

PALEOECOLOGY AND ECOSYSTEM HISTORY OF FLORIDA BAY AND THE LOWER EVERGLADES

Perspectives on the January 22-23, 1998 Workshop

Report of the

Florida Bay Science Oversight Panel

Ad Hoc Committee on Paleoecology

Submitted to the

**Program Management Committee
Florida Bay Research Program**

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Florida Bay Science Oversight Panel
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Introduction

Because of the need to understand the environmental changes that have affected Florida Bay and the adjacent coastal regions of the Everglades over the past decades and to set appropriate ecosystem restoration goals, studies that lead to historical reconstruction of the environmental conditions and ecology of the region are a major element of the Interagency Florida Bay Science Program (Armentano et al., 1997). The objective of this Science Program is to guide the restoration of Florida Bay and it is directed by a Program Management Committee (PMC), representing the federal and state agencies sponsoring research and monitoring in the Bay. On January 22-23, 1998 the PMC convened a workshop on the Paleoecology and Ecosystem History of Florida Bay and the Lower Everglades in Key Largo, Florida to exchange data, information and perspectives on a series of questions concerning nutrients that the PMC considers critical for understanding the functioning of Florida Bay as an ecosystem, for defining restoration goals for Florida Bay, and for understanding its relationships to restoration of the larger ecosystem, in particular the lower Everglades.

The workshop dealt with the use of paleoecological information and concepts for defining historical conditions, including those before substantial human influence, in Florida Bay and the lower Everglades as an approach to identifying restoration goals. The Florida Bay Science Program is being pursued within the framework of the south Florida ecosystem restoration program being implemented by the Working Group of the South Florida Ecosystem Restoration Task Force. As such, this workshop represented the first organized, interagency effort to define ecological restoration goals in south Florida.

The Florida Bay Science Oversight Panel is a board of experienced scientists from outside of the region that provides peer reviews, assessments and recommendations to the PMC. At the request of the PMC, the Oversight Panel assembled an *Ad Hoc* Committee on Paleoecology to participate in the Workshop. The six individuals on the Committee included the Oversight Panel chairperson, Dr. Donald Boesch, and others invited because of their experience in the scientific issues concerning paleoecology and ecosystem history. The PMC specifically asked the Committee to provide an evaluation of the status of the Research Program elements dealing with paleoecology, assist in synthesis of results, and advise on the need for additional research.

This report presents the perspectives of the Committee on the information presented and discussed at the Workshop. We first present our overall comments and main recommendations as developed during discussions during and after the meeting. Following this brief section, more detailed perspectives are presented on geological methods, the ecosystem history of Florida Bay and the lower Everglades, and scientific synthesis leading to the development of restoration goals. These reflect an amalgamation of the opinions of specific experts on the Committee, but this has been reviewed and approved by the full Committee.

Overall Comments and Recommendations

1. **Salinity.** The results of paleoecological and isotope studies consistently indicate that salinity has increased in the central and eastern parts of Florida Bay during this century, at least in part as a result of reduction of fresh water reaching the bay from the Everglades. Analyses of results should specifically focus on this issue. Statistical analyses related to this hypothesis should be expanded and intercomparisons among studies should be a priority. However, the effects of other factors should not be excluded. The longer term salinity trends should be compared with water management and climatic variations. Existing and ongoing physical modeling should be consulted to determine potential functional linkages.
2. **Seagrasses.** The extensive loss of seagrasses in Florida Bay that began in the late 1980s and continued through the early 1990s was one of the principal causes for alarm concerning the degradation of this ecosystem. Evidence presented at the workshop suggests that the extent of seagrasses has varied greatly over time and that seagrasses were less extensive in the 1800s. As a matter of priority, these results should be discussed and debated with the seagrass ecology team both to improve paleointerpretation and to provide a historical context for modern seagrass ecology. Modern studies can provide information regarding the factors affecting the health and abundance of seagrasses. Paleoinvestigations can then extend the understanding of past expansion and contraction of seagrasses in the Bay in response to environmental conditions (salinity, water circulation, storms, etc.). Specifically, such a synthesis is critical in determining realistic restoration goals for seagrasses and associated living resources.
3. **Environmental Modeling.** A variety of environmental models are being employed in the Science Program and South Florida restoration effort. These include a hydrodynamic-water quality model of Florida Bay, a seagrass model, and the Natural System Model of the Everglades. In developing and applying these models it must be appreciated that these ecosystems are geologically dynamic, affected by hurricanes as well as long-term changes, e.g. sea level rise. In that regard, the paleoecological studies should prove very useful in verifying the models and positing scenarios of future conditions. The models should be applied in hindcast mode and compared to past conditions. Conversely, the models should help greatly in interpretation of the paleoecological results. For example, the Florida Bay hydrodynamic model will predict the salinity field under various freshwater inputs from the Everglades to the north. Currently, the Natural System Model indicates that Taylor Slough contributed about 200,000 acre feet per year to Florida Bay. Current research on paleo-salinities (based on ostracods, forams, and geochemistry) will eventually enable the hydrodynamic model to produce an estimate of the flow from Taylor and Shark River sloughs. For all of this to come together, there needs to be enhanced communication among those developing the hydrodynamic model, those involved in research on contemporary processes, and those performing paleoecological reconstructions. An example of this coordinated use of modeling in Quaternary paleoenvironmental research is found in the CLIMAP program.
4. **Sea-Level Rise.** Sea-level rise had important effects on Florida Bay and the lower Everglades over the past century and may have even greater effects in the future because there is a high probability that global warming will increase the rate of eustatic sea-level rise. This will affect sedimentation, the degree of saline intrusion in the eastern Bay and northern transition zone,

and the ability of mangroves and wetlands in the estuaries to maintain themselves in the face of marine transgression. Sea-level changes should be made a more explicit part of Florida Bay research and restoration and management strategies. For example, managing wetlands in order to maximize their accretion of plant and mineral soils will be key to sustaining them in the face of rising sea level.

