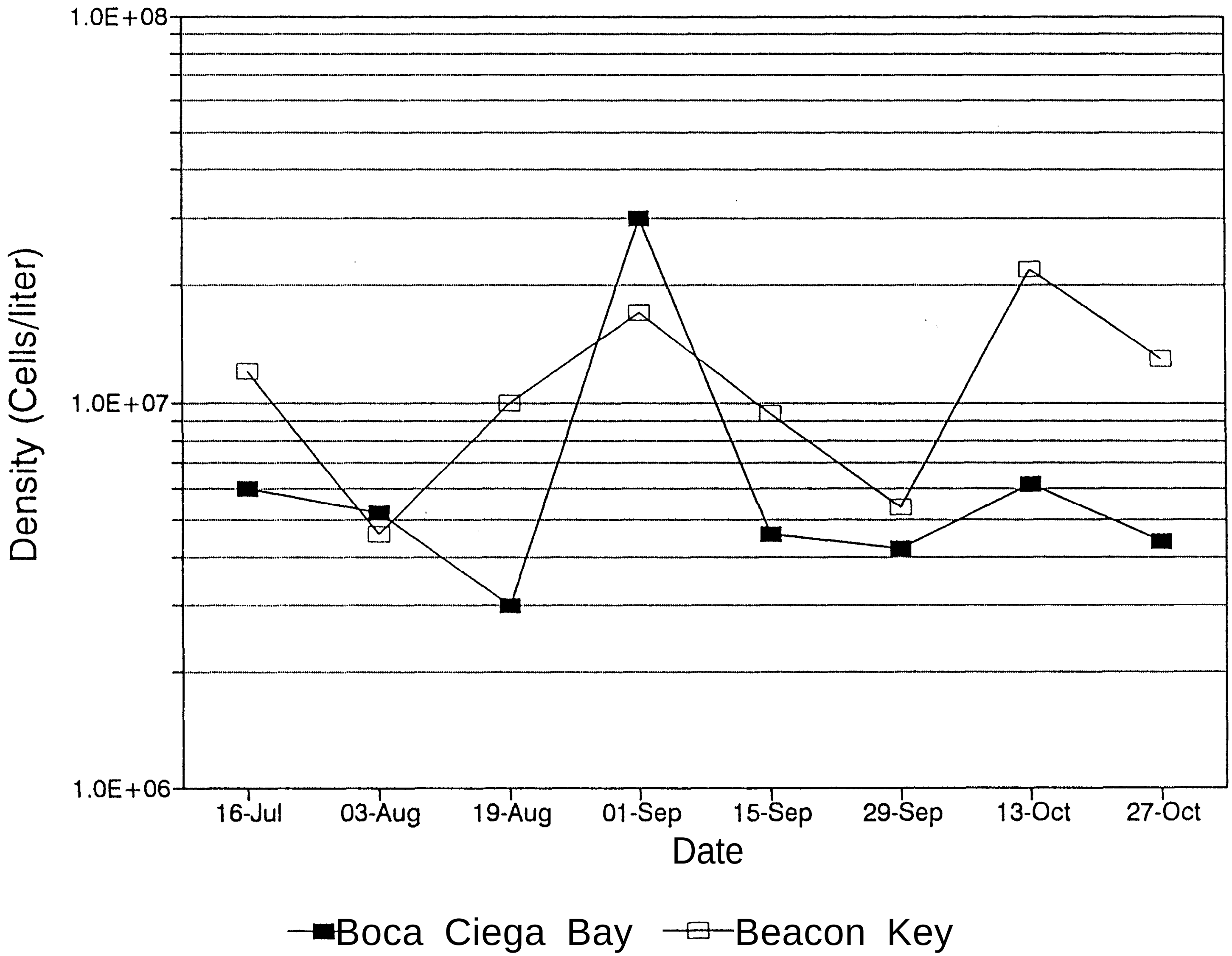

Figure 13. Phytoplankton densities (cells/liter) at Boca Ciega Bay and Beacon Key from July 16 through October 27, 1992.

