# Synopsis

# Algae bloom workshop

# March 14, 2008

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# PREFACE

During the summer of 2007, the Florida Keys National Marine Sanctuary received numerous reports from both scientists and concerned citizens about sponge die-offs and poor water clarity in central Florida Bay. Testing by the Florida Fish and Wildlife Research Institute (FWRI) confirmed the presence of cyanobacteria (*Synechococcus* spp.), but could not offer details about the bloom's environmental triggers or its sustaining mechanisms. This cyanobacterial "algae" bloom was similar in effect and extent to those that occurred in the early 1990's, and was comprised of the same organism responsible for an on-going cyanobacterial bloom present in eastern Florida Bay. Thus there was a need to bring together various scientists engaged in Florida Bay research to discuss this ecosystem perturbation in more detail.

To facilitate discussion between resource managers and scientific experts, the FKNMS coordinated a technical workshop about cyanobacterial bloom (*Synechococcus* spp.) dynamics in Florida Bay and their effects on the benthos. The workshop was coordinated in partnership with Everglades National Park (ENP), the South Florida Water Management District (SFWMD), and FWRI. The general goal of this interagency effort was to provide a collaborative forum to discuss potential ways in which resource managers could alter the detrimental impacts of these blooms, or at least enhance their predictive capabilities of future cyanobacterial blooms. For example, the FKNMS needed to determine if their seagrass natural resource damage assessment (NRDA), restoration, or monitoring protocols should be modified in areas affected by these cyanobacterial blooms.

The public workshop occurred on March 14th, 2008, and had an "Algae blooms 101" morning session followed by a facilitated discussion in the afternoon. Presentations during the morning session came from experts in cyanobacterial bloom biology and physiology, cyanobacteria genomics, Florida Bay water quality, climatology, oceanography, and benthic ecology (e.g., sponge, seagrass, and invertebrates). Abstracts of the presentations are included in this synopsis in order to provide supporting graphics and technical information to their respective summaries. The afternoon session engaged all workshop attendees in discussions about the causes of blooms and the current and future management responses to them.

# CONTENTS

**Algae bloom workshop: re-evaluation of management needs in Florida Bay**

**Date:** March 14th, 2008

**Location:** NPS Krome Center offices,
950 N. Krome Ave (1st floor conference room)
Homestead, FL 33030 Ph: (305) 224 – 4200

Workshop Goals:

- Review algae bloom history and relevant highlights from the Florida Bay synthesis report (http://research.myfwc.com/dg.lts/id.52697/publications.publication_info.htm)
- Discuss algae bloom causes and develop assessment strategies that may enhance our predictive capabilities
- Evaluate management actions that could alter bloom dynamics
- Examine Everglades restoration (generally), and its potential effect on bloom frequency, duration, and intensity
- Determine if the FKNMS current natural resource damage assessment (NRDA), restoration, and monitoring protocols need to adapt to changing conditions from cyanobacterial blooms
- Summarize recommendations to trust Agencies about adaptive management response, NRDA, restoration, and monitoring strategies
- Provide workshop summary to the public at the next FKNMS Sanctuary Advisory Council meeting, April 15, 2008

Agenda:

| Time | Topic | Presenter |
|---|---|---|
| **8:30am** | **Introduction and review of goals** | Scott Donahue/ Carol Mitchell |
| | **Bloom history (past and present occurrences), biology, physiology, genomics, etc.** | |
| 9:00 | What do we know about blooms in the 1990's (before, during, and after) | John Hunt |
| 9:15 | What do we know about blooms during the hurricane seasons | Dave Rudnick |
| 9:30 | What do we know about blooms in 2007 (before, during, and after) | Cindy Heil |
| 9:45 | Mechanics of bloom regulation and algal life cycle | Cindy Heil |
| 10:00 | Bloom proliferation and physiology (salinity and phosphorus triggers) | Cindy Heil |
| 10:15 | **BREAK (15 min)** | |

| | | |
|---|---|---|
| 10:30 | Bloom genomics | Joe Boyer |
| 10:45 | Climatology of FL Bay, and connectivity of regions | Chris Kelble |
| 11:00 | Water quality and residence times | Chris Kelble |
| 11:15 | Sponge grazing rates | Brad Peterson |
| | **Ecosystem effects of blooms** | |
| 11:30 | Seagrass | Jim Fourqurean |
| 11:45 | Hard-bottom | Mark Butler and Michael Childress |
| 12:15 | Time frame for sponge recovery | Don Sweat |
| | | |
| **12:30 p** | **LUNCH** | |
| **1:30 p** | **Discussion of bloom causes and current and future management responses to blooms** | |
| | What do we know from the FL Bay synthesis report? (the five hypotheses should help frame ensuing discussion) | John Hunt to begin with, then open floor to discussion |
| **Example talking points** | Which hypothesis is strongest or is it a combination? | |
| | What research needs to be done to differentiate between these hypotheses? | |
| | Will CERP reduce or increase likelihood of bloom reoccurring / or their frequency? | |
| | What research needs to be done to answer this question? | |
| | Is there anything managers can do to help ameliorate these blooms? | |
| | Are the blooms anthropogenic? Can we do anything about them? | |
| | Is there any benefit to other strategies like 'seeding' hard-bottom habitat with sponges after a bloom associated die-off (i.e., enhance recovery of the sessile taxa)? | |
| | How should FKNMS vessel grounding response, assessment, restoration, and monitoring be modified to maximize recovery rates of seagrass services when blooms present? | |
| | | |
| **4:00 p** | **Workshop wrap-up and action item assignments (if necessary)** | |
| | | |
| **4:30 p** | **Open discussion time for other interests** | |
| | | |
| **5:00 p** | **Adjourn** | |

# SUMMARY OF MORNING SESSION

## Introduction

General recap of recent history (from 1980's to present) of Florida Bay and cyanobacterial (*Synecococcus* spp.) blooms:

- Generally, during the 1980's there was a net increase in salinity in FL Bay (because of drought conditions), which peaked in 1989; however, this change in salinity was not linear (i.e., there were periods of decreasing salinity).
- There was a major seagrass die-off in the late 1980's, caused by sulfide toxicity – why this occurred we don't know, but grasses died and later the blooms came
- Fall 1991, first *Synechococcus* spp. bloom lasted about 3 months, then dissipated in some areas. Bloom hit again the following year and lasted for extended time period; it formed in central Florida bay.
- Simultaneously, blooms in western FL Bay and south of Cape Sable were dramatic, but they were not *Synechococcus* spp. – they were mostly diatoms.
- The *Synechococcus* spp. bloom in the central Bay totally disappeared by 1995.
- The early 1990's blooms did not adversely affect the Bay's seagrass community, but they resulted in a large sponge die-off.
- There is a regular *Synechococcus* spp. bloom cycle that happens in Rankin Basin each year, but it usually does not affect other basins.
- A *Synechococcus* spp. bloom has been present in the Eastern part of the Bay since 2005.
- A similar *Synechococcus* spp. bloom has been present in the central part of the Bay since summer of 2007.
- A Harmful Algal Bloom (HAB species; *Prymnesium saltens*) also occurred in south Key Largo resulting in fish kills, but this was very localized and quickly dissipated.

## Summary of Presentations

### Florida Bay Phytoplankton Blooms: Considerations of Hurricane Effects (Dr. David Rudnick, SFWMD) – Abstract on page 20

- Hurricanes are common sources of disturbance and are cyclic over a multi-decadal time scale.
- Long-term data shows Florida gets an average of about one hurricane or tropical storm per year.
- 2005 was a very active year.
- Hurricane Irene (1999) produced widespread salinity effects; large portion of FL Bay can be freshened in a short time; 30 ppt. to 10 ppt. quickly (within weeks).
- A widespread algal bloom occurred in Florida Bay after Hurricane Irene in 1999, but this bloom was relatively short-lived (1 to 4 months).

- Following the hurricanes of 2005, an unprecedented algal bloom began in eastern Florida Bay and southern Biscayne Bay. Bloom initiation appeared to be linked to phosphorus inputs (elevated concentrations observed October 2005). Despite the broad range of hurricane influence (e.g. Katrina had rainfall and runoff similar to Irene), no pronounced algal bloom occurred in central Florida Bay after the 2005 storms. This points to the site-specific nature of hurricane influence (and the possible interaction of US1 widening disturbance).
- No direct major hurricane impact since 1965 (hypothesized to be one cause of major ecosystem change – via sediment, organic matter, nutrient accumulation)
- There has been a recent increase in hurricane frequency.
- Wide range of ecosystem and water quality / phytoplankton responses cited in literature (storm and site specific) – see Estuaries and Coasts 29 (6A), 2006.

<u>Cyanobacterial (*Synechococcus* spp.) biology and physiology (Dr. Bill Richardson and Dr. Cindy Heil, FWC-FWRI; Dr. Patricia Glibert, University of Maryland Center for Environmental Studies; Dr. Cindy Heil presenting) – Abstract on page 22</u>

- What is *Synechococcus* spp.?
    1. A 'picoplankton' – very small (~1 um), unicellular cyanobacterium
    2. A cyanobacteria: a phylum of bacteria that obtain energy through photosynthesis
    3. AKA 'Blue-green algae'
    4. Free floating
    5. Widespread globally in the marine environment

- Is it toxic? Not directly toxic, but it can be 'harmful'
    1. One report of toxicity of *Synechococcus* spp. from the Salton Sea
    2. Directly harmful: as a food source of 'poor' quality for filter feeders
    3. Indirectly harmful:
        - Changes in water quality
        - Reduces light penetration
            a. affects seagrasses and benthic microalgae
            b. affects food webs dependent upon both
        - High plant biomass - oxygen depletion could become an issue
        - Economic
        - Quality of life

- What favors *Synechococcus* spp. over other microalgae?
    1. Fast growing: 0.75 – 1.0 divisions per day over a wide range of salinities (5-60 ppt salinity) (Richardson, 2004)
    2. Small Size: 1 µm, essentially neutrally buoyant
    3. Light: Grows well at lower light intensities
    4. Food Quality: Not especially 'good' nutritional food for classic grazers
    5. Nutrient Strategy: Can use both inorganic and organic (or recycled) nutrients

- General conclusions about recent blooms
    1. Turbidity does not give *Synechococcus* spp. a competitive advantage over diatoms, but the water column is usually less than 1m deep in Florida Bay, so time spent at low irradiance levels is probably very short. Therefore, *in situ* light limitation is probably not limiting the growth of these blooms.
    2. All things considered (light, nitrogen, phosphorus, salinity), *Synechococcus* spp. is competitively favored early in bloom cycles
    3. Generally, eastern bay bloom is limited by nutrients (bottom-up control) - western bay by both grazing and nutrients (top-down and bottom-up controls, respectively) in 2006-2007.
    4. *Synechococcus* spp. can tolerate wide range of salinities, and can potentially out compete other microalgae in very low (<10ppt) and very high (>50ppt) salinities.

*Synecococcus* spp. Genomics (Dr. Joe Boyer, Florida International University) – Abstract on page 23

- Both phytoplankton blooms (central and eastern Florida Bay) have been found to be dominated by cyanobacteria.
- Cyanobacteria are primarily in genus *Synechococcus* (but not *S. elongatus*) found in estuaries and coastal ocean worldwide.
- They are well adapted to low nutrient conditions, can use organic nitrogen, thrive under fluctuating salinities, and can access iron (Fe) at extremely low concentrations.
- The dominant species of cyanobacteria in eastern Florida Bay is also the dominant species in central Florida Bay blooms.
- The Eastern Bay community dominated by two (*Synechococcus*) organisms in the same clade
- This dominant species of cyanobacteria within the water column is not present in sediments and therefore sediment resuspension is not “seeding” the bloom.
- Once blooms initiate they are moved around by wind and water currents;
- Bloom organisms we find here in FL Bay are almost indistinguishable from other organisms found in other coastal areas around the world

Florida Bay climatology, connectivity, residence times and salinities (Dr. Chris Kelble, NOAA/AOML) – Abstract on page 25

- Large-scale meteorological processes significantly effect Florida Bay
- Tropical cyclones cause significant changes to the Florida Bay environment
- This response may be delayed in the south due to restricted circulation
- Strong hypersalinity (increased salinity)results from the delayed onset of the wet season and the loss of the two annual rainfall peaks in February and September
- Basin water residence times are on the order of 2-7 months
- Mean Florida Bay circulations are typically low, but are higher through the Florida Keys

- Net flow of water is from Florida Bay out to the Atlantic
- Circulation is largely wind driven
- Circulation responds to physical forcing (e.g. cold fronts, tropical cyclones, etc.)
- Wet/Dry season is the most significant driver of salinity fluctuations
- Because of shallow nature of basins, salinities in the Bay are driven by rainfall, not run off from land
- What does all this potentially mean for algal blooms?
    1. Advection of nutrients and the algal bloom itself
    2. Potential for recycling within the basin when residence times are long
    3. Large perturbations may increase sediment re-suspension and damage seagrass (benthic-pelagic coupling)
    4. Connectivity with north-central bloom

Grazing control of cyanobacteria (*Synechococcus*) by sponges (Dr. Brad Peterson, Stony Brook University) – Abstract on page 27

- Sponges are the dominant filter feeder in Florida Bay
- Sponges are capable of filtering suspended particles from 0.5-20 µm with >80% retention rate
- Recent incurrent / excurrent comparisons suggest that grazing is 4-6X greater than previous grazing estimates.
- Under non-bloom conditions, 40-50% retention rates on both total Chlorophyll *a* and cyanobacteria are common.
- Under bloom conditions, grazing is suppressed, growth rates and survival are reduced.
- Picoplankton such as cyanobacteria are typically under tight top-down control via grazing (Calbet and Landry 2004). A loss of this top-down control can cause algal growth to outpace its removal, resulting in a subsequent bloom (Sunda et al 2006).
- Our preliminary data suggests the abatement of benthic and pelagic grazing may be responsible for the occurrence of cyanobacterial blooms in this estuary.

How do phytoplankton blooms affect the seagrass community? (Dr. Jim Fourqurean, Florida International University)

- Seagrass has high light requirement – 10-25 % of sun's light needs to reach them, meaning phytoplankton are bad for seagrass
- Seagrass needs this much light because muds are anoxic and full of sulfides - they need to continuously oxygenate the roots or they die, which is what happened in the late 80s – the dense beds lost the ability to oxygenate the meristem for some reason
- Seagrasses grow under the water column…
    1. They have a high light requirement (more than 10% of direct sunlight)

2. Secchi depth is roughly correlated with 10% light penetration and maximum seagrass depth – if you can't see the bottom, there is probably not enough light reaching the bottom to support seagrass.
3. Turtle grass (*Thalassia testudinum*) needs more light than Shoal grass (*Halodule wrightii*) and Manatee grass (*Syringodium filiforme*) which need more light than Paddle grass (*Halophila* spp.)
4. …this is because each has different morphologies thus differing light requirements, and different abilities to withstand losses of light
5. However, *Thalassia* meristems are down in the sediment, and their rhizomes also have greater internal storage of resources than other species – so it reacts more slowly to decreases in light, or fresh water pulses

- Higher nutrient conditions promotes growth of faster growing species
- Seagrass die-offs occurred well before phytoplankton blooms in Florida Bay; Unfortunately, there was no water quality data for FL Bay until late 80's, and this happened well after seagrass die offs
- Regarding losses of *Thalassia* in northern bay - when people (scientists) outside our system saw blooms in FL Bay, they thought phosphorus levels increased in the system therefore phytoplankton became the competitive dominant… then we lost the seagrass...and <u>that's not what happened</u>.
- What about epiphytes? Epiphytes did not kill the seagrass either
- Beginning in 1995, study sites throughout FL Bay have been sampled twice a year; *Thalassia* has maintained, but *Syringodium* and *Halodule* dropped out of central bay, and *Halophila* moved in;
- Although the benthic system is different from before, it is still a seagrass ecosystem
- SFWMD has done benthic surveys in eastern bloom area - loss of seagrass in deepest part has occurred, but the edges (shallow) are still intact; Lake Surprise is still lush, but we can't see the bottom so that will affect seagrass - survivors will be there and will survive if water clears up
- Right now *Thalassia* is doing okay in western/central bloom; it's still fixing carbon and growing new leaves in spite of the bloom
- *Halophila* will move into bay if blooms continue over time, *Halophila* is common in deeper waters of the gulf;

<u>Algae bloom impacts on hard bottom communities (Dr. Mark Butler, Old Dominion University) – Abstract on page 29</u>

- The 1991-1992 cyanobacterial bloom studies …
- Documented changes in sponge community structure
- Documented changes in juvenile lobster population structure, shelter use, & seasonal recruitment at local, regional, & Keys-wide scales
- Hypothesized ecological linkages: blooms → sponges → lobster

- "Scientific Cascades" in Methodologies & Research

1. Modeling: Estimate Keys-wide impacts on lobster recruitment & forecasting effects of environmental change (blooms, salinity)
2. Sponge Research:
    a. Population dynamics (growth, reproduction, recruitment)
    b. Tolerances for salinity, temperature & various environments
    c. Filtration rates & particle selectivity
    d. Sponge fishery effects
3. Monitoring of Hard-bottom

- Consequences of sponge die-off
    1. Top-down control (grazing rates) of cyanobacterial is eliminated or reduced
    2. Critical shelter habitat for myriad invertebrates removed from the system (e.g., sponges are key habitat for smallest lobsters which are subject to predation)

- Results of recent research:
    1. Vase sponges die fairly quickly in bloom conditions
    2. Only 2 of 22 sponge species are tolerant of these blooms
    3. 2007 bloom impacts were severe on loggerhead, vase, and other sponges (including the commercially targeted species)
    4. Some sponges can recover after partial die-off
    5. Impact of blooms on hard-bottom communities appears to be similar to that in 1991-1992 – but we have more data and more investigators now.
    6. Sponges have really short larval periods, thus recovery of sponge communities in the die off area is likely to be very slow due to limited transport capabilities
    7. Sponges are fairly good sentinels of bloom conditions because different species have different tolerances
    8. Based on past and present surveys within the *Synechococcus* bloom areas, other hard-bottom fauna are not affected by blooms (includes tunicates, soft corals, hard corals, etc.)
    9. We have data on changes in sessile benthic fauna & lobsters:
        - sponges: abundance & size structure
        - lobsters: abundance, size structure, shelter use, condition, aggregation, and disease
    10. Results of monitoring and targeted experiments on tolerances of sponges, octocorals, & lobsters can be compared with and integrated into our existing spatial model

Impact of sponge loss on lobster and crab recruitment, Dr. Michael Childress, Clemson University – Abstract on page 30

- Behavior of species matters—how organisms find and use shelter habitat is important for their survival

- Bottom-up control factors – are spiny lobsters influenced by structures or numbers of recruits?
- Lobster densities in some areas may be recruitment limited while in other areas by predators
- As more and more structure is lost, predation becomes a more important (top down) density control mechanism
- In 1991, the relationship of the density of sponges to the density of lobsters was not that closely coupled - other things affect lobster populations
- What did this sponge die-off do to the community of organisms that are normally associated with sponges?
    1. Before and after sponge die-off, there was no impact on toadfish abundance
    2. Octopus - no affect
    3. Stone crabs - no affect
    4. Spider crabs – had significant change in abundance - before the die-off, a significantly higher number of spider crabs were found on the survey sites than after the die-off.
    5. Juvenile lobsters—no sign before and after bloom;
    6. Post algal lobsters— seemed like sponge die-off was good for this size class– but our sites also have artificial shelters available, which likely brings them into site. This explains the observed increase of juvenile lobsters after the sponge die-off

<u>Long term monitoring of sponge recovery. (John Stevely and Don Sweat, Florida Sea Grant; Don Sweat presenting)</u>

- We have long-term on sponge population response to the mortality events in the early 1990's. Abundance data for 23 species for 15 years (1991-2006).
- By 1993, two study sites (Marathon and Long Key) lost greater than 90% of sponge biomass.
- Loss of volumetric biomass was greater than numerical decline due to loss of abundant massive species (*Spheciospongia vesparia* and *Ircina campana*) that dominated sponge community biomass.
- Pattern of recovery of S. *vesparia* was different at the two study sites. At Marathon, all recruitment was from sexual reproduction (settlement and survival of larvae). At Long Key, initial recovery (1993-1998) apparently was due to recovery of specimens that had not been completely killed.
- Recovery takes a long-time. *I. campana* had not fully recovered 15 years after mortality.
- We were able to identify long-lived sponge species that showed gradual recruitment.
- We were able to identify short-lived (opportunistic species) that fluctuated dramatically in abundance over the course of the study.

- Our data tend to confirm work by Butler, et al., that *Cinachyra alloclada, Niphates erecta,* S. *vesparia* and possibly *T. crypta* were somewhat resistant to bloom conditions.
- We were able to evaluate the effects of Hurricane Wilma on sponge populations - Saw effects on sponge abundance at Marathon, but little effect at Long Key.
- Massive, strongly attached sponges were highly resistant to hurricane conditions.
- Effects of bloom conditions were much greater than effects of a hurricane. Hurricane conditions probably either pulverized or transport off site the opportunistic species. Bloom conditions kill long-lived sponges that take much longer to recover.

- We will be submitting a manuscript on our long-term study to Bulletin of Marine Science by August, 2008. A summary of our initial (1991) sponge community biomass survey will be published in the 2008 proceedings of the Gulf and Caribbean Institute.

## NOTES FROM AFTERNOON DISCUSSION

- From a historical standpoint, prior to late '80s we don't have the right kind of information to say much about historical (blooms) past, other than to say there were times of murky water or turbid water
- FL Bay is a really dynamic system – it is not static and should not be thought of that way
- Our real knowledge base starts in mid to late 80s, at least to changing conditions in the bay that have led to blooms of these types
- A possible relationship between drought periods and *Synechococcus* blooms may exist, but we need to investigate this correlation further. For example, starting from the 80s (because no literature prior), we might see that severe droughts (i.e., early 90s) were followed by influxes of freshwater that potentially triggered blooms. If that's the case, we could look at the drought in 2001 then look 3 to 5 years later for another bloom. So if there's one link (correlation) that appears to exist is that if we have drought followed by abnormally high fresh water, blooms could occur after some time-lag
- The observed increases in *Synechococcus* spp. biomass in northeastern Florida Bay corresponds with organic matter inputs to the region (dissolved organic nitrogen (DON) and dissolved organic phosphorus (DOP)). This suggests that *Synechococcus* spp. is both autotrophic (photosynethetic) and mixotrophic (i.e., able to take up and utilize both inorganic and complex organic dissolved nutrients). The ability to utilize organic nutrients could be one reason for the initial growth and subsequent dominance of the *Synechococcus* spp. bloom. We know that drought conditions concentrate organic matter, seagrass die-offs produce dissolved organic matter, mulching mangroves put dissolved organic nutrients into the water. All these factors could contribute nutrients to the bloom.

- There are two instances (1982 & 1988) of high fresh water flows (i.e., low salinity events) that did not result in cyanobacterial blooms
- *Synechococcus* spp. is both autotrophic (photosynthesizes) and mixotrophic, able to utilize both inorganic and organic nutrients for growth.
- Total phosphorus (TP) was a trigger for Eastern bloom; TP elevated <u>prior</u> to the main Eastern bloom
- While we may not have good info about *Synechococcus* in the past, we do have documentation of salinity variability; and good info on changes of water levels upstream when coastal ridge dropped 4-5 ft.
- What we do know it is that this is not an invasive organism that gets transported into the system and takes over; it's there and well adapted to system and when conditions are just right, it takes off.
- We also have to realize there are other bacteria in the system and it's those other heterotrophs that are mobilizing nutrients out of organic pool that allow cyanobacteria to get a hold of that material; product transferred to next community, so blooms kick in when the quality of that organic matter is such that it can be turned over quite rapidly...a flush of nutrients waiting to be released;

**Question: we have a seasonal little bloom in Rankin... we had smaller blooms late 91-92 that were localized in areas, but then they went crazy. What makes that happen?**

- One thing to consider is droughts and rain. So if you have large fluctuation in salinity, Thalassia might not die, but might shed leaves, which would be significant input of organic matter into the water column...this could be a connection with the droughts.
- Think of a bloom as the result of growth (cell division) exceeding losses (cell death, viral infection, grazing, advection, etc). Blooms occur when growth exceeds losses, but what contributes to growth?
- Anecdotal observations suggest big blooms can move upwind and uptide, so not 100% sure we can see these bloom events as strictly wind or tide driven...if this was the case, we would see these blooms flush out of the system with the tide
- On moving against tide issue – you can have net flow through cuts (in FL Bay) in one direction and net flow across the banks in the opposite directions; so just because tide is going one direction, don't assume net water flow is doing the same thing
- Sponges are not just affected by blooms, salinity also affects them. Certain species have differing salinity tolerances, so between the blooms and salinity changes we loose a significant grazing component of the Bay. This is contributes to the loss of a buffering capacity. From Brad Peterson's work, sponges can graze effectively at lower concentrations but once a certain point of higher concentrations of cyanobacteria is reached, they die. This is not a gradual thing, there's a tipping point
- Sponge response to salinity is quick... pulse experiments with sponges, after two day pulse of hyposalinities, got massive die-off of these animals, Blooms could be a longer process, whereas salinities could be quite acute - the buffering

capacity of the system may have been diminished during those salinity events (via sponge mortality)

- There are a lot of factors contributing to *Synechococcus* spp. blooms, no one factor in particular seems to be the trigger for these blooms.
- Other filter feeding organisms not affected by the blooms are grazing on larger prey, like diatoms and dinoflagellates. Sponges are actually net producers of viruses and net producers of nitrogen
- Two potential research needs: 1) We need to understand the role of dissolved organic nutrients in Synechococcus blooms as data (C. Heil, P. Glibert) suggests that dissolved organic nutrients contribute significantly to the initiation and maintenance of these blooms in Florida Bay; 2) We also need to understand more about the effects of salinity on grazing rates as well as the mortality associated with grazing. Those two things we need to know in order to put a model together that would allow us to incorporate all these multiple causal effects we see that have some imperfect correlation with the blooms.
- Since 1990, there may be a link between that short period of time between droughts, flushing activities and cyanobacterial blooms...I'm not seeing any of these conditions apply to the July 2007 bloom in Twin Key:
- The southern bloom is clearly not driven by hypersalinity, it's not driven by any watershed activity because it is pretty far away, it's likely driven by something else (e.g., Twin Key or somewhere in that region)
- Biomass of cyanobacteria is minute compared to biomass of seagrass, so it doesn't take a lot of loss of seagrass to support a lot of plankton biomass
- We can't wait to have perfect scientific knowledge to manage the system
- There are triggers and there are sustaining processes. This is such a nutrient depauperate system that evolved to be extremely efficient at keeping phosphorus in the system.
- There has been a hypothesis out there regarding the railway, freshwater inflow as a forcing of flushing, major hurricanes as sediment disturbance. Basically FL Bay is a nutrient sink, with slow chronic nutrient inputs (probably natural), but augmented by anthropogenic sources.

**Question: Is there anything management can do to ameliorate blooms, short term or long term, major ecosystem focus?**

- "Will the Comprehensive Everglades Restoration Project (CERP) reduce or increase the likelihood of bloom occurring?" – CERP's likely influence is affected by current difficulties to convey more water from the northern and central Everglades and the influence of the Gulf of Mexico and Atlantic Ocean. Water management does have an influence on the system and changing this management (e.g. via CERP implementation) likely will change the bay's ecological status. The likely magnitude of these changes is still being evaluated, but given the small changes in freshwater flow through the southeastern Everglades (with CERP), ecological changes in Florida Bay may be strongest at the northern boundary of the bay and modest elsewhere. Additionally, implementation of the first phase of the C111 Spreader Canal Project (which is both a CERP and an Acceler8 project) is expected within 3 years and will likely change the distribution of water flowing toward Florida Bay, with a greater proportion following along the natural path of Taylor Slough and less water flowing through the C111 Canal.

- The difference between rainfall and evaporation across FL Bay is five times greater than the water that flows into the Bay. It's a precipitation/evaporation driven system - The drought upstream isn't affecting our salinities in the Bay because we don't have a drought (there).

- Anytime restoration of a system occurs, there will be change in the system, and those organisms and characteristics that have become prominent are going to get shifted and there will be winners and losers.

- In the 1994-1997 wet period, water was coming out the Taylor River slough…dramatic changes in the prey based fish community occurred during that period and it became far more productive that it ever was before or has been since. That happened over a 3 year period then disappeared over one year (high salinity) period.

**Question: does it make sense now to try to mitigate, or perform restoration, and get filter feeders back into the system that have been removed because of bloom effects (via mortality). Can that have an impact in maintaining lower plankton densities**?

- The effect grazing has on the magnitude of these blooms is unknown, but what we do know is that in non bloom situations, sponges can retain ~40%of cyanobacteria, so they are a loss term for *Synechococcus* spp. blooms.
- ...but there's devils in the details…other issues include size specific fecundity (smaller ones are really not reproducing). However, once we reestablish sponges in those die-off areas, we could see some success. But we have to put them into these areas, otherwise it will take decades to happen. It's worth considering that if you put a certain suite of sponges in an area, they can act as sentinels. So this type of restoration would serve two purposes: 1) restoring the populations, 2) they can serve as early warning
- In a lot of discussions, the variability and predictability of restoration are very low sometimes, and we can not get away from that. If you look at the data used to support other restoration decisions in other systems, there is a lot of guess work. For example, there was a 3 year timelag between restoration and measurable results in the Tampa Bay area. Likewise, it took 6 years for Sarasota Bay – now we have 95% of the seagrass we had back in 1950's. Keep expectations right for people…we don't have 100% of the knowledge, but it seems to be the right thing to put water from a canal through the slough system when you know the efficiency of removal of nutrients will be better than in a canal.
- Water column grazers are a small component of the system (most grazing done by sponges) thus not a good candidate for 'restoration' per se.

- The seagrass community is more resilient than it appeared to be when those rapid changes were occurring (early 1990's).
- Point: With the exception of the sponge die off, our sport fish monitoring network did not show any changes in overall catch throughout the year, and when you put this into perspective of the hypothermic event we had, which was completely natural and resulted in fish kills, the Bay will likely bounce back from that.
- Counterpoint: from the animal side of the coin, the issue of alternative stable states is evident. In many places from the 91-92 bloom, e.g., Twin Key basin, sponges and lobsters have never recovered to the pre-bloom state. Sponge communities, and their associated fauna, take a long time, if ever, to come back to what they were.
- We only know the intensity and duration of those blooms we have lived through.
- Also be prepared for hurricane effects. E.g., when 'Charlie' hit Punta Gorda it made 100 miles of the Peace River anoxic, and it stayed that way for 3 months. We had 60mi2 of Charlotte Harbor without O2. The harbor recovered quickly – the fish moved in and out. It's not a pristine watershed at all, but that didn't slow down the need for restoration (upstream), and it didn't make people feel bummed out about restoration is not working…once a hurricane is involved, all bets are off.
- What we know about the Florida Bay system is that it is variable, and it varies from clean water times to turbid water times and we don't really understand why, but so far that variation has continued…and we're worried in the future that if we change the inputs we may shift the balance so that it's dirty more often. But right now, the history of the system is one that is variable, from all the paleo data and anecdotal records and now scientific data so no one should expect the environment to be static.
- If you see sponges dying, it doesn't mean the system is collapsing
- Generally, scientists have not answered the management questions yet, which have stayed the same since the first Florida Bay meeting in the late 1980's, but the knowledge void was so huge back then…we have made a lot of progress since then and are working towards those answers

  - ❖ Point: there is very little difference in way we are managing water today than Test 6. We have not advanced at all in the way we manage flows into FL Bay, it's almost identical to what it was. This is worrisome...SAV, fish, and birds have been monitored and we have seen no ecological difference. A lot of what we are seeing in the Bay, with blooms and the things I work with, are likely all tied to anthropogenic (water delivery) problems.
  - ❖ Counter point: The distribution of water between what goes down C-111 and Highway creek vs. going into Taylor slough has dramatically changed since Test 6 (1992-94). The management of the system is much better than it was, and part of the incentive is spurred by scientific information… we're on a positive course, just that it has been slow one

- The fact we found out in the wet years of the 1990's that we could get increased productivity in certain areas (because of increased water flow) is a good thing….

- Do not think about dry years/wet years as if they're an aberration…the aberration is average. When you look at rainfall throughout Florida (for the period of record), the mean is 52 inches in our part of Florida, but the 95% CI is 40-80 inches. So the reality is that we need to expect that variation…it's not really wet or dry year, but it's within the range of expectation. We should not manage the system for the average rain fall year.

**Question: how should sanctuary vessel grounding response modified to recovery rates of seagrass service when blooms are present?**

- Generally, if we use a secchi disc measurement, and can see it on the bottom, we should attempt restoration immediately. If we can't see it on the bottom don't do it whether there is a bloom or not.
- Also consider that a transplant may need more light than normal…minimum light is different from mature than immature plant. The minimum light requirements are derived from mature seagrass beds, if you plant it at that mature bed there may not be enough light for a 'little sprig'. But again, this may not matter considering the shallow nature of the bay and location/characteristics of the vessel groundings

# CONCLUSIONS OF THE FLORIDA KEYS NATIONAL MARINE SANCTUARY

For the purposes of describing trends in cyanobacterial bloom frequency, and their associated ecological impacts, the collective knowledge base starts in the late 1980's. We have learned that the blooms are not necessarily triggered and/or sustained by a single change in nutrient load, rather a combination of multiple biotic and abiotic factors contribute to their intensity and duration. Unfortunately, we do not have sufficient data to predict cyanobacterial bloom initiation or longevity yet, thus there is a need to integrate existing biological, climatological, and oceanographic research efforts so that predictive models can be further developed and refined. This type of predictive tool would help resource managers (e.g., FKNMS and ENP) prepare the public for the biological impacts of these blooms, and modify resource assessment, restoration, and monitoring protocols where applicable.

For example, the FKNMS would only modify its existing vessel grounding damage assessment or restoration monitoring protocols when bloom conditions prevent utilizing Braun-Blanquet estimates of seagrass shoot counts and areal coverage. Because this technique is a visual assessment method, biologists could not accurately quantify these parameters until water clarity improves. Likewise, restoration of seagrass beds would need to consider light penetration as a limiting factor, thus restoration of a seagrass injury should not occur during times when secchi depth is less than the seagrass restoration depth. Exclusive of vessel groundings, there is evidence that over longer time scales, the seagrass community of Florida Bay is resilient to *Synechococcus* bloom disturbances.

However, the sponge community in Florida Bay may not have the ability to completely rebound from bloom associated die-offs without some form of management intervention. Current research on sponge ecology in Florida Bay suggests they are the dominant grazers of picoplankton (*Synechococcus* spp.), and without this trophic interaction, algal growth during non-bloom conditions may outpace its removal in some areas. In this system, sponges face barriers to dispersal, including climatological forcings and short larval periods, thus natural recovery of sponge communities in areas where they were once found will take decades, if it occurs. In consideration of the ecosystem services provided by these sponge populations, they should also be considered a viable restoration alternative after natural disturbances such as cyanobacterial blooms.

# ABSTRACTS

Florida Bay Algal Bloom Workshop, 3/14/08
Summary of presentation by David Rudnick
*Florida Bay Phytoplankton Blooms: Considerations of Hurricane Effects*

*I. Hurricane Effects on Florida Bay Phytoplankton Blooms: Overview*

- Hurricanes are a common source of disturbance
- No major hurricane has impacted Florida Bay since 1965, possibly resulting in sediment, organic matter and nutrient accumulation. Seagrass expansion and subsequent die-off (starting in 1987) may have been associated with this accumulation.
- The recent increase in frequency of hurricanes (since 2004) appears to have had a strong effect on some of Florida Bay's regionalized phytoplankton blooms (especially the recent eastern bay bloom) and a less dramatic effect on other blooms (central and southern bay blooms).
- A wide range of ecosystem and water quality / phytoplankton responses have been cited in literature – these responses appear to be storm-specific and site-specific. See the December 2006 issue of the journal *Estuaries and Coasts*, (volume 29, 6A) for a recent compilation of studies.

*II. Mechanisms of Ecosystem Disturbance by Hurricanes*

- Hurricanes can greatly increase estuarine water flushing and transport (freshwater or seawater), strongly affecting water residence time and salinity (magnitude and rate of change).
- Mechanical disturbance (via wind, wave, storm surge) results in erosion, sediment and other material transport
- Pulsed nutrient input to estuary from:
  - watershed
  - suspended sediment
  - vegetation or algal detritus
    (e.g. SAV, mangrove leaves stripped and transported)
  - pore water
  - ground water

The bottom line: hurricanes have both direct and indirect effects on phytoplankton

*III. Summary of findings*

- Since Florida Bay water quality monitoring began in 1991, hurricane events in 1999 (Hurricane Irene) and 2005 (Hurricanes Katrina, Rita, Wilma) provide a basis for assessing effects of minor (less than category 3) hurricanes.
- Hurricane Irene resulted in a large discharge of fresh water from the Everglades and a rapid decrease in bay-wide salinity. A sharp increase in algal (phytoplankton) blooms occurred bay-wide with this event, but this increase was short-lived (roughly 1 to 4

months). In the eastern bay, this was the first recorded occurrence of a bloom, but it should be noted that this bloom was 5 to 10 times smaller in magnitude (lower chlorophyll *a* concentration) than in the central bay.

- The three hurricanes of 2005 resulted in a complex combination of high runoff (especially from Katrina), high rainfall over the bay (from Katrina and Rita), and high wind energy and storm surge (from Wilma). Despite this strong and prolonged period of disturbance, no pronounced algal bloom occurred in the central bay. In contrast, an unprecedented (over our monitoring period of record) algal bloom occurred in the eastern bay with chlorophyll *a* concentrations more than 10 times that of the eastern bay baseline and similar to the concentration of past central bay blooms. The eastern bay bloom has lasted more than two years.
- This contrast in algal bloom response between the eastern and central bay in 2005, and between the 1999 and 2005 responses in the eastern bay, points toward the likely influence of factors in addition to hurricanes. Disturbance from the widening of U.S. Highway 1 and the interaction of hurricanes and roadway disturbance (e.g. rainfall and wave energy may have mobilized materials from the highway area) likely contributed to these blooms.

**Florida Bay *Synechococcus* Blooms**

C. A. Heil[1], W. R. Richardson[1], P. M. Glibert[2]

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Beginning in September of 2005, an unprecedented phytoplankton bloom appeared it he historically clear waters of northeastern Florida Bay. The dominant species are the same as those prevalent in both the recent 2007 and late 1990s central Bay blooms, a suite of picocyanobacteria dominated by *Synechococcus* spp. *Synechococcus* spp. are small (<2 µm), single celled, non $N_2$-fixing cyanobacteria that are common in the worlds ocean. Although not directly toxic, *Synechococcus* blooms can be harmful to marine ecosystems due to 1) its poor quality as a food source for higher trophic levels, 2) its negative effects upon water quality at high cell densities and 3) its potential for depleting oxygen levels. At high densities *Synechococcus* discolors water a 'pea-soup' green and decreases water quality by reducing light penetration.

*Synechococcus* is able to dominate the phytoplankton community for a variety of reasons: it grows relatively fast, it is neutrally buoyant due to it's small size, it is an excellent competitor for both N and P nutrients compared to other microalgae, it is able to grow over a wider range of salinities (1 to 60 $^{o}/_{oo}$) then other algae and it grows well at low light levels. With Florida Bay the combination of different and spatially distinct nutrients sources, along with the dominance of carbonate sediment in the eastern Bay has historically led to a system that is phosphorus limited in the eastern Bay and nitrogen limited to the west. *Synechococcus* blooms have typically occurred in the central bay in both the late 1990's and 2007 where both phosphorus and nitrogen limitation is alleviated, however two major system perturbations in the northeastern Bay in 2005, the passage of 3 hurricanes and the beginning of road construction along the 18 mile causeway, contributed significant amounts of both inorganic and organic nutrients to the northeastern Bay. Recent research has focused on the ability of *Synechococcus* in Florida Bay to preferentially utilize organic nitrogen and organic phosphorus sources compared with inorganic (e.g. nitrate, ammonium, phosphate) nutrient sources. Short-term (2 day) nutrient enrichment bioassays conducted with both northeastern and central Bay blooms have demonstrated that bloom populations respond to organic nitrogen and phosphorus enrichment, suggesting that these blooms are persisting due to organic nutrient availability in both regions. The longevity of these blooms may thus be resulting from a combination of nutrient supply from both allochthanous (outside) and autochthanous (*in situ*) organic nutrient sources combined with restricted flushing and circulation in the central and eastern basins and a tolerance for a broad salinity range.

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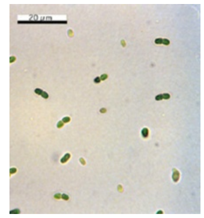
Glibert, P. M., C. A. Heil, D. Hollander, M. Revilla, A. Hoare, J. Alexander and S. Murasko. 2004. Evidence for dissolved organic nitrogen and phosphorus uptake during a cyanobacterial bloom in Florida Bay. Marine Ecology Progress Series, 280, 73-83.

# Cyanobacterial Blooms in Florida Bay

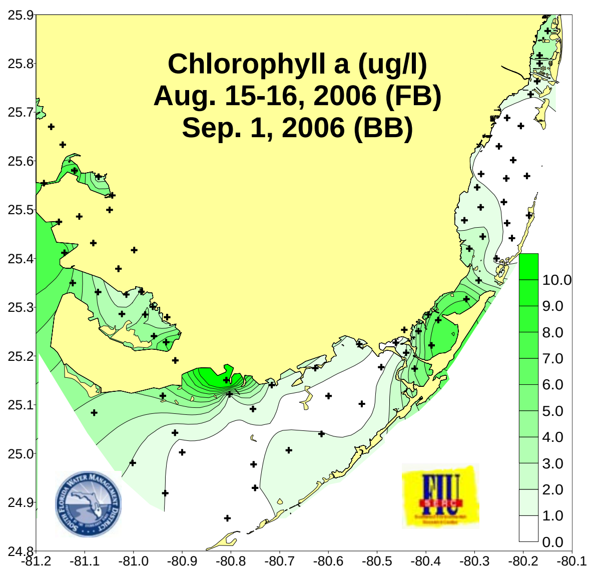
Joseph N. Boyer, Makoto Ikenaga, Amanda L. Dean, and Cristina Pisani
Southeast Environmental Research Center
Florida International University

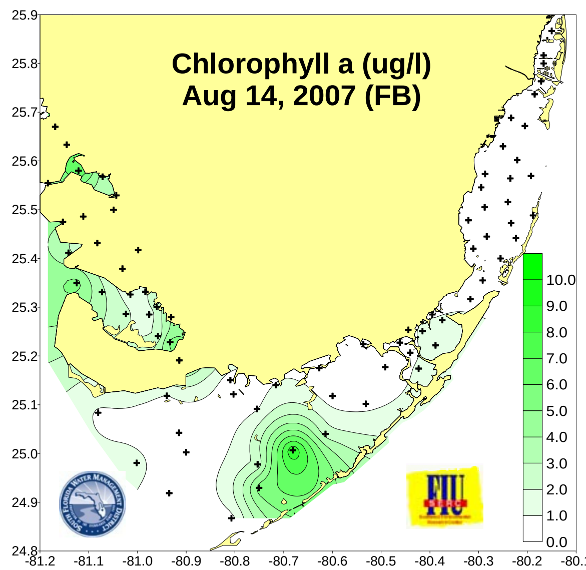


### *What are Cyanobacteria?*

- They are photosynthetic bacteria, not algae.
- Most have chlorophyll *a* as well as phycoerythrin or phycocyanin as photosynthetic pigments
- They are very small, ~1 µm.
- Cyanobacteria in Florida Bay are of marine origin and generally non-toxin forming; they are not similar to the those found in freshwater lakes and rivers.

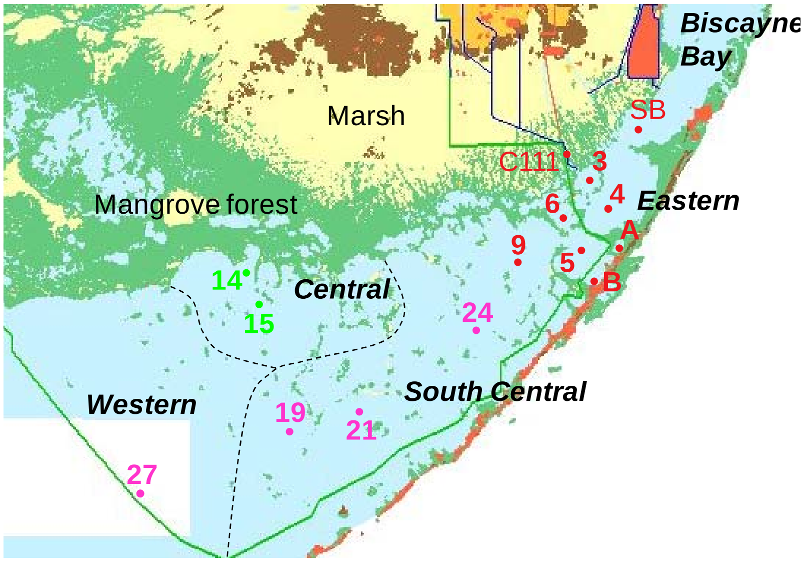
| **Eastern Florida Bay Bloom** | **Western Florida Bay Bloom** |
|---|---|
| • A highly unusual phytoplankton bloom has persisted in eastern Florida Bay and southern Biscayne Bay since at least Oct 2005.<br>• The bloom was probably initiated by a large increase in total phosphorus (TP) due to:<br>1) Water releases from C-111 canal in response to 2005 hurricane season<br>2) Disturbance associated road construction activity along US-1 between the Florida mainland and Key Largo | • Another phytoplankton bloom began in SW Florida Bay in July 2007.<br><br>• We have no smoking gun as to its initiation.<br>•No direct connection to land<br>•Limited connection to Gulf<br>•Benthic flux event??<br>•Rainfall event (with foreign dust input)?? |



**Cyanobacteria Community Analysis**

•Seawater and sediments were collected from 15 sites.
•Analyzed by PCR-DGGE
•Cluster analysis showed 3 different Cyanobacteria communities




## Summary

• Both phytoplankton blooms have been found to be dominated by Cyanobacteria.

• Cyanobacteria are primarily in genus *Synechococcus* (but not *S. elongatus*) found in estuaries and coastal ocean worldwide.

•The Cyanobacteria found are not toxic to humans or animals, however the high densities may clog marine sponge filter-feeding and cause mortalities. In addition blooms decrease light penetration to the bottom and may cause some seagrass mortality if the bloom persists too long.

•These Cyanobacteria are well adapted to low nutrient conditions, can use organic N, thrive under fluctuating salinities, and can access Fe at extremely low concentrations.

• The dominant species of Cyanobacteria in eastern Florida Bay (*Synechococcus* WH 8101) is also the dominant species in central Florida Bay blooms.

•*Synechococcus* WH 8101 is not present in sediments and therefore sediments are not "seeding" the bloom.

This research was supported by the National Science Foundation through the Florida Coastal Everglades Long-Term Ecological Research Program (DEB-9901514).

FIU Southeast Environmental Research Center

FCE LTER

**Climatology, Connectivity, Residence Times, and Water Quality in Florida Bay**

Christopher Kelble, Nelson Melo, Tom Lee, Peter Ortner (UM/RSMAS)
Elizabeth M. Johns, Jia-Zhong Zhang (NOAA/AOML)

Florida Bay is made up of a collection of shallow basins separated by mud banks and mangrove islands situated between the Florida mainland and the Florida Keys. The bay is located downstream of the Everglades discharge that has been altered over the past century due to South Florida land use practices, leading to reduced water delivery to Florida Bay and subsequently elevated salinities. The reduced water flow has had the strongest impacts in the north-central region of the bay where extreme hypersalinity can develop along with degradation of water quality and sea grass die-off. Hypersalinity development was found to be caused by the combination of reduced fresh water inputs during the dry season and weak basin water renewal rates. Using direct measurements of the volume transports through connecting channels, indirect estimates of the total transport to the sub-regions from mean sea level variability, and a computer generated animation model of observed sub-tidal sea level anomaly fields combined with wind vectors in the region, we show that interior basin water exchanges are weak and are controlled by local wind forcing.

Moreover, circulation, transport, and sea level in Florida Bay are significantly altered by large, sustained wind events (i.e. tropical cyclones, cold fronts, and high pressure systems). These wind events can cause significant exchange between basins within Florida Bay, as well as between Florida Bay and the adjacent waters on the southwest Florida shelf and the Atlantic coastal zone. These events result in a net transport downwind during the wind event and a net transport in the reverse direction shortly after the wind event has ceased and sea level returns to normal. From May 20 until June 1, 2007 there was a period of consistent east winds from 8 to 12 m $s^{-1}$ (Fig. 1). This period of consistent wind likely decreased sea level within Florida Bay by transporting water west onto the southwest Florida shelf. After these winds relaxed on June 1, sea level within Florida Bay likely returned to normal as water was transported from the southwest Florida back into Florida Bay. The water on the southwest Florida shelf typically has higher phosphate concentrations than within Florida Bay, and thus as water moved back into Florida Bay it may have resulted in a significant flux of phosphorous at least to the basins along the western border of Florida Bay. The affected area may have included Rabbit Key basin, which saw a dramatic increase in Chlorophyll *a* from May 17-18, 2007 to July 10-11, 2007 (Fig. 2). To fully resolve if this event resulted in a significant input of phosphate to Rabbit Key basin which may in turn have initiated the algal bloom in south Florida Bay in 2007, the sea level data from 2007 will be analyzed along with the relevant water quality data and an estimate of the phosphate flux for this time period will be calculated.

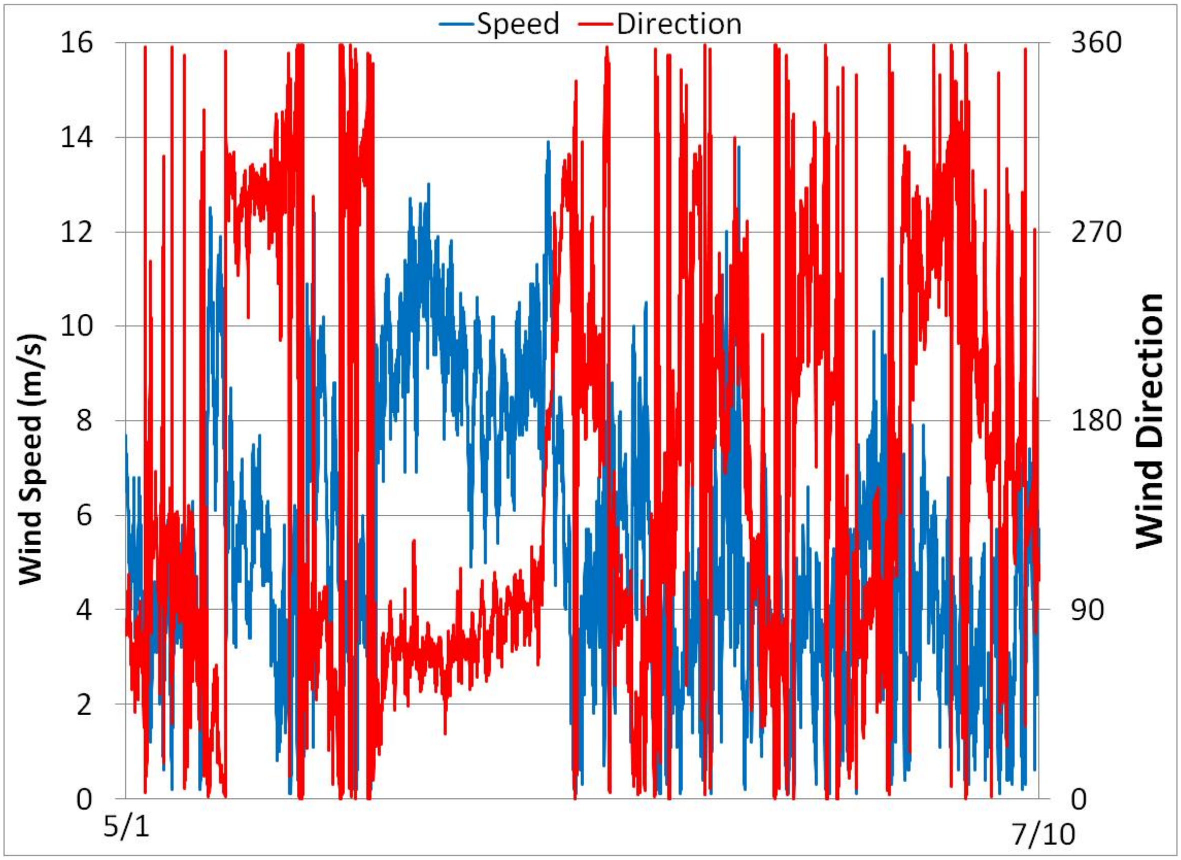



**Figure 1.** Wind speed and direction measured at the Long Key C-MAN station from May 1, 2007 until July 10, 2007.

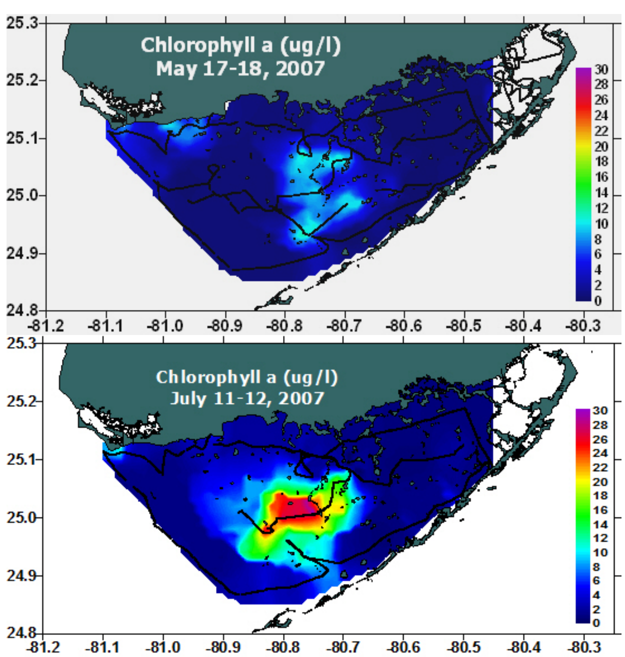



**Figure 2.** Chlorophyll *a* biomass measurements from flow-through instrumentation aboard the *R/V Virginia K* from the May 17-18, 2007 survey and July 10-11, 2007 survey conducted by NOAA/AOML.

## Benthic and pelagic grazing of phytoplankton in Florida Bay

### Dr. Brad Peterson, Stony Brook University

<u>Peterson and Fourqurean</u> (2001)

- 217 sponge surveys conducted throughout the boundaries of Florida Bay National Park
- Suveys collected sponge species specific densities and biomasses / m2
- Series of grazing experiments (lab and field)

<u>Peterson and Boyer</u> (2003)

- 58 sponge survey sites throughout boundary of Great White Heron National Reserve
- Surveys collected sponge species and densities  m2

<u>Peterson and Gobler</u> (2006 – present)

- Conducted *in situ* benthic grazing estimates, sponge growth rates and survival at seven (7) sites in Florida Bay
- Concurrent pelagic grazing rate experiments were conducted at sites to estimate whole water column grazing (pelagic grazing conducted at two additional sites; Flamingo and Barnes Sound).
- Quarterly flow cytometry data on water column phytoplankton composