An Investigation of Nutrification in the Florida Reef Tract and the
Management of Water Quality in the Florida Keys

INTERNSHIP REPORT

by

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I. INTERNSHIP OVERVIEW

The first part of my research internship was fulfilled with Dr. Alina Szmant of the University of Miami's Rosenstiel School of Marine and Atmospheric Science (RSMAS). We conducted nutrient studies as part of the SEAKEYS (Sustained Ecological Research Related to Management of the Florida Keys Seascape) program. The SEAKEYS program began in 1989 through a grant from the John D. & Catherine T. MacArthur Foundation to the Florida Institute of Oceanography. In the Summer and Fall of 1992, our study was expanded to conduct intensive weekly nutrient sampling throughout the Keys with additional support from The Nature Conservancy (TNC). Our investigation was carried out at Long Key, with the assistance of the Keys Marine Laboratory. Sampling was also conducted simultaneously at Key Largo by the National Undersea Research Center (NURC), and at Looe Key by the Harbor Branch Oceanographic Institute on Big Pine Key. The goal of this investigation was to provide a short, but intense database on the concentrations of nitrogen and phosphorus macronutrients and chlorophyll to compare nutrient conditions in different areas of the Florida reef tract. This data will help scientists and resource managers gain insight into the question of whether nutrification of the Florida Reef Tract occurs at present.

My role in this project was that of research assistant to Dr. Szmant. My responsibilities included field sampling, sample processing, and data analysis, in addition to those duties involved with managing the laboratory. For the second portion of my internship, I was contracted by TNC to prepare the final report of the weekly nutrient sampling project. The following document is a modification of that final report as presented to TNC in April 1994, which includes the findings from this project, as well as a study of the management of water quality in the Florida Keys.

II. INTRODUCTION

As one of 67 counties in the State of Florida, Monroe County could be considered one of the most unique. Within this county lies a 225 mile long chain of 97 islands extending southward from the southern tip of Florida, called the Florida Keys. These islands maintain some of the richest natural resources in Florida, if not in the entire United States. What best characterizes the Keys, however, is its intimate relationship with the sea. Here, mangrove forest, seagrass meadow, and coral reef communities all interact to create a complex, subtropical ecosystem that supports enough plant and animal species to rival any tropical rainforest (Beatley, 1991).

The Keys depend physically and economically on this subtropical biodiversity. The mangroves that fringe the islands shoreline help to decrease coastal erosion while acting as a filter for nutrients and sediment (De Freese, 1991). Existing as the third largest barrier reef system in the world and the only extensive inshore living coral reef system in the continental United States, the Florida Reef Tract protects the Keys from strong ocean currents, wave action, and storms. The coral reefs create a low energy environment that is necessary for the survival of the mangroves and seagrass beds, which act as important nursery grounds for many juvenile marine organisms including reef fishes (Booker, 1991). The coral reef, which can only survive in low nutrient, clear waters, is the backbone to a very profitable commercial and recreational fishing industry in the Keys. It is this abundance of wildlife that attracts so many divers, naturalists, and tourists from all over the world. Therefore, the economy of the Florida Keys is tied directly to the preservation of these water resources (EPA, 1993).

The common linkage of these habitats is the constant flow of seawater between them and their dependence on high water quality (De Freese, 1991). Under unaltered conditions, this association between communities is responsible for maintaining the quality of the water. Traditionally, this refers to the physical and chemical properties of the water (Karr & Dudley, 1981). While there is no data to support the position that extensive nutrification is occurring in the Florida reef tract waters, after years of human interference in the Keys, evidence of degraded water quality in inshore and confined waters is becoming visible (EPA, 1992b). Furthermore, the potential does exist for lower quality inshore waters to eventually reach offshore reefs, affecting the ability of the waters surrounding the Keys to support its diverse biomass. If this ecosystem is weakened, it will be unable to withstand and recover from natural disturbances, let alone be able to survive further human intrusion.

Directly or indirectly, any water quality problems in the Keys result from human activity, specifically, urbanization. Land based human activities in Monroe County, as well as in adjacent lands, introduce a variety of chemical pollutants into ground waters and surface waters that can be divided into two categories. The first are those pollutants that have direct toxic effects on marine organisms, for example, oils and greases from highway and marina runoff, pesticides and herbicides from residential and agricultural land uses and heavy metals from industrial sources. The second category is nutrient pollution or eutrophication from fertilizers and from the wastewaters of human sewage (LaPointe, 1991). People often perceive nutrients (ammonium, nitrate and phosphate plus organic forms of N and P) as "natural" and therefore less harmful, as opposed to pollutants, which evoke a sense of being "unhealthy". However, the marine organisms in the Keys, specifically the coral reefs, are adapted to living in waters with low nutrient concentrations. An increase in nutrient levels could potentially cause the decline of the coral species and shift the ecosystem to one that is dominated by algae (EPA, 1992a).

III. SOURCES OF WATER QUALITY DEGRADATION

Land based pollution enters the marine environment through two sources: (1) point-sources in which discharge flows directly into surface waters (e.g. sewage outfalls), and (2) non-point sources in which discharges enter the water in a diffuse form (e.g. stormwater runoff and submarine ground water discharge) (LaPointe, 1989; EPA, 1992a). There are several point-source discharge facilities scattered throughout the Keys. Domestic wastewater treatment facilities and municipal waste treatment plants comprise the majority of active dischargers in the Keys. Other point-source facilities include five federal installations and two industrial dischargers (EPA, 1992a). Directed by Florida Statute, sec. 403.021(2), this waste must receive a degree of "treatment necessary to protect the beneficial uses of the water." Under the Federal Water Pollution Control Act, also known as the Clean Water Act (CWA), a Federal permit is required whenever pollutants are discharged into navigable waters from a point source. In order for these facilities to operate, they must receive a permit from the Environmental Protection Agency (EPA), which is responsible for issuing National Pollutant Discharge Elimination System permits (33 U.S.C.A. sec 1342). Under the Florida Air and Water Pollution Control Act, most of these facilities must also receive permits from the former Florida Department of Environmental Regulations (FDER), now replaced by the Florida Department of Environmental Protection (FDEP) (F.S. sec 403.061).[1] According to an

EPA study (1992a), the number of facilities operating with permits in 1992 decreased by 50 percent since 1991. This has been partially attributed to more stringent FDER water quality standards that have recently been adopted by the State.

While non-point sources of discharge are not as concentrated as point-sources, they are now regarded as a greater threat to marine systems because they are much more difficult to monitor and/or control (LaPointe, 1991; Paterson *et al*.,1991). In the Keys, a large portion of non-point discharge originates from small domestic wastewater facilities, commonly called package plants. The effluent from package plants is disposed into boreholes or injection wells. However, most of non-point source wastewater originates from on-site sewage disposal systems (OSDS), which are either septic tanks or cesspits (EPA, 1992a). All of these systems rely upon the soil to filter and oxidize the wastewater before it reaches the ground water (Latham & Ethridge, 1989). However, the Keys are formed out of limestone and there is virtually no sub-surface soil. The limestone is very porous and anything dumped on the ground soon filters into the groundwater (Ward, 1990). Therefore, effluent from these sources, contaminated with heavy nutrient loads, most likely enters sub-surface ground water and eventually flows into adjacent canals, the bay, and ocean waters (LaPointe, 1989).