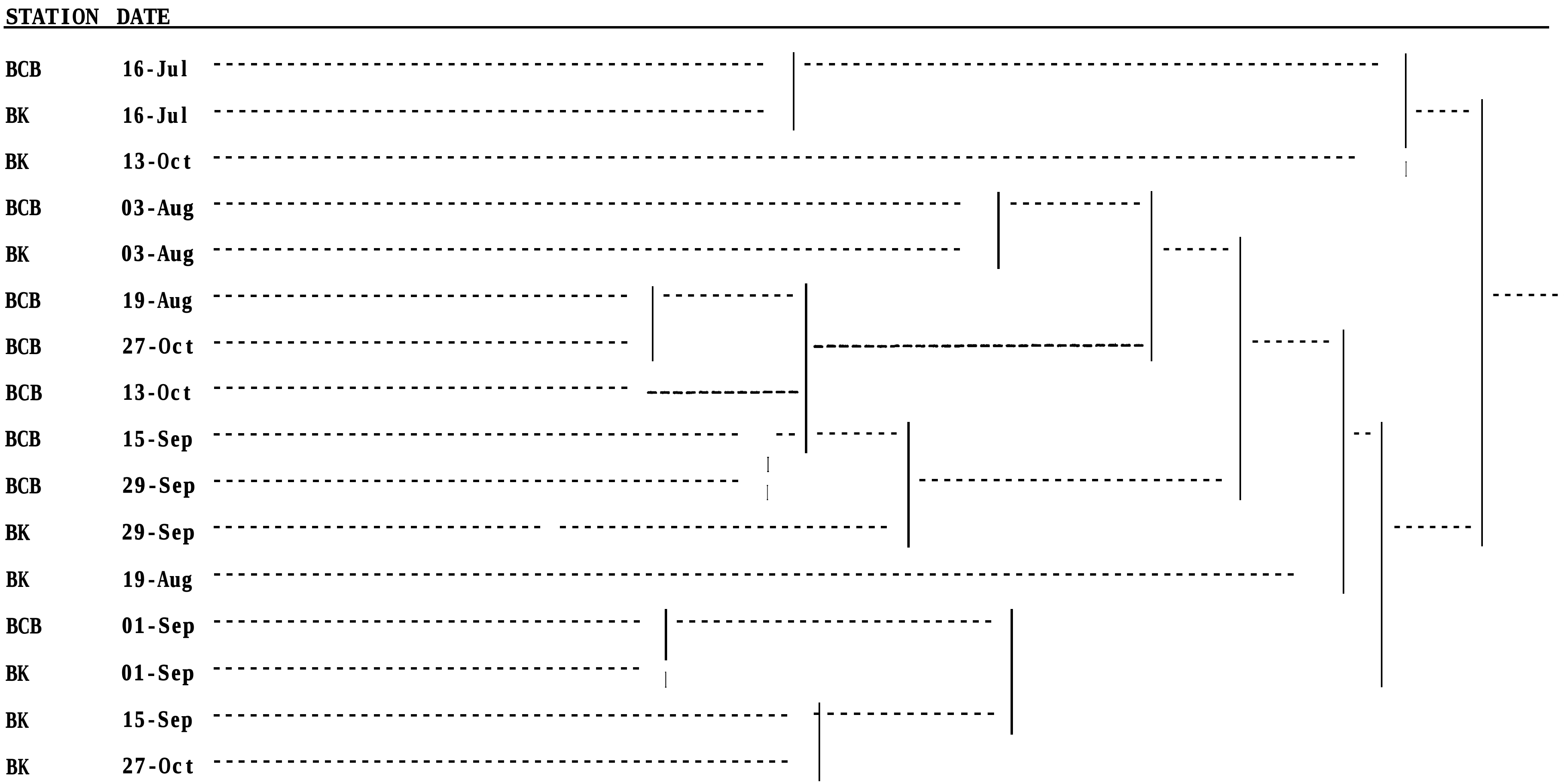

Figure 14. Dendrogram from Bray-Curtis values, based on group averaged sorting, for Boca Ciega Bay and Beacon Key phytoplankton species composition.

STATION	STATION DATE	BCB 16-Jul	BK 16-Jul	BCB 03-Aug	BK 03-Aug	BCB 19-Aug	BK 19-Aug	BCB 01-Sep	BK 01-Sep	BCB 15-Sep	BK 15-Sep	BCB 29-Sep	BK 29-Sep	BCB 13-Oct	BK 13-Oct	BCB 27-Oct	BK 27-Oct
BCB	16-Jul		+++	...	...	...	...	...	...	...	...	...	...	...	...	...	...
BK	16-Jul	.413		...	...	...	...	...	...	...	...	...	...	...	...	...	...
BCB	03-Aug	.816	.944		---	---	...	...	...	...	...	...	---	...	...	---	...
BK	03-Aug	.595	.774	.558			...	...	...	...	...	---	---	...	...	---	...
BCB	19-Aug	.891	.997	.609	.751		---	...	...	...	...	...	---	---	...	+++	---
BK	19-Aug	.926	.971	.741	.832	.655		...	...	...	...	...	...	...	...	...	...
BCB	01-Sep	.926	.937	.863	.856	.958	.809		+++	...	---	...	...	...	...	...	---
BK	01-Sep	.916	.931	.787	.828	.928	.807	.327		...	+++	...	...	...	...	...	---
BCB	15-Sep	.961	.985	.859	.814	.949	.966	.925	.901		...	+++	---	...	...	...	...
BK	15-Sep	.967	.976	.758	.776	.942	.941	.616	.481	.738		...	---	...	...	...	+++
BCB	29 Sep	.769	.911	.736	.677	.819	.891	.892	.850	.396	.741		+++	...	...	...	...
BK	29-Sep	.837	.920	.524	.617	.633	.766	.879	.803	.574	.672	.405		---	...	---	...
BCB	13-Oct	.866	.996	.700	.702	.503	.785	.928	.915	.732	.803	.732	.584		...	+ + +	---
BK	13-Oct	.823	.860	.838	.823	.950	.846	.776	.809	.965	.878	.894	.852	.965		...	...
BCB	27-Oct	.834	.983	.567	.657	.312	.719	.926	.890	.838	.872	.786	.596	.337	.925		---
BK	27-Oct	.934	.978	.711	.836	.674	.805	.651	.522	.982	.427	.906	.726	.536	.867	.645	

■ High Similarity
+++ Moderate Similarity
--- Low Similarity
••• Very Low Similarity

Figure 15. Bray-Curtis trellis diagram based on abundance data for phytoplankton from Boca Ciega Bay and Beacon Key.

Table 7. Summary statistics for phytoplankton collected from Boca Ciega Bay (BCB) and Beacon Key (BK).

Station	Date	No. of Taxa	Cells per liter($x10^3$)	Shannon (log10)	Shannon (ln)	Shannon (log2)	Pielou J'	Margalef	Simpson	Gini
BCB	7/16/92	14	6000	0.79	0.34	1.14	0.30	0.83	0.689	0.311
BK	7/16/92	4	12000	0.12	0.05	0.18	0.09	0.18	0.957	0.043
BCB	8/03/92	26	5200	2.55	1.11	3.68	0.78	1.62	0.106	0.894
BK	8/03/92	12	4600	1.87	0.81	2.70	0.75	0.72	0.194	0.806
BCB	8/19/92	17	3000	1.21	0.53	1.75	0.43	1.07	0.513	0.487
BK	8/19/92	16	10000	2.04	0.89	2.94	0.74	0.93	0.172	0.828
BCB	9/01/92	15	30000	1.44	0.63	2.08	0.53	0.81	0.448	0.552
BK	9/01/92	17	17000	1.59	0.69	2.30	0.56	0.96	0.369	0.631
BCB	9/15/92	17	4600	0.94	0.41	1.36	0.33	1.04	0.597	0.403
BK	9/15/92	13	9400	1.29	0.56	1.86	0.50	0.75	0.405	0.595
BCB	9/29/92	23	4200	1.84	0.80	2.66	0.59	1.44	0.285	0.715
BK	9/23/92	23	5400	2.00	0.87	2.88	0.64	1.42	0.200	0.800
BCB	10/13/92	14	6200	1.14	0.50	1.65	0.43	0.83	0.483	0.517
BK	10/13/92	28	22000	2.48	1.08	3.58	0.75	1.60	0.118	0.882
BCB	10/27/92	22	4400	1.69	0.74	2.45	0.55	1.37	0.341	0.659
BK	10/27/92	12	13000	1.14	0.49	1.64	0.46	0.67	0.409	0.591

Table 8. Summary of laboratory trials exposing adult bay scallops to low dissolved oxygen levels, including exposure conditions, exposure duration, and observations (findings).

TRIAL	TEMP (°C)	SALINITY (o/oo)	DISSOLVED OXYGEN (mg/l)	DURATION (h)	FINDINGS
1	25	27-29	7.5	48	Positive tactile response; no mortality.
2	24	32	2-4	2.5	Positive tactile response; no mortality.
3	24	30	<2	6	Positive tactile response; no mortality.
4	30	30	<2	6	One test organism → broken hinge → died.
5	30	25	<2	3	Two controls died; one test died; negative tactile response.
6	24	33	1-3	24	Two test organisms died within three days; negative tactile response; curled mantles.
	30	33	<2	24	One test organism died; another died three days later. Negative tactile response; curled mantles.

to death). All other test organisms during this trial showed normal behavioral responses. When the temperature was raised to 30°C and the salinity lowered to 25 ppt (Trial 5), mortality was observed in both the control and test aquaria. All organisms exhibited reductions in tactile and behavioral responses. Under more extreme conditions of reduced oxygen levels (Trials 6 and 7), all test organisms exhibited depressed activity and/or response. Mortality in these trials was approximately 67 percent as late as three days after a return to normoxic conditions.

VI. DISCUSSION

A. Growth

Scallop growth at both sites exhibited a characteristic asymptotic pattern. This pattern was similar to growth of a natural population from the Anclote Anchorage monitored by Barber and Blake in 1983. Growth rates were significantly higher at Boca Ciega Bay than Beacon Key, suggesting that conditions for growth were more optimal at Boca Ciega Bay. Growth in adult scallops is primarily influenced by both temperature and food supply (Kirby-Smith, 1970). Since no differences in temperature were observed between sites in the present study, differences in scallop growth must be a result of differences in either the quantity and quality of food. These differences are discussed in a subsequent section on water quality parameters. In any event, scallops at Beacon Key did not appear to be limited by food supply to the degree where it affected their ability to initiate gametogenesis and eventually spawn.

B. Mortality

The life expectancy of bay scallops appears to be associated with a latitudinal gradient. Florida populations have the shortest life span of any North American population. Bay scallops in Alligator Harbor, Florida, apparently do not live longer than 19 months (Sastry, 1961), and animals from farther south, including the Tampa Bay area, probably have even shorter life spans (12-14 months).

Barber and Blake (1981) witnessed high post-spawning mortality in natural scallop populations from Anclote Anchorage from 1979-1981. They suggested that energy reserve depletion contributed to the high post-spawning mortality in those populations. The southern range in scallop distribution is ultimately limited by the energetic demands placed on populations subjected to high temperatures and limited food supplies. The period of highest mortality during the second deployment (late September through October) was also the period when overall spawning had peaked. Although mortality in the present study was higher at Beacon Key, a substantial portion of the overall mortality can be attributed to this post-spawning condition. (Differences in mortality between the two sites, however, must be due to differences in water quality.) The ultimate success of scallop populations in Tampa Bay depends on the ability of each year class to survive long enough to spawn in the fall. Results from this study indicate that this was accomplished at both the Boca Ciega Bay and Beacon Key test locations.

Sources of scallop mortality mainly involve predation (Peterson et al., 1989; Prescott, 1990), and, to a lesser degree, parasites and disease (Arnold, 1990). Few data are available on presenecence mortality rates from natural populations. Cumulative mortalities of 9 percent from Long Island, NY (Bricelj et al., 1987) and 13 percent from Virginia (Castagna and Duggan, 1971) have been reported for bay scallops maintained in the field in cages and trays. Mortality of the great scallop *(Pecten maximus)* kept in ponds was as high as 67 percent (Andersen and Naas, 1993). Although the cumulative mortality rates in the present study were relatively high (53 to 85%), these rates were generally in line with results from the limited number of studies incorporating caging techniques. As long as mortality was associated with spawning, then attention should be focused on the success of the spawning event, which will ultimately determine the potential success of the following year's scallop population.

A substantial percentage (ca. 25%) of mortality from the first deployment (= laboratory spawned scallops) was preceded by a condition tentatively referred to as "hinge disease", whereby the two valves became separated due to a deterioration of the ligament at the hinge line. This condition prevented the organism from properly closing its valves and had serious detrimental effects on many biological processes. All scallops that had this condition were dead within two weeks. The cause of this "condition" is unknown, although it has infrequently been observed in the field (Blake, personal communication). The high percentage of "hinge disease" in this study may be partly due to a combination of aquaculture and caging related stresses. Further research into the cause(s) of this disease should be conducted.

C. Reproduction

The scallop gametogenic cycle has been considered to be a genetically controlled response to the environment, most notably to water temperature and food supply (Sastry, 1979). Gametogenic cycles in scallops include periods of inactivity, cytoplasmic growth, vitellogenesis (maturation), spawning, and resorption of unspawned gametes (Barber and Blake, 1991). For southern populations of the bay scallop, the cytoplasmic growth phase of oogenesis is initiated in July and continues through September when maximum oocyte diameters are found (Barber and Blake, 1981, 1983). Spawning commences in early October in conjunction with a decrease in water temperature. After spawning the population as a whole experiences mass mortality.

Microscopic determinations of mean oocyte diameter and gonad condition have been used to monitor reproductive development in *Argopecten irradians* (Sastry, 1970; Barber and Blake, 1981, 1983). Mean oocyte diameter is reflective of the gametogenic cycle, as oocytes gradually increase in size as they develop, reaching maximum size prior to spawning. Mean oocyte diameter decreases sharply after spawning, as mostly larger, mature ova are released. Gonad condition may be classified as empty, filling, full (mature), partially spawned or spent (fully spawned).