5. **Additional Strategic Sampling.** Much understanding has been gained in a relatively short period of time as a result of the paleoecological investigations of Florida Bay and the lower Everglades. Subject to more synthesis of results, the findings regarding salinity and seagrass changes described above go a long way to fulfilling the objectives set forth for historical reconstruction studies. However, many of these results are based on cores from just a few study sites. Over and over again information from cores at Bob Allen and Russel Bank stations was cited. While it makes sense to concentrate multidisciplinary research on a few cores, sampling should be strategically expanded to other sites to make sure that conclusions regarding these initial cores is applicable to other areas in the Bay. This does not require major expansion or systematic sampling over the entire Bay, but a few additional cores to verify whether the temporal pattern regarding seagrass, for example, is consistent over the bay.
6. **Further Synthesis and Restoration Goals.** The Workshop provided a timely opportunity for researchers to present and discuss their results and thereby to search for commonalities and differences. However, a workshop is not alone adequate to synthesize the results thoroughly nor to develop restoration goals from this synthesis. As a priority the Science Program should complete a written synthesis of paleoecological results that key addresses management questions regarding Florida Bay and the lower Everglades. This could be accomplished either by one or two scientists taking the lead or by a larger task force of individuals. Well founded restoration goals, an urgent need, must await this synthesis and improved integration of paleoecological and modern environmental studies.

Dating, Sedimentation and Environmental Conditions

Isotopic Dating.

Appropriately dated sediments and biological remains are essential for determination of rates of change and correlation of paleoecological change to anthropogenic activities (such as engineered structures). The research teams have used appropriate dating techniques involving the isotopes ^{137}Cs , ^{210}Pb and ^{14}C . The progress in the short-span ^{210}Pb chronology and excess-Pb dating is very impressive. The time scale in Florida Bay appears to have been tied down by Trefry and Kang impressively compared CIC and CRS models to assess error in ^{210}Pb dating. The time scale developed shows that there is rapid deposition in Florida Bay compared with rates of deposition in the Everglades itself where ^{14}C is used for dating. However, the various labs (FIT/NOAA & USGS; W.J. Kang and C.W. Holmes, respectively) must establish communication to ascertain that methodologies are consistent, standards are compatible, etc. It appears that the same models are in use, but terminologies used are rather different.

For the scientists using these dating data the limits of resolution, decreased resolution with increasing age, and dependence on an extrapolation that assumes constant sedimentation rates at

T> ~90 years must be made very clear. The last technique is especially tenuous because sites selected have anomalously high sedimentation rates (possibly by an order of magnitude over long-term, Bay-wide averages) that clearly cannot have applied throughout the history of the Bay. The Bay would have been full of sediment long ago. Another red flag was raised when Wanless indicated that 1935 aerial photos showed almost no change in morphology of Bay features from present day. This is not what would be expected when sea level is rising at about 25 cm/century, with high depositional rates as determined by ^{210}Pb , and movement of the banks as determined by Wanless by northeasterly storms. More changes in morphology of the banks would be expected given the time scale that has been developed and the rates of deposition.

The limited application of ^{14}C dating is less impressive. Some investigators have used bulk dating, which by including roots could provide anomalously recent dates, and by including reworked material, anomalously old dates. In heterogeneous sediments or those susceptible to reworking (e.g., estuarine sediments) the preferred method of ^{14}C dating is to isolate an organic fragment of known origin (e.g., seeds, leaves, pollen). Such samples are too small for conventional ^{14}C dating, but can be done by the more expensive but cost effective accelerator mass spectroscopy (AMS) method. It is widely recognized that over the Holocene atmospheric production of ^{14}C has not been consistent, and most researchers now calibrate their ^{14}C years to calendar years. This procedure is simple (the program is freeware on the web) and essential for cross correlation.

For future research, an effort to bridge the gap between the maximum ages for ^{210}Pb and the minimum for ^{14}C should be pursued. It could involve analytical refinement of these methods or use of another decay scheme. In the interim, ^{14}C dates deeper in the cores could be used to test the limits of extrapolation. Correlation between ^{210}Pb dating and ^{14}C dating on autochthonous sediment is desirable to make sure that they are in agreement. The cores that Brewster-Wingard took in the south end of Taylor Slough show multiple zones of freshwater calcitic muds and peats. It would be of interest to date these zones of calcitic muds and peats using both techniques to see if they are in agreement. Further correlations with the coral record are also encouraged; this is the Rosetta Stone of Florida Bay. Any method devised to correlate pre-1900 sediment levels to corals would solve a number of problems associated with the multiplicity of stressors and human impacts of the 19th century.

Some standardization may be needed in determining sedimentation rates. Calculations used to derive sedimentation rates and especially to convert $\text{g}/\text{m}^2/\text{yr}$ to cm/yr (accretion rates) should be presented and coordinated among researchers. This is not trivial; the conversion involves assumptions or measurements of percent coarser material (the undated portion), of grain density and water content, or of porosity. The porosity varies with percent fines and with depth in cores (Enos & Sawatsky, 1981; Ginsburg, 1957). These methods are not discussed in an otherwise very thorough manuscript by Robbins, Holmes, et al.

Although most of the dating (and most of the detailed studies) have been undertaken in areas of finely laminated sediments, most of the Bay sediments are moderately to thoroughly bioturbated. Dating techniques should be extended to bioturbated sediments, if at all possible, and the limits of resolution, presumably somewhat reduced, should be evaluated.

Within all cores, the variations in sedimentation rate within cores should initially be analyzed rather than smoothed. Fluctuations may reflect limitations in technique or real variations

in sedimentation rate. The latter might be correlative between sites. Limitations of resolution are relevant to the extrapolations mentioned above. Discontinuities in depth versus age (i.e. sedimentation rate) are keys to recognition of erosion events, such as hurricanes.

