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CHAPTER 7

A CENTURY OF ENVIRONMENTAL VARIABILITY IN OYSTER BAY USING OSTRACODE ECOLOGICAL AND ISOTOPIC DATA AS PALEOENVIRONMENTAL TOOLS

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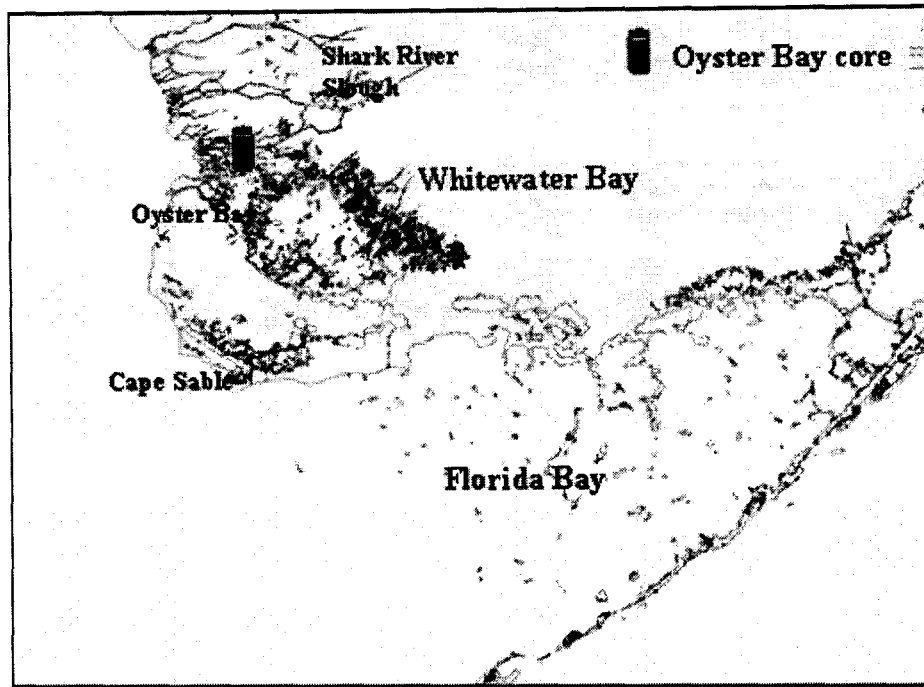
ABSTRACT

Stable isotopic analysis ($\delta^{18}\text{O}$ and $\delta^{13}\text{C}$) and characterization of the ostracode community structure were carried out from a high-resolution sediment-core recovered from Oyster Bay in the west of the Everglades National Park. Because of its location, between the Shark River Slough (SRS) and the Gulf of Mexico, the Oyster Bay core locality experiences extreme salinity fluctuations due to the interaction of freshwater run-off, precipitation, and marine water inputs. Ostracode population dynamics and isotopic variability over the 20th century are linked to natural and anthropogenic forces that affect the South Florida coastal ecosystem on interannual to decadal time scales. Three ostracode assemblages can be recognized within the 100-year sediment-core record: the first extending from the turn of the century to about 1950; the second, from the early 1950s to the late 1970s; and the third to core recovery in 1995.

An abrupt decrease in ostracode abundance, species diversity, and shifts in species dominance occur in the mid-1980s and reflect episodes of environmental stress. Markedly enriched $\delta^{18}\text{O}$ values from the ostracode *Peratocytheridea setipunctata* and the benthic foraminifer *Ammonia parkinsoniana typica* at this time are concurrent with a major regional drought in South Florida, as well as with documented algal blooms and major die-off of sea grasses in Florida Bay. In addition, the timing of these events is contemporaneous to the onset of the South Florida Water Management District (SFWMD) "Rainfall Plan" and the closing of the Buttonwood canal. Higher ostracode abundance and species richness occurs between the late-1950s and late-1970s. Stable isotopic data and ostracode assemblage characteristics suggest a period of relative environmental stability and possibly improved water circulation in Whitewater Bay and Oyster Bay. Fluctuations in community structure during this time are more systematic and appear to be temporally correlated to rainfall variability patterns. Water management policies at this time are also discernable from the microfaunal and isotopic record, particularly the Congressionally mandated Monthly Minimum Allocation Plan of water supply to SRS. Before 1950, hurricane events and their effects are the major cause for immediate modifications within the ostracode community, though our data show that ostracode populations are capable of rapid recovery. Over the complete record of the last century, the effects of water management practices can be assessed from information embedded in the ostracode record. Nevertheless, the effects of natural climatic variability in Oyster Bay appear to outweigh the impact of anthropogenic forces.

INTRODUCTION

Over the past decade, scientists have used proxy records of environmental conditions in Florida Bay and its environs to examine the paleoecological history of this region (Brewster-Wingard *et al.*, 2000; Halley and Roulier, 1999; Swart *et al.*, 1996 and 1999; Nelsen *et al.*, in press). Benthic microfaunal communities preserved in undisturbed sediment records have shown great promise for the reconstruction of paleoenvironmental fluctuations (Alvarez Zarikian *et al.*, 1999a, 1999b; Brewster-Wingard and Ishman, 1999; Cronin *et al.*, 2000; Dwyer and Cronin, 2000; Hood *et al.*, 1998; Ishman, 2000). Ostracodes have proven particularly valuable for such reconstructions because they are abundant in the marine and brackish water environments of South Florida (Puri and Hulings, 1957; Puri, 1960; Benda and Puri, 1962; and Keyser, 1975, 1977). In addition, they have specific ecological requirements and well defined salinity tolerances (Neal, 1988). Moreover, ostracodes rapidly secrete a calcitic bivalve shell (Turpen and Angell, 1971), which with genetic influences, records the isotopic composition of the aquatic environment, thus providing a geochemical snapshot of the chemical conditions of the water in which they lived.



Text-figure 1.- Location map of Oyster and Florida Bays. Sediment core location in Oyster Bay represented by black cylinder.

The lower Everglades National Park is comprised of a north-south ecosystem succession ranging from large flat wetlands in the north to shallow bays, lakes and channels in the south, which are mostly filled with mangrove swamp deposits and bordered by mangrove forests. The environmental transition into the coastal zone is gradual and it extends into the shallow mudbanks and semi-restricted basins of Florida Bay. To the west and north of Cape Sable, the 1-2 meter-deep Whitewater Bay extends to the northwest through the mangrove forest and Oyster Bay until opening up to the Gulf of Mexico. Direct freshwater runoff from the Everglades into Florida Bay and adjacent bays is primarily through the natural drainage basins of Shark River and Taylor Sloughs, and artificially from the C-111 Canal. To the west, the park is heavily influenced by the marine waters of the Gulf. Freshwater input from canals and watersheds that flow into Florida Bay is strongly influenced by rainfall and freshwater management policies of the South Florida Water Management District (Nelsen *et al.*, in press; Rudnick *et al.*, 1999).