Although there are an estimated 5000 cesspits in the Keys, they have never been permissible in Florida and continue to be unregulated (Latham & Ethridge, 1989; EPA, 1992a). Cesspits are simply a hole in the ground into which raw sewage is released. This discharge flows directly into local groundwater without any treatment. In contrast to

' As of July 1993, FDER merged with the Department of Natural Resources (DNR) to become the Florida Department of Environmental Protection (FDEP).

cesspits, the 24,OOO septic tanks in the Keys are regulated.[2] While a functioning septic tank sufficiently rids wastewater of bacterial contamination, the effluent is similar to wastewater after primary treatment which means it is still high in nutrients (EPA, 1992a). Because of the soil limitations, this effluent eventually contaminates groundwater. In fact, septic tanks are often placed directly into the groundwater and so cracks result in the direct release of untreated wastewater into the groundwater (Latham & Ethridge, 1989).

Another recognized pathway of non-point source discharge is stormwater runoff, which is the surface runoff that occurs due to a rain storm. Although the composition of stormwater runoff can vary significantly from one area to another and from one rainfall event to another, preliminary evaluations of stormwater loads suggest that they could be a contributing factor to poor water quality (EPA, 1992a). The major cause behind stormwater runoff problems is land development. Oils and heavy metals in highway runoff and pesticides and fertilizers in land runoff wash into canals and other nearshore areas (LaPointe, 1991). As transitional wetlands and mangroves give way to roads, beach-front homes, and shopping centers, the natural filtering effect of the land is lost. Manmade canals aggravate the problem by interrupting the normal runoff patterns and concentrating low quality waste water in areas that are easily linked with nearshore waters (Duquesnel and Grimm, 1991).

The EPA (1992a) also identifies the discharge from marinas and boat live-

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[2] On-site sewage disposal systems are the responsibility of the Florida Department of Health and Rehabilitative Services under F.S. sec. 381 and the Florida Administrative Code, chapter 10D-6.

aboards, the mosquito control program, and landfills as additional non-point sources of seawater contamination. There is additional concern that external sources of water pollution may also affect the Keys. For example, the irrigation and flood control canal system in southern Dade County are alleged to deliver residential and agricultural surface runoff into Monroe County waters, such as Florida Bay (LaPointe, 1991).

Numerous factors affect water quality in the Keys, and trying to control them requires a comprehensive approach that includes land, as well as water management. In Hawaii, rainwater runoff and sewage effluent devastated coral reefs within Kaneohe Bay. When changes in land use and discharge practices were taken, the ecosystem began to shift back to normal (Banner, 1974; Smith et a1., 1981). Confined waters in the Keys show evidence of degraded water quality, especially where there are large numbers of OSDS's or marinas. While it is suspected that non-point source discharge is also affecting nearshore waters, demonstrated linkage is weaker than for the case of confined waters (EPA, 1992b).

In the Keys, a constant struggle exists between the uses of land and water. The marine environment is the backbone to the economy in the Keys. As more people enter the Keys to consume the resources, the economy grows and stimulates land development and urbanization. This development not only destroys natural habitats, but also increases the man-made stresses on the environment and environmental degradation.

IV. FLORIDA KEYS NATIONAL MARINE SANCTUARY

Our society has recognized the need to preserve the marine environment of the Keys through water quality protection. The numerous areas in the Keys awarded special protection embody this priority. Some of these areas are State Parks, a National

Monument, State Aquatic Preserves, and National Marine Sanctuaries. However, the creation of the Florida Keys National Marine Sanctuary (FKNMS) on November 16, 1990, is the ultimate recognition of the value of the Key's unique, yet fragile ecosystem (16 U.S.C.A. sec 1433, Florida Keys National Marine Sanctuary and Protection Act). The geographical boundaries of the FKNMS can be seen in Figure 1 and include 28,000 square nautical miles of nearshore waters that extend to, and include the Florida Reef Tract. The FKNMS physically encompasses the Key Largo National Marine Sanctuary and the Looe Key National Marine Sanctuary, which will operate as separate entities until their eventual incorporation into the FKNMS. However, all other areas of special protection are excluded from the FKNMS and maintain their original designation (EPA, .1992a).

In recognition of the critical role of water quality in maintaining these resources, the FKNMSP Act mandates the development of a Water Quality Protection Program (WQPP) for the Sanctuary (the first program of its kind ever developed for a marine sanctuary). The purpose of the program is to

> recommend priority corrective actions and compliance schedules addressing point and non-point sources of pollution to restore and maintain the chemical, physical, and biological integrity of the Sanctuary, including restoration and maintenance of a balanced, indigenous population of corals, shellfish, fish and wildlife, and recreational activities in and on the water (FKNMSP Act, sec 8 (a)(A)).

In addition to corrective actions, the Act also requires the development of a water quality monitoring program with provisions for public participation in all aspects of developing and implementing the program. The Act directs the EPA and the state of Florida, represented by FDEP, to develop the program, with cooperation from the National Oceanic and Atmospheric Administration (NOAA)(EPA, 1992b).

The management of Florida's coastal zone has been criticized because there has been a greater emphasis on land use practices than on the oceans that nearly surround the state (Christie & Johnson, 1990). This practice is not entirely ineffective, however, because the origin of most water quality problems lies with land use practices. In addition, the networking statutes and agencies that comprise the Florida Coastal Management Program do provide the necessary authority to protect water quality. Despite this, twenty years after the Federal Coastal Zone Management Act of 1972, Congress had to interfere with the management of Monroe County and mandate the WQPP.3 In 1973-1974, the Florida Coastal Coordinating Council (1974) conducted a study of the Florida Keys. This study found the "ecological balance" of the 'Keys to be very fragile and expressed recommendations for the management, research, and monitoring of water quality, specifically for sewage effluent, septic tanks, urban runoff, and even nutrient inputs. Twenty years later, Congress found that disturbances to the marine environment could cause damage to the "ecological integrity" of the Keys. The resulting draft of the WQPP has expressed recommendations for the management, research, and monitoring of water quality, specifically for sewage effluent, septic tanks, and urban runoff.

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[3] This was not the first time that Monroe County failed to properly implement its land use and environmental regulations. Conflicts between resource protection and an accelerating growth trend, led to Florida's designation of the Keys as an Area of Critical State Concern in 1975 (Garrett, 1991).

IV. HISTORY OF WATER QUALITY REGULATION IN FLORIDA

Although the Florida Constitution set forth its policy by requiring the abatement of water pollution, this was as much in response to conserving and protecting scenic beauty as it was for conserving and protecting natural resources (Florida Constitution, Article 11, Section 7). Historically, water quality protection has been achieved through a health-based approach concerned mostly with maintaining safe drinking water and protecting human health (Swihart *et al*., 1986). This approach has recently been broadened to include the preservation of aquatic ecosystems in an attempt to manage resources from a more holistic or system perspective (Karr & Dudley, 1981).

