Florida Keys Reasonable Assurance Documentation

LIVING RESOURCE POINTS FOR FKRAD

Compiled by Pat Fricano
Florida Department of Environmental Protection

2/20/07

SEA GRASSES & ALGAE

2002-03 FKNMS SANCTUARY SCIENCE REPORT CARD

Results from the Water Quality Monitoring Project, an element of the Water Quality Protection Program (WQPP; http://ocean.floridamarine.org/fknms_wqpp/), indicate that overall nutrient concentrations were greatest in waters on the Gulf of Mexico side of the Keys and lowest on the Atlantic side along the reef tract and in the Tortugas region. Inshore waters differed from reef tract waters mainly by having higher concentrations of nitrate. Inshore waters of the less-inhabited Upper Keys exhibited lower nitrate concentrations than the Middle and Lower Keys. Interestingly, inshore waters in the Tortugas area were similar to those of reef tract sites off the less-inhabited Upper Keys. Essentially, there was no elevation of nitrate in the inshore waters of the Tortugas, supporting the suggestion that the source of nitrate in the Keys is shoreline development.

Waters on the Gulf side of the Keys exhibited the highest total phosphorus concentrations and turbidity. Waters on the north side of the "Backcountry," extending west over the northern Marquesas Keys, exhibited the highest chlorophyll *a* concentrations. This area is most heavily influenced by advection of Southwest Florida Shelf waters.

The seagrass bed that carpets 80% of the Sanctuary is part of the largest documented contiguous seagrass bed on earth. Seagrasses were completely lost at 3 of 30 permanent sites during recent hurricanes; benthic communities were relatively stable at the remaining 27 sites.

The spatial pattern of seagrass variation and agreement of these changes with model predictions of nutrient-induced modifications of the system suggest a regional-scale change in nutrient availability. Nevertheless, it appears that there **have not** been large-scale trends in abundance of dominant plants over the past seven years, even though increases in macroalgal abundance have occurred at several sites, consistent with an increase in nutrient availability. There have been long-term shifts in the N:P ratio in seagrass leaves, which also indicate increases in nutrient availability. It is noteworthy that these sites were relatively close to shore in the Middle and Lower Keys. The response of

seagrasses to eutrophication may be on the order of decades, so long-term monitoring and further research clearly are continuing needs.

FLORIDA KEYS CARRYING CAPACITY STUDY ASSESSMENT OF NEARSHORE BENTHIC COMMUNITIES OF THE FLORIDA KEYS by Dr. James W. Fourqurean, Leanne Miller Rutten and Tom Philippi

The coastal marine ecosystems of the Florida Keys comprise three dominant habitats: mangroves, seagrasses, and coral reefs. Mangroves are a dominant feature of the land-sea margin throughout the Florida Keys. Seagrasses are the principle component of benthic marine habitats in the Florida Keys; they occupy over 70% of the FKNMS. The structure and distribution of seagrass communities varies throughout the Florida Keys; they form extensive meadows and patchy beds, and are also found scattered throughout other habitats. Coral reefs, patch reefs, and hardbottom habitats cover approximately 7%, 1% and 19% of the FKNMS, respectively.

Evidence suggests nutrient limitation, and consequently plant response to nutrient enrichment, may differ throughout the Florida Keys. Studies have shown that there is more phosphorous available offshore, near the reef tract, while groundwater and Florida Bay water are relatively rich in available nitrogen. It can be expected that the effects of nutrient enrichment may vary due to the different nutrient limitations and regimes of nearshore and offshore benthic communities. Studies by Lapointe et al. indicate that anthropogenic nutrient enrichment of groundwater may be occurring locally in the Florida Keys and that nutrient enrichment can have an effect on benthic marine communities.

Time series analyses of the black and white DOT aerial photographs revealed very little change in the distribution of nearshore benthic communities in the Florida Keys since 1959. There were no significant differences in the amount of keys-wide benthic macrophyte cover with respect to time (1959-1997, six time steps), location (oceanside or bayside), or land use (heavily or slightly developed). However, there were differences in the magnitude and direction of the minimal changes detected with respect to study area. The mean temporal change at most Key Largo and Marathon sites was positive, reflecting small net increases, while the mean temporal change at most Big Pine and Key West sites was negative, reflecting slight net decreases. The mean temporal variability was significantly higher in Key Largo and Marathon, indicating a greater number of points at sites in those study areas were changing through time. The mean temporal variability was significantly lower in Big Pine and Key West, indicating more stability at sites in those study areas.

We have determined that both nearshore benthic communities and their associated nutrient regimes do exhibit spatial variation throughout the Florida Keys. However, nearshore benthic communities were found to exhibit very little temporal variation through the past 40 years, even in the face of tremendous land development in the Florida Keys. The second working hypothesis, that there is a significant relationship between

human land use activity and spatial or temporal variation of nearshore benthic communities and their associated nutrient regimes throughout the Florida Keys, merits further investigation. Results indicate that substrate, not land use, is the most important factor associated benthic community composition. Two separate analytical approaches have identified potential relationships between a few individual taxa, taxa groups, nutrient parameters, and land use, but very few of these relationships are significant throughout the Florida Keys.

BENTHIC COMMUNITY MONITORING FOR THE LITTLE VENICE SEWAGE COLLECTION AND TREATMENT PROJECT IN MARATHON, FLORIDA by Joseph Boyer, Danielle Mir-Gonzalez and Ronald Jones (2004) Technical Contribution #T-231 of the Southeast Environmental Research Center at Florida International University.

Inshore waters off the canals of little Venice subdivision are clearly impacted by land use and the associated septic treatment systems. It is clear that Thalassia and Halodule abundance is highest in sites furthest from the canal mouth. Seagrass densities are lowest at the canal mouth. Sites closest to the canal mouths have the greatest abundance of green algae, which are typically considered to be strong indicators of elevated nutrient conditions. Brown algae are also primarily found at the nearshore area along with lowered DO. The authors expect that with decreased nutrient inputs, one would see a migration of *Thalassia* back into the nearshore waters off the canals.

SEAGRASS MONITORING REPORT IN THE FLORIDA KEYS NATIONAL MARINE SANCTUARY – ANNUAL REPORT – FY 2003 by James Fourqueen, Michael Durako and Joseph Zieman

These data are being collected at three different types of sites within the FKNMS:

- **Level 1 Stations:** Sampled quarterly for seagrass abundance, demographics, productivity and nutrient availability. These stations are all co-located with the water quality monitoring project's stations (Figure 1)
- **Level 2 Stations:** Randomly selected locations within the FKNMS, sampled annually for seagrass abundance, demographics and nutrient availability. Each year, new locations for Level 2 stations are chosen.
- **Level 3 Stations:** Randomly selected locations within the FKNMS, sampled annually for seagrass abundance. Each year, new locations for Level 3 stations are chosen.

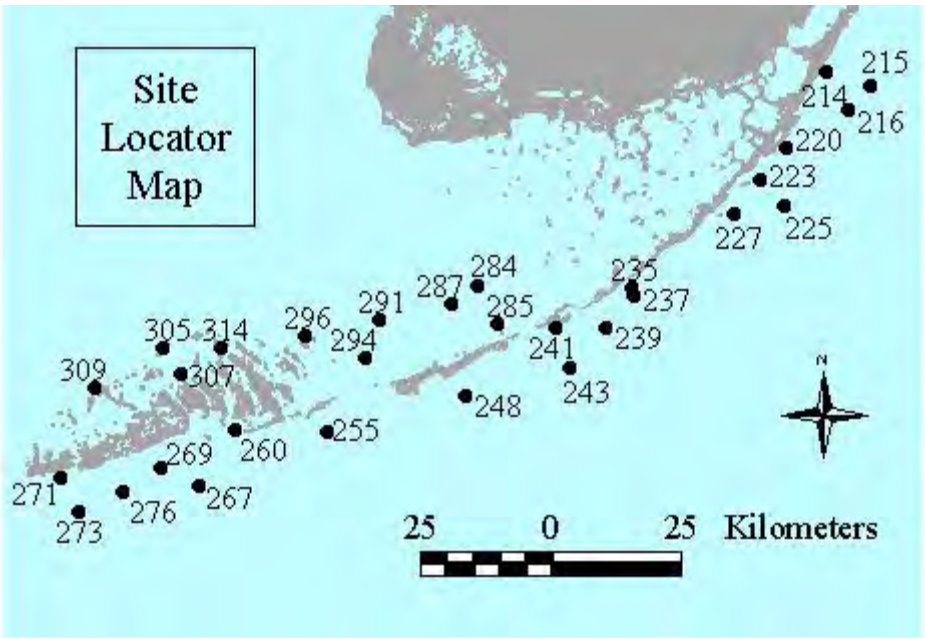


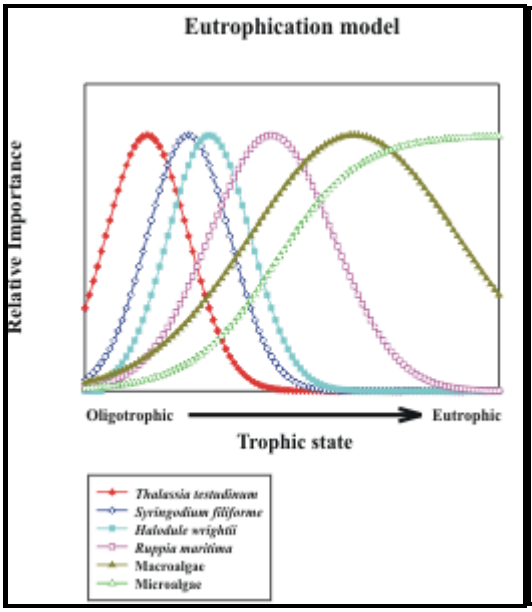
Figure 1. Location of Level 1 seagrass status and trends monitoring sites in the Florida Keys National Marine Sanctuary. Site numbers correspond to water quality monitoring locations.

The significant changes in seagrass communities at the permanent Level 1 stations that we reported last fiscal year continue to be present after an additional year of sampling. These changes are consistent with model predictions of nutrient-induced changes of these systems. The spatial pattern of changes and the agreement of the changes with models of the system suggest that there is regional-scale change in nutrient availability that is causing changes in seagrass beds over a wide portion of the FKNMS.

In 2003, we resurveyed 202 Level 2 and Level 3 stations that were last visited during the summer of 1996. The data collected on these visits is still being assessed, but preliminary analyses indicate that there are no large spatial scale trends in the abundance of the dominant benthic plant types between the 2 years.

In general, nutrient addition to aquatic environments shifts the competitive balance to faster-growing primary producers. The consequences of this generality in seagrass-dominated environments is that seagrasses are the dominant primary producers in oligotrophic conditions. As nutrient availability increases, there is an increase in the importance of macroalgae, both free-living and epiphytic, with a concomitant decrease in seagrasses because of competition for light. Macroalgae lose out to even faster-growing microalgae as nutrient availability continues to increase: first, epiphytic microalgae replace epiphytic macroalgae on seagrasses; then planktonic microalgae bloom and deprive all benthic plants of light under the most eutrophic conditions. The south Florida case is more complicated than the general case described above because there are 6 common seagrass species in south Florida, and these species have different nutrient and light requirements, hence they have differing responses to eutrophication. Large expanses

of the shallow marine environments in south Florida are so oligotrophic that biomass and growth of even the slowest-growing local seagrass species, Thalassia testudinum, are nutrient-limited; at this very oligotrophic end of the spectrum, increases in nutrient availability actually cause increases in seagrass biomass and growth rate. As nutrient availability increases beyond what is required by a dense stand of *T. testudinum*, there are other seagrass species that will out-compete it (Figure 2). The relative importance of the various primary producers, then, can be used to assess the trophic state of the community.



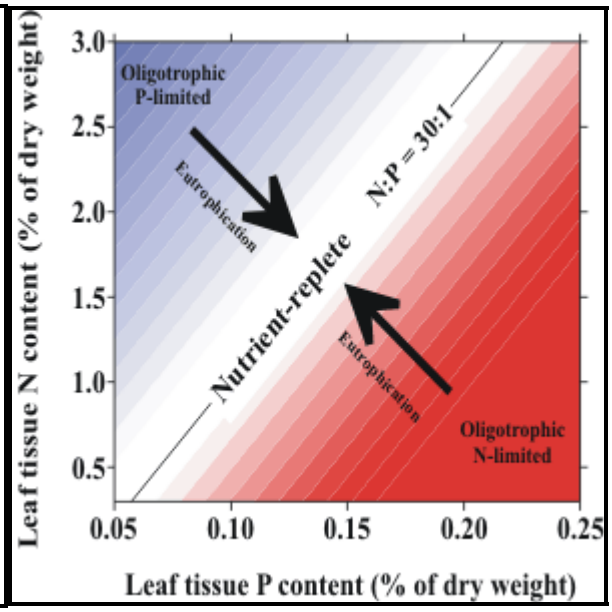


Figure 2. Conceptual model showing theFigure 3. Conceptual model indicating how elemental change in importanceof primary producers asratios of seagrasses respond to increasing nutrient nutrient availability increases from lowavailability.
(oligotrophic) to high (eutrophic).

Each species in the species dominance-eutrophication gradient model (Figure 2) can potentially dominate over a range of nutrient availability and the model predicts a change in species dominance as nutrient availability changes. These changes are not instantaneous, however. Field evidence suggests that species replacements may take place on a time scale of a decade or more. It is desirable that we be able to predict the tendency of the system to undergo these changes in species dominance before they occur, so that management actions can be taken. Tissue nutrient concentrations can be monitored to assess the relative availability of nutrients to the plants. For phytoplankton communities, this idea is captured in the interpretation of elemental ratios compared to the familiar "Redfield ratio" of 106C:16N:P. For the seagrass *T. testudinum*, the critical ratio of N:P in green leaves that indicates a balance in the availability of N and P is ca. 30:1, and monitoring deviations from this ratio can be used to infer whether N or P availabilities are limiting this species' growth. Hence, *T. testudinum* is likely to be replaced by faster-growing competitors if nutrient availability is such that the N:P of its leaves is ca. 30:1. A change in the N:P in time to a value closer to 30:1 is indicative of

eutrophication (Figure 3). These models lead directly to a definition of trends likely to be encountered in the seagrass communities of south Florida if humans are causing regional changes in nutrient availability because of alterations to quantity and quality of freshwater inputs to the marine ecosystem:

1) regional eutrophication will cause N:P ratios of seagrasses to approach 30:1 from higher or lower values indicative of oligotrophic conditions; and

2) regional eutrophication will cause a shift in species dominance in south Florida seagrass beds. The first responses to eutrophication will be evidenced by an increase in the relative abundance of fast-growing seagrass species (*H. wrightii* and *S. filiforme*) at the expense of the now-dominant, slow-growing *T. testudinum*. At later stages of eutrophication, macroalgae and microalgae will become the dominant primary producers.

At 4 nearshore Level 1 sites in the Florida Keys, there has been an increase in the relative abundance of macroalgae over the period 1995 - 2003 that is consistent with an increase in nutrient availability. At none of these has there yet been a decrease in seagrass abundance, but our conceptual model predicts that increases in fast-growing macroalgae should precede decreases in seagrass abundance (Figure 2). One example, from site 235 offshore of Lower Matecumbe Key, shows how macroalgae have steadily increased in abundance over the monitoring period (Figure 4). In addition to these sites where relative abundance of primary producers has changed, at 4 more Level 1 sites there have been long-term shifts in the ratio of nitrogen to phosphorus in seagrass leaves that are consistent with increases in nutrient availability (Figure 5).

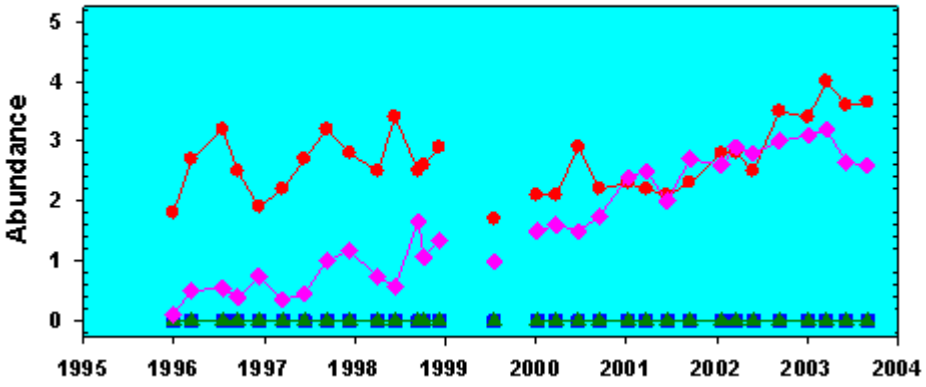


Figure 4. At Level 1 station 235 (see figure 1 for location) there has been a slow and consistent shift in species abundance, with faster-growing macroalgae becoming more abundant over the time period. This change is consistent with model predictions of the consequences of increases in nutrient availability.

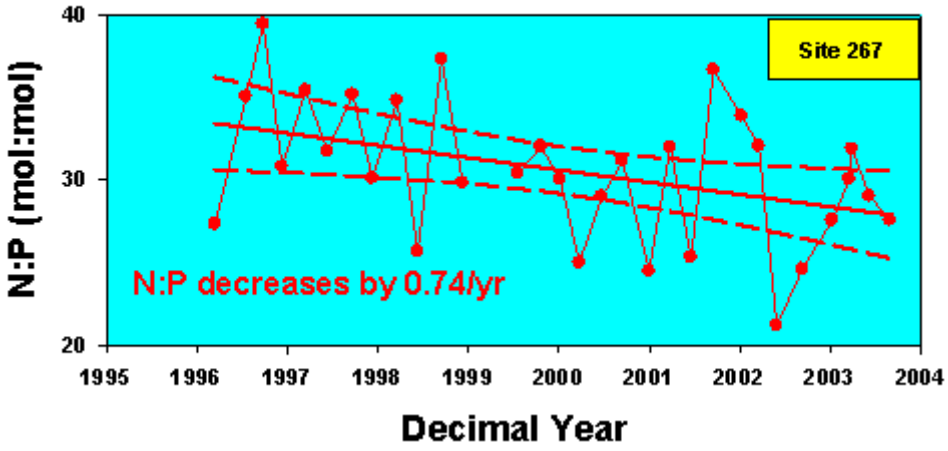


Figure 5. At the Level 1 station 267 (see Figure 1 for location) there has been a slow and consistent shift in N:P ratios from values consistent with P limitation towards values indicating an increase in phosphorus availability.

The sites that showed changes consistent with increased nutrient availability were not randomly distributed across the Sanctuary - rather, all of these sites were relatively close to shore in the Middle and Lower Florida Keys (Figure 6). The lack of any such changes in the Upper Florida Keys suggests that the factor driving the observed changes is not present across the entire Sanctuary, so factors acting at the global scale (like global warming or coastal overfishing) are not likely responsible for the observations. In addition to Level 1 sites that are exhibiting changes that are consistent with long-term increase in nutrient supply, two additional sites were severely impacted by hurricanes over the course of the monitoring period.

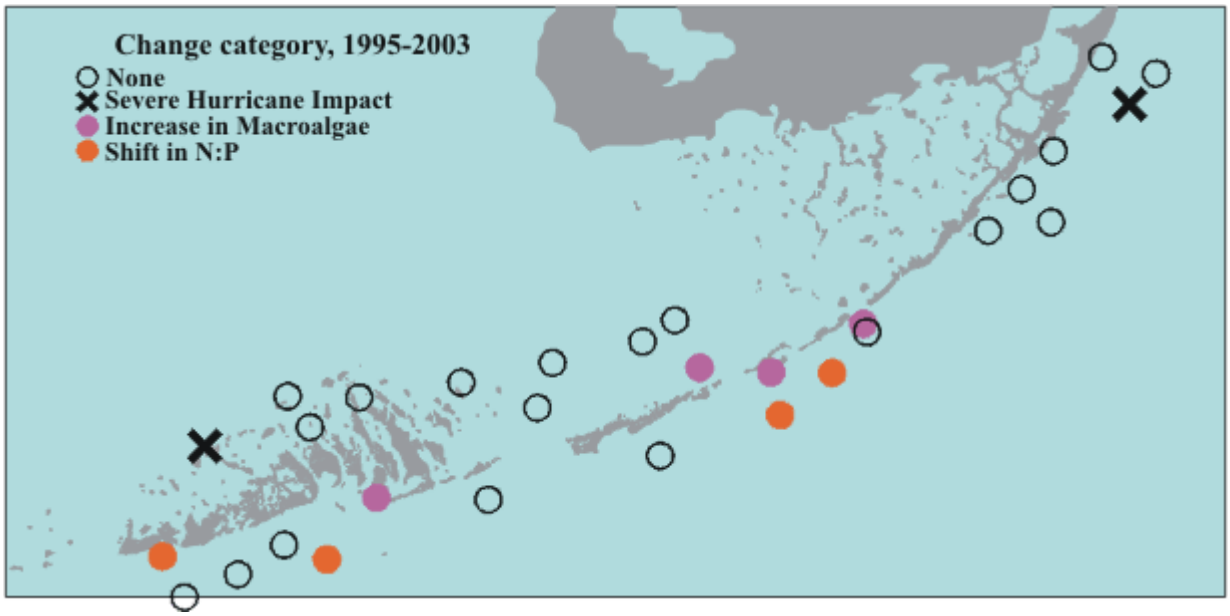


Figure 6. Long-term changes in seagrass beds at the Level 1 sites.

Resurveying the Level 2 and Level 3 sites revealed no spatially consistent patterns in changes in relative abundance of seagrass communities from throughout the sanctuary. The mean changes in Braun Blanquet density for the major taxa for the period 1996 and 2003 were not significantly different from zero, but there were some locations that had large differences between 1996 and 2003. Whether these changes were real changes in the benthic communities or artifacts caused by small scale spatial heterogeneity is currently being investigated. There were some areas, like around Islamorada, that showed declines in *Thalassia* in a large area contiguous with Level 1 permanent sites that exhibited changes that are consistent with eutrophication (See figure 8 for spatial pattern of change, and Figure 6 for Level 1 site summary). However, other regions of apparent change were not consistent with the patterns seen at the permanent sites. In FY 2004, we will resample an additional 200 sites that were surveyed in 1997.

Our surveys have provided clear documentation of the distribution and importance of seagrasses in the FKNMS. The seagrass bed that carpets 80% of the FKNMS is part of the largest documented contiguous seagrass bed on earth. These extensive meadows are vital for the ecological health of the FKNMS and the marine ecosystems of all of south Florida. Maps of spatial distributions can be found on the web or DVD.

Our permanent monitoring sites have provided valuable data on the inter- and intra-annual variability of seagrass cover and abundance. Time series of species composition, seagrass productivity, nutrient availability and physical parameters can be found for each permanent monitoring site on the web site or the DVD. There have been some striking trends in the seagrass communities at these permanent sites: seagrasses were lost completely at 3 of the 30 sites during hurricanes over the last 4 years. At the remaining 27 sites, the benthic communities are relatively stable. There are no common trends across the sites in seagrass cover or community composition. This can be interpreted to mean that there are no regional trends in the health of the seagrass beds represented by

the permanent monitoring sites that can be detected with the 6 years of monitoring data. But, manipulative experiments in seagrass beds in south Florida demonstrate that the time course of the response of seagrass beds to eutrophication is on the order of decades, and we do not understand completely the interaction man has with the natural dynamics of these systems. These 30 sites should continue to be monitored on a quarterly basis.

EUTROPHICATION AND TROPHIC STATE CLASSIFICATION OF SEAGRASS COMMUNITIES IN THE FLORIDA KEYS by Brian E. Lapointe, David A. Tomasko, and William R. Matzie (1994) Bulletin of Marine Science, 54(3) 696-717.

We assessed relationships among total nitrogen and total phosphorus concentrations of the water column and the productivity, biomass, and epiphyte levels of the seagrasses, *Thalassia testudinum* and *Halodule wrightii*, along three onshore-offshore transects (Key West, Big Pine Key, and Long Key) stratified a priori into hypereutrophic, eutrophic, mesotrophic and oligotrophic communities with increasing distance from shore.

Macroalgal biomass and alkaline phosphate activity (APA) of macroalgae and attached seagrass epiphytes were also determined along the eutrophication gradients.

H. Wrightii was the dominant seagrass within inshore hypereutrophic strata whereas T. testudinium was dominant in eutrophic, mesotrophic, and oligotrophic strata.

Seagrasses at the hypereutrophic and eutrophic strata had low shoot densities, low production rates, low area biomass values, low areal production rates, but high levels of attached epiphytes and mat-forming macroalgae. Seagrasses at the oligotrophic strata had the highest shoot densities, highest areal biomass values, highest areal production rates, and typically the lowest or second lowest epiphyte levels of all strata and typically the lowest or second lowest epiphyte levels of all strata.

Alkaline phosphatase activity was lowest for macroalgae at the offshore oligotrophic strata, and highest at the nutrient-enriched hypereutrophic strata where extensive populations of mat-forming macroalgae occurred. Higher alkaline photphosphatase activity in macroalgae and attached blade epiphytes in hypereutrophic and eutrophic strata reflected increased phosphate-limitation in these dystrophic environments resulting from high concentrations of total nitrogen relative to total phosphate.

Sustained nutrient enrichment from land-based activities results in increased biomass of attached epiphytes and macroalgae, which attenuate light, reduce dissolved oxygen, and leads to the decline of T. testudinum and a gradient of damage from nearshore to offshore waters.

NUTRIENTS

AN EVALUATION OF THE SCIENTIFIC BASIS FOR "RESTORING" FLORIDA BAY BY INCREASING FRESHWATER RUNOFF FROM THE EVERGLADES by Larry E. Brand (2000) Unpublished report.

The dominant hypothesis for explaining many of the ecological changes that have occurred in Florida Bay in the past 2 decades is that reduced water flow into Florida Bay from the Everglades led to hypersaline conditions, which then led to massive seagrass dieoff. This hypothesis further proposes that the seagrass dieoff and subsequent organic decomposition and sediment resuspension released nutrients which then generated the algal blooms. The data, however, show that hypersaline conditions cannot explain either the spatial or temporal distribution of seagrass dieoff in Florida Bay. Furthermore, seagrass dieoff cannot explain the spatial or temporal distribution of nutrients and algal blooms in Florida Bay.

It is hypothesized that the large algal blooms in Florida Bay are the result of N-rich waters in eastern Florida Bay meeting P-rich waters in western Florida Bay. Nutrient bioassays confirm that P is the limiting nutrient in the east and N is the limiting nutrient in the west, as predicted by the spatial distribution of N:P ratios.

It is hypothesized that much of the P comes by way of Peace River and by way of groundwater through phosphorite-rich quartz sand deposits underneath certain areas of the coastal waters. It is argued that this P source has not changed significantly over the past few decades. It appears that much of the N comes from freshwater runoff from agricultural lands through the Everglades. Changes in water management practices in the past two decades have led to an increase in N inputs to eastern Florida Bay. Mixing of this water from the east with the P-rich water from the west has led to the large algal blooms that have developed in northcentral Florida Bay, altering the entire ecosystem. Some of this enriched water is transported to the middle and lower Florida Keys, where it may be adversely affecting the coral reefs and other oligotrophic ecosystems there.

In conclusion, it is hypothesized that if more freshwater from the Everglades-agricultural system is pumped into Florida Bay, as proposed by the USACOE, the algal blooms will increase and the ecological problems of Florida Bay will get worse, not better. It is also hypothesized that if more passages along the Florida Keys between Florida Bay and the coral reefs are opened up, as proposed, the coral reefs will experience lower water quality.

PHOSPHORUS AND NITROGEN INPUTS TO FLORIDA BAY: THE IMPORTANCE OF THE EVERGLADES WATERSHED by D.T. Rudnick, D. L. Childers & T.D. Fontaine (1999) Estuaries 22:398-416.

A large environmental restoration project designed to improve the hydrological conditions of the Florida Everglades and increase freshwater flow to Florida Bay is underway. Here we explore how changing freshwater inflow to the southern Everglades

is likely to change the input of nutrients to Florida Bay. We calculated annual inputs of water, total phosphorus (TP), total nitrogen (TN), and dissolved inorganic nitrogen (DIN) to Everglades National Park (ENP) since the early 1980s. We also examined changes in these nutrient concentrations along transects tiltrough the wetland to Florida Bay and the Gulf of Mexico. Based on a nutrient budget of Florida Bay, both N and P inputs from the Gulf of Mexico greatly exceed inputs from the Everglades, as well as inputs from the atmosphere and the Florida Keys. We estimate that the freshwater Everglades contribute < 3% of all P inputs and < 12% of all N inputs to the bay. Evaluating the effect of ecosystem restoration efforts on Florida Bay requires greater understanding of the interactions of the bay with the Gulf of Mexico and adjacent mangrove ecosystems.

FY 2005 ANNUAL REPORT OF THE WATER QUALITY MONITORING PROJECT FOR THE WATER QUALITY PROTECTION PROGRAM OF THE FLORIDA KEYS NATIONAL MARINE SANCTUARY by Joseph N. Boyer and Henry O. Briceño

Several important results have been realized from this monitoring project. First, is documentation of elevated DIN in the inshore waters of the Keys (Fig 1). This result was evident from out first sampling event in 1995 and continues to be a characteristic of the ecosystem. Interestingly, this gradient was not observed in a comparison transect from the Tortugas. This type of distribution implies an inshore source which is diluted by low nutrient Atlantic Ocean waters. Presence of a similar gradient in TOC and decreased variability in salinity from land to reef also support this concept. There were no trends in either TP or CHLA with distance from land.

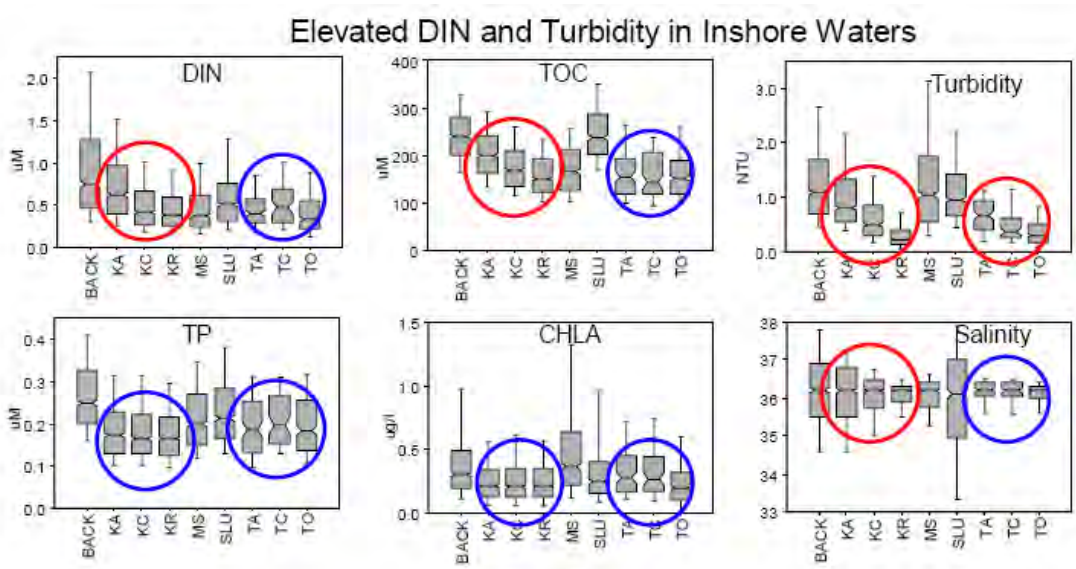


Figure 1.

Another observation is that the Backcountry exhibits elevated levels of DIN, TOC, turbidity, TP, and CHLA. I believe most of these distributions are driven by the SW Florida Shelf waters moving through this area (median DIN = 0.7 μM, TOC = 298 μM,

Turbidity = 6.4 NTU, TP = 0.48 μM, and CHLA = 1.6 μg l-1). In addition to Shelf influence, elevated NO3 - is a regular feature of Backcountry waters, where some of the highest concentrations are observed in nonpopulated areas (Fig. 2). This is probably the result of the benthic flux of nutrients in this very shallow water column.

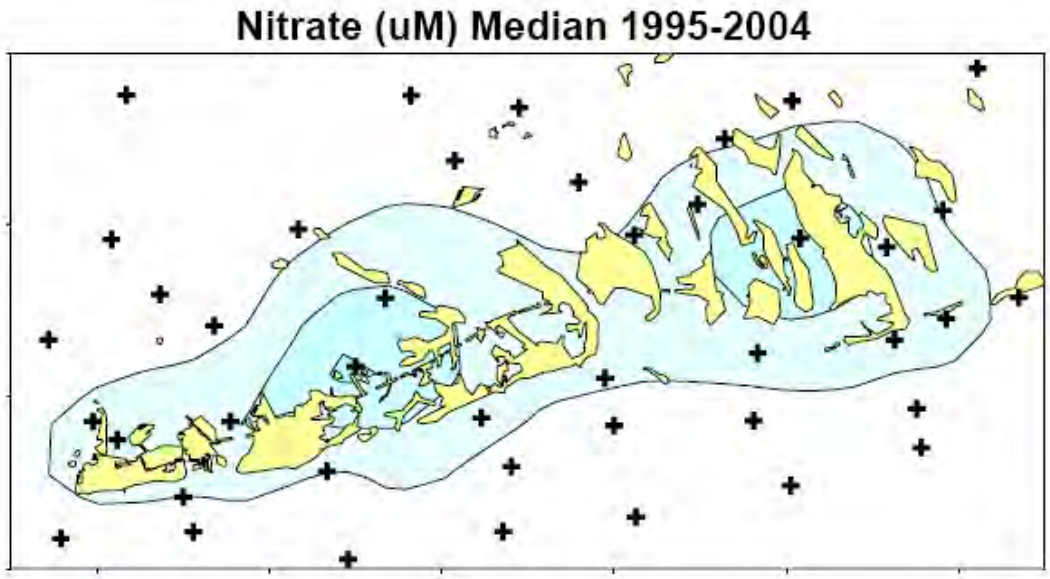


Figure 2.

The third important result is that highest CHLA concentrations occur on the Shelf and show a strong N-S gradient towards the Marquesas and Tortugas (Fig. 3). This is due to higher TP concentrations on the Shelf as a result of southward advection of Gulf of Mexico waters along the coast with entrainment of coastal rivers and runoff.

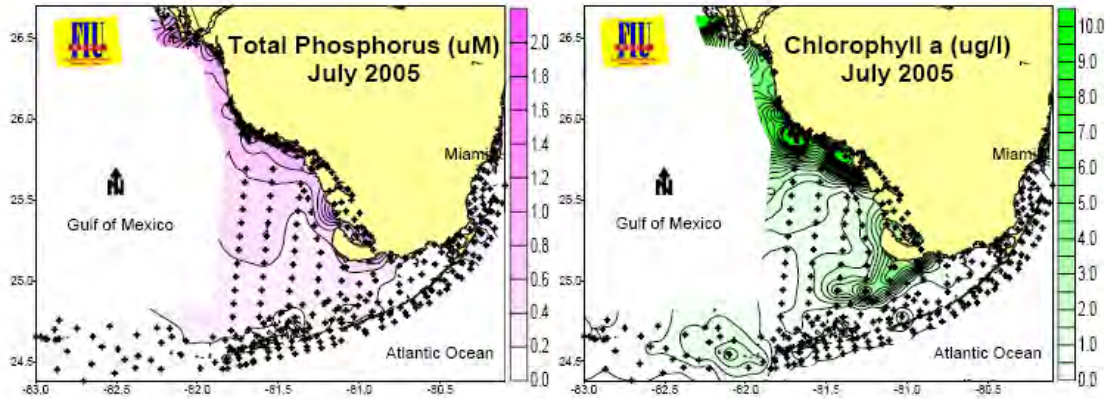


Figure 3.

The forth result is that trends in water quality showed most variables to relatively consistent from year to year, with some showing seasonal excursions. Overall, there were statistically significant decreases in DIN, TON (except for increases in Tortugas), TP, TOC, and DO throughout the region. Clearly, there have been large changes in the

FKNMS water quality over time, and some sustained monotonic trends have been observed, however, we must always keep in mind that trend analysis is limited to the window of observation. Trends may change, or even reverse, with additional data collection.

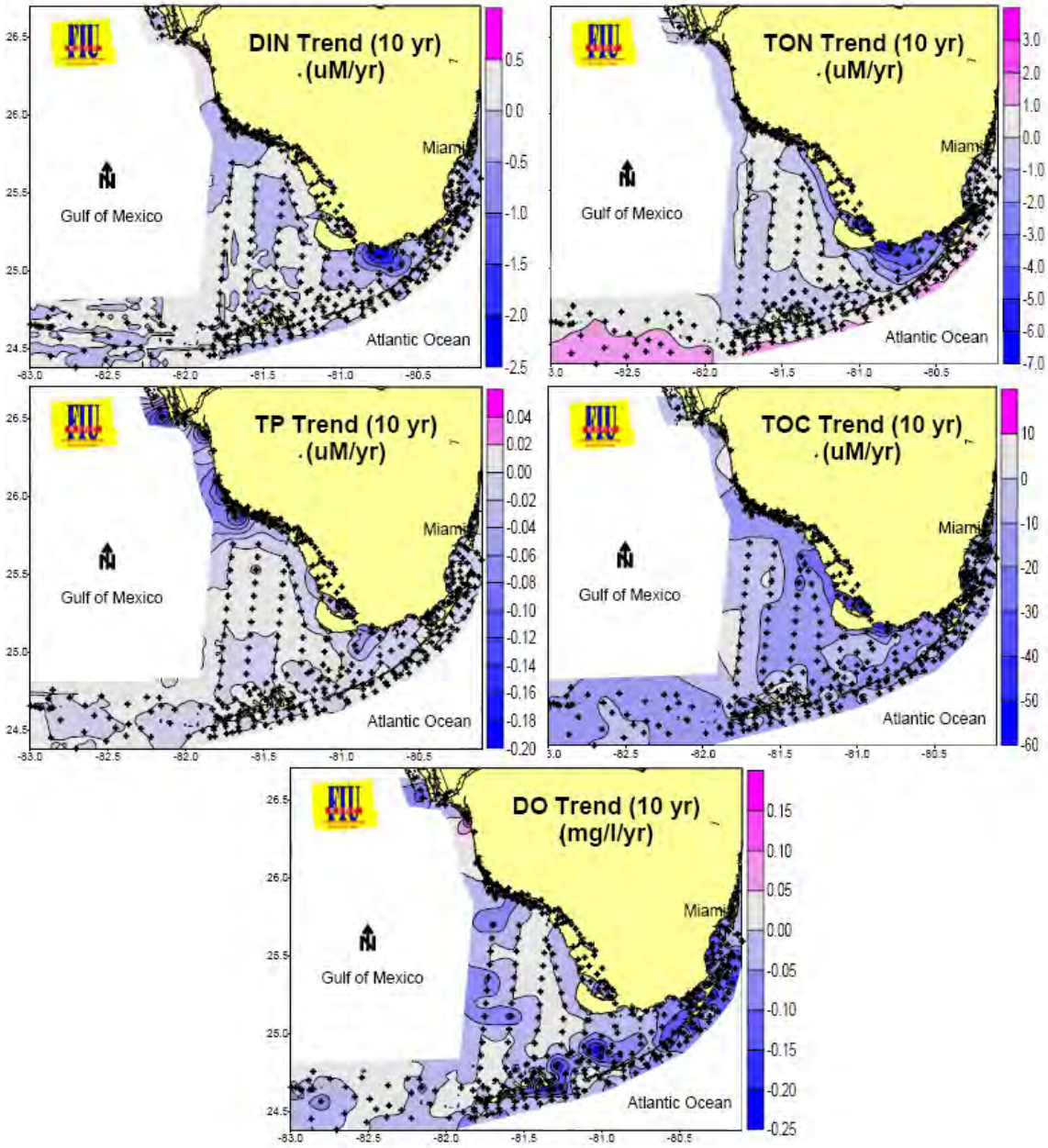


Figure 4.

HIGH FREQUENCY MONITORING OF WASTEWATER NUTRIENT DISCHARGES AND THEIR ECOLOGICAL EFFECTS IN THE FLORIDA KEYS NATIONAL MARINE SANCTUARY by Brian Lapointe and William Matzie (1997) Harbor Branch Oceanographic Institution; Submitted to USEPA Water Quality Protection Program.

The study assessed how physical forcing mechanisms (rainfall, wind, tides) linked land based wastewater discharges with the initiation of algal blooms in shallow (<10m) inner shelf waters between Big Pine Key and Looe Key National Marine Sanctuary (LKNMS) from January to October 1996. Three stations were selected along the offshore gradient that included: 1) an inshore station (Avenue J, "AJ") down-gradient of ~ 2,000 septic tanks/cesspits in Spanish Harbor Channel, 2) a nearshore station ("PR") near patch Reef ~ 0.5 km south of Munson Island, and 3) an offshore station ("LK") in the back reef at LKNMS.

During and following a wind event (~20 knots, NE) in mid-February, elevated DIN, SRP, and CHLa concentrations were observed at PR and LK but not at the more protected inshore station AJ. The highest DIN (mostly NH4+) and SRP concentrations of the entire study were measured at AJ during low tide on March 19. With the onset of the wet season in late May and early June, DIN concentrations (mostly NH4+) reached maximum values at PR and LK, which were followed by maximal CHLa concentrations at all three stations during the mid-summer period. CHLa concentrations were high at all stations throughout the study and averaged 1.86 ug/L at AJ (n=87), 0.55 ug/L at PR (n=86), and 0.60 ug/L at LK (n=83).

Fleshy macroalgal biomass averaged <100 g dry wt per meter squared at all three stations in winter and early spring but increased to levels of 100-300 g dry wt per meter square at AJ and PR following the onset of the rainy season in May. The red macroalga Laurencia poiteaui was abundant all three stations and δ15N of this plant were highest at AJ, intermediate and PR and lowest at LK, indicating increasing wastewater N contributions to this alga with increasing proximity to shore.

The highest algal epiphyte loads on *Thalassia testudium* occurred at LK rather than the inshore stations, a result of high DIN concentrations combined with high submarine irradiance at this station.

In summary, these results corroborate pervious findings that episodic stormwater discharges of land based wastewater nutrients initiate harmful algal blooms in nearshore waters of the FKNMS, including the offshore bank reef at LKNMS.

NUTRIENT THRESHOLDS FOR BOTTOM-UP CONTROL OF MACROALGAL BLOOMS ON CORAL REEFS IN JAMAICA AND SOUTHEAST FLORIDA by Brian E. Lapointe (1997) Limnology & Oceanography, 42 (5, part2) 1119-1131.

During the past two decades coral reefs in the greater Caribbean area have been altered by phase shifts away from corals and toward macroalgae or algal turfs. This study tested the hypothesis that because the phase shift on reefs in Jamaica and southeast Florida involved frondose macroalgae, bottom-up control via nutrient enrichment must be a causal factor.

Despite research demonstrating bottom-up control of macroalgal standing crops on coral reefs that extends back more than 20 yr, single-factor top-down interpretations concerning the cause of macroalgal blooms on coral reefs are still found in the literature. For example, Hughes (1994) concluded that dramatic phase shifts on Jamaican coral reefs from >50% coral cover in the early 1970s to the current ~5% resulted from a "spectacular algal bloom" due to reduced grazing from overfishing coupled with die-offs of the sea urchin Diadema antillarum; the possible role of nutrient enrichment as a factor enhancing macroalgal productivity and standing crop was dismissed without supportive data. Although herbivory is a significant factor in the benthic dynamics of coral reefs, its effects occur on limited temporal and spatial scales. Thus, studies addressing macroalgal blooms on coral reefs need to examine the potential for bottom-up control via nutrient enrichment, especially considering that eutrophication associated with exponentially expanding human populations is a major mechanism altering coastal ecosystems world-wide

The results showed that in both Jamaican and southeast Florida reef locations, concentrations of dissolved inorganic nitrogen (DIN) and soluble reactive phosphorus (SRP) exceeded nutrient thresholds noted to sustain macroalgal blooms on Caribbean coral reefs. Increased DIN concentrations were associated with reduced salinity on both reefs, indicating submarine groundwatcr discharge was a significant source of DIN. Elevated δ15N values of Codium isthmocladum tissue further points to wastewater DIN as a source of nitrogen contributing to the blooms in southeast Florida.

The importance of groundwater discharges to the ecology of reefs in both Jamaica and southeast Florida underscores the earlier work of Johannes (1980) who noted the growing evidence for the role of groundwaters as a nutrient source in shallow coastal waters. The evidence presented here adds a further dimension of complexity to Hughes' (1994) conclusion that macroalgal blooms in Jamaica resulted only from loss of herbivory. The importance of top-down control of macroalgal standing crops is much more compelling when combined with the larger scale, synergistic effects of bottom-up control via groundwater nutrient enrichment.

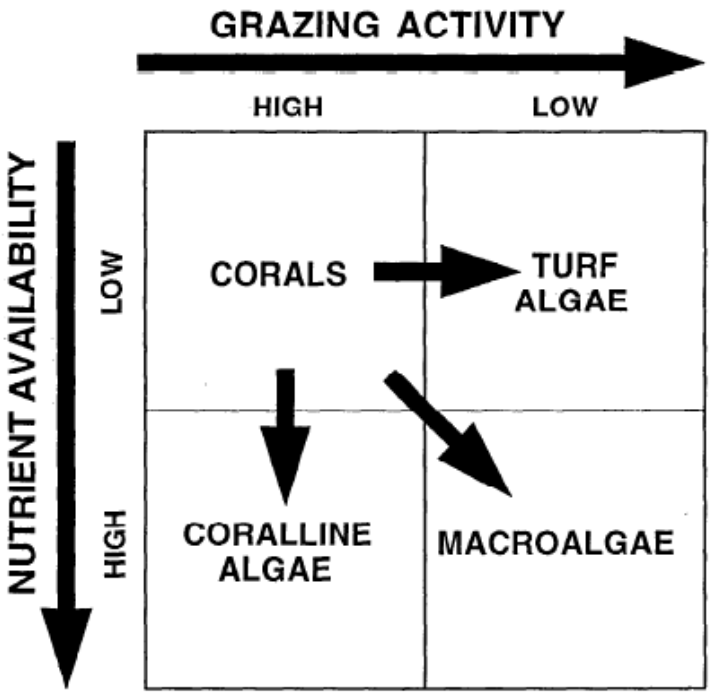


Fig. 1. Diagram illustrating the relative dominance of major space-occupying primary producers on tropical and subtropical reefs. The relative dominance is predicted to be a function of bottom-up control by nutrient availability and top-down control by herbivory. Human activities inevitably reduce grazing animals and increase nutrient availability, which shifts reefs from coral to macroalgal dominance.

FATE OF WASTEWATER NUTRIENTS IN FLORIDA KEYS GROUNDWATER by Lee Kump; Final Report to EPA [X98429297-0-PA].

Secondarily treated wastewater from the City of Key Colony Beach is injected between 60-90' below the surface thought a series of Class V injection wells. Monitoring wells were installed around the injection field to sample the groundwater at three levels (25-30', 45' & 60').

Results show that the wastewater plume rises buoyantly to the bedrock/unconsolidated mud interface at ~ 20' subsurface depth , and then migrates in an easterly – southeasterly direction with the dominant flow path. Slower flow paths and dispersion of the plume causes it to spread in all directions.

Despite the spread of the plume, which likely extends to the canal on the eastern side of the study area, nutrients are preferentially removed from the plume through interactions in the subsurface. Phosphate is strongly sorbed to the calcite surface of the bedrock limestone, and likely precipitates as an apatite phase, rendering it essentially immobile. Nitrate, however exhibits high (several ppm) concentrations far from the point of injection, along the most rapid flowpaths. Elsewhere, nitrate concentrations are reduced

by a combination of denitrification and nitrate ammonification microbial processes favored in the reducing groundwaters.

Overall, the secondary treatement of wastewater and its injection into the Keys Largo Limestone is followed by effective removal of phosphate, but variably effective removal of nitrate from the wastewater plume.

THE IMPACT OF ANTHROPOGENIC WASTE ON THE FLORIDA REEF by Peter Swart, Geoffrey Ellis and Peter Milne (2000) University of Miami, Final Report to USEPA Water Quality Protection Program.

It is suggested that septic tanks leak wastewaters into the groundwater, eventually negatively impacting the reefs by various mechanisms. This study attempted to trace components of this human waste in the reef environment along several transects from the Florida Keys towards the reef tract and therefore demonstrate unequivocally whether this hypothesis is correct. Specifically we have (i) attempted to use the organic compound coprostanol to detect the presence of septic tank sewage in the sediments, (ii) determined the origin (fixed atmospheric nitrogen, recycled municipal waste or upwelled nitrogen) of the nitrogen in sedimentary organic material as an indicator of the source of nitrogen in the corals and other biota based on the nitrogen isotopic composition, and (iii) determined the relative importance of input of nitrogen compounds from Florida Bay.

The investigation revealed that:

- No unusually high $\delta^{15}N$ value which could be ascribed to major input of anthropogenic waste in the reef environment.
- Low coprostanol values throughout the study area with the exception of isolated sites in some canals in the keys.

The data indicate that there is no discernable direct evidence for sewage contaminants from the Florida Keys reaching the reef tract.

Sewage sterols (& other domestic pollution markers – eg. Trialkymines) are useful in assessing transport to the open sea; however as a result of the instability of coprostonal in oxic environments it might not be useful to use this tracer in coral reef environments.

ALGAL TISSUE NUTRIENTS AS INDICATORS OF NUTRIENT ENRICHMENT IN THE FLORIDA KEYS by M. Dennis Hanisak (1999) Harbor Branch Oceanographic Institution, Draft Final Report to USEPA Water Quality Protection Program.

Spatial variation in tissue nutrients of dominant macroalgae were assessed, both as ratios and absolute values along 12 inshore-offshore transects in the Florida Keys (three

transects for each of the Biscayne Bay, Upper Keys, Middle Keys, and Lower Keys "segments"), and at 10 stations in nearby Florida Bay.

The transect data revealed no universal inshore-offshore patterns in tissue nutrients and no obvious "hotspots" of nutrient enrichment. Similarly when data were compared among segments, there was no universal geographical pattern in tissue nutrients for all species. The most striking result was that the N and P status of macroalgae in Florida Bay was significantly different than other locations. Macroalgae collected from Florida Bay generally had higher N and lower P levels than algae collected elsewhere.

Comparisons among the four other segments (Biscayne Bay & U, M & L Keys) revealed a much more uniform tissue nutrient level and the relatively few differences were rather species specific. When there were significant differences among segments, the Biscayne Bay and Upper Keys tended to have lower N levels than the Middle and Lower Keys, and the Middle Keys segment tended to have higher P levels than the other segments.

The most common but by no means universal, inshore-offshore pattern was higher %N and lower %P availability inshore, however both nutrients were generally readily available in proportional mounts required by the various species.

REPORT ON ALGAE BLOOMS IN EASTERN FLORIDA BAY AND SOUTHERN BISCAYNE BAY by David Rudnick, Christopher Madden, Stephen Kelly, Robin Bennett, and Kevin Cunniff (2006) Coastal Ecosystem Division, South Florida Water Management District.

A highly unusual algae bloom has persisted in eastern Florida Bay and southern Biscayne Bay (Manatee Bay, Barnes Sound, and Card Sound) since at least November 2005. Similar algae blooms have been observed in central and western Florida Bay, but never in eastern Florida Bay. Chlorophyll a concentrations (an indicator of the amount of algae in the water column) peaked in the fall and early winter in 2005 and after decreasing in the spring, increased again in June and July 2006.

Causes of the bloom are not certain, but may be related to at least two factors: 1) disturbance associated road construction activity along US Highway 1 between the Florida mainland and Key Largo (Eighteen Mile Stretch), and 2) hurricane impacts from August through October 2005 (Katrina, Rita, Wilma).

Hurricane disturbances included a large discharge of fresh water and phosphorus from the C-111 canal and the impact of high winds, waves, storm surge and abrupt salinity change on plants, soils, sediments, and ground water. The proximity of the blooms to both sides of US Highway 1 – an area where blooms have not been previously recorded – points to the likelihood that the unique disturbance of road construction is involved as a cause of the bloom. A summary of hypotheses regarding the cause of the blooms is presented in Table 2.

Table 1. Timeline of Florida Bay & Biscayne Bay algae bloom and potentially associated events.

	WATER QUALITY IN NORTHEAST FL BAY – S. BISC BAY REGION	U.S. HIGHWAY 1 ACTIVITIES	TROPICAL STORM EVENTS	C-111 CANAL DISCHARGE
Apr 2005	No change from historic baseline (low chl *a* with median 0.4 ppb, and TP with median 6 ppb)	Mangrove clearing begins near Jewfish Creek		
May	No change	0.6 miles cleared N of Jewfish Creek		
June	No change	Clearing continues N and S of Lk Surprise		S197 open, 7,000 acre-ft discharge
July	No change	Clearing to Barnes; mixing of soil, mangrove mulch, and cement begins		
Aug	After Katrina, rapid salinity drop, TP increase (84 ppb) in Manatee	Clearing and soil mixing continues N (Barnes Sound area)	Hurricane Katrina (high rainfall, runoff, 47 mph wind, 2 ft. surge)	S197 opens 8/26 (5 d; 27,000 acre-feet; P load 0.8 metric tons)
Sept	TP near baseline in region, chl *a* increase in Manatee and Barnes (7 to 16 ppb)	Clearing and soil mixing continues N (Barnes Sound area)	Hurricane Rita (38 mph wind, 2 ft surge)	S197 open for 3 periods (20 d; 21,000 acre-ft)
Oct	High TP in region (60 to 100 ppb) before Wilma; chl *a* still low except Manatee and Barnes (6 ppb)	Clearing and soil mixing continues N (Barnes Sound area)	Hurr. Wilma (66 mph wind, 2 to 3 ft surge)	S197 opens for 2 periods (10 d; 2,000 acre-ft)
Nov	Regional chl *a* increase (bloom in Blackwater and Barnes to 15 ppb); TP decrease (slightly > baseline)	Clearing to Manatee Bay marina; soil mixing continues N		
Dec	Bloom continues – highest in Barnes (near 10 ppb)	Soil mixing S of Lk Surprise		
Jan 2006	Bloom increases – mapping shows highest chl *a* near US1 and Key Largo (peak 20 ppb), high turbidity	Mangroves cleared near Manatee Bay		
Feb	Bloom continues – chl *a* decrease (< 12 ppb in Blackwater, Barnes, Manatee)	Soil mixing near Barnes Sound		
Mar	Bloom continues – chl *a* decrease (3 to 12 ppb in Blackwater, Barnes, Manatee)	Soil mixing near Barnes Sound		
Apr	Bloom continues - chl *a* less than 10 ppb in Blackwater, Barnes, Manatee	Soil mixing near Manatee Bay		
May Jun July	Bloom decrease in early May (chl *a* < 6 ppb); increase in June–July (> 12 ppb in Blackwater, Barnes, Manatee)	to be determined		

Table 2. Hypotheses that may explain the cause of 2005-2006 algae blooms.

HYPOTHESIS	EVIDENCE SUPPORTING	EVIDENCE REFUTING
US Highway 1 road construction	• No similar algae bloom known to occur in the region prior to road construction • Bloom spatial pattern brackets highway (especially Blackwater-Barnes) • Bloom sustained 9 months after hurricane events, while construction continued • Mangrove mulch decomposition and soil disturbance likely to yield large nutrient release to adjacent waters	• Five months of construction activity before start of bloom • Bloom started immediately after Hurricane Katrina and Rita • Bloom spatial pattern within basins adjacent to road do not show increasing chlorophyll *a* near road
Hurricane Katrina related discharge and P load through S-197 (C-111 Canal)	• High P load event occurred and primary production known to be P limited • Bloom began in Manatee Bay and Barnes Sound immediately after pulse discharge and measured TP increase in Bay	• Elevated TP observed in areas beyond (west of) influence of S-197 discharge • Regional TP peak occurred one month after TP decreased to near baseline in Manatee Bay • TP load associated with particles – bloom does not follow gradient from canal mouth; chlorophyll *a* concentrations higher near Key Largo than mainland • Similar blooms did not occur after similar C-111 releases and TP loads (even after late 1980s – early 1990s drought)
Hurricane wind, waves, surge eroded sediment & plants, stripped leaves, pulsed ground water nutrients	• P increase after Katrina and Rita; regional bloom after Wilma • Spatial pattern of highest chlorophyll *a* appears parallel to Key Largo coastline, as could occur with line of storm deposits or ground water pulse	• Regional TP increase occurred prior to storm with highest surge (Wilma) • No similar blooms after previous storms (e.g. Hurricane Georges)
Hurricane disturbance: salinity drop & seagrass	• Salinity drop near coast with Katrina rapid enough to kill plants	• Salinity drop also occurred in areas with little TP increase and no bloom
Combination of road and hurricane disturbance	• Storm energy could move nutrients from road fill - turbidity barriers next to US1 removed prior to storms • Spatial pattern of bloom follows road for 9 months, while bloom initiation timing follows hurricanes	

Monitoring results indicate that the bloom was most likely initiated by a large increase in total phosphorus (TP) – a sharp peak in TP concentrations (to record high values) was measured in a small area (Manatee Bay) in late August immediately following Hurricane Katrina and also in the large region of eastern Florida Bay and southern Biscayne Bay in October.

The timing of the TP peak and subsequent bloom appears more associated with hurricane activity, with the TP peak occurring after Hurricanes Rita. Despite major road construction activity during the late spring and through the summer, no blooms or unusually high TP was measured prior to Hurricane Katrina. Thus, while the spatial pattern of the bloom points toward the importance of road disturbance as a cause of the blooms, the timing of these blooms points toward hurricane disturbance as a cause. An interaction of these two factors (disturbance from road construction plus hurricanes) appears to be the likely cause of the blooms.

A major runoff event occurred in late August 2005 in association with high rainfall from Hurricane Katrina. This resulted in a large loading of TP into Manatee Bay from the C-111 Canal along with a lower quantity of TP loading into Florida Bay through the southeastern Everglades. After this runoff event, TP concentrations in Manatee Bay sharply increased and then returned to near pre-storm concentrations within one week. TP in Barnes Sound and all Florida Bay waters remained low for more than one month before peaking regionally in October. This one month time lag, along with the absence of a concentration gradient away from Manatee Bay, indicates that the widespread October peak was unlikely to be caused by canal inputs. It is more likely that storm surge transported sediments, seagrasses, organic matter (perhaps including materials from the US 1 worksite) and ground water nutrients. Furthermore, when the TP peak did occur, those areas with low salinity (associated with the most runoff) had lower TP than those areas with higher salinity. Similar discharges of water and TP into Manatee Bay in the 1990s did not result in algae blooms similar to those observed between November 2005 and March 2006.

HUMAN FECAL INDICATOR BACTERIA AND PATHOGENIC VIRUSES IN OFFSHORE REEFS AND HUMAN RECREATIONAL RISK IN NEARSHORE WATERS OF THE FLORIDA KEYS by Erin K. Lipp, Dale W. Griffin & Joan B. Rose (2006) Final Report to USEPA, Project #X7-97480103-0.

The goals of this project were to evaluate the extent of human sewage contamination along a near-shore to offshore transect in the Upper Keys using human enteric viruses as sewage markers and to assign risks to human health.

Samples (coral mucus [also referred to as surface mucopolysaccharide layer or SML], water column and groundwater) were collected in the spring and summer between July 2003 and September 2005 from 5 stations along a near shore to offshore transect originating at Key Largo. All samples were assayed for fecal indicator bacteria and two human enteric viruses (enteroviruses and adenoviruses). Results from the field study showed that fecal indicator bacteria were low in all sample types but were generally higher nearshore and in the coral mucus samples. In particular, enterococci were most often detected throughout the study and tended to have higher accumulation rates in coral mucus relative to groundwater or surface water.

The fecal indicator bacteria may be derived from a variety of sources, including human feces, but they tend to experience rapid decay in marine waters, especially when exposed to UV light. Their detection in predominantly nearshore stations suggests that land-based sources may be a significant contributor to loading. Furthermore, results from studies of plumes originating from canals on outgoing tides revealed that surface waters carrying microbial contaminants are transported to the near shore environment.

Adenoviruses were found at a greater frequency from all sample types when compared to enteroviruses. Adenoviruses were detected in 35 of 75 samples collected (46.7%) whereas enteroviruses were only found in 9 of 75 samples (12%). When compared by sample type, both virus types were detected more often in coral SML than in either water type. Unlike bacterial indicators, enteric viruses were evenly distributed across the transect stations. While adenoviruses were consistently found in all samples types, enteroviruses were more likely to be found in the coral samples at the nearshore stations. Both viruses were most likely to be found in groundwater at the most offshore stations, indicating that sewage contaminated groundwater is reaching at least 11 km offshore. While adenoviruses showed no seasonal variation, enterovirus detection doubled in summer months, coincident with typical peaks in human infections. Both virus types were also more frequently found in groundwater in the summer which may reflect increased migration during the wet season.

This work supports previous research which indicates that enteric microbes are more often detected in coral mucus relative to water samples. The results of transect sampling reveal that groundwater flow beneath the Florida Keys contains human enteric viruses at distances greater than 11 km. Seepage of groundwater at porous reefs could provide a mechanism for contaminants to travel without sunlight inactivation, increasing survival time, to the offshore water column.

CORALS

REEF CORALS AND THEIR SYMBIOTIC ALGAE AS INDICATORS OF NUTRIENT EXPOSURE by Clayton B. Cook, Erich M. Mueller, and M. Drew Ferrier (1997) Final Report to USEPA / South Florida Water Management District.

There is a widely held view that Florida Bay water have an adverse effect of reef corals in the Florida Keys, based on the distribution of corals which are generally lacking offshore of the wide passes between the Keys. Possible causes for this effect include elevated nutrients, wide temperature and salinity range, and increased turbidity. Two sites were chosen near Long Key; one inshore and one offshore. The species studied was the massive reef-building coral *Montastraea faveolata*.

It is generally agreed that the zooxanthellae of reef corals from normal oligotrophic reefs are nitrogen limited. The typical response to the addition of ammonium or nitrate to corals is an increase in the density of zooxanthellae. Virtually all of the samples that were examined in this study exhibited N-sufficiency and did not follow the classical

pattern of N-limitation. The data show that nitrogen sources available to corals o both sides of Hawk Channel in the vicinity of Long Key appear to be sufficient if not excessive. We do not know whether this nitrogen was transported across Hawk Channel, if it had and offshore source (Pourtales Gyer), if it was being generated on the reef tract itself, or resulted from some combination of all three. What is clear is that if the corals at this site are receiving all of the N that they can use, increases in N supplies will be in excess, and this N likely would be utilized by other algae – particularly benthic macro-algae.

Typically the waters around carbonate-rich coral reefs are P-limited, in part due to the absorption of inorganic phosphate to carbonate sediments. The data suggest that the zooxanthellae from our corals at both experimental sites generally exhibited moderate P-limitation.

The only consistent between site differences found between the two coral sites (inshore versus offshore) was the increased chlorophyll-a content of the zooxanthellae from the coral at the inshore site. This was thought to be a photoadaptive response to decreased light levels there. The amount of suspended matter in the water column was more likely to be responsible, as the water was always murkier at the inshore site than the offshore site. Growth measurements clearly showed that total calcification by corals was reduced at the inshore site by an average of 40% over the entire experiment. The most direct effect of this increased turbidity would be reduced light transmission. We believe that the main effect of Florida By water on coral growth at our sites resulted from increased turbidity and not elevated nutrients in the waters emanating from the bay.

CORAL REEF EVALUATION & MONITORING PROJECT – 2004 CREMP EXECUTIVE SUMMARY, May 2005

Sanctuary-wide from 1996 to 2004, for a total of 105 stations, the number of stony coral species declined at 83 (79%) stations, increased at 15 (14%) stations, and remained unchanged at 7 (6%) stations. The large decline in mean stony coral cover was evident in all three regions in the Florida Keys (Lower, Middle, and Upper Keys), as well as three habitat types (offshore deep, offshore shallow, and patch reef stations).

Between 1996 and 2004, stony coral cover declined from 11.9% to 6.6%. The significant declines in mean percent stony coral cover between 1997 and 1999 were largely due to losses in *Montastraea annularis*, *Acropora palmata*, and *Montastraea complanat*a. Sanctuary-wide.

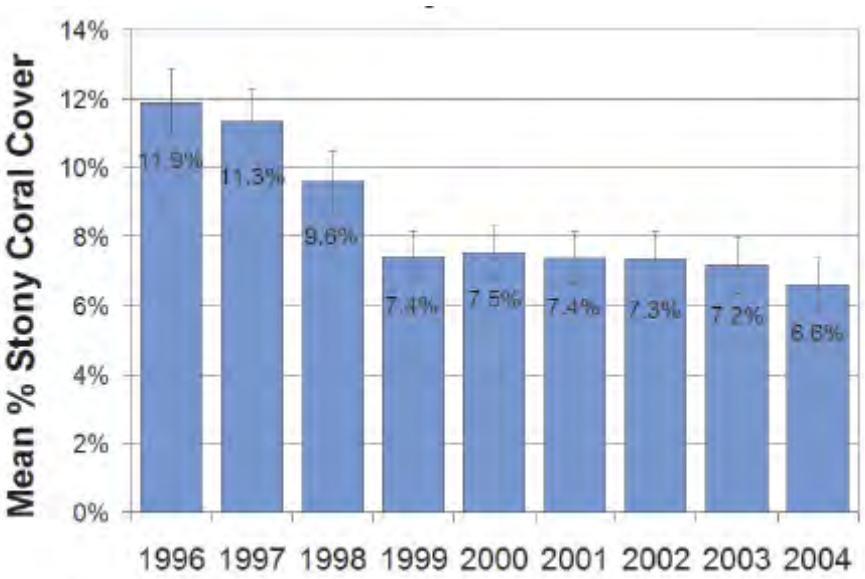


Figure 4. Stony coral cover Sanctuary-wide (1996-2004).

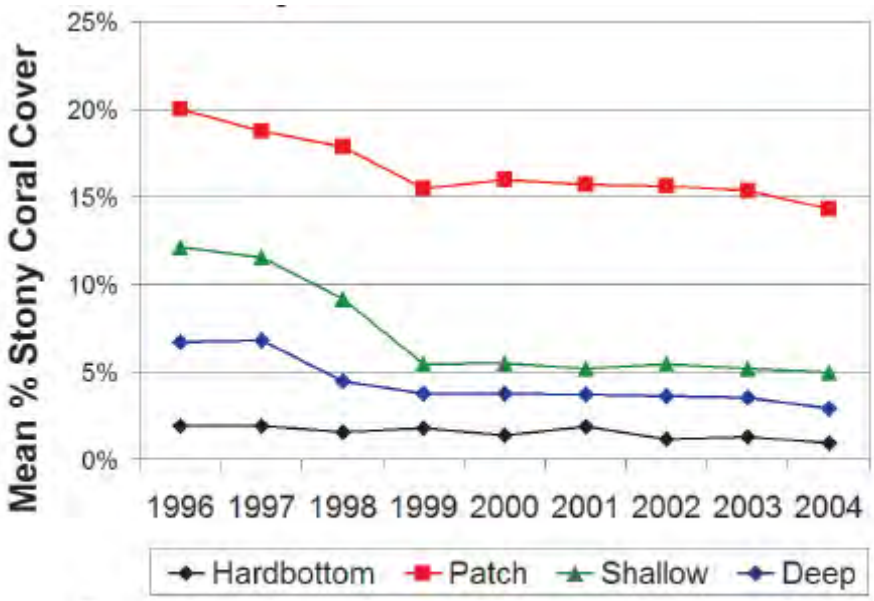


Figure 6. Stony coral cover for all habitat types (1996-2004).

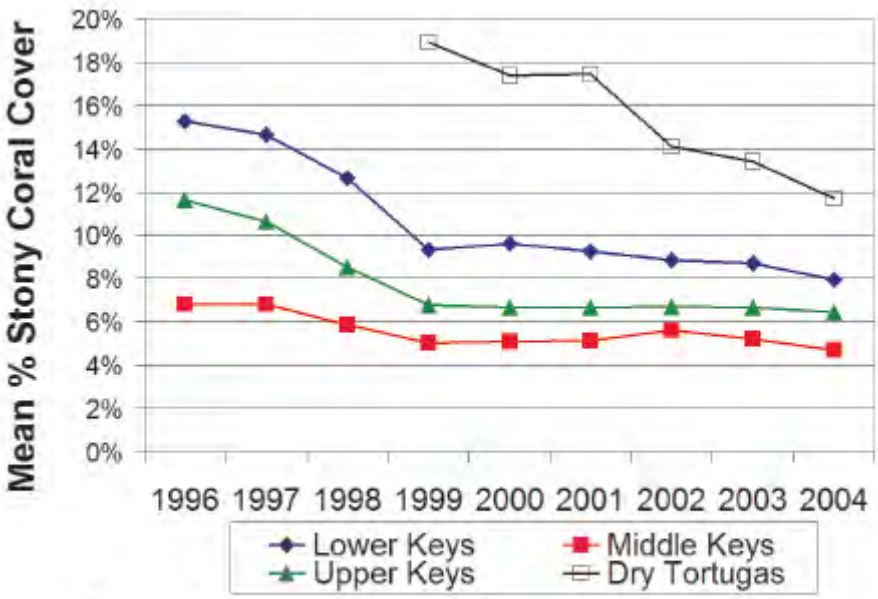


Figure 7. Stony coral cover for all regions (1996-2004).

Between 2003 and 2004, both the number of stations with diseased coral and the number of infected species decreased. In 2004, black band disease was observed at three stations, down from 7 in 2003, while "white" disease was observed at 54 stations, down from 72 stations in 2003. "Other" disease was recorded at 74 stations in 2004. "Other" disease was reported at 89 stations the previous year. Incidence of coral bleaching was also down in 2004. Bleaching was reported at 57 stations in 2003 and 37 stations in 2004. CREMP data indicates that coral disease is not impacting stony coral cover Sanctuary-wide.

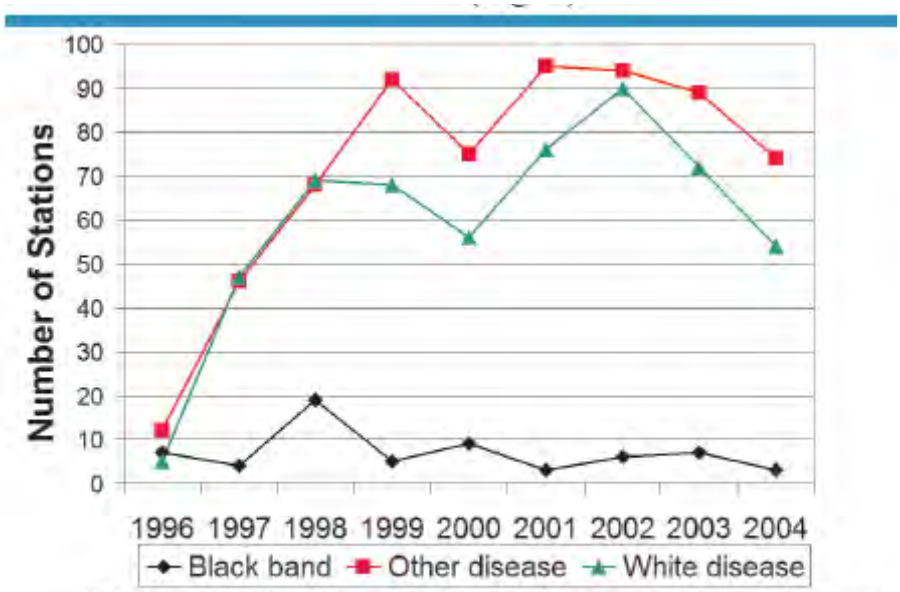


Figure 10. Number of stations with a presence of disease conditions.

The decreases in stony coral cover and species richness documented by the CREMP are evidence that multiple stressors acting at local, regional, and global scales are continuing to have negative impacts on coral reefs in the Florida Keys National Marine Sanctuary

The CREMP has recorded a decline in stony coral cover at the Dry Tortugas every year since sampling began in 1999. The continued decline of stony coral cover at the Dry Tortugas sites is alarming. Although the Dry Tortugas sites still have greater species diversity and greater stony coral cover than the Keys, Dry Tortugas reefs appear to be declining at a greater rate than the Keys. The recent addition of monitoring sites in the Dry Tortugas National Park may help define the causes of the decline.

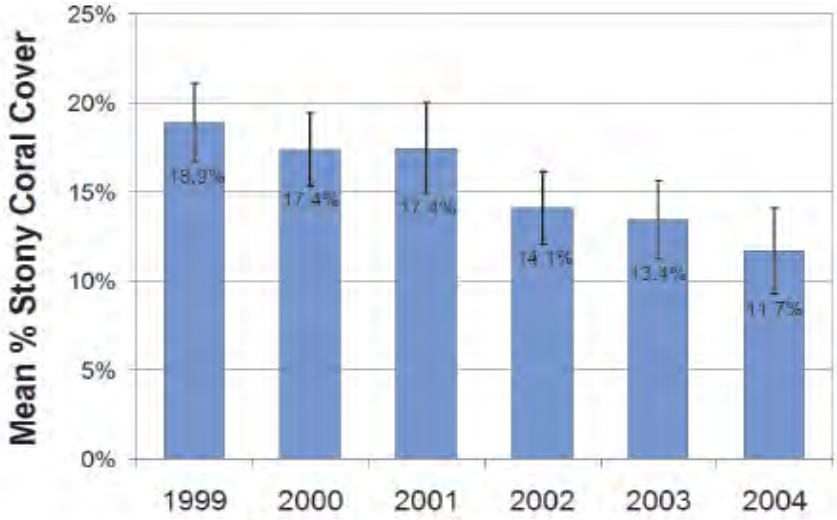


Figure 17. Stony coral cover in the Dry Tortugas (1996-2004).

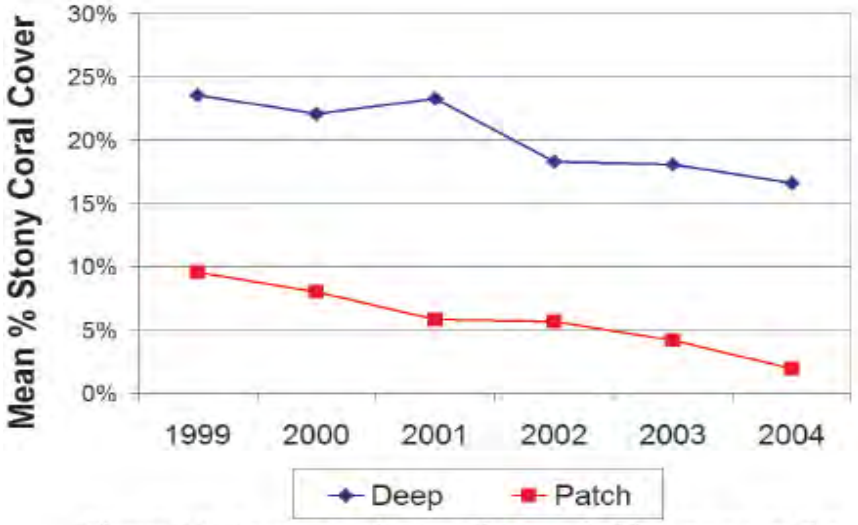


Figure 18. Stony coral cover for two habitat types in the Dry Tortugas (1996-2004).

REEF FISHES

FISHING, TROPHIC CASCADES, AND THE PROCESS OF GRAZING ON CORAL REEFS by Peter J. Mumby, et al (2006) Science, Volume 311.

Since the mass mortality of the urchin Diadema antillarum in 1983, parrotfishes have become the dominant grazer on Caribbean reefs. The grazing capacity of these fishes could be impaired if marine reserves achieve their long-term goal of restoring large consumers, several of which prey on parrotfishes. Here we compare the negative impacts of enhanced predation with the positive impacts of reduced fishing mortality on parrotfishes inside reserves. Because large-bodied parrotfishes escape the risk of predation from a large piscivore (the Nassau grouper), the predation effect reduced grazing by only 4 to 8%. This impact was overwhelmed by the increase in density of large parrotfishes (presumably protected from being caught), resulting in a net doubling of grazing. Increased grazing caused a fourfold reduction in the cover of macroalgae, which, because they are the principal competitors of corals, highlights the potential importance of reserves for coral reef resilience.

QUEEN CONCH

PROGRESS REPORT - ANTHROPOGENIC EFFECTS ON QUEEN CONCH REPRODUCTIVE DEVELOPMENT IN SOUTH FLORIDA by Robert A. Glazer (2006) Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute.

Oxidative stress is a biomarker that is being investigated and characterized in nearshore and offshore populations of conch. Heavy metal content for copper, cadmium, tin, and mercury of near shore and offshore conch hemolymph were analyzed and compared. All four metals were significantly lower in the near-shore females, which for copper may not be a good thing since the oxygen carrier in mollusks is copper-based. The same results are noted for these metals in the digestive gland and the neural ganglia, except for Hg which is higher in the neural ganglia of the nearshore females than the offshore females. The significance of these results is not yet understood.

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