Sedimentation

Laminated sediments (LS) have emerged as the best recorders of Bay history. That is where the action is, but they are not ideal for everything. They certainly do not contain the record of seagrass cover. Over-reliance on LS cores may bias views on extent and duration of grass cover. Sedimentation rates cannot be applied elsewhere in the Bay; these are certainly areas of accelerated accumulation. Any parameters influenced by sedimentation rates must be reconciled with more representative sediment-accumulation rates. Examples are trace-element concentrations; carbon content; absolute, as opposed to relative, fossil abundances, etc.

Attempts to evaluate the role of winter storms versus hurricanes, in either relative or absolute terms, may be influenced by over-reliance on LS sites. Winter storm effects are incorporated in annual sedimentation rates; hurricanes are not. Hurricanes generally show up as a perturbation in the laminated record, the very thing that is deliberately avoided.

The daily increment of sedimentation can perhaps be backed out of annual sedimentation rates. Water is generally turbid, there must be continual fallout. This could be quantified from sediment concentration, water depth, and Stokes Law settling velocities. The balance is presumably storm sedimentation. Daily deposition may be reworked in storms, but that does not mean storms transported this sediment, even to its 'final' resting place. These are important considerations in modeling.

The Committee does not understand why the NOAA-supported studies of sediments and microfossils are so focused in Whitewater Bay and Coot Bay and how, if at all, these will be related to the broader issue of salinity and other environmental changes in Florida Bay. Although the sedimentary record there presents a well-preserved record of change, is this a case of looking for lost keys only under the lamplight? These bays are important areas in their own right, but relatively small, hydrologically very different, and, in their natural states, totally isolated from Florida Bay.

Integration with the elements of the Florida Bay Science Program that are addressing sedimentation and sediment dynamics is critical. Research results differ on sedimentary depositional rates and sediment production for Florida Bay. The banks were attributed to northeasterlies but the data were not presented that would substantiate that northeasterlies would be the driving force in causing the banks to form. Also, when El Niño occurs, the wind is out of the west and southwest and it may blow from those directions for a year or more. Is there any apparent relationship between wind directions during El Niño and the banks? More supporting data are required, such as wind roses that show statistics on how the wind blows around the Bay.

Rainfall, Freshwater Flow and Salinity

The analysis by Nelsen et al. of rainfall and salinity patterns needs to be strengthened in order for it to be used as the basis for comparison with other paleoecological findings. Hood et al. made comparisons to the Nelsen data, but the Nelsen et al.'s findings do not appear to be strong enough yet to warrant comparison. The use of two rainfall stations is inadequate when the

SFWMD has a very extensive data base. Belle Glade rainfall is probably strongly affected by lake effects from Lake Okeechobee; the assumption that rainfall is the same between the two stations (Belle Glade and Tamiami Trail) is probably not valid. The use of the Tamiami Trail rainfall station is reasonable, but should be used in conjunction with other rainfall data. For example, why not use Homestead rainfall data as representative of northern Taylor Slough? The use of flows through the S-12 structures may not be meaningful unless a stronger relationship can be established between flows out of Shark River Slough and salinities in Florida Bay. While there is evidence of along-shore currents past Cape Sable to the south, the effects of flows out of Shark River Slough on central and eastern Florida Bay remains unquantified without a hydrodynamic salinity model. The distribution of salinity in the Bay suggests that central and eastern Florida Bay are more affected by flows out of Taylor Slough, about which nothing was said. Much more needs to be addressed about Taylor Slough rainfall and flows. Cal Neidrauer at the SFWMD has modeled flows out of Taylor Slough to Florida Bay for the period 1965-1995 using the Natural System Model. These data may provide some insight into flows affecting the Bay.

Trace Elements

The various studies that addressed trace elements (Dodge & Anderegg; Swart; Trefry, Kang, & Metz; and Orem) are not very conclusive nor mature to date, but are potentially important to the evaluation of nutrient or pollutant fluxes. Researchers must effectively communicate, beginning at the present stage. Trace-element analyses are very time-consuming and costly; the possibilities for analyses (which elements, which materials, which techniques, which correlations?) are innumerable. Workers should coordinate efforts to recognize critical tracers, standardize methods, and divide labor, as well as dividing the available, well-dated samples.

Chronology of Human Intervention

A dateline of human intervention is needed. A case in point, C-111 canal was cut in about 1962, not 1967 as stated by Meeder. Spoil banks were modified later and a floodgate added, partly in response to catastrophic kill-off of vegetation through ponding of sea water during Hurricane Betsy. There is some vagueness on dates of railway building, in particular causeway construction. The FEC RR was opened about 1915; many abutments were washed out in 1936 Labor-Day storm and were rebuilt by 1939. Various canal digging, water-release programs, and the like should be included the dateline. The dateline should be circulated to all researchers, as a common base for probing anthropogenic influences.

Recent Ecosystem History of Florida Bay

Salinity

A central question to which these retrospective analysis are expected to contribute concerns the effects of changing freshwater flows and other factors on circulation and salinity in the Bay (Armentano et al., 1997). This question is very important because the management options being considered mainly concern regulating freshwater inflows.

A consensus seemed to emerge among various investigators participating in the workshop

that the salinity of Florida Bay has increased during the historic period. The biotic indicators include ostracods, forams and mollusks (Brewster-Wingard, Alvarez-Zirikian), diatoms (Pyle, Cooper), and corals (Lisa and Swart). The causes appear to be both natural and human-caused, with increased salinity during 1910-1920 attributed to construction of a railroad causeway, increased salinity after 1940-1950 related to reduced frequency of hurricanes and to construction of canals that divert fresh water away from the Bay; and salinity increases after 1970 associated with drought.

It is not clear whether management practices should be expected to mitigate the effects of high salinity, because the pre-settlement history of high-salinity periods is not known. That is, intervals (decadal) of high salinity might be part of the natural variability (century, millennial) of Florida Bay. Periods of high salinity might be destructive in the short term, but the ecosystem might rapidly recover. Winkler and Brewster-Wingard indicate that 200-500 years ago, droughts in the Southern Everglades were more extensive or more frequent than during the historic period. It would be instructive to know if Florida Bay experienced intervals of high salinity coincident with the terrestrial droughts.