Numerous hydrological modifications have impacted the Everglades natural ecosystem during the 20th century. Among these are the fragmentation of the wetlands due to construction of a massive network of canals and levees for water supply and flood control, and the loss of extensive wetland area to agriculture and residential development (Davis and Ogden, 1994). Prior to human impact, natural forces and seasonal climatic variability were the main factors controlling hydrological conditions in the area. Increased salinity and nutrient concentration in Florida Bay (McIvor *et al.*, 1994), as well as algal blooms and major seagrass die-offs (Fourqurean and Robblee, 1999; Robblee *et al.*, 1991), have raised growing concerns as to whether the origin of these changes are anthropogenic or are part of a natural cycle of climatic variability.

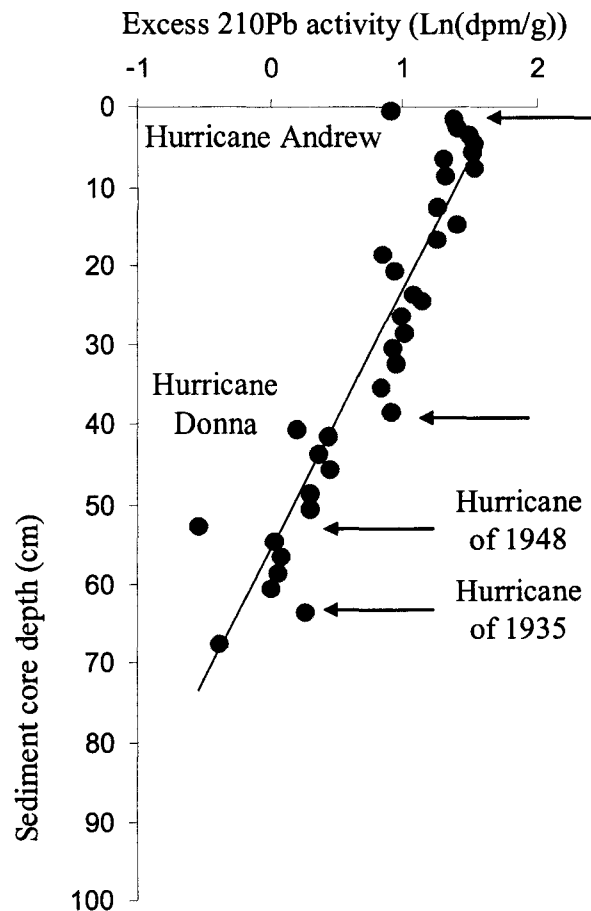
Micropaleontological and stable isotopic data obtained from a high deposition rate sediment-core collected in Oyster Bay are presented here. These data have allowed interpretation of interannual to decadal changes in hydrological conditions from this area within the Everglades National Park. Because of its location, adjacent to Shark River and the Gulf of Mexico, the Oyster Bay core locality experiences extreme salinity fluctuations (4 to >40 parts of salinity, Boyer *et al.*, 1997) due to the interaction of freshwater runoff, precipitation and marine water inputs. Because of the wide range of environmental conditions, this site

is ideally located to examine the response and sensitivity of ostracode populations and their isotopic composition to environmental change over the last century.

CORE SELECTION AND GEOCHRONOLOGY

An undisturbed sediment record is a pre-requisite for the meaningful interpretation and reconstruction of paleoenvironmental changes. The Oyster Bay core (Text-fig.1) used in this study is one of many collected in Florida and adjacent bays during the last four years. It was recovered from seagrass-free soft bottom sediments in shallow water (1 m). This high sedimentation rate core has been the focus of an interdisciplinary study to reconstruct Oyster Bay's paleoenvironmental record. Analyses that have been completed include microfaunal and pollen assemblage, stable isotope, organic and inorganic carbon, mineralogy and heavy metals (Nelsen *et al.* in press).

The location of the sediment core was carefully targeted from review of sequential aerial photographs (1927-present) and published data on the dynamics of banks and deltas in Florida Bay (Wanless and Tagett, 1989). Aerial photographs helped identify sites that had been free of macro vegetation since the time of the earliest aerial photograph. Subsequent reconnaissance coring sought to verify that the site was an area of active sediment accumulation and that it had well-preserved stratification (minimal bioturbation activity) (Nelsen *et al.*, in press).



Text-figure 2.- Excess ^{210}Pb profile used to establish the geochronology for the Oyster Bay core (from Nelsen *et al.*, in press)

The 1.5-m long Oyster Bay core was examined for stratification/disruption utilizing X-radiography to assure that sediment geochronology would yield interpretable sequences. Stratification in the sediment core

was clear, with laminations consisting of alternations of mangrove organics, carbonate silt, and fine quartz. The core was age-dated using the ^{210}Pb -dating technique (Nelsen *et al.*, in press), described, and photographed for evaluation of sediment type and structures. The sediment accumulation rates derived from the profile of excess ^{210}Pb were approximately 1.1cm/yr (0.6g/cm²/yr). The geochronology for the Oyster Bay core was extended back to the turn of the century by extrapolating the activity of excess ^{210}Pb downcore. In addition to providing a time-line and accumulation rate information, fine-structural features were observed in the excess ^{210}Pb profile including sediment erosion/deposition bands that are tied by year to hurricane events. These discontinuities appear as lower levels of excess ^{210}Pb than would be expected from the overall trend. These lower levels are most likely a result of the combined effects of losing sediment from the core site during a storm and input of sediments with lower levels of excess ^{210}Pb , i.e. older sediments or organic-rich debris, from upland or other sources (Nelsen *et al.*, in press). In the Oyster Bay core site, sudden shifts in the ^{210}Pb activity correspond (within ± 3 years) to the years of 1960, 1948, and 1935 (Text-fig. 2) and are likely the result of sediment movement due to Hurricane Donna, the hurricane of 1948, and the Great Labor Day Hurricane in 1935, respectively.

Given the established age model, the Oyster Bay core was sub-sampled at 1-cm intervals for geochemical (organic carbon, heavy metals, stable isotopes), micropaleontological (ostracodes and benthic foraminifers) and palynological characterization. These data were complemented by an analysis of historical rainfall, gauged freshwater flow, and limited near shore salinity data (see Nelsen *et al.*, in press).

It is important to note that geochronology-based ages have associated error estimates that increase downcore. As a result, ^{210}Pb -derived core ages in the 1940s and 1920s, for example, have a range of ± 3 and ± 4 years at the core location in Oyster Bay. For more recent years, between 1980 and 1995, sediment geochronology varies by only ± 1 year (Nelsen *et al.*, in press).

ACKNOWLEDGEMENTS

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METHODS

MICROFAUNAL ANALYSIS

Core sediment intervals were sub-sampled, wet-sieved using a 63 μm mesh, and the coarse fraction retained for microfaunal characterization. High organic content in the Oyster Bay core required the use of ashing and 30% hydrogen peroxide treatments. Sub-sample weights were used to determine total population abundances expressed as tests or valves per gram dry sediment weight. A minimum of three hundred specimens of both ostracodes and foraminifers were counted for each sample unless limited by sample size.