The large oocyte diameters measured at the beginning of this study indicate that the organisms were well along in their reproductive development by the time they were placed in the field. Laboratory spawned scallops from the first deployment already had large, developed oocytes and full (mature) gonads by mid-July and maintained this condition through mid-September. Scallops from the second deployment (natural populations) were also mature at the time they were transferred to Tampa Bay (August 19). Although scallops from both deployments showed signs of partial spawning throughout the summer, no major spawning episodes were noted until the latter part of September.

A decrease in mean oocyte diameter and a change in gonad condition indicate that scallops from both deployments initiated a major spawn as early as September 15. By October 13, most scallops from the second deployment had spawned. This major spawn was coincident with a drop in water temperature at the end of September.

The course of reproductive development, the successful spawning and the timing of spawning with a drop in water temperature all indicate that environmental conditions at both the Boca Ciega Bay and Beacon Key locations were adequate for adult bay scallops to survive and reproduce in these regions of the Tampa Bay system.

D. Water Quality Data

The degree to which scallop growth and reproductive output differed between Boca Ciega Bay and Beacon Key may be attributable to differences in water quality between the two sites. (Differences in scallop survival, on the other hand, are more closely aligned with post-spawning mortality than water quality.)

Temperature regimes at both locations appear well suited for southern populations of bay scallop. Maturation of oogonia takes place in July with water temperatures near 28°C, and maximum gonad condition and oocyte diameter occur in late September and early October when water temperature is near 30°C. These conditions may restrict bay scallops from more shallow, quiescent waters of Tampa bay, where midday temperatures during the summer may soar to above 35°C due to intense solar radiation.

The range of salinity during this study (22 to 31 ppt) should not pose any detrimental effect on adult bay scallops, which are the most euryhaline of the pectinid species. Bay scallops are seldom found in areas where salinities are below 20 ppt (Rhodes, 1991), although no definitive limits have been established. However, temperature and salinity often act synergistically, especially on larval and juvenile scallops (Mercaldo and Rhodes, 1982). The inability to remain closed for extended periods of time increases their vulnerability to low salinity stress (Tettlebach and Rhodes, 1981; Tettlebach et al., 1985), especially at higher temperatures (Mercaldo and Rhodes, 1982). Because of this, any major summer storm event could be potentially devastating for established or reintroduced bay scallop populations in Tampa Bay.

Dissolved oxygen, and its effects on bay scallop behavior and survival, was closely monitored during field and laboratory studies. While periodic episodes of oxygen depletion have been an occasional source of scallop mortality (Wolf, 1987; Ropes et al., 1979), this study showed scallops to be remarkably tolerant of moderate to prolonged exposures to DO concentrations less than 2 mg/L. Moreover, field measurements revealed no recurring hypoxic events at the two study sites. Respiration in bay scallops is independent of DO concentration to about 2 mg/L (Van Dam, 1954). The critical DO concentration, as well as adaptive strategies to reduced DO, may be related to animal size and temperature (Voyer, 1992). As a result, shallow restricted grassbeds within Tampa Bay that would normally offer ideal habitat for bay scallops under most environmental conditions, may become the most vulnerable habitat during periodic conditions of high temperatures and low dissolved oxygen.

Scallops are active suspension feeding bivalves which rely on suspended detrital material and phytoplankton as their food source (Bricelj and Shumway, 1991). Scallops are vulnerable to high suspended sediment concentrations because they regulate ingestion primarily by reducing clearance rates (Bricelj and Malouf, 1984). High suspended sediment loads have the effect of "diluting" the available food, and therefore may reduce scallop growth rates. Growth rates of juvenile bay scallops were unaffected, however, by natural sediment concentrations between 5 and 44 mg/L fed in combination with an algal diet (Korol, 1985). An overabundance in food concentration (phytoplankton) can cause a reduction in the absorption efficiency in scallops, leading to a reduction in growth. In summary, proper levels of food and suspended material are essential to provide scallops with the necessary energy for somatic and gonadal growth.

The potential for scallop growth and reproductive development in this study are derived in part from measurements of turbidity, chlorophyll *a*, and suspended solids. Significant differences ($p < 0.05$) in chlorophyll *a*, turbidity and volatile suspended solids were observed between Boca Ciega Bay and Beacon Key during September and October. These three parameters were positively correlated ($r > 0.90$) at both locations throughout the study. During July and August, these parameters were at levels considered optimum for efficient filtering and clearing rates, absorption efficiencies and growth. The higher levels of suspended solids at Beacon Key (coupled with the overall high phytoplankton levels) starting in September placed extra metabolic demands on those organisms, which still had to expend energy filtering this extra material without any nutritional benefit. The "cost" of this expenditure may be partly reflected in the reduced growth rates at Beacon Key.

While much of the higher particulate levels (especially chlorophyll *a*) at Beacon Key can be assigned to higher phytoplankton densities, a substantial portion came from benthic sources. Preferential resuspension of surficial sediments at Beacon Key could account for some of the differences in water quality. Higher levels at Beacon Key could be generated by either 1) the direction of prevailing winds and currents, or 2) finer grain sediments with higher organic content. Data from the Tampa Bay Physical Ocean Real Time System (PORTS) revealed that wind speed and direction could not account for a preferential resuspension of sediments at Beacon Key. Higher current speeds and/or finer sediments are offered as the probable cause of increased turbidity and suspended solids at Beacon Key, although additional data need to be analyzed to substantiate this theory. In any event, scallops at Beacon Key were not affected by an overabundant food supply or higher suspended solids to the degree where it affected their ability to initiate gametogenesis and eventually spawn.

E. Phytoplankton Species Composition

Phytoplankton species encountered in this study have been previously reported from Tampa Bay (review by Steidinger and Gardiner, 1982). The most common species included the chrysophytes *Rhizosolenia setigera* Brightwell, *Rhizosolenia calcar-avis* Schultze, *Campylosirus cymbelliformis* Grunow, and *Skelotonema costatum* (Greville). The cyanophyte *Chroococcus dispersa* was also occasionally dominant.

Phytoplankton concentrations were higher than levels reported as optimum for bay scallops, especially at Beacon Key, where phytoplankton densities remained near 1 x 10^7 throughout the study. Although far from conclusive, Barber and Blake (1981) suggested that Florida bay scallop populations may be food limited, based on annual primary productivity measurements. Under current conditions in Tampa Bay, this does not appear to be the case. Assuming that present phytoplankton assemblages are suitable prey, there are ample food resources available to Tampa Bay scallop populations. Ironically, scallops may be periodically at risk due to an <u>overabundance</u> of food during phytoplankton blooms, because, as mentioned earlier, they must expend energy processing this additional material without the nutritional benefit.

Skelotonema costatum accounted for the high phytoplankton abundance at Beacon Key from September through October. This species is one of the most common and abundant estuarine species, and is known to produce fall blooms in Tampa Bay (Steidinger and Gardiner, 1982). Although very little information is available on species preference from field studies, *Skelotonema* has been reported as a prey species for the bay scallop (Chipman and Hopkins, 1954).

Blooms of picoplanktonic algae *(Aureococcus anorexefferens)* have caused mass mortalities of the northern bay scallop in Long Island Sound and Rhode Island since 1985 (Bricelj et al., 1987; Pollack, 1988). The first-ever documented outbreak of red tide *(Ptychodiscus brevis)* in North Carolina caused a catastrophic decline in bay scallop abundance in 1987 and 1988 (Summerson and Petterson, 1990). Although Sarasota Bay experienced an intense red tide during the summer of 1992, no *P. brevis* was found at either Boca Ciega Bay or Beacon Key. A severe red tide in Tampa Bay would be devastating for resident scallop populations.

F. Growth and Survival of Bay Scallop Larvae and Juveniles in Tampa Bay Waters - Summary

A concurrent study was conducted by the Shellfish Biology Laboratory of the Department of Marine Sciences at the University of South Florida to demonstrate the feasibility of spawning bay scallops in Tampa Bay water and releasing juvenile scallops to areas of the bay where survival, growth and reproduction could be maximized. This section summarizes the results of that study as they relate to the water quality and habitat requirements of these other life stages of the southern bay scallop. Life stage specific environmental requirements which differ from those of the adult are incorporated into the overall requirements of the bay scallop for Tampa Bay.

Adult scallops were maintained in the laboratory at 24-30 ppt salinity and 28-30°C. Reproductively mature scallops were induced to spawn in early August of 1992 by lowering the water temperature by 1-2°C. Approximately 2 million fertilized eggs were collected and maintained at 25°C and 25 ppt salinity.

Settled scallop spat were placed in cages and suspended from docks at Bayboro Harbor, St. Petersburg. Eventually, these scallops were used to seed three seagrass meadows in Tampa Bay. These meadows were the mouth of Big Bayou, Cockroach Bay and Mullet Key Basin. The latter two were in the vicinity of the Beacon Key and Boca Ciega Bay sites, respectively, from the current study.

Growth was monitored from the day of settlement (August 16, 1992) through August 18, 1993. Faster growth was observed in the mesh bags suspended in Bayboro Harbor. The rate of growth of caged scallops remained constant until they reached 20 mm in size (March). Growth accelerated through June (mean size = 46.8 mm), then slowed through August 18, reaching a final size of 49.7 mm.

Mortality was highest (50%) during the larval stage. An additional 30 percent died after metamorphosis and settlement, resulting in a cumulative mortality from fertilized egg to juvenile of 65 percent. Forty percent more died before they reached 6-8 mm. Mortality during the winter was attributed to poor water clarity and low temperature (20-21°C). From February through June, the cumulative mortality was 27 percent, which equates to an overall cumulative mortality of 86 percent. This relative mortality was very similar to adult mortality from the present study (85%).

Environmental conditions monitored for larval and juvenile scallops were temperature and salinity. Based on this study, the optimal temperature for juvenile southern bay scallops is 25-30°C while salinities, which must remain above 20 ppt, are optimal between 24-30 ppt.

G. Comparisons to Historical Data

Historical water quality data from Tampa Bay has recently been reviewed and synthesized for the Tampa Bay National Estuary Program (King Engineering Associates, 1992). These data were used to compare water quality results from the present study with site specific trends over the last fifteen years. Hillsborough County Environmental Protection Commission (HCEPC) monitoring stations "25" and "84" were chosen for comparisons because of their proximity to the Boca Ciega Bay and Beacon Key study sites, respectively.

Historical data were summarized by monthly (climatological) average (Appendix Table B) and yearly average (Appendix Table C) for the period 1974-1990. Understanding the historical climate of water quality serves to: 1) establish a connection between current results and long term water quality trends and 2) refine specific living resources based water quality criteria which can then be used to make wiser target resource conservation or management decisions.

General water quality in the bay, with respect to chlorophyll *a*, turbidity and nutrients, has been steadily improving since 1980 (King Engineering Associates, 1992). This trend is evident at station 84 (Beacon Key), where chlorophyll and turbidity levels are roughly half their 1980-1983 values. Average annual turbidity has ranged from 7-11 NTU's from 1984-1990; chlorophyll *a* ranged from 7-8 µg/L over the same period. Turbidity levels of 5-6 NTU's and chlorophyll *a* levels of 10-13 µg/L were found in this study when phytoplankton blooms were not present. Overall, water quality at Beacon Key during this study (1992) was fairly representative of recent trends at this location during the last nine years.

Station 25 (Boca Ciega Bay) never showed the historically poor water quality trends that were evident in the upper reaches of Tampa Bay during the period 1974-1980. Except for 1979, yearly averages of both turbidity and chlorophyll *a* fell between 5 and 9 NTU's and µg/L, respectively. Turbidity and chlorophyll *a* levels from Boca Ciega Bay during this study closely followed recent historical trends.

No unusual deviations from historical averages (monthly and yearly) were noted in temperature, salinity or dissolved oxygen. However, continuous measurements of dissolved oxygen in the present study revealed strong diurnal patterns that are not apparent from the EPC historical data base, where values were obtained from single midday measurements. In summary, overall water quality during this study (1992) was fairly typical of recent trends from these Tampa Bay segments during the last nine years.

VII. RESOURCE BASED WATER QUALITY TARGETS

The stated purpose of this technical project was to gather species-relevant environmental data in addition to synthesizing current and historical information on the bay scallop, *Argopecten irradians concentricus*. This project focused on defining the limits and ranges of environmental conditions including water quality that are necessary for adult bay scallops to survive, grow and propagate in Tampa Bay. The targets listed below define the range of each pertinent parameter. This information can then be used by Tampa Bay resource managers to help set water quality management guidelines for the bay.

Certain water quality and habitat parameters measured for the purpose of defining limits and ranges for the bay scallop are of themselves dependent upon more basic water quality criteria that were not investigated in this study (e.g., color and nutrients). It is hoped that these relationships and connections are being explored and defined by other Tampa Bay environmental researchers.

While management recommendations are not included in this report, one important consideration needs to be stressed. Since bay scallops are a harvestable resource, the attainment of environmental and habitat requirements alone cannot guarantee the establishment and maintenance of harvestable levels within Tampa Bay. Eventually, management practices will need to include harvest criteria as well.

WATER QUALITY PARAMETER	TARGET
Bottom Temperature	25-30°C ideal (for all stages), not to exceed 32°C for prolonged periods
Bottom Salinity	Greater than 20 ppt (24-30 ppt optimal)
Bottom Dissolved Oxygen	Not less than 2 mg/L, for less than 2 hours
Turbidity	5-10 NTU's
Total Suspended Solids	Less than 40 mg/L
TSS/VSS Ratio	Greater than 1.282 (inorganic % of seston <78%)
Chlorophyll *a*	5-10 µg/L (= mg/m^3)
Phytoplankton	Density: less than 5×10^6 cells/L; Species: blooms harmful; *Ptychodiscus* and *Chroococcus* fatal
Seagrass	*Thalassia/Syringodium* mix ideal. Density: >75 $shoots/m^2$ *(Thalassia)* beds continuous (not patchy)

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APPENDIX A

Phytoplankton Composite List

Appendix Table Al. **Phytoplankton composite species list with counts in cells** $(x10^3)$ **per liter,** July 16 to **September** 1, 1992.

Species	BCB 16-Jul	BK 16-Jul	BCB 03-Aug	BK 03-Aug	BCB 19-Aug	BK 19-Aug	BCB 01-Sep	BK 01-Sep
Achnanthes spp.	0	0	104.0	0	0	0	0	0
Amphora spp.	48.0	0	0	0	24.0	0	120.0	0
Anabaena spp. (trichome)	0	0	0	0	6.0	0	0	0
Arthrospira jenneri	0	0	10.4	0	0	0	0	0
Asterionella japonica	0	0	0	0	0	0	300.0	0
Bacillaria paradoxa	0	0	0	0	0	0	0	0
Campylosirus cymbelliformis	12.0	0	0	0	0	0	360.0	340.0
Ceratium hircus	0	0	10.4	0	0	0	0	0
Ceratium trichoceros	0	0	0	0	0	0	0	0
Chaetocerus compressa	0	0	166.4	0	0	0	0	0
Chaetocerus decipiens	48.0	0	10.4	515.2	0	0	0	0
Chlamydomonas sp.	0	0	0	0	0	20.0	540.0	170.0
Chlymentomonas sp.	0	0	0	0	0	500.0	0	544.0
Chroococcus dispersa	0	0	104.0	0	150.0	1760.0	1860.0	646.0
Chroococcus dispersa var. *minor*	0	0	124.8	0	60.0	2940.0	960.0	476.0
Chroococcus varius	0	0	0	0	0	160.0	0	0
Coscinodiscus eccentricus	0	0	0	0	0	0	0	0
Cryptomonas caroliniana	0	0	0	0	0	1480.0	0	0
Cryptomonas ovata	0	0	0	0	0	0	1140.0	442.0
Cryptomonas sp. A	0	0	20.8	0	48.0	0	0	0
Cyclotella sp.	0	0	0	0	0	60.0	180.0	0
Dinophysus caudata	0	0	0	0	0	0	0	0
Diploneis sp.	0	0	10.4	0	0	0	0	0
Entomoneis alata	0	0	0	0	6.0	0	0	34.0
Euglena sp.	0	0	0	0	0	20.0	0	0
Eunotia sp.	0	0	0	0	12.0	0	0	0
Gleocapsa punctata	0	0	426.4	0	0	0	0	0
Gleothece (Anacystis) rupestris	0	0	0	0	0	360.0	0	0
Gonialux palustre	0	0	20.8	0	24.0	0	0	0
Grammatophora marina	0	0	0	0	0	0	0	0

Species	BCB 16-Jul	BK 16-Jul	BCB 03-Aug	BK 03-Aug	BCB 19-Aug	BK 19-Aug	BCB 01-Sep	BK 01-Sep
Gymnodinium simplex	0	0	0	0	6.0	20.0	0	34.0
Gymnodinium splendens	0	0	20.8	0	0	0	0	0
Gyrosigma **(Pleurosigma) sp. A**	0	0	10.4	0	0	0	0	0
Gyrosigma **(Pleurosigma) sp. B**	0	0	0	18.4	0	0	0	0
Hemiaulus sinensis	0	0	20.8	0	0	0	0	0
Merismopedia glauca	0	0	0	0	0	0	0	0
Navicula lanceolata	0	0	0	0	0	0	60.0	0
Navicula **sp.**	0	0	0	0	0	0	0	34.0
Navicula spicula	0	0	0	0	12.0	0	0	0
Nitzschia closterium	12.0	0	187.2	9.2	126.0	120.0	540.0	374.0
Nitzschia delicatissima	0	0	322.4	0	0	0	0	0
Nitzschia fruticosa	0	0	0	0	0	0	660.0	272.0
Nitzschia longissima	0	0	0	0	18.0	0	0	34.0
Nitzschia palea	12.0	0	0	0	54.0	0	0	34.0
Nitzschia pungens **var.** *atlantica*	0	0	384.8	220.8	0	0	0	0
Nitzschia sigma	12.0	0	0	9.2	0	0	0	0
Odentella chinensis	0	0	0	0	12.0	0	0	0
Oscillatoria rubescens **(trichome)**	0	0	0	0	6.0	0	0	0
Paralia (Melosira) sulcata	312.0	0	280.8	0	0	0	0	0
Peridinium cerasus	12.0	0	0	0	0	0	0	0
Plagiotropis lepidoptera **var.** *proboscidea*	72.0	48.0	52.0	73.6	0	0	0	0
Prorocentrum micans	0	0	0	0	0	0	0	0
Protoperidinium oblongum	0	0	10.4	0	0	0	0	0
Rhizoclonium **sp.**	0	0	0	0	0	160.0	0	0
Rhizosolenia calcar-avis	336.0	24.0	946.4	717.6	2112.0	1580.0	0	0
Rhizosolenia setigera	4956.0	11736.0	197.6	1527.2	0	100.0	1080.0	782.0
Rhizosolenia stolterfothii	108.0	0	395.2	220.8	324.0	540.0	1680.0	2414.0
Schroederella dellicatula	0	0	322.4	846.4	0	0	720.0	442.0
Skeletonema costatum	36.0	192.0	1029.6	404.8	0	180.0	19800.0	9928.0
Synedra ulna	24.0	0	0	0	0	0	0	0
Tropideneis lepidoptera	0	0	10.4	36.8	0	0	0	0

Appendix Table A2. **Phytoplankton composite species list with counts in cells ($x10^3$) per liter, September 15 to October 27, 1992.**

Species	BCB 15-Sep	BK 15-Sep	BCB 29-Sep	BK 29-Sep	BCB 13-Oct	BK 13-Oct	BCB 27-Oct	BK 27-Oct
Achnanthes **spp.**	0	0	0	0	0	220.0	0	0
Amphora **spp.**	0	18.8	16.8	0	0	44.0	52.8	0
Anabaena **spp. (trichome)**	0	0	50.4	0	0	1452.0	26.4	0
Arthrospira jenneri	0	0	0	0	0	0	8.8	0
Asterionella japonica	0	470.0	193.2	0	0	88.0	0	416.0
Bacillaria paradoxa	0	0	0	97.2	0	2156.0	0	0
Campylosirus cymbelliformis	3486.8	1015.2	2083.2	1630.8	632.4	88.0	0	0
Ceratium hircus	0	37.6	0	108.0	0	0	0	0
Ceratium trichoceros	9.2	0	0	10.8	0	0	0	0
Chaetocerus compressa	92.0	0	100.8	0	0	2420.0	0	0
Chaetocerus decipiens	0	0	0	0	0	0	0	0
Chlamydomonas **sp.**	0	0	0	0	0	44.0	0	0
Chlymentomonas **sp.**	0	0	8.4	21.6	0	0	0	0
Chroococcus dispersa	18.4	0	0	0	0	5456.0	8.8	0
Chroococcus dispersa **var.** *minor*	36.8	0	109.2	75.6	0	0	35.2	0
Chroococcus varius	0	0	0	0	0	0	0	0
Coscinodiscus eccentricus	0	0	0	0	0	44.0	8.8	0
Cryptomonas caroliniana	0	0	0	0	0	0	0	0
Cryptomonas ovata	0	0	0	10.8	0	0	0	0
Cryptomonas **sp. A**	0	0	0	0	0	660.0	0	0
Cyclotella **sp.**	0	0	0	0	12.4	572.0	0	0
Dinophysus caudata	0	18.8	0	0	0	0	0	0
Diploneis **sp.**	0	0	8.4	0	0	0	0	0
Entomoneis alata	0	0	0	0	0	0	8.8	26.0
Euglena **sp.**	0	0	0	0	0	0	0	0
Eunotia **sp.**	0	0	0	0	0	0	0	0
Gleocapsa punctata	0	0	0	0	0	0	0	0
Gleothece (Anacystis) rupestris	0	0	0	0	0	0	0	0
Gonialux palustre	9.2	0	0	0	0	88.0	8.8	0
Grammatophora marina	0	0	8.4	0	0	2376.0	0	0

Species	BCB 15-Sep	BK 15-Sep	BCB 29-Sep	BK 29-Sep	BCB 13-Oct	BK 13-Oct	BCB 27-Oct	BK 27-Oct
Gymnodinium simplex	0	0	0	0	0	0	0	0
Gymnodinium splendens	0	0	0	0	0	0	0	0
Gyrosigma **(Pleurosigma) sp. A**	0	0	0	32.4	0	132.0	0	0
Gyrosigma **(Pleurosigma) sp. B**	0	0	0	32.4	12.4	44.0	17.6	52.0
Hemiaulus sinensis	0	0	0	0	0	0	0	0
Merismopedia glauca	0	0	0	0	0	0	132.0	0
Navicula lanceolata	0	0	8.4	0	24.8	88.0	26.4	0
Navicula **sp.**	27.6	56.4	8.4	54.0	24.8	0	17.6	26.0
Navicula spicula	0	0	0	0	0	0	0	0
Nitzschia closterium	27.6	0	42.0	21.6	24.8	924.0	325.6	208.0
Nitzschia delicatissima	0	0	0	0	0	0	0	0
Nitzschia fruticosa	0	0	0	0	0	88.0	0	0
Nitzschia longissima	18.4	0	0	43.2	12.4	660.0	114.4	26.0
Nitzschia palea	9.2	18.8	8.4	32.4	12.4	0	26.4	26.0
Nitzschia pungens **var.** *atlantica*	0	0	0	32.4	0	0	0	0
Nitzschia sigma	0	0	8.4	10.8	0	440	0	0
Odentella chinensis	9.2	0	0	0	0	880	0	0
Oscillatoria rubescens **(trichome)**	0	0	25.2	10.8	0	0	0	0
Paralia (Melosira) sulcata	9.2	0	25.2	43.2	384.4	0	290.4	52.0
Peridinium cerasus	0	37.6	84.0	64.8	12.4	0	26.4	0
Plagiotropis lepidoptera **var.** *proboscidea*	0	0	16.8	0	12.4	220.0	0	156.0
Prorocentrum micans	0	0	8.4	0	0	44.0	0	0
Protoperidinium oblongum	0	0	0	0	0	0	0	0
Rhizoclonium **sp.**	0	0	0	0	0	0	0	0
Rhizosolenia calcar-avis	18.4	0	310.8	1404.0	4178.8	220.0	2464.0	5148.0
Rhizosolenia setigera	101.2	56.4	646.8	453.6	0	2068.0	8.8	0
Rhizosolenia stolterfothii	46.0	338.4	201.6	0	124.0	0	176.0	364.0
Schroederella dellicatula	671.6	1673.2	226.8	237.6	731.6	88.0	519.2	0
Skeletonema costatum	0	5621.2	0	939.6	0	1584.0	96.8	6500.0
Synedra ulna	0	0	0	0	0	0	0	0
Tropideneis lepidoptera	9.2	37.6	0	32.4	0	0	0	0