It is important at this point to coalesce and solidify the informal consensus expressed at the workshop by the creation of a synthesis report that summarizes and contrasts all of the evidence related to salinity trends, including paleoecological and geochemical results, and salinity, inflow, precipitation and other climatic records.

Seagrasses

Another central question for the Florida Bay Science Program concerns the causes of the recently observed changes in the seagrass communities of the Bay. Based on the abundance of ostracod, foram, and mollusk species that live in or in the vegetation in dated cores, seagrasses were apparently much less abundant in central Florida Bay prior to ca. 1900. Species that live today only on seagrass or algal mats are abundant in sediments dated to the mid-1950's, but were rare before ca. 1900. These biotic indicators were less abundant after ca. 1970. If these results are broadly representative rather than influenced by just the local conditions near the core sites, this means that seagrass meadows may come and go both in time and space, and this impermanence may be "natural" for the Florida Bay. Furthermore, stratigraphic profiles across a mud bank assembled by Wanless show three seagrass horizons (reflected in characteristically bioturbated deposits) interspersed among layers of finely-layered sediment, suggesting periodic colonization and abandonment of that particular mud bank by seagrass. However, the seagrass layers beneath the surface are undated so the frequency with which these invasions occur is unknown.

Lower and more variable salinities may have been a factor influencing the abundance of seagrasses. For example, Ishman found that seagrasses, as reflected by the presence of epifaunal indicator species, only came into Manatee Bay around the turn of the century as the previously brackish water conditions became more saline. In Florida Bay Cronin reported that there were few ostracods that inhabited seagrasses prior to 1940. He also found a relationship between the ostracod fauna, particularly in the abundance of abundance of *Malzella* sp., and presumably wetter El Niño years. However, we caution against over-interpreting this relationship, particularly during the earlier part of this century when the dating control on the sediment horizon has potential error which is as great as the frequency of El Niño events!

Even if salinity were increasing, at this point one may not be able to exclude additional factors influencing the paleoassemblages. Based upon the workshop presentations, conclusions that a single factor—salinity, nutrients, sea-level change, or precipitation regime—was driving changes in seagrasses must be regarded as preliminary. One needs, minimally, a second proxy for seagrasses. Perhaps the lignin technique could be used to tease out these covariants, although the lignin may be overwhelmed by allochthonous contributions from mangroves. An unanswered question is the distribution of core sites. Seagrass biologists should be consulted to determine how representative the available core sites are and where any additional cores should be taken.

Hurricanes

Several investigators mentioned potential effects of hurricanes on the sedimentary record. Hurricanes produce erosional gaps in the sedimentary records studied by Kang and Hood. Wanless showed that the abundance of mangrove root hairs in the sediments of the Western Bay increases after hurricanes, due to erosion of mangrove peats. Hood speculated that certain ostracod species respond to increased nutrient flux to Florida Bay after hurricanes; Terfry showed that carbon and nitrogen levels in some cores increased after hurricanes; and Swart is exploring the use of fluorescent layers in Florida Bay corals as potential records of hurricanes over the last 150 years.

Nutrients and Algal Blooms

Other major questions for the Science Program concern the influx and internal cycling of nutrients and the regulation of planktonic algal blooms. To tease out changes in the nutrient regime one must look to the period prior to potential nutrient increases, a challenging but not impossible task. Proxies which would be expected to address this are diatom analysis, pigment analysis, and dinoflagellate cyst analysis. These analyses all seem to be an afterthought to the program and are just beginning. We know that algal blooms occurred in North American coastal waters prior to European colonization. It could be possible to document frequency of blooms in Florida in the past, but this is not an easy task.

Diatom analyses should provide some information about diatom blooms, if one "hits" the appropriate deposit. The diatom analyses, as presented by the Cooper and colleagues has begun with development of some modern analogs—assessment of species complexes and related nutrient regime. Diatom analyses are more common in oceanic and limnological systems. Application to estuarine systems has been rare and therefore taxonomic assessments and interpretations require some backstepping, particularly for the notoriously under studied tropical environments.

In the Florida Bay environment the applicability of pigment analyses seems to be limited to detection of cyanobacteria. Pigments of diatoms and dinoflagellates are degraded, probably by a combination of physical and biological processes. There have been few documented attempts to apply this technique in estuarine systems and considerable research is required to fully assess its feasibility, particularly in shallow, carbonate-dominated systems.

Dinoflagellate cysts have been used as indicators of paleo-sea surface temperatures for the Tertiary, particularly the Quaternary. It has been assumed that temperature and salinity control their distribution in the ocean system, but there has been suggestion that nutrients play a role in coastal waters. There is no history of estuarine studies of dinoflagellate cysts and few taxonomic

models to use as guides. There probably have been three or fewer journal articles which report late Quaternary records of cysts in estuarine deposits. As compared to oceanic systems, cyst recognition is much more difficult in estuaries as they are hidden by pyrite and refractory organics. Relatively rapid deposition in estuarine environments means that many cysts have not undergone ecdysis, so that diagnostically important archeopyles are not visible. One of the USGS teams had started to examine dinocysts, but showed only *Polysphaeridium* and *Spiniferites* sp., (which should probably be designated as “*Spiniferites* complex”). These are the two most recognizable cyst types in estuarine systems and are non-monospecific taxa, representing a number of living dinoflagellate species. There was no mention of a search for specific types indicative of blooms.

The Lower Everglades

Paleoclimatic Variations

Sanford's poster on northeast Shark River Slough that showed that much of the sediment was calcitic mud indicating a shorter hydroperiod. This information needs to be communicated to the Restudy modeling group. Current management efforts are to attempt to put much more water into northeast Shark River Slough than in the recent past. This may be contrary to conditions that existed there in the past.