Temporal fluctuations in microfaunal community structure were evaluated using relative and absolute abundances, and the Shannon-Weiner diversity index (SWDI). The SWDI is defined as: $H = -\sum_{i=1}^N p(i) \ln p(i)$, where H is the measure of diversity, N is the number of species counted and $p(i)$ is the proportion of the total number of individuals which belong to the i^{th} species (MacArthur, 1983). This index incorporates a measure of species evenness as well as number (communities with many species with equal-size populations have the highest index) (Patrick, 1983), making it sensitive to the presence of rare species.

STABLE ISOTOPE ANALYSIS

Stable isotopic analyses ($\delta^{18}\text{O}$ and $\delta^{13}\text{C}$) were carried out on valves of the ostracode *Peratocytheridea setipunctata*. This species was chosen for isotopic analysis due to its ubiquitous occurrence throughout the Oyster Bay core as well as its high abundance in surface sediment samples collected from Oyster and Whitewater bays and Florida Bay. Well-preserved adult valves of *P. setipunctata* were isolated from the $>63\mu\text{m}$ sediment fraction prior to the ashing/ H_2O_2 treatments. Specimens were cleaned with a small paintbrush in a distilled water bath and then in an ethanol solution to remove adhering debris. Between 6 to 8 valves of *P. setipunctata* were then immersed in methanol-filled "copper boats" and crushed to a powder. The carbonate samples were processed by an automated device attached to a Finnigan-MAT 251 mass spectrometer. The external precision (0.02‰ for $\delta^{13}\text{C}$ and 0.08‰ for $\delta^{18}\text{O}$) was calculated from replicate analyses of the RSMAS Stable Isotope Laboratory calcite standard. All isotopic data are reported in per mil (‰) units relative to the Pee Dee Belemnite (PDB) standard and are corrected for the usual isobaric interferences. The stable isotopic composition of the sediment's organic C fraction was analyzed as well (Nelsen *et al.*, in press).

RAINFALL AND FRESH WATER FLOW DATA

Continuous monthly freshwater flow data for Shark River Slough extending from 1939 to the present were obtained from the United States Geological Survey (<http://fl.water.usgs.gov/>). Rainfall data were obtained from NOAA's National Climate Data Center. Continuous monthly data from the Everglades, Flamingo, Homestead and Tavernier stations were obtained, extending from present back to 1926, 1951, 1911, and 1936, respectively (Nelsen *et al.*, in press).

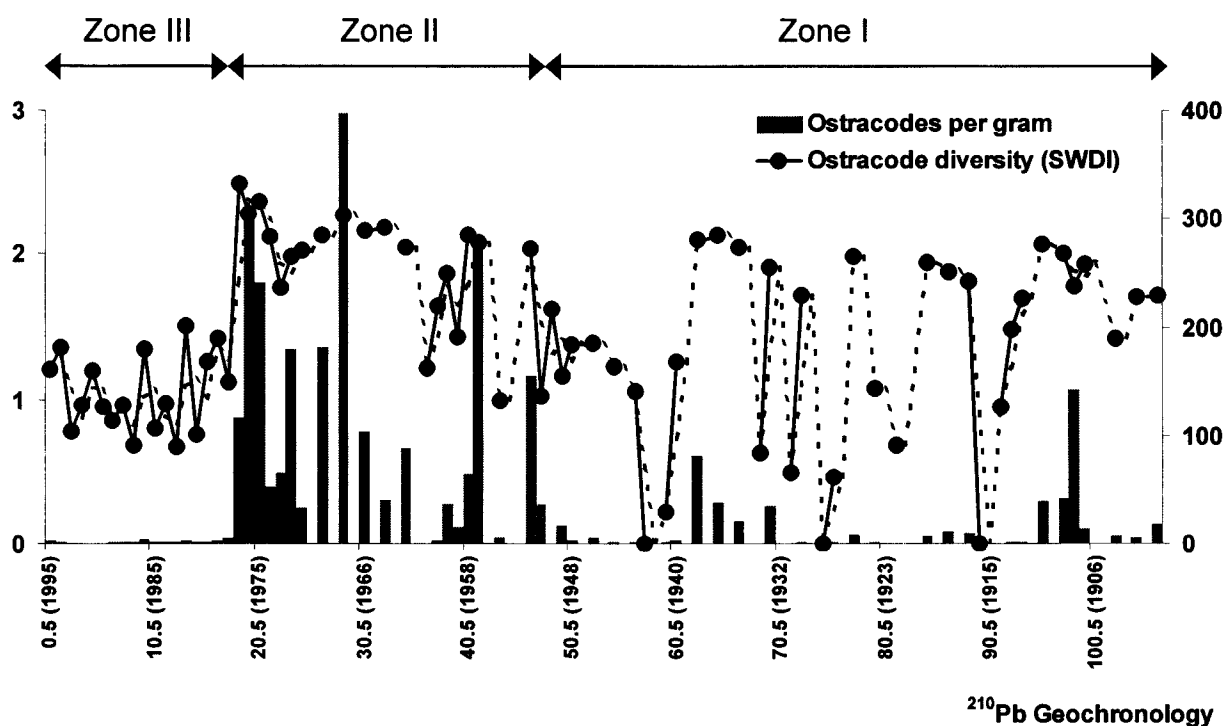
RESULTS

The three major sediment components in the Oyster Bay core are carbonates, alumino-silicates and organic matter. The average CaCO_3 content is $75 \pm 5\%$ and is comprised mostly of benthic foraminifers, ostracodes, small mollusks and calcareous fragments. The organic C content averages $7.1 \pm 1.3\%$, while the alumino-silicate contribution is minor, averaging only $1.6 \pm 0.3\%$ (Nelsen *et al.*, in press).

OSTRACODE ASSEMBLAGE

The Oyster Bay core contained 43 ostracode species. The number of species in any one sample ranged from 2 to 27, with an average of 11 species per 1-cm sample. Ostracode diversity, total abundance and species evenness show large temporal fluctuations (Text-fig. 3). Significant variability in species dominance and temporal loss of numerous species towards the present time also occurred. In addition, microfaunal preservation is lower towards the top of the core.