APPENDIX B

Hillsborough County EPC
Water Quality Summary
(Monthly Average)

Appendix Table B. Hillsborough County EPC Water Quality Summary. Monthly (Climatological) Average for the years 1974-1990. (Station 25 = Boca Ciega Bay; Station 84 = Beacon Key).

TEMPERATURE (BOTTOM)

Station	Month	Temperature (°C)
25	1	15
25	2	17
25	3	21
25	4	23
25	5	26
25	6	29
25	7	30
25	8	30
25	9	29
25	10	26
25	11	22
25	12	19
84	1	17
84	2	18
84	3	20
84	4	23
84	5	26
84	6	29
84	7	29
84	8	29
84	9	28
84	10	25
84	11	22
84	12	19

SALINITY (BOTTOM)

Station	Month	Salinity (ppt)
25	1	33
25	2	32
25	3	33
25	4	33
25	5	33
25	6	35
25	7	34
25	8	32
25	9	30
25	10	31
25	11	33
25	12	32

SALINITY (BOTTOM) Continued.

Station	Month	Salinity (ppt)
84	1	27
84	2	26
84	3	27
84	4	27
84	5	28
84	6	30
84	7	30
84	8	27
84	9	24
84	10	26
84	11	28
84	12	28

DISSOLVED OXYGEN (BOTTOM)

Station	Month	0.0. (mg/l)
25	1	8
25	2	8
25	3	8
25	4	8
25	5	7
25	6	7
25	7	7
25	8	7
25	9	6
25	10	7
25	11	8
25	12	8
84	1	8
84	2	7
84	3	8
84	4	7
84	5	6
84	6	5
84	7	4
84	8	5
84	9	5
84	10	5
84	11	7
84	12	8

TURBIDITY

Station	Month	NTU's
25	1	3
25	2	3
25	3	5
25	4	6
25	5	7
25	6	8
25	7	8
25	8	9
25	9	11
25	10	11
25	11	8
25	12	4
84	1	6
84	2	7
84	3	9
84	4	10
84	5	10
84	6	13
84	7	17
84	8	17
84	9	16
84	10	13
84	11	12
84	12	9

CHLOROPHYLL A

Station	Month	Chl *a* (µg/l)
25	1	3
25	2	3
25	3	5
25	4	6
25	5	7
25	6	8
25	7	8
25	8	9
25	9	11
25	10	11
25	11	8
25	12	4

CHLOROPHYLL A (continued)

Station	Month	Chl a (µq/l)
84	1	6
84	2	7
84	3	9
84	4	10
84	5	10
84	6	13
84	7	17
84	8	17
84	9	16
84	10	13
84	11	12
84	12	9

TOTAL SUSPENDED SOLIDS

Station	Month	TSS (mq/l)
25	1	38
25	2	45
25	3	38
25	4	54
25	5	40
25	6	42
25	7	37
25	8	50
25	9	56
25	10	65
25	11	53
25	12	58
84	1	35
84	2	32
84	3	38
84	4	40
84	5	35
84	6	41
84	7	43
84	8	48
84	9	39
84	10	40
84	11	45
84	12	43

APPENDIX C

Hillsborough County EPC
Water Quality Summary
(Yearly Average)

Appendix Table C. Hillsborough County EPC Water Quality Summary. Yearly Average for the years 1974-1990. (Station 25 = Boca Ciega Bay; Station 84 = Beacon Key).

DISSOLVED OXYGEN

Station	Year	D.O. (mg/l)
25	75	8
25	76	8
25	77	8
25	78	8
25	79	8
25	80	7
25	81	8
25	82	8
25	83	7
25	84	7
25	85	7
25	86	7
25	87	7
25	88	7
25	89	7
25	90	7
84	75	6
84	76	7
84	77	7
84	78	7
84	79	7
84	80	6
84	81	6
84	82	7
84	83	6
84	84	6
84	85	6
84	86	6
84	87	6
84	88	6
84	89	5
84	90	6

TURBIDITY

Station	Year	Average of NTU's
25	74	5
25	75	7
25	76	8
25	77	8
25	78	8
25	79	11
25	80	8
25	81	9
25	82	7
25	83	8
25	84	6
25	85	6
25	86	6
25	87	5
25	88	5
25	89	7
25	90	6
84	74	7
84	75	11
84	76	6
84	77	15
84	78	15
84	79	15
84	80	15
84	81	16
84	82	23
84	83	21
84	84	9
84	85	11
84	86	8
84	87	7
84	88	7
84	89	8
84	90	8

CHLOROPHYLL A

Station	Year	Chl *a* (uq/l)
25	74	5
25	75	7
25	76	8
25	77	8
25	78	8
25	79	11
25	80	8
25	81	9
25	82	7
25	83	8
25	84	6
25	85	6
25	86	6
25	87	5
25	88	5
25	89	7
25	90	6
84	74	7
84	75	11
84	76	6
84	77	15
84	78	15
84	79	15
84	80	15
84	81	16
84	82	23
84	83	21
84	84	9
84	85	11
84	86	8
84	87	7
84	88	7
84	89	8
84	90	8

APPENDIX D

Photomicrographs of Scallop Gonadal Development

Photomicrographs are on file with the Tampa Bay National Estuary Program.