Gator Lake in Water Conservation Area 3 should be cored through its entire thickness since it would be a perfect record of everything that has happened in the Everglades since its beginning. Winkler indicated that they had only cored 7 m of the sediment because they ran out of rods and the base of the 7 m core only dated to 2000 years BP. The portion of the core below 7 m should be subject to diatom/charcoal/pollen analysis as well as geochemical analyses such as $\delta^{18}\text{O}$ ratios and ^{14}C dating. Apparently Delfino (University of Florida) also took a core here but results were not presented. Information from the Gator Lake core should be then used for correlation with other sites. It would be of interest to determine whether events in the Gator Lake core could be correlated with cores showing alternating peats and calcitic muds from the south end of Taylor Slough. The alternating calcitic muds and peats at the south end of Taylor Slough should be ^{14}C dated for possible correlation with other sites as well as Gator Lake.

Palynological Methods and Interpretation

To assure the validity of statistical analyses based upon percentage data it is critical that counts be a minimum of 300. It seemed that lower counts were avoided in the microfaunal investigations, but at least two of the teams (Tedesco and Winkler) were using pollen data sets with lower counts. In coastal sediments pollen concentrations are characteristically low, thus palynological observation is more laborious. It is possible to reduce labor investment by increasing sample size and varying processing or mounting techniques.

Percentage pollen data are affected by changes in inputs of pollen from systems outside the region of interest (through aerial or tidal sources). For example, a reduction in supply of pine pollen (a consistent and large component of most pollen assemblages) would result in a corresponding increase in percentage of another taxa. This pitfall can be avoided in two ways, neither was effectively addressed by presenters at the workshop. Variations in pollen concentration can be used as a check, but these must be calculated on a volume or weight basis. Variations in grain size and organic content will skew concentration calculations, thus

normalization to weight is not advisable in Florida Bay deposits. Variations in volume are affected by sediment accumulation rates, also problematic in Florida Bay. A second means to avoid misinterpretation of percentage changes is to eliminate pollen from external sources (such as pine and oak) from the pollen sum (the sum of grains used to calculate percentages) and include only those taxa known to grow in the target habitats. This is a common practice which also serves to increase the sensitivity of the palynological signal. External (sometimes called extra-regional) pollen need not be ignored, but simply shown as an abundance "outside the sum". Palynology has been most advanced by those studying ecology of terrestrial forests, those investigators commonly ignore all wetland pollen types. For those of us interested in the wetland signal the reverse is appropriate and effective. Removing external pollen from the sum, of course, requires that counts be larger to assure that one has a minimum of 300 grains of the target species.

More extensive and reliable modern analogs would help in the paleontological and palynological assessments of habitat changes and related environmental factors. Some analogs have been developed by the the USGS microfaunal team. However, the only palynological comparison (Tedesco) with modern analogs used an unpublished data set based on very low pollen counts (as low as 100). Cluster analysis of these data yielded less clear resolution of the previous interpretation. Perhaps a more informative approach would be to use the *a priori* classification and apply discriminant analysis to the groups corresponding to the vegetation zones in order to discriminate the most important environmental factors underlying the floristic patterns. A related observation that pertains both to the pollen and microfossil analyses is that, in general, analyses could more effectively use multivariate techniques (ordination by principal components and other analyses, canonical analysis of covariance, etc.) to examine multi-taxa and multi-factor data sets.

The lack of characterization of modern analogs seems to be due funding limitations rather than lack of recognition of the value of a modern calibration set. A suite of modern palynological analogs available to all researchers should be developed. Sample sites should be located in habitat centers as well as ecotones and accompanied by measurements of appropriate environmental variables, such as water chemistry. Variation in physiographic settings can be addressed by appropriate replication. A valid question posed by Committee was "What is the spatial significance of the record?" This can be addressed by the suite of modern analogs, if the sample sites and environmental data can be appropriately mapped. This would encourage interaction between paleoecologists and modern ecologists assessing habitat variability and monitoring appropriate physical variables. Field work teamed with modern ecologists would be the most effective way to develop a suite of appropriate modern analogs.

A better perspective can be obtained by pooling data from all cores available. More information on responses of habitats can be derived by merging data sets from various cores; e.g., examining all seagrass or mangrove deposits. This approach has shown to be valuable in other systems which have interrupted sedimentary records.

There is a danger of calibrating proxies simply to a minimum, maximum, or mean in a physical variable (particularly salinity). Estuaries are extremely variable, and the degree of variation may vary spatially or temporally. Investigators should continue to evaluate the sensitivity of proxies to ecosystem variability. A good example of an indicator of variability is the intermediate marsh of the Mississippi Delta. This marsh zone has the greatest variation in salinity,

which is reflected by the composition of the macrophyte community, in turn reflected by the palynological signal of the community.

Micropetrographic Approaches

The “micropetrographic” analytical method described by Cohen is unique in its techniques and its products. Various degraded remnants of plant organs, tissues, cells and sub-cell materials are taxonomically identified at each level in the peat sediment providing specific information as to the plants and plant communities that occupied that site at the point in time represented by the level in the sediment. This is possible because essentially all peats are autochthonous deposits as opposed to other sediments which have been transported and deposited in sites foreign to those of the deposited material. As discussed above, pollen analyses constitute another approach to understanding past vegetational histories and while such analyses are of major importance in certain applications, they cannot provide the type of ecological and environmental information made available by this phytolitic (micropetrographic) approach. There are a number of reasons for this, including the exclusion of insect pollinated plants from the record, the role of the winds in transporting the pollen, the vast differences in the volume of pollen production in the case of many plants, the minimal resistance to degradation on the part of certain pollens, and the fact that most of the pollen in the deposit comes from outside the confines of the sampling site involved.

An unfortunate omission was highlighted in the presentation by Cohen. This involves the fortuitous preservation of the complete vegetational history of Florida Bay contained in the complete peat sequence on Pigeon Key which extends from the bedrock some 3+ m to the present day surface with its mixed mangrove environment. This sequence can provide not only an overall framework to which other events can be related, but in itself can provide specific information on such phenomena as hurricanes, fires, sea level and salinity fluctuations, toxin and nutrient excursions, and periods of organic matter degradation and dispersal. The analytical method described by Cohen provides an unambiguous documentation and description of the sequence of vegetational communities and environments occupying the site through time, with every level in the sequence readily dated as to absolute time. Because of its aerial implications (the aerial occurrence of the vegetational communities extended well beyond the confines of Pigeon Key), a spatial framework is also provided. This would be substantially enhanced if similar analyses were performed on a representative number of the partial peat sequences that occur at various locations and at various levels throughout the Bay. Over 100 sites scattered in all “regions” of the Bay have been identified as containing land-based phytogenic sediments.