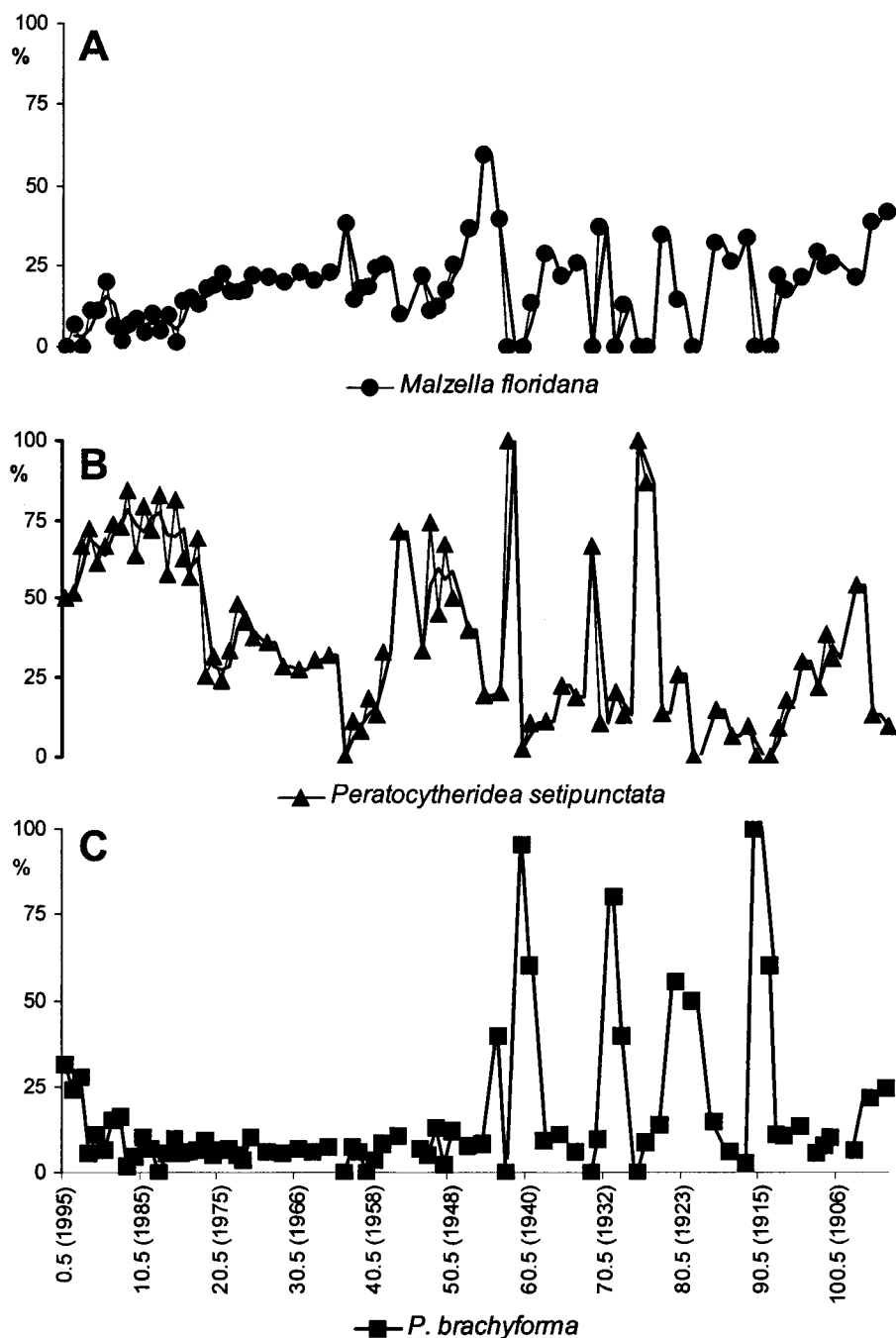
The Shannon-Weiner diversity index (SWDI), used here to expressed ostracode diversity, is sensitive to the presence and absence of minor species, such that larger positive values reflect greater diversity while lower numbers indicate a community dominated by fewer species. The SWDI ranged from 0.22 at a depth of 18.5cm (~1977) to 2.51 at a depth of 59.5cm (~1941). Ostracode abundance in the sediment core ranged from 0 to 397 valves per gram. Highest ostracode abundance and diversity occurred in sediments deposited in the mid-1970s, and in the late-1960s and 1950s. In contrast, the bottom half of the core, recording deposition between the turn of the century and the late-1940s, is characterized by a fairly diverse and stable community and a relatively low ostracode abundance (Text-fig. 3). The lowest abundances were found in sample intervals at 90, 74 and 57 centimeters. These samples contained less than 10 ostracode valves each, mainly of *Perissocytheridea brachyforma*, and represent the years of 1915 ± 4 , 1929 ± 4 and 1941 ± 3 , according to the extended ^{210}Pb -derived geochronology. The timing of two of these events temporally correlates with hurricanes that occurred over areas of Florida Bay: the Hurricane of 1929, and the Great Labor Day Hurricane of 1935.



Text-figure 3.- Ostracode diversity (Shannon-Weiner diversity index; left axis) and abundance (valves/g; right axis) in the Oyster Bay core. Geochronology based on ^{210}Pb and ^{137}Cs dating techniques (cm (year)).

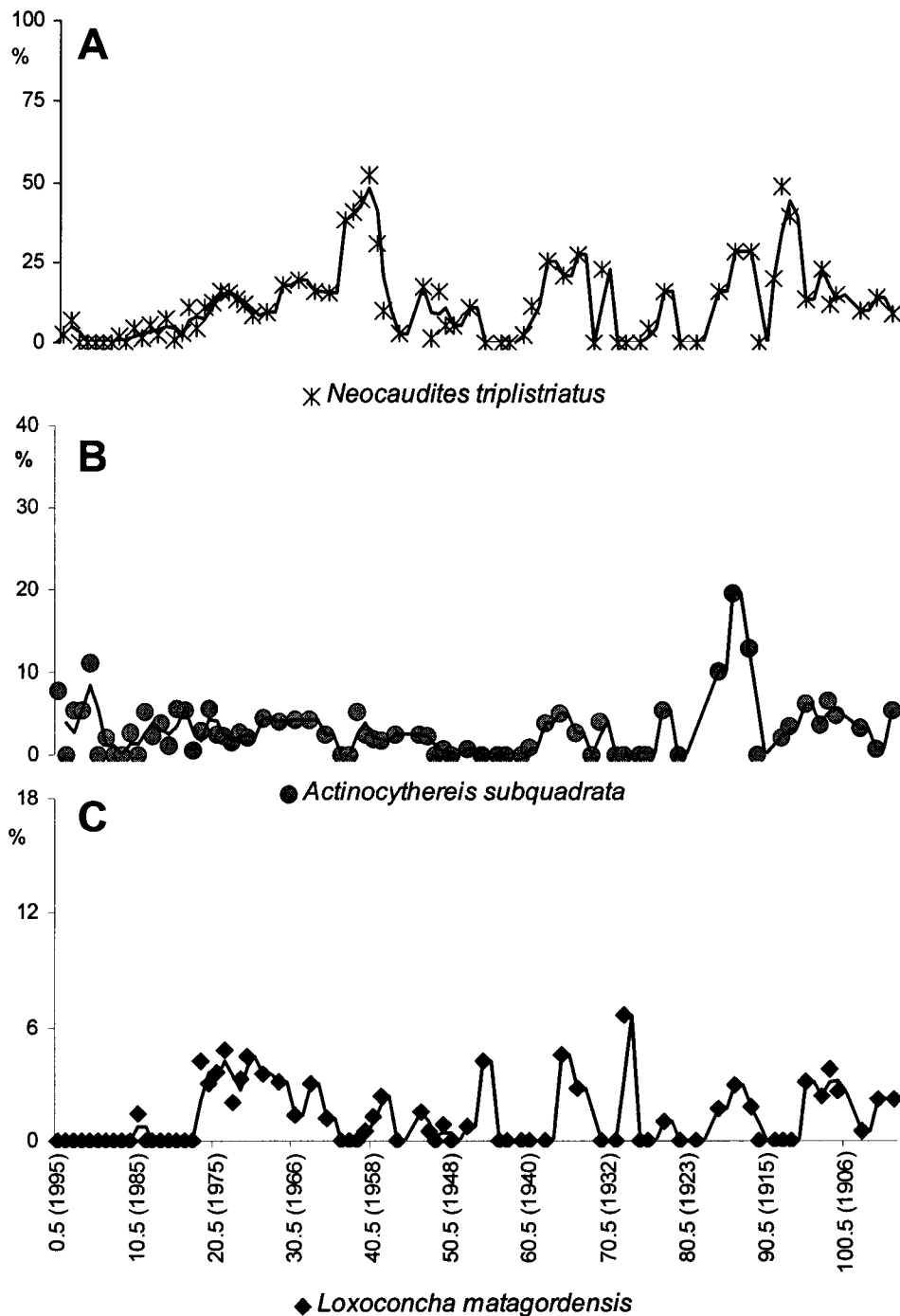
From 1956 ± 2 to 1977 ± 1 , the ostracode assemblage at this location exhibited high abundance and species diversity indicating a stable and robust ostracode community. Population evenness was relatively high and constant at this time. Following this long, stable interval, in about 1978 ± 1 , a dramatic decline in assemblage diversity (Text-fig. 3) occurred. The SWDI was reduced by half (from ~ 2 to ~ 1) and ostracode abundance dramatically declined from more than 300 ostracodes per gram to less than 50. This marked the second long-term decline in ostracode community structure during the 20th century. The number of species dropped from an average of 18 species per sample to less than five and the ostracode assemblage became dominated by *Peratocytheridea setipunctata* (Text-fig. 4b). However, despite its high relative abundance, *P. setipunctata* displays low absolute abundance which suggests survivor type dominance rather than opportunistic behavior. SWDI and evenness increase slightly at the top of the core, although, ostracode abundance remains low.