Florida's water plan emerged with the Florida Water Resources Act of 1972 (F.S. sec. 373). This plan joined the state water use plan, under the responsibility of the former Department of Natural Resources (DNR), with the water quality standards and classification system of the Department of Pollution Control (F.S. sec. 373.039). While the primary function of Florida's water use plan was to maintain an adequate supply of water, DNR was also responsible for improving water quality while giving consideration to the "protection and procreation of fish and wildlife" (F.S. sec. 373.036). The Department of Pollution Control was created to administer Florida's anti-water degradation policy under the Florida Air and Water Pollution Control Act of 1967. However, in 1975, the Environmental Reorganization Act created the FDER to assume the duty of formulating both the water use plan and the water quality standards. DNR was re-assigned to the management of state-owned lands and parks and to direct activities, such as boat registration and beach restoration (Blake, 1980; Christie, 1989). The amended Air and Water Pollution Control Act became part of Chapter 403 of the Florida

Statutes, and along with several other sections, provides the statutory basis for the regulation of most aspects of water quality in Florida (Maloney *et al*.,1980).

The Federal Water Quality Act of 1965 directed states to establish water quality standards or face imposition of federal standards. To effectively determine the applicable water quality criteria, Florida classified the waterbodies within its jurisdiction into general categories based upon the intended use of the waterbody (Maloney *et al*.,1980). Florida designated the surface waters of the state into five classes arranged in order of the degree of protection required, with Class I (drinking water) having the most stringent water quality criteria and Class V (waters for navigation) the least (Rule 17-302.400, F.A.C.). In addition to these five classifications, the state can designate water bodies "worthy of special protection" as Outstanding Florida Waters (OFW) (F.S. sec 403.061(27)). These waters, because of their exceptional recreational or ecological significance, are afforded the highest protection, which means there should be "no degradation of water quality" (Rule 17-302.700, F.A.C.). Currently, the entire FKNMS is classified as OFW and all canals in the Keys are designated as Class III, which are waters maintained for recreation and the propagation of fish and wildlife (Matthews, 1993).

There is a significant difference in the regulations between the protection of OFW's and surface waters. The criteria for surface water quality standards is set by the "minimum levels which are necessary to protect the designated uses of a water body" (Rule 17-302.100(9), F.A.C.). OFW's, on the other hand, must maintain "existing ambient water quality," which would severely limit most activities in the Keys (Rule

174.242(2)(a)2.b., F.A.C.). The restriction of direct discharge that would lower ambient water quality is accomplished by the permit process through FDER.

A problem exists in quantifying existing ambient water quality, which should be assessed by what was "expected to have existed" for a baseline year of the OFW (Rule 17-4.242(2)(c), F.A.C.). In the Keys, data for a baseline year does not exist and ambient water quality standards are based on the water quality data from the year before its OFW designation (Matthews, 1993). On the other hand, indirect discharge will not be permitted if it "significantly degrades" the OFW (Rule 17-4.242(2)(a), F.A.C.). While this allows OFW regulations to be site specific, there is much controversy in defining "significant degradation." Water managers never know the exact relationships between new activities and the ecological integrity of a water body (Swihart *et al*., 1986).

Another problem with the regulation of the OFW designation is that some activities that might degrade an OFW, which do not require a FDER permit, are almost entirely unaffected by the OFW designation (Swihart *et al*., 1986). Examples of such activities include stormwater runoff and septic tank installations.

Regardless of the OFW standards, the Key West Wastewater Treatment Plant operates with a FDER permit, although the effluent is discharged directly into surface waters and does not come close to meeting current regulations (EPA, 1992b). This can be explained by a loophole in the Codes that permits this discharge because "there is no alternative to the proposed activity, including the alternative of not undertaking any change, except at an unreasonable higher cost" (Rule 17-4.242(2)(b)3., F.A.C.). The economic costs to Key West must surely outweigh the environmental costs to the sensitive marine ecosystem.

Although research is the basis for sound, scientific knowledge, politics is the reality of management. Ultimately, the policymakers are the ones who must arrive at some generally acceptable decision based on the often conflicting scientific evidence. Without public support, however, management plans cannot be effective. Swihart *et al*. (1986) asserts that the OFW designation has strong support by local residents and local governments and is helping to protect Florida's most valuable waters from additional degradation. He attributes this to the limited number of OFW classifications assigned, which means that this is not an overall antidegradation policy for the waters in Florida. However, this is now an antidegradation policy for most of the waters in the Keys. While the residents of the Keys may be very supportive of environmental protection to correct a problem, it is a basic concept in belief system literature that when confronted with real-life policy, these residents will evaluate it in light of its cost to them and effects on their circumstances and lifestyles (deHaven-Smith, 1991).

IV. NUTRIENT PROJECT

While there is a general agreement among researchers that persistent nutrient enrichment can cause species shifts and deterioration of the Florida Keys reef communities, there is disagreement concerning the extent of present water quality degradation and whether there is on-going impact by nutrients to Florida reefs. Some contend that nutrients entering the coastal zone are triggering algal overgrowth that is smothering corals (Keating, 1992). However, with the exception of a phenomenon called "Algal Reef" within the Key Largo National Marine Sanctuary where algae are overgrowing gorgonians, there is no direct evidence of widespread overgrowth of reef corals by algae. In addition, while it is true that there are few nutrient data with which to describe the nutrient regime of the Florida Keys nor to assess the extent of impact by anthropogenic nutrients to reef areas, those that exist suggest that reef tract waters and sediments are characterized by generally low nutrient concentrations (Szmant & Forrester, 1993). Consequently, there is a need for more information of the distributions and concentrations of nutrients in order to evaluate the current status and trends of water quality in the Keys. However, a direct measurement of water column nutrients alone is not always a sufficient method for identifying nutrification. Excess nutrients in the water column can degrade water quality by stimulating algal blooms, which in turn can create toxic by-products, increase turbidity, cause a "greening" of the water, and deplete oxygen as they decay (EPA, 1992b; Nixon & Pilson, 1983; Parsons et al., 1984a). If increased concentrations of nutrients in the water column cause phytoplankton blooms, the phytoplankton can quickly deplete the nutrients from the water column to unmeasurable levels. Consequently, chlorophyll measurements were also used as a tracer of nutrient enrichment. The following short, but intense, sampling program was organized to provide a baseline on nutrient conditions for future programs and to address the question of present nutrification of offshore waters.

The Florida Reef Tract is characterized by greater reef development in the upper keys, less development in the middle keys and somewhat renewed reef development off the lower keys (Jaap, 1984; Shin *et al*., 1989). It is believed that historical, flow of naturally poor quality water from Biscayne and Florida Bay to the reef tract is the reason for this distribution of the coral reefs (Jaap, 1991; Shin *et al*.,1989). Long Key, situated in the middle keys, is surrounded by wide passes that allow unrestricted flow of water between Florida Bay and the Atlantic Ocean. Consequently, the reef tract offshore of

Long Key is characterized by few and less developed reefs. In contrast, the reef tract offshore of Key Largo, located in the upper keys has extensive reef development. This large island has only a single opening from the bay to the Atlantic Ocean, thus forms a natural dam that restricts water flow from Florida Bay onto the reef tract (Jaap, 1991).

Given these natural differences in water quality, one of the objectives of this study was to provide a nutrient data base that could be used to compare and contrast between the water column nutrient regimes of the three major regions of the Florida Reef Tract: the Key Largo area, with the best reef growth and possibly the highest potential for locally-derived anthropogenic impact; the Long Key area, with only a few patch reefs that receives most of the out-flow from Florida Bay; and the Big Pine-Looe Key area, with good reef development that receives out-flow from the southern reaches of Florida Bay/Gulf of Mexico and potentially from developments in the Big Pine area.

VII. METHODS

<u>LONG KEY AREA:</u> Two transects were selected at Long Key from nearshore locations to the offshore reef tract, in alignment with the large passes (Figure 2). The eastern transect had six stations from the Channel 5 Bridge to Tennessee Reef and the western transect included four stations from the Long Key Viaduct to the 12' Bank. Once the stations were established, Loran C and GPS were used to relocate the stations each week. Weekly sampling began in June 1992 and continued until December 1992. Sampling occurred once a week (approximately every 7 days, weather permitting) during low tide. Within 24 hours of this day, stations were being sampled at similar Key Largo and Looe Key transects.

Water samples were collected at each station with 3.0 liter Niskin bottles deployed from a small boat. Samples were taken 1m below the surface and 1 m above the bottom. If the water depth was less than 3m, then a single sample was taken at mid-depth. Water samples were transferred to conditioned 1 liter polyethylene bottles after rinsing three times with the sample. These bottles were kept on ice and in the dark until being returned to the laboratory for processing. 60-120mls of the sample water was filtered through GF/F glass-fiber filters to collect particulates for chlorophyll analysis. Filters were frozen dry and transferred to RSMAS where they remained frozen until analysis. Subsamples of both filtered and unfiltered water were placed into duplicate 250ml conditioned polyethylene bottles and stored frozen until transfer to either NURC (filtered samples analyzed for nitrate plus nitrite, ammonium and phosphate by Alpkem autoanalyzer techniques), or RSMAS (unfiltered samples analyzed for total nitrogen and total phosphorus by the persulfate method of D'Elia *et al*. (1977)). In the RSMAS laboratory, chlorophyll filters were placed in 15mí centrifuge tubes with 90% acetone and extracted in a freezer in the dark overnight. Chlorophyll concentrations were measured with a Turner Model 112 fluorometer calibrated against a chlorophyll a solution from spinach leaves (Parsons et al., 1984a).

<u>KEY LARGO AREA:</u> The Key Largo transect extended from the Tavernier Creek Marina to offshore of Conch Reef, and had 7 stations. Weekly sampling began in June 1992 and continued until October 1992. Sampling protocol was similar except that water samples were filtered while still on the boat. Chlorophyll filters were placed into microcentrifuge vials with 1 ml of 90% acetone and vials stored on ice in the dark. Vials were frozen upon return to shore and transferred to RSMAS for analysis. Filtered water

samples were analyzed for dissolved inorganic nutrients as described above. There was not a complete analysis of total nitrogen and phosphorus done on the Key Largo samples.

BIG PINE-LOOE KEY AREA: A transect was sampled weekly from the Big Pine area to Looe Key from June 1992 until August 1992. Information and data from this area was unavailable.

VIII. RESULTS

Figure 3 presents all of the nutrient and chlorophyll data for the Long Key or Key Largo transects, as a time-series. This data set illustrates the high variability of concentrations from week to week. The fluctuations are not only from the introduction of new nutrients into the water column, but also because nutrient and chlorophyll levels in the water column are influenced by factors, such as storms that resuspend sediments and release stored nutrients, the amount of rain fallen, and surface run-off. Seasons and tides can also play a role in the variability of these measurements, but in this project all sampling was done during low tide in the wet season.

The nutrient and chlorophyll data from Key Largo demonstrates how storms can increase water column nutrients. On August 24 (marked by a triangle on Figure 3), Hurricane Andrew crossed South Florida. Although the Hurricane did not reach as far south as Key Largo, the area did experience strong storm conditions. During the following two weeks, total phosphorus concentrations were almost double and total nitrogen and reactive PO_4^{3-} concentrations increased as well.

Temporally, the plots do not reveal new information. Therefore, to gain insight into this database, the data was plotted as a summary of the mean concentrations for each station sampled along each transect (Figure 4). The stations are plotted from nearshore to offshore; the surface and bottom samples from the most offshore stations were plotted separately. These figures include only the data collected through October 16, 1992 (last sampling date for Key Largo). Excluding this data was necessary in order to avoid a phenomenon called the "algal bloom" that otherwise would have biased the analysis of the data.

The "algal bloom", that has plagued Florida Bay waters since early 1992, is thought to be the after effect of a massive sea grass die off. The cause of the sea grass die off is unknown, but proposed causes include high water temperatures and salinity, excess nutrients from fertilizer runoff, a mysterious slime mold, and the lack of a hurricane in Florida Bay (Reiss, 1992). The bloom of microscopic algae has now affected an area as large as 100,000 acres. It turns the once clear waters a turbid green, destroying organisms and habitats in its path (Boesch *et al*.,1993).

While sampling on October 30, 1992, very green, cloudy water was observed as far out as the inshore side of Hawk Channel at both the Long Key Viaduct (LKV) and Channel 5 transects. On this date, nearshore chlorophyll concentrations averaged 18.9 and 11.6 ug/1, respectively, and nearshore total phosphorus concentrations at both transects were 1.9 uM. These concentrations are exceptionally high as compared to a value typical for oligotrophic water ($\leq$0.25 ug/1) and to mean nearshore chlorophyll and total phosphorus concentrations prior to the bloom (0.3 ug/1 and 0.1 uM, respectively) (Parsons *et al*., 1984b) Concentrations remained high over the next and last two sampling dates.

Table 1 shows a comparison of mean nutrient and chlorophyll concentrations from October 30-December 14,1992, when the "algal bloom" waters were observed, with concentrations measured up to October 16. As might be expected, $N0_3^-$ and $P0_4^{3-}$ concentrations were as low or lower in the post algal bloom samples. Although there is no statistical difference ($p>0.05$) between the two transects, mean nearshore concentrations of total nitrogen, total phosphorus and chlorophyll at LKV were higher than at the Channel 5 transect. This might be due to the physical difference between the two Long Key transects'. The pass out to the reef tract along the LKV transect is much wider than that of the Channel 5 transect (Figure 2). Although the path of the algal bloom is dependant on currents and wind, this could allow for a greater flow of Florida Bay water toward the reefs.

Prior to the "algal bloom", the mean concentrations along the two transects had some variability (Figure 4). Inshore mean concentrations of $N0_3^-$, $P0_4^{3-}$, total phosphorus, and chlorophyll were statistically the same ($p>0.05$), however, inshore concentrations of NH_4^+ and total nitrogen were higher at the Channel 5 transect than at LKV. For offshore stations, mean concentrations were statistically the same except for total phosphorus which was 1.5 times greater at LKV than at the Channel 5 transect.

Both Long Key transects show a significant trend of decreasing concentration from nearshore to offshore of $N0_3^-$, NH_4^+, and total nitrogen (Figure 4). Similar nearshore concentrations for total nitrogen and $N0_3^-$ during low tide have been recorded in previous nutrient research from the Long Key area (Szmant and Forrester, 1993). This research offers concentrations which were about twice those as in high tide samples. These data suggest the input from Keys, nearshore areas and/or Florida Bay are potential sources for nitrogen for reef tract coastal waters. Although inshore concentrations of nitrogen were elevated, offshore concentrations of $N0_3^-$ and NH_4^+ were typical of coral reef environments ($N0_3^-$: 0.1-0.3 uM; NH_4^+: 0.2-0.5 uM) (Crossland, 1983).

By contrast the data shows no significant difference between nearshore and offshore concentrations of total phosphorus, $P0_4^{3-}$, or chlorophyll, although the mean concentration of total phosphorus increased from nearshore to offshore along both transects (Figure 4). The data from Szmant and Forrester (1993) also found this increasing trend which suggests that both Florida Bay and offshore upwelling are sources of phosphate for this area. Evidence of offshore upwelling is also supported by the discovery of an oceanographic gyre system that occurs off the Middle and Lower Florida Keys, called the Portales Gyre, that results in the upwelling of deeper nutrient-rich water from below the thermocline into the upper photic zone (Lee *et al*.,1991).

Nitrogen to phosphorus ratios (N:P) can also be used as indicators of nutrient sources. Figure 5 is a plot of the N:P ratios for the inorganic nutrients in the Long Key and Key Largo water samples. Plots of the Redfield ratio (16:1) in which phytoplankton generally consume nutrients ace included for reference (Parsons *et al*., 1984b; Szmant, 1991). There is a significant relationship between offshore inorganic N:P ratios. Overall, Key Largo waters had much lower phosphorus and higher nitrogen concentrations than Long Key. Offshore, the N:P ratio for Long Key was near 16:1 while that offshore of Key Largo was 33:1, indicating greater phosphorus enrichment (upwelling?) in the Long Key area.

In the Key Largo transect, inshore concentrations of total nitrogen, $N0_3^-$, NH_4^+, and, chlorophyll were also statistically higher than those offshore (Figure 4). No difference was detected between inshore and offshore concentrations of $P0_4^{3-}$, total phosphorus, or chlorophyll.

A comparison of Long Key and Key Largo nutrient concentrations shows that the mean inshore concentrations of NH_4^+ and total nitrogen were significantly higher at Key Largo than at both Long Key transects, while concentration of $P0_4^{3-}$ at Long Key was 2.5 times greater than at Key Largo. However, the mean concentration of $P0_4^{3-}$ at Long Key was only 0.1 μM, a value that is still lower than typical reef $P0_4^{3-}$ concentrations of 0.4 uM (D'Elia and Wiebe, 1990). There were no differences in the mean inshore $N0_3^-$ and chlorophyll concentrations between Key Largo and Long Key. Offshore, mean concentrations of all nutrients were higher in the Long Key area than off Key Largo except, for total phosphorus which was statistically the same.

IX. DISCUSSION AND CONCLUSIONS

Extensive development and general human activity in the Keys has prompted the need for research to determine whether nutrification of the Florida Reef Tract occurs at present. The results from this project, however, do not demonstrate that the reef areas off of Long Key and Key Largo are receiving elevated loads of land-derived nutrient via surface water flow.

Although this study did find elevated concentrations of nitrogenous nutrients nearshore, offshore concentrations are at levels typical for reef waters. This pattern indicates terrestrial and nearshore sources of nitrogen, likely including both natural and anthropogenic inputs. At Long Key, this pattern could also be the result of Florida Bay water flowing through the wide passes on either side of the Key. In contrast, phosphorus and chlorophyll concentrations do not change from inshore to offshore. The low pre-bloom chlorophyll concentrations, a tracer for nutrient enrichment, found at Key Largo and Long Key, both inshore and offshore, are the strongest evidence to support this conclusion.

The effects of anthropogenically introduced nutrients entering the coastal waters are of great concern. Population size and land use patterns are very different between Long Key and Key Largo, which may explain some of the differences in the mean nutrient and chlorophyll concentrations. The population of Lower Key Largo is seven times greater and uses seven times as many OSDS's than the population of Long Key and Fiesta Key combined. Estimated discharge from septic tanks and cesspits into the groundwater is much higher at Key Largo (0.34 million gallons per day (MGD)) compared to 0.05 MGD at Long Key (EPA, 1992b). Since NH_4^+ is the principal form of nitrogen in sewage, contaminated groundwater seepage could be the reason that canal NH_4^+ and total nitrogen concentrations at Key Largo are significantly higher than inshore at Long Key (Smith *et al.*,1981). However, mean NH_4^+ concentrations offshore at Long Key are higher than at Key Largo which could be the result of water flow from Florida Bay onto the reef tract.

Nutrient loadings from anthropogenic sources cannot be ignored, but there is no evidence in this study that this lower quality inshore water is making its way offshore. There is a decreasing trend of nitrogenous nutrients from inshore to offshore at Key Largo and Long Key and all offshore concentrations were within or under those described as. typical reef values. However, further research needs to be done on the groundwater flow beneath the reef tract, since there. is concern that nutrient-contaminated groundwater could eventually reach the reef areas.

One of the best studies of the effect of sewage and run-off pollution impact on coral reefs in that of Kaneohe Bay, Hawaii. In contrast to Key Largo and Long Key sewage inputs listed above, point-source sewage discharge into Kaneohe Bay was approximately 5.0 MGD (Smith *et al*., 1981). This outfall resulted in the near obliteration of all coral reef communities in lower and central Kaneohe Bay. Upon the diversion of this outfall, sewage discharge in the Bay decreased to 0.29 MGD, similar to the estimated rate of discharge at Key Largo. With a flow rate of 0.29 MGD into Kaneohe Bay, Smith *et al*. (1981) reported a very rapid response of the entire system after the sewage diversion. An inventory of the mean nutrient concentrations at Key Largo and Long Key reveals some similarity between the Florida waters inshore nitrogen concentrations and pre-diversion nitrogen concentrations at Kaneohe Bay (Table 2). Although this might seem alarming, inorganic and total phosphorus concentrations at both Key Largo and Long Key were much lower than those recorded at the Kaneohe Bay sewage outfall and the rest of the Bay as well. This suggests that little sewage is entering Florida Keys reef waters at present.

The database generated by this study not only addresses the problem of nutrification, but is also an integral part of the water quality related monitoring and research programs needed throughout the FKNMS. Presently, there is a minimal number of existing agencies and organizations that actually perform water quality monitoring programs in the Florida Keys. It is the lack of consistent, long-term data that prompted the creation of the water quality monitoring program as part of the WQPP. This program will focus on documenting the status and trends of water quality and biological resources, as well as, measuring the success of remedial actions assumed by the research program (EPA, 1992b).

This type of information is vital to policy development and implementation, and, therefore, Congress gave this program a high priority. According to Fred McManus (1993), EPA Sanctuary Liaison, Congress authorized $3 million for 1994 and $4 million for 1995 to implement the research and monitoring program. However in September 1993, this money was not appropriated and only $185,00 was allocated for the fiscal year of 1994. Since then, the EPA has gathered funds from other sources, but has only accumulated a total of $380,000. Unfortunately, this is not enough to implement the original design of the WQPP, since a "bare bones" research and monitoring program would require a minimum of $2.25 million. The EPA is now concentrating on lobbying different agencies to re-direct some money toward the implementation of the plan, instead of implementing the program.

Maintaining the natural resources in the Florida Keys and in turn, its economy, depends upon the future of its water quality. While this research does not support a present nutrification problem in the areas studied, history has shown that without intervention, environmental disasters have occurred when resource management decisions have been made without adequate information (Christie, 1989). There is no doubt that the potential problem of water quality reduction in the Keys should receive further attention, although exactly how to proceed may be in question.

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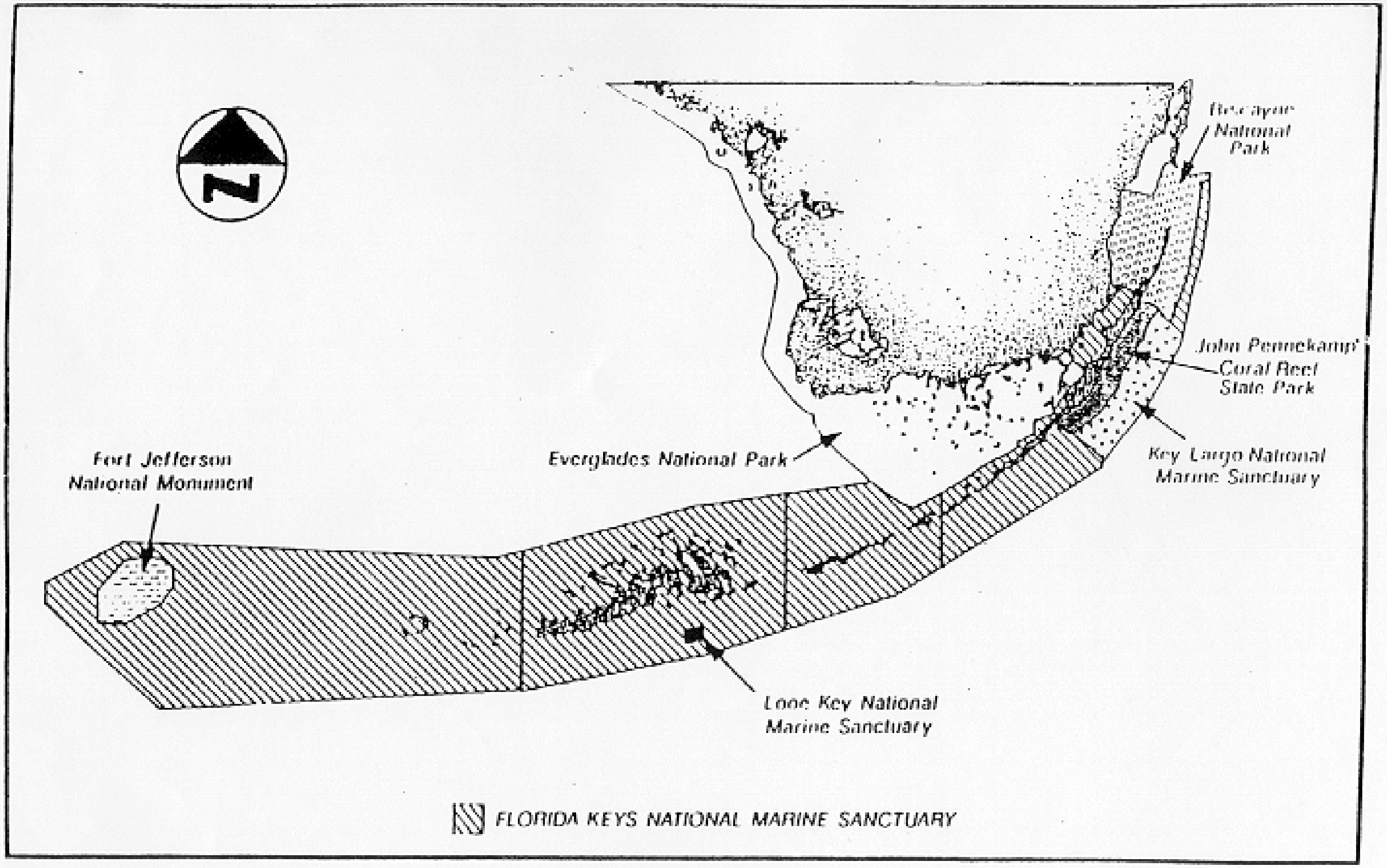

Figure 1 The Florida Keys National Marine Sanctuary.

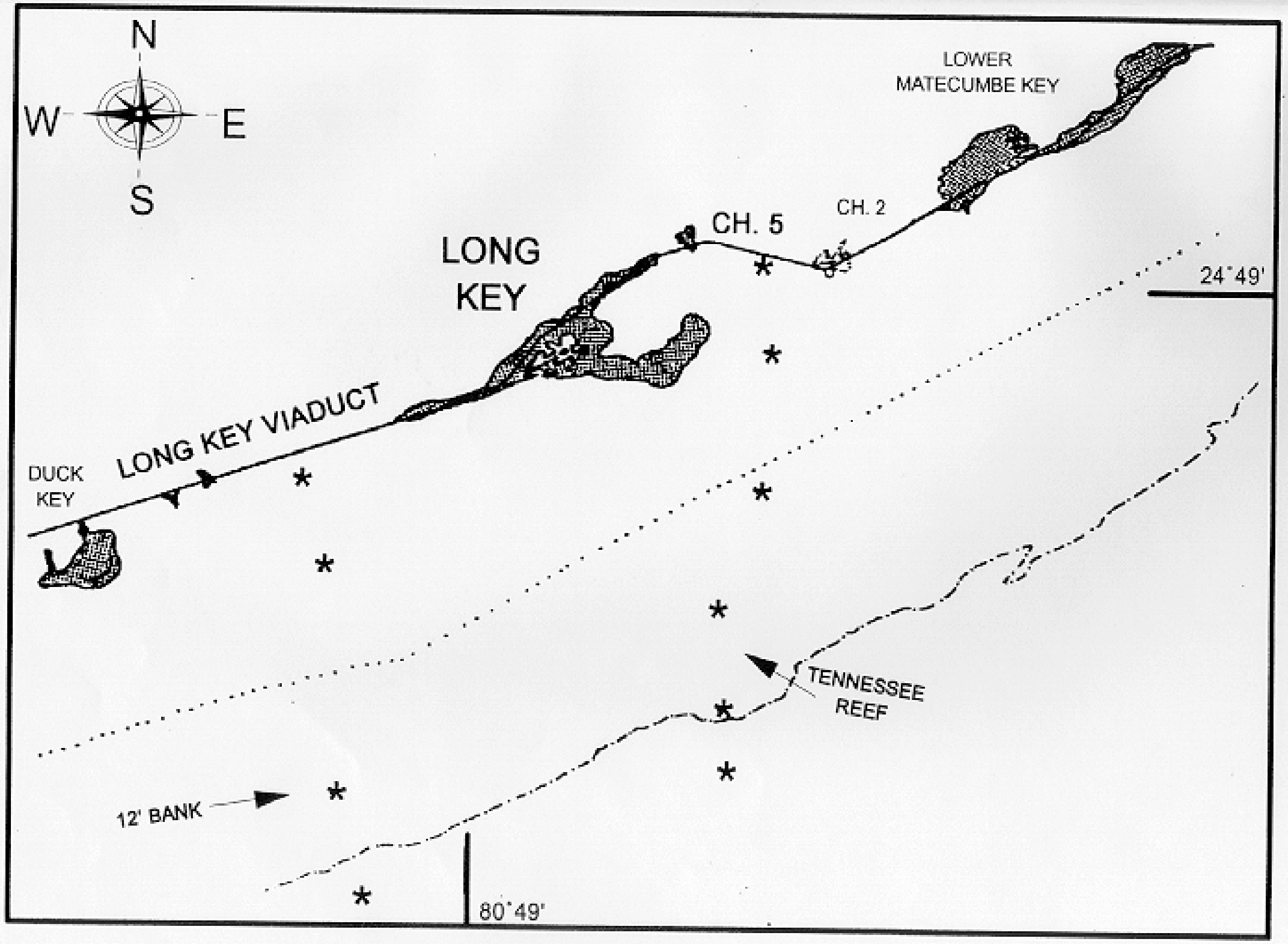

Figure 2. Map of Long Key showing sampling stations (indicated by stars).

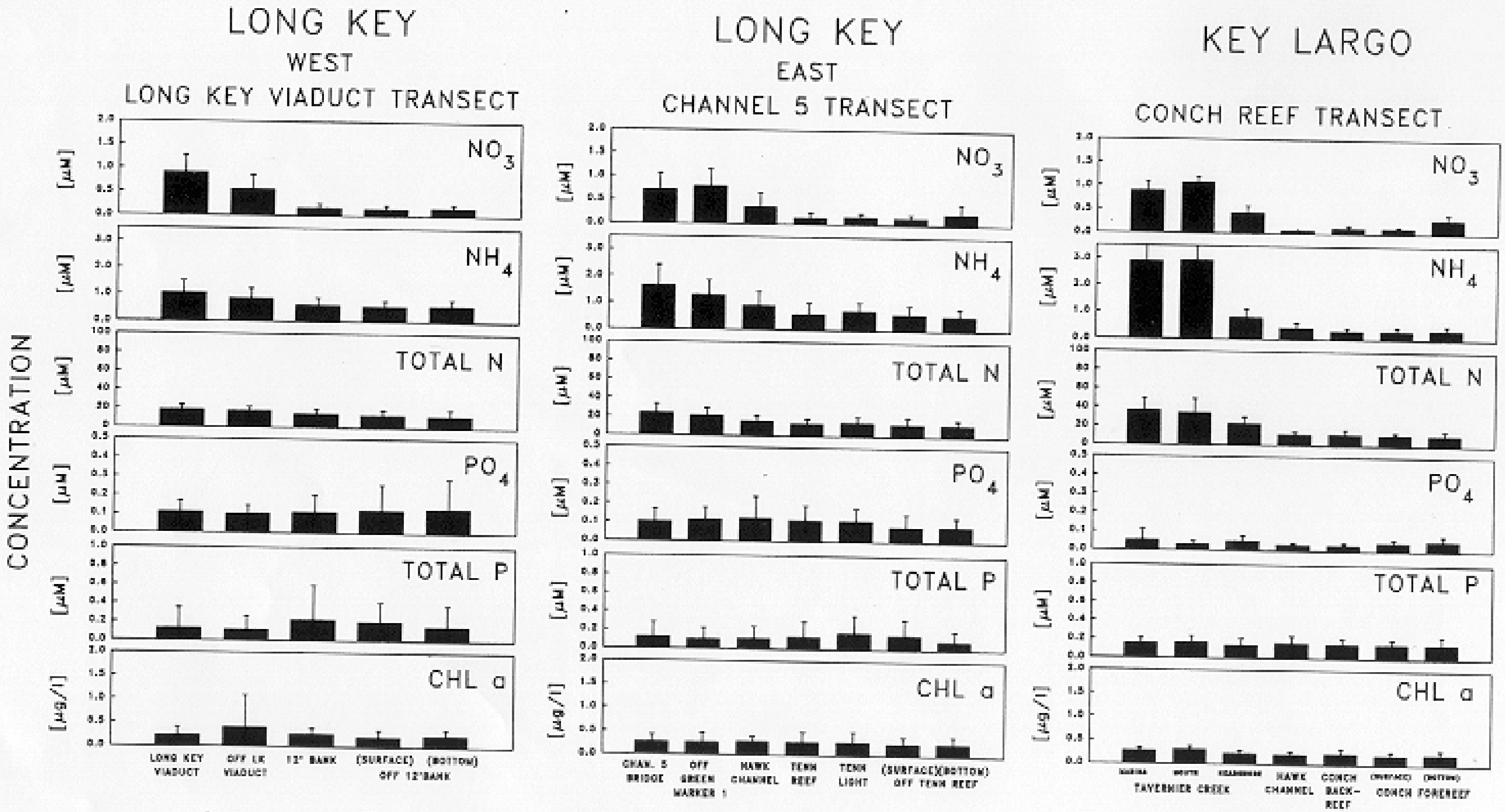

Figure 4. Dissolved ammonium, nitrate and phosphate and total nitrogen, total phosphorus, and chlorophyll a concentrations measured from nearshore to offshore at Long Key sampling locations from June 9– October 16, 1992 and at Key Largo sampling stations from June 10– October 16, 1992.

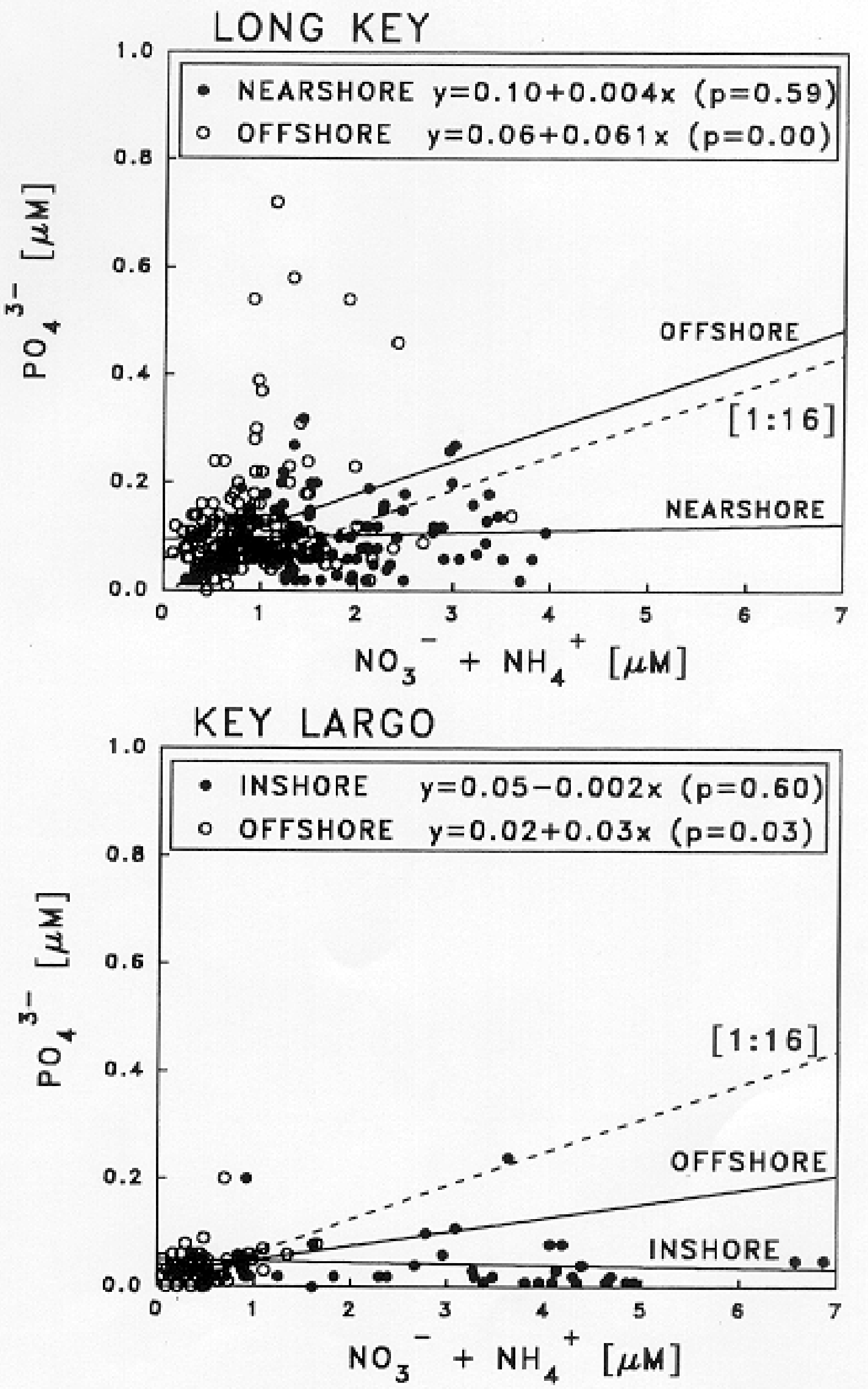

Figure 5. Inorganic N:P plots for Long Key and Key Largo. Nearshore and offshore stations are plotted separately and includes data from June–October 16, 1992.

TABLE 1

COMPARISON OF MEAN NUTRIENT CONCENTRATIONS (± STD DEV) BETWEEN LONG KEY SAMPLING STATIONS
PRE-ALGAL BLOOM (JUNE 9-OCTOBER 16, 1992) AND
POST-ALGAL BLOOM (OCTOBER 30-DECEMBER 14, 1992)

	NO_3^-		NH_4^+		TOTAL N		PO_4^{3-} (μmoles/l)		TOTAL P		CHL a	
STATION	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
LKV	0.90 ±0.37	0.15 ±0.00	1.03 ±0.47	1.40 ±0.29	18.3 ±4.77	79.0 ±47.1	0.11 ±0.06	0.15 ±0.03	0.13 ±0.22	1.79 ±1.16	0.22 ±0.19	9.30 ±7.12
OFF LKV	0.54 ±0.31	0.50 ±0.02	0.85 ±0.38	1.28 ±0.00	17.3 ±4.98	74.9 ±43.9	0.10 ±0.05	0.18 ±0.00	0.11 ±0.15	0.88 ±0.82	0.40 ±0.68	9.40 ±9.43
12′ BANK	0.15 ±0.10	0.19 ±0.01	0.58 ±0.29	0.69 ±0.15	14.6 ±5.41	20.7 ±4.72	0.11 ±0.09	0.06 ±0.01	0.22 ±0.37	0.34 ±0.21	0.25 ±0.14	0.55 ±0.36
OFF 12′ BANK	0.15 ±0.08	0.19 ---	0.58 ±0.23	0.67 ±0.09	12.6 ±6.59	12.1 ±2.40	0.12 ±0.15	0.10 ±0.03	0.18 ±0.22	0.19 ±0.26	0.22 ±0.15	0.39 ±0.18
CHANNEL 5	0.71 ±0.35	0.56 ---	1.62 ±0.79	1.51 ---	24.1 ±9.20	68.1 ±46.8	0.10 ±0.07	0.48 ±0.00	0.12 ±0.16	0.96 ±0.82	0.25 ±0.17	5.09 ±3.39
OFF G-1	0.80 ±0.36	0.07 ---	1.26 ±0.59	1.10 ---	21.2 ±8.25	62.8 ±39.3	0.11 ±0.07	0.18 ±0.00	0.10 ±0.12	0.93 ±0.70	0.25 ±0.21	3.73 ±2.53
HAWK CHANNEL	0.35 ±0.30	0.65 ±0.16	0.88 ±0.54	0.81 ±0.08	15.5 ±5.54	32.1 ±18.5	0.12 ±0.12	0.14 ±0.07	0.11 ±0.13	0.60 ±0.69	0.27 ±0.13	2.59 ±3.12
TENN REEF	0.13 ±0.11	0.07 ±0.01	0.59 ±0.42	0.62 ±0.15	13.3 ±4.83	10.4 ±3.92	0.11 ±0.08	0.16 ±0.05	0.13 ±0.16	0.44 ±0.39	0.28 ±0.20	0.51 ±0.24
TENN LIGHT	0.15 ±0.08	0.19 ±0.01	0.70 ±0.34	1.78 ±0.06	14.3 ±6.58	16.3 ±11.6	0.11 ±0.07	0.25 ±0.13	0.17 ±0.19	0.54 ±0.67	0.28 ±0.24	1.35 ±0.22
OFF TENN REEF	0.18 ±0.17	0.22 ±0.01	0.56 ±0.32	0.86 ±0.08	12.3 ±6.80	11.3 ±8.00	0.08 ±0.06	0.09 ±0.01	0.12 ±0.14	0.49 ±0.44	0.24 ±0.16	0.42 ±0.18

TABLE 2

NUTRIENT INVENTORY (MEAN ±STD DEV) FROM KANEOHE BAY, HAWAII, LONG KEY, AND KEY LARGO
(μmoles/l)

	KANEOHE BAY[1]		LONG KEY				KEY LARGO	
			LKV		CHANNEL 5			
	Pre-Diversion	Post-Diversion	Near shore	Off shore	Near shore	Off shore	Inshore	Offshore
NO_3^-	0.91	0.52	0.75 ±0.36	0.20 ±0.21	0.73 ±0.39	0.15 ±0.09	0.79 ±0.35	0.14 ±0.15
NH_4^+	2.28	0.57	1.46 ±0.74	0.68 ±0.44	0.94 ±0.44	0.58 ±0.27	2.20 ±1.50	0.34 ±0.28
TN	15.8	10.9	22.7 ±8.99	13.8 ±6.15	17.8 ±4.93	13.6 ±6.15	31.0 ±14.3	11.2 ±4.20
PO_4^{3-}	0.88	0.18	0.10 ±0.07	0.10 ±0.08	0.10 ±0.06	0.12 ±0.13	0.04 ±0.05	0.04 ±0.03
TP	1.65	0.58	0.11 ±0.15	0.13 ±0.16	0.12 ±0.19	0.20 ±0.31	0.15 ±0.07	0.15 ±0.07

1. (Smith, et al., 1981). For station OF near sewage outfall.