In view of the above, it is recommended that micropetrographic analysis of the peats should be extended to Pigeon Key and Florida Bay. Not inconsequential from the standpoint of the National Park, and as an incidental byproduct of the effort, will be the availability of information that will be of use to the Park in its educational interface with the general public.

The Lower Everglades Ecosystem

Although the emphasis in the Workshop has been, appropriately, on Florida Bay as opposed to the adjacent “Everglades,” it must be recognized that the two are components of a single environmental complex in which the southern sector and the western sector happen to be inundated by marine water with serious impacts on both. And, just as sea-level rise has destroyed

essentially all of the peat-forming environments in the "Florida Bay Sector", it has similarly destroyed more than a one mile strip of the "Western Sector" and is impacting in a significant way a large portion of the mainland Everglades. Because of the latter, the mainland Everglades will be the first impacted by restoration efforts which will involve the input of large volumes of fresh water into the system.

While some of the important problems have been identified in Florida Bay (seagrass destruction, algal blooms and turbidity), there has been less attention to the problems of the coastal transition region of the lower Everglades. Recognition of these problems is vital to defining the goals of restoration as well as perceiving its impacts. In this Workshop (with the exception of the report by Tedesco) there was relatively little attention to the ecological components of the mainland Everglades beyond the recognition that there are "mangrove areas" and "saw-grass areas," with neither of these being really understood. This is not unique to this group of researchers, but it represents a lack of the fundamental knowledge that is necessary to begin to describe the undesirable impacts of an invading sea and a diminution of freshwater input on the components of the ecosystem, to say nothing of the potential effects of contaminating substances from the north.

The most pressing need is for the development of a detailed map of environments on a microenvironmental scale: basically a vegetational map which differentiates, for example, between the *Juncus* and *Distichilis* marshes and the *Rhizophora* and *Rhizophora-Avicennia* environments plus the co-existent *Batis* environment. To this should be added information of the dependent bird, fish and other animal populations. The reason for this detail is the fact that it is the micro-environments that have been affected first by the invading sea and they will be the first to be affected by restoration efforts. So, it is recommended that efforts be initiated to develop this fundamental descriptive information.

Wanless and others called attention to the possible, or maybe even probable, effects of material entering Florida Bay from the western coast of the Everglades via longshore currents and tidal action. If there is a significant input of material from these sources, there is the potential of materially influencing the nutrient and or toxin content in the waters of the Bay. In this connection it is useful to recognize that differing segments of the western coast provide significantly different materials to the southward moving longshore currents. There are at least five startlingly different "sectors" to the coastline, and the material issuing forth from the Big Sable Creek Sector is compositionally quite different from the material issuing forth from the Shark River Sector. and this is different from the more northerly "Inland Bay Sector," etc. Accordingly it is suggested that these areas and their various products be investigated and described as a means of evaluating their possible significance. Another source of "strange" and foreign organic material that would enter Florida Bay if large volumes of fresh water are added to the system is the Hell's Bay area. This may happen with or without the opening of the Buttonwood Canal, and it would be prudent to know what is being added to the system from this source.

Sea-Level Rise and Saline Intrusion

Another area of the mainland Everglades that might usefully be studied prior to the onset of restoration efforts is the brackish-to-freshwater transition zone in the vicinity of the Flamingo road in association with the *Paurotis* palm zone. At the moment it is unclear as to whether the

freshwater environments are holding their own against the onslaught of the brackish environments or whether the rising sea level is about to result in their destruction. This is not a matter of major consequence but it is a very visible area that stands to be considerably altered, perhaps for the better, by restoration efforts. It may be desirable to understand the present ecological dynamics of the area.

Environments of the Everglades marine transition zone bordering of Florida Bay have been destroyed by the rising sea and the initiation of a similar history is beginning to be evident in Whitewater Bay and in the adjacent Oyster Bay. Islands are being destroyed and with them the elimination of rookery sites that until recently were white with ibis at dusk. Along with this there has been a lowering of the land surface through peat degradation and transport as far inland as Tarpon Bay and sites in Hell's Bay. The name "Clearwater Pass" (and its correspondingly clear water) is evidence that the water in Whitewater Bay is not uniform in quality. It would appear that the lesson learned in Florida Bay suggests that it would be useful to undertake a vigorous research effort aimed at preserving Whitewater Bay and its environs and protecting it, if possible, from the fate suffered by Florida Bay.

Recognizing that the uncontrollable rise in sea level has been a fundamental cause of the alteration of the Florida Bay area and the lower Everglades the question arises as to whether any restoration effort can be more than a temporary solution. In this connection, it may be useful to document the fact that there are natural forces that are, in fact, opposing the effects of the rising sea. Shifting the advantage in favor of these natural forces might, at least, force a stalemate in the battle. The "buried forest" at Northwest Cape Sable with its standing stumps of black mangrove trees (recently destroyed) and its peat substrate that extends out into the Gulf, coupled with the peat horizon buried more than a meter beneath the beach and also extending out into the Gulf, provides evidence that the sea is not completely dominant at this point in time. This suggests that if the vigor of the peat-forming coastal vegetation could be increased and a re-invasion of the sea by mangrove forests initiated, the impact of the rising Gulf could be minimized. A study of the Northwest Cape and similar areas could reveal the responsible processes and might suggest constructive courses of action.

Pre-Settlement Humans in the Southern Everglades

Fire is acknowledged as an important factor in the Everglades ecosystem, and sediment studies by Winkler and by Brewster-Wingard indicate that burning became more frequent in the historic period in some areas, but not in others. Prehistoric human-caused fire may have been an important factor in shaping the vegetation of certain parts of the Everglades. Reduced fire frequency, following settlement, may have favored the spread of exotic and undesirable plant species during the historic period. Charcoal analyses of dated cores are needed for parts of the Everglades known to have been population centers by native Americans.

Synthesis and Restoration Goals

Coordination

Answering questions applicable to concerns of management requires a synthesis of data sets by comparisons based on core records, paleo-habitats, and time (producing a paleogeography

of the Bay at selected time periods). Before interpreting change in the historical period the records of anthropogenic activity and climate (precipitation, temperature, storm frequency, tide gauge data) must be compiled. It was not clear that a compilation has been made by any research team. An appropriate approach would be to have one investigator or team responsible for compilation and distribution of the chronology so that all teams would be using the same chronology. Unless this is standardized it is impossible to contrast interpretations of paleoenvironmental responses.

Communication is also essential among modelers, paleoecologists, and geologists. Perhaps a most important interaction will be hindcasting to calibrate and evaluate process models. Paleoenvironmental reconstructions hold essential clues to evaluating cause and effect on scales of decades, centuries, and, certainly, millennia.

Based upon presentations at the Workshop it is difficult to conclude whether the research effort has been adequately extensive. All research to date needs to be pulled together for an adequate assessment. In fact, the Committee was surprised that a common reference map showing sampling locations was not available for the Workshop. All coring locations ("bad" and "good" cores) should be documented in a GIS. Where possible one should include sites outside but near Florida Bay, as cross-system comparisons may provide useful indications of broader regional impacts. In the GIS there should be layers for bathymetry, hydrology (as available), modern and surface sedimentology (if available), and habitats. This would also foster communication between the paleoecological team and other environmental scientists and modelers.

In this database a number of attributes should be recorded for each core: depth, dating conducted, proxies studied (e.g., foram, pigments, diatoms, etc.). Where proxy data collection is intended, but not completed, the expected date of completion should be indicated. This task can help address the lament that there are not enough records and lead to more confident determination of the adequacy of the spatial resolution of the paleoecological research.

In spite of the Workshop title, efforts aimed at elucidating the "paleoecology and ecosystem history of the lower Everglades" by relating paleoindicators to modern ecological studies were virtually absent! Although the problems in Florida Bay have been identified as being associated with seagrasses, algal blooms and turbidity there was little reference to the direct investigation of these entities or their occurrence in the Bay and factors which typically control them. Seagrass health, vigor, colonizing capacity and response to nutrient and toxin levels is basically a matter of plant physiology, but there was no inclusion of critical thinking of plant physiologists in the paleoecological assessment. Similarly, the phenomenon of algal blooms or "green tides" is likely to become more understandable with the contributions from perceptive phytoplankton ecologists. The Bay is not now, and never has been, uniformly turbid but hard evidence of the character, nucleation, growth, distribution and waxing and waning of turbidities in the present system appears to be lacking. Such information will be of critical importance in predicting and controlling this phenomenon in the future. The Science Program would benefit materially from the generation of some simple maps displaying the aerial occurrences of sea grass, turbidities and algal blooms, today and at various points in time. In other words, the focus of the paleoecological studies could benefit from relatively minor additions and re-adjustments, and the improved input of research expertise in other parts of the Science Program.

The Program should guard against channeling its efforts in a single preferred direction which may, or may not, provide the required information and products. Much expertly produced data has been generated on a variety of parameters (some pertinent, some not), and these data have been correlated with a well-controlled time scale in an effort to relate these data to anecdotally described and imprecisely (temporally and spatially) located events of the past. Such correlations and coincidences may or may not represent causal relationships. In the lower Everglades this problem is further exacerbated by limited experience in, and knowledge of, the complex environmental settings that characterize the area. Without this experience and knowledge, causal relationships often are misinterpreted because of a lack of an understanding of the possible, and indeed, probable causes. This calls for greater efforts to attract additional experienced and imaginative researchers to the effort, particularly university scientists who, in the process, train the scientists needed to address problems in the decades to come.

Toward A Synthesis

Because of the seeming imminence of a major restoration thrust aimed at the Everglades and Florida Bay ecosystems, it is essential that a vigorous undertaking be initiated to synthesize and summarize the pertinent research results developed to date in the paleoecology elements of the Science Program. Normally, this would be done through publication of results by individual investigators in the scientific literature and the “post-digestion” interaction of investigators in closely related fields. However, the urgency of the need for scientific synthesis to guide the restoration dictates that another course be followed. This can be accomplished one or two individuals who would receive summarizing information from the contributing researchers and from these generate the kinds of information and recommendations that are likely to be most useful to planners and decision makers. Alternately, this could be accomplished by a multidisciplinary team constituting a task force for the purpose. However, it should be recognized that latter approach requires major commitment of time and energy by the investigators. One innovative output that might be appreciated, and hence have a possible impact, could be in the form of one or more concise information leaflets that could be made available to those concerned with moving the restoration effort forward.

In any event, this synthesis effort should not unduly disrupt the efforts to contribute to the development of new data and information on these ecosystems. It must be emphasized that the continuation and expansion of the basic research effort is absolutely essential to provide the information required to monitor and control the impacts of the chosen restoration procedures.

Because Everglades restoration efforts focus heavily on the introduction and management of freshwater in the ecosystem, determining salinity variations in Florida Bay and the marine transition zone is one of the most important objectives of the Science Program. The Corps of Engineers (COE) Restudy of the Central and Southern Florida Project (Restudy) will need to determine how much water to put down Taylor Slough and, potentially, Shark River Slough to optimize the productivity of Florida Bay and maintain a healthy ecosystem. Past salinity variations as revealed in paleoecology research will help the COE determine how much water to discharge into the Bay. Research undertaken by a number of individuals appears to be closing in on this information including Hood, Ishman and Cronin on ostracods, forams, and Sr/Ca ratios as well as Swart's use of $\delta^{18}\text{O}$. The molluscan indicators of salinity variation do not appear to be as useful as the above indicators. Meeder indicated that there had been a movement of the “white

zone” north particularly east of U.S. 1 as a consequence of a decrease in flows; this information needs to be conveyed to the COE to ensure that they put sufficient flow east and west of U.S. 1 to move the white zone farther south. Any additional research and the synthesis effort should focus on the determination of historical variations in salinity and the relationship of these variations to the abundance of seagrass and living resource productivity.

The modelers at SFWMD and the COE (Richard Punnett) who are currently performing Restudy modeling need to be fully informed of the results of the paleontological research to see how it can affect the alternatives that they are currently modeling. Because the modeling will only last until April, this coordination should be done as soon as possible. It is apparent from meetings of the Restudy, that the COE appears to be disconnected from the work going on in Florida Bay, and this gap needs to be bridged.

Issues that should be specifically addressed in the synthesis of results include the following:

A. Salinity variation.

Analyze all data on salinity variation including rainfall proxies such as Everglades vegetation and ENSOs, $\delta^{18}\text{O}$ fluctuations, ostracodes, forams, and mollusks. Specifically,

1. Compare magnitudes of fluctuations, to extent possible.
2. Carefully scrutinize chronologies. In general, all seem to agree on elevated salinity, in recent years, but rates and times of onset seem to vary considerably.
3. To the extent possible try to objectively weigh anthropogenic causes (drainage, water management, and railway construction) versus natural causes (drought; sedimentation, especially in tidal channels and shoreline levees; mangrove growth or destruction; erosion of peat; and shoreline erosion).
4. Evaluate proxies or covariants, e.g. could the $\delta^{18}\text{O}$ signal be in part a temperature signal? (Swart has incorporated this in analyzing coral data). In particular resolve the effects on $\delta^{18}\text{O}$ by sea-water mixing versus Everglades run-off. Miami rainwater has $\delta^{18}\text{O} \sim -3\text{‰}$; evaporated runoff from the Everglades is $\sim 1\text{‰}$, but would vary with rainfall and temperature, seasonally and annually; normal sea water is 0 to -2‰ , but Florida Bay water is characteristically somewhat higher, because of evaporation and Everglades inflow. These complex interrelations probably preclude quantitative estimates of Florida Bay paleosalinity except by empirical calibration from measurements going back to the 1950's (e.g. RM Lloyd, 1962). However, $\delta^{18}\text{O}$ probably is the most sensitive paleosalinity indicator, has the highest temporal resolution from coral banding, and remains the best hope for quantification.

B. Salinity and water flow.

ENP has a holy grail quest, to restore as much water flow as possible, which is probably justified for Everglades “restoration” and is certainly understandable. However, this should not temper scientific results from Florida Bay via too much focus on salinity as the causal factor.

1. Possible side effects of increased water flow to Florida Bay, such as increased nutrients, need to be carefully evaluated.
 2. Increased water to Everglades does not necessarily mean increased water to the Bay. Most of the water in the Everglades is carried through the Shark River Slough, which exits through Whitewater Bay and westward into the Gulf. Florida Bay directly receives runoff only through Taylor Slough and related short drainages rising south of the oolite ridge or “Pine Islands.”
- C. Marine transition zone changes.

The effects of changing freshwater flows on the marine transition zone of the lower Everglades should be synthesized in order to allow an understanding on the effects of restoration strategies on this important environment. Because these areas are directly affected by the influx of fresh water from restoration activities they will be those parts of the greater ecosystem most immediately impacted.

Restoration Goals and Management Guidelines

One of the objectives of the Workshops was to (at least begin to) develop restoration goals for Florida Bay and the lower Everglades. The Workshop fell far short of meeting that objective, in large part because a concerted synthesis as described above had not yet been accomplished. Another limitation is that these ecosystems, as all ecosystems, are naturally variable and subject to secular changes (e.g. sea-level rise). To think that, even if we knew what we would like to “restore” them to, we could do so is somewhere between arrogant and naïve. As Hal Wanless said during the Workshop discussion, managing these ecosystems is something like “walking a big dog.” We can only do so much to move it in the desired direction.

In general, the restoration goals should be to maintain the environment in a state free of the unwanted environmental changes that have occurred during the historic period. This implies the establishment of conditions that promote the existence and well-being of members of the natural ecosystem, and it implies active human regulation of the environment. The above synthesis will contribute substantially to the specific goals, but will need to be integrated with the modern environmental studies, including those that relate environmental conditions to valued resources, and to the consideration of management options that are technically feasible.

Management guidelines should be flexible enough to respond to changing environmental conditions. Several investigators (e.g., Ross, Meader, Hood) document strong interactions between management practices (e.g., construction of canals, periodic release of water in Taylor Slough) and environmental change (e.g., sea-level rise, droughts). Data of Ross and Hood show that the rate of retreat of coastal vegetation zones in response to sea-level rise is twice as fast where construction of canals has reduced water flow to the coast. Hood indicated that the a drought during the “MAP” management period produced fewer changes in the foraminifers and ostracods preserved in Bay sediments than did a drought during the “RFP” management period.

The only available long-term (century, millennia) environmental data presented at the workshop are for the vegetation history of the Everglades (Winkler, Willard). These pollen studies indicate that during the last 2000 years the Everglades have been both drier than and wetter than the historic extreme values. For managers this is a reassurance and a warning. It indicates some resiliency of the ecosystem, because the Everglades vegetation types (Tedesco)

have persisted despite major climatic perturbations. However, the communities that existed during the prehistoric extremes probably would have precluded some of the agricultural, fishing, and tourist activities that the current ecosystem supports.

Finally, it should be recognized that Florida Bay and the lower Everglades are being subjected to a regime of increased sea-level rise during the 20th Century and that there are compelling reasons to suspect that sea-level rise will continue to accelerate in the next century. This will obviously place some limits on what can be achieved in ecosystem restoration, but it also dictates that a significant part of the management, if not restoration, strategy should be enhancement of the wetlands' ability to aggrade soil (peat as well as carbonates) to keep up with rising sea level.