The most common ostracode species in the core were *Peratocytheridea setipunctata*, *Malzella floridana*, *Neocaudites triplistriatus* and *Perissocytheridea brachyforma* with maximum absolute abundances of 113, 80, 71 and 22 valves per gram, respectively. *Actinocythereis subquadrata*, *Loxoconcha matagordensis* and *Xestoleberis mixohalina* were also common throughout the core, but their relative abundances never exceed 15% of the total assemblage at any particular sediment interval. Inter-specific dominance among *P. setipunctata*, *M. floridana*, *N. triplistriatus* and *P. brachyforma* has changed through time (Text-fig. 4a,b,c; and Text-fig. 5a). The ostracode *Peratocytheridea setipunctata* showed a marked increase in relative abundance in about the late 1970s and remained the dominant species ($>50\%$) well into the mid-1990s. In contrast, the relative abundance of *Malzella floridana* remains rather constant throughout the core, exhibiting a peak in abundance in the mid-1940s, and a decline during the 1980s. Although *P. setipunctata* and *M. floridana* are the two most common species in the Oyster Bay core, their relative abundance appears to be inversely correlated ($r: -0.72$).



Text-figure 4. Relative abundances of: a) *Malzella floridana*; b) *Peratocytheridea setipunctata* and; c) *Perissocytheridea brachyforma* in the Oyster Bay core. X-axis: ^{210}Pb geochronology (cm (year)).

In the other hand, the mesohaline species *Perissocytheridea brachyforma* is found sporadically in the lower portion of the Oyster Bay core in abundances of up to 50%. This corresponds to the time before 1950. Since then, abundance of *P. brachyforma* remained generally low until the early 1990s when its relative abundance increased again reaching 25% of the total ostracod assemblage. On the contrary, *Neocauditius triplistriatus* exhibited its greatest abundance just before *P. brachyforma* in the early 1910s (>40%), and at about 1960 (~50%). Although present to some extent throughout the core, *N. triplistriatus* has been essentially absent from the Oyster Bay core since early in the 1980s (Text-fig. 5a).

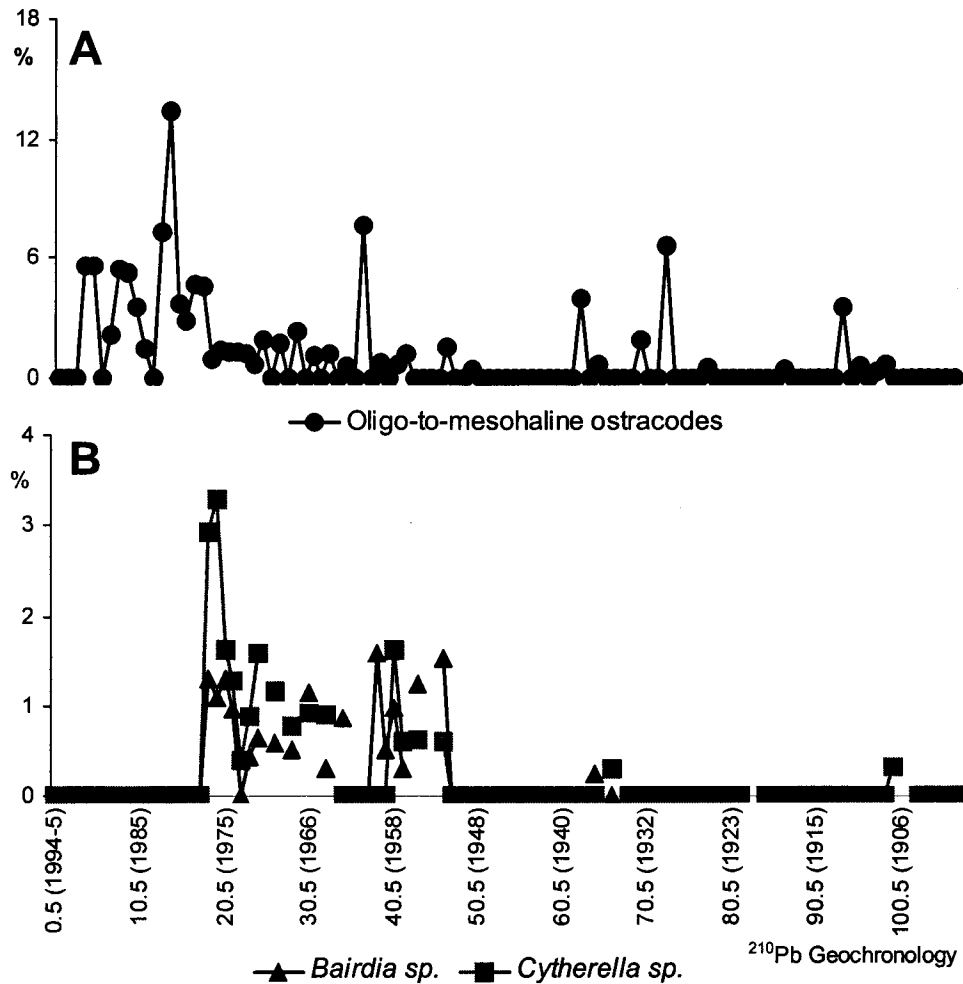


Text-figure 5.- Relative abundances of a) *Neocaudites triplistriatus*; b) *Actinocythereis subquadrata* and; c) epiphytic ostracode species *Loxoconcha matagordensis* in the Oyster Bay core. X-axis: ^{210}Pb geochronology (cm (year)).

A group of oligo-mesohaline species, such as, *Candona* sp, *Cypridopsis ockeechobei*, *Cytheridella ilosvayi*, *Darwinula stevensoni*, *Dolerocypria fastigata*, *Limnocythere floridensis* and *Physocypria* sp. occurred at sporadic intervals in the sediment core corresponding to the mid-1910s, early 1930s, early 1960s, early 1980s, and in the early-1990s (Text-fig. 6a). *Cypridopsis ockeechobei*, *Cytheridella ilosvayi* and *Darwinula stevensoni* are the most common species of this group, reaching in some intervals over 7% of the total ostracode assemblage.

In contrast, euhaline species such as *Bairdia* sp. and *Cytherella* sp. are only present in the Oyster Bay core at lower percentages (<4%). Although less significant in number, their distribution is clearly limited to

the period of highest diversity and population abundance that occurred between the early 1950s and late 1970s (Text-fig. 6b). A gap in the occurrence of euhaline species is visible around 1960.



Text-figure 6.- Relative abundance of: a) Grouped oligohaline and β -mesohaline species: *Candona* sp., *Cypridopsis okeechobei*, *Cytheridella ilosvayi*, *Darwinula stvensoni*, *Limnocythere floridensis* and *Physocypria* sp. A; and b) Euhaline species: *Bairdia* sp. and *Cytherella* sp. in the Oyster Bay core. X-axis: ^{210}Pb geochronology (cm (year))

The $\delta^{18}\text{O}$ isotopic composition of the ostracode *Peratocytheridea setipunctata* ranged from -2.80 to +2.37‰. Strong negative excursions are found prior to 1925 $\pm$ 4, while the most positive values occurred during the 1980s (Text-fig. 7). Between the early 1950s and 1970s, the ^{18}O values do not show large deviations. During this time, values oscillate between -1 and +1‰ on time scales of 1 to 3 years. The $\delta^{13}\text{C}$ of *Peratocytheridea setipunctata* at Oyster Bay exhibits very negative values, ranging from -7.59 to -10.72. Relatively constant and lighter values (approximately -10‰) occur between early 1900s and late 1950s. Isotopic trends during this time are gradual, trending to more positive or negative values in roughly decadal timescales. In contrast, abrupt positive shifts in the $\delta^{13}\text{C}$ record take place at about 1970 $\pm$ 1 and 1983 $\pm$ 1. The $\delta^{13}\text{C}$ of *P. setipunctata* at these times is enriched by more than 2‰. An increase in the magnitude of fluctuations of the $\delta^{13}\text{C}$ is evident upcore.

DISCUSSION

MICROFAUNAL RESPONSE

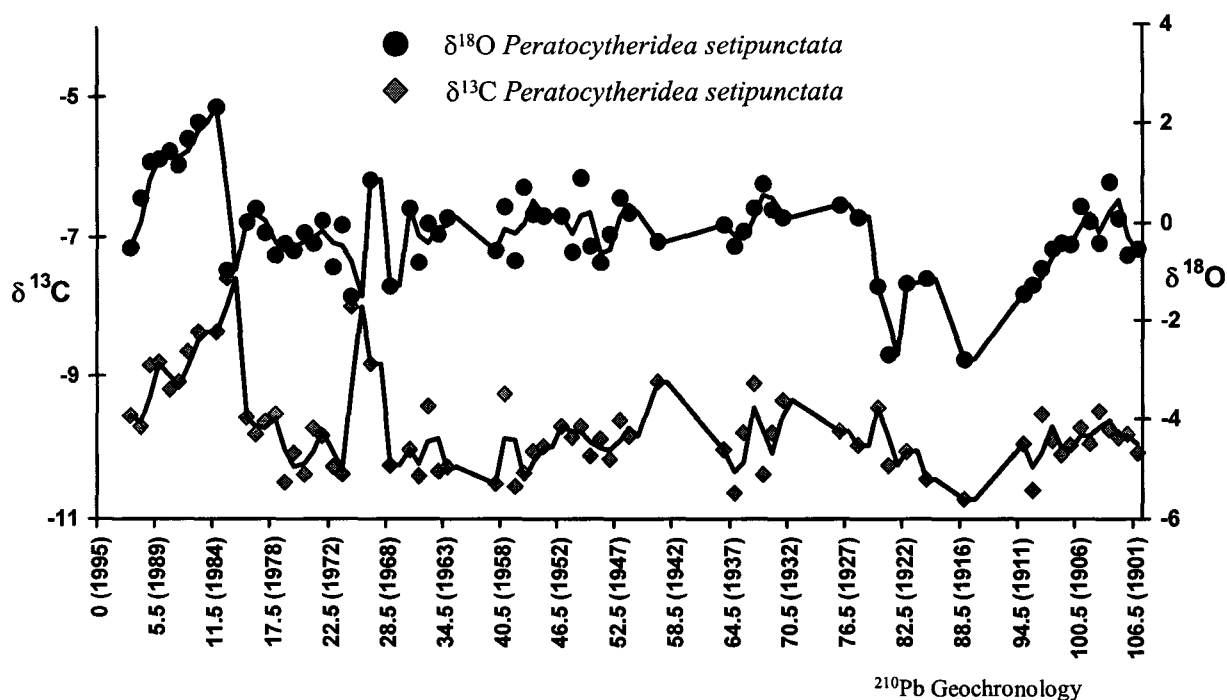
Large decreases in ostracode abundance and diversity and shifts in species dominance that occurred in the Oyster Bay core represent episodes of environmental stress due to natural and/or anthropogenic forces. Distinctive characteristics of the ostracode assemblages from the core locality were used to divide the 100-year ostracode record into three zones. The first zone extends from the turn of the century to about 1950; the second, from the early 1950s to the late 1970s; and the third to the time of core recovery in 1995. Before 1950, the significant declines in ostracode community structure that occurred in 1915 $\pm$ 4, 1929 $\pm$ 4, 1941 $\pm$ 3 and 1948 $\pm$ 2 are temporally coincident with severe tropical storms or hurricanes: the tropical storm of 1916, the hurricane of 1929, the Great Labor Day hurricane in 1935, and the hurricane of 1948. Hurricanes are capable of causing immediate or long-term environmental changes in coastal areas due to sediment erosion and deposition, and storm induced bi-directional sediment transport (Tabb and Jones, 1962; Smith *et al.*, 1994 and Wanless *et al.*, 1994). Decline in the ostracode populations and the input of reworked freshwater species as seen in the Oyster Bay core are evidence of hurricane disturbance. However, according to our data, reasonably rapid population recoveries from these events indicate a relatively resilient community. The first zone culminated with a decade-long diversity low, and an ostracode assemblage dominated initially by *Malzella floridana* and later by *Peratocytheridea setipunctata*. Rainfall data from the Homestead station (Nelsen *et al.*, in press) showed lower than average rainfall during the early 1940s, with a later increase in rainfall from the mid to late 1940s (Text-fig. 8). In contrast, freshwater flow data for Shark River Slough during that time shows a diminished flow during most of the 1940s (Nelsen *et al.*, in press). The Homestead rainfall data are used as a comparison in this case because the record is longer (back to 1911) than that of the Flamingo meteorological station, whose data only extend from 1951 to the present.

The second zone, between the late 1950s and late 1970s, exhibited the richest ostracode fauna (average: >200 valves/g) and the highest diversity (SWDI >2). Community fluctuations during this interval are more gradual and can be temporally correlated to SFWMD policies. The second zone generally represents a "bloom" period interrupted only by a brief hiatus in the ostracode assemblage continuity about 1960, coincident with Hurricane Donna. During this period major construction also occurred (1960-63) with vast areas of the Everglades north of Tamiami Trail delimited with new levees and canals. Water flow into the Shark River Slough (SRS) at this time, began to be controlled by a series of gate spillways in order to create the current system of Water Conservation areas (Light and Dineen, 1994). In addition, higher concentrations of organic carbon in the sediment intervals of this period, and at about 1935 (Nelsen *et al.*, in press), support the hypothesis of hurricane effects. Large amounts of organics derived from sediment transport and subsequent settling of suspended material occurred at this time. Oxidation of high concentrations of organic material at the sediment/water interface may have reduced oxygen levels, temporarily inhibiting occupation by most of the benthic microfaunal assemblage.

During the late 1950s through late 1970s, small numbers of the euhaline ostracodes *Bairdia* sp. and *Cytherella* sp. also appeared (up to 4%, see Text-fig. 6b). Typical marine species were not present in relative abundances greater than 0.3% anywhere in the core until this time. Two reasons potentially explain the appearance of euhaline taxa at the core locality. First, hurricane-related onshore sediment transport due to the Hurricane of 1948 and Hurricane Donna (1960). Second, less than average rainfall in the area during the 1950s may have favored marine water input from the Gulf of Mexico, allowing shelf taxa to adapt to the otherwise brackish waters of Oyster and Whitewater bays. Between the 1960s and early 80s, the SFWMD implemented a series of short-term water management plans (1963-70), and more importantly the congressionally mandated Monthly Minimum Allocation Plan of water supply to SRS (Light and Dineen, 1994). The latter practice resulted in essentially, no correlation between rainfall and flow ($r = -0.06$) (Nelsen *et al.*, in press). The time interval encompassed in zone 2 was also temporally coincident with the opening and closing of the Buttonwood Canal (late-1950s and late-1970s). The Buttonwood Canal may have led to improved water exchange between Florida Bay, Whitewater Bay and the Gulf of Mexico by means of tidal water movements, ultimately improving water quality in Whitewater Bay. The second

ostracode zone ended circa 1979, when an abrupt decline in population diversity and abundance occurred, from which the ostracode assemblage had not yet fully recovered as of 1995.

The third zone extends from about 1979 until 1995 when the sediment core was taken. It is highlighted by a large decline in ostracode diversity and abundance at about 1980 and the survivor-mode dominance exhibited by *Peratocytheridea setipunctata*, one of the two most common species in the core, known to be tolerant to extreme salinity fluctuations (<5 to 42)(Keyser, 1977; pers. comm., 1999). The early 1980s marked the end of the SFWMD's Monthly Minimum Water Delivery Plan, which was replaced by a regulated flow plan believed to be more natural, known as the Rainfall Plan. In addition, a great part of the natural flow of freshwater running through Shark River Slough was deviated into the drainage basin of Taylor Slough. This cutback in freshwater renovation is likely to have induced strong evaporative conditions in Oyster Bay at this time. Natural climatic variability (the mid-1980s drought in South Florida) appears to have further impacted environmental conditions and probably outweigh the impact of anthropogenic forces in this time period. Extracting information embedded in the ostracode record to assess and isolate the effects of water management practices may then, not be easy in this case. The modest presence of the oligohaline species *Cypridopsis vidua*, *Cytheridella ilosvayi*, *Darwinula stevensoni* (7, 3 and 7% respectively) in the early 1980s is considered the result of sediment transport.



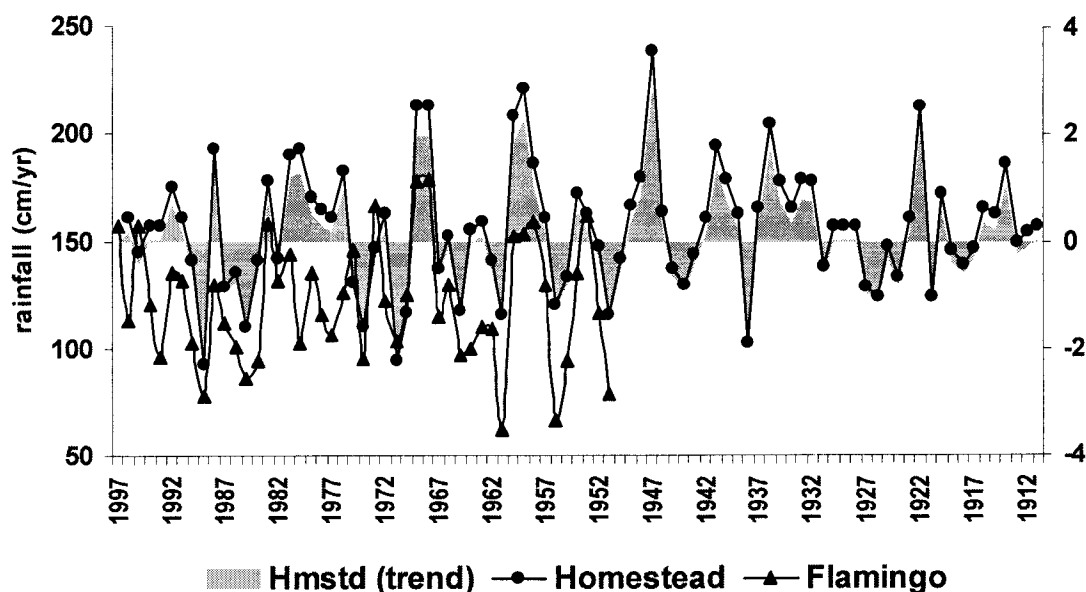
Text-figure 7.- Staple isotopic composition ($\delta^{18}\text{O}$ and $\delta^{13}\text{C}$) of the ostracode species *Peratocytheridea setipunctata* in the Oyster Bay core.

INTERPRETATION OF STABLE ISOTOPIC COMPOSITION

Stable isotopic analysis of coastal ostracodes is not routine and it is fraught with many complexities as such studies are still in an early stage. Freshwater and deep-sea ostracodes are comparatively simpler than in coastal taxa because variations in salinity and temperature in those environments are relatively small and require the understanding of control by only a few parameters (i.e. ice volume). Coastal species are controlled by many other environmental parameters (i.e., rainfall, evaporation) that have the potential to change dramatically in a seasonal basis. Therefore, the understanding of the interaction between these processes and the isotopic composition of ostracode valves is not straightforward, but we will attempt to demonstrate the feasibility of such studies in paleoenvironmental reconstruction of coastal ecosystems.

The ubiquitous occurrence of *Peratocytheridea setipunctata* made this species ideal for an evaluation of the utility of stable isotopic analysis as a paleoenvironmental tool. The stable isotopic composition ($\delta^{18}\text{O}$ and $\delta^{13}\text{C}$) of ostracodes principally responds to two factors: water chemistry and temperature (Chivas *et al.*, 1986). Differences in the physiology of organisms give rise to the so-called vital effects (von Grafenstein *et al.*, 1999). This means that different species inhabiting the same environment have similar responses to environmental factors, but can be offset from one another. Vital effects can explain when an organism appears to be out of equilibrium from the predicted values.

Important to this study is the understanding of the environmental factors that control $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ incorporation in ostracode valves. These are primarily water chemistry and in the case of $\delta^{18}\text{O}$, temperature, rainfall and evaporation (Swart *et al.*, 1996). Strong excursions to more negative values of $\delta^{18}\text{O}$ of *Peratocytheridea setipunctata* that take place prior to 1925 ± 4 correlate to high-rainfall years, and are consistent with relatively fresher conditions or rather constant brackish water conditions in a typical estuary. In contrast, strong positive excursions to heavier $\delta^{18}\text{O}$ values occurred during the mid-1980s. As evaporation proceeds, it preferentially removes ^{16}O and leaves the water behind enriched in ^{18}O ; thus, the $\delta^{18}\text{O}$ value of the water becomes more positive. This may have been the case for the mid-1980s when heavier oxygen isotopic values were concurrent with a major regional drought in South Florida, as well as with algal blooms and a major die-off of sea grasses (Swart *et al.*, 1999). Evaporation of marine or brackish waters will result in a correlation between salinity and $\delta^{18}\text{O}$, whereas evaporation of freshwater produces no such correlation. Some of the intricacies this difference causes in interpretation of ^{18}O results in the Everglades/Florida Bay system are as follows.



Text-figure 8.- Rainfall record during the 20th century from the Flamingo and Homestead meteorological stations (NOAA's National Climate Data Center). Gray area: trend analysis for Homestead rainfall station (right axis).

Commonly marine waters have $\delta^{18}\text{O}$ values between 0 and +1‰ SMOW, while freshwater values are more negative. In South Florida, the $\delta^{18}\text{O}$ of rainfall is approximately -3‰ (Swart *et al.*, 1989). During drier years, when precipitation is appreciably lower than the annual mean of 150 cm, the intense evaporation in the Everglades can cause freshwater to have a $\delta^{18}\text{O}$ value as high as +3‰ (in contrast to the marine signal of 0 to +1‰). Reduction in freshwater flow may also allow a greater intrusion of marine water resulting in an increase of isotopic composition as well. However, in this instance the $\delta^{18}\text{O}$ will increase because of the movement of the salt water/freshwater transition inland and not because of the enhanced evaporation. Both cases will result in a negative correlation between salinity and $\delta^{18}\text{O}$. In wet years, the Everglades water is closer in isotopic composition to the original rainfall value ($\sim -3\text{‰}$). Finally,

during very wet periods, the freshwater will retain its original negative $\delta^{18}\text{O}$ value and when mixing with marine water it will produce a positive covariance between oxygen and salinity (Nelsen *et al.*, in press).

In coastal waters, the $\delta^{13}\text{C}$ is also highly variable and the dissolved inorganic carbon (DIC) will be highly depleted as a result. The carbon isotopic composition of calcareous organisms can be principally related to the $\delta^{13}\text{C}$ of the DIC pool as well as the physiological state of the organism. Under normal marine conditions, physiological processes are probably most important in controlling interannual variations in the $\delta^{13}\text{C}$ of the calcitic skeleton. In situations such as Oyster Bay, variations in the DIC probably dominate. Variations in the $\delta^{13}\text{C}$ of the DIC are caused by a combination of the oxidation of organic material, which produces water highly depleted in $\delta^{13}\text{C}$, and the introduction of marine waters, which are relatively enriched in $\delta^{13}\text{C}$ (Nelsen *et al.*, in press). During the wet season, Oyster Bay will be inundated by freshwater that will be isotopically depleted in $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$. In contrast, during the dry season, the area will be influenced more by marine water from the Gulf, which will be heavier in $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$. Generally, the ostracode isotopic data from Oyster Bay shows positive correlations between ^{13}C and ^{18}O suggesting a normal interaction between freshwater and marine waters (Text-fig. 7). Positively correlated $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ deviations suggest an association between terrestrially derived, isotopically light, C and O.

Exceptions to the positive correlation between the $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ in the ostracode data occur in the 1970s, and the 1930s and 1940s. The offset in the 1970s is significant because it occurs immediately prior to a substantial shift towards more positive oxygen and carbon isotopic compositions that are evident in the ostracode isotopic record. At this time, flow in the Shark River Slough and the rainfall record at Homestead and Flamingo are decoupled (Nelsen *et al.* in press), suggesting a major modification in water flow prior to this time period. The other periods (1930s and 1940s), which exhibit a negative correlation between $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$, are more difficult to understand because of an absence of hydrological data and the lower abundance of ostracodes.

CONCLUSIONS

The following conclusions can be derived from the ostracode fauna and isotopic data. Natural variability in the ostracode communities over time is the result of natural seasonal fluctuations in climate and hydrological conditions. Hurricane events and their effects are the major cause for immediate modifications within ostracode populations. However, these populations are capable of a rapid recovery. Rainfall is the dominant natural driving force behind long-term variability in microfaunal assemblages.

The Oyster Bay core showed a large decline in ostracode diversity and abundance at about 1980. The timing of this event is best correlated to the onset of the SFWMD "Rainfall Plan" and the modification of the natural flow of freshwater running through Shark River Slough to the drainage basin of Taylor Slough. This cutback in freshwater renovation to Oyster Bay is likely to have induced strong evaporative conditions. In addition, the closing of the Buttonwood canal, also at this time, may have reduced water exchange between Whitewater Bay and Florida Bay, and further stressing Oyster Bay's microfaunal communities.

Strong positive deviations in $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ for both species, *Peratocytheridea setipunctata* and *Ammonia parkinsoniana* in the mid 1980s were concurrent with a documented major regional drought in South Florida, as well as with algal blooms and a major die-off of sea grasses in Florida Bay (Fourqurean and Robblee, 1999; Robblee *et al.*, 1991).

In general, the isotopic data from Oyster Bay shows positive correlations between ^{13}C and ^{18}O for both *P. setipunctata* and *A. parkinsoniana* suggesting a normal interaction between freshwater and marine waters. An exception that occurred in the 1970s is probably the result of decoupling of rainfall and freshwater flow down Shark River Slough during this time period due to changes in water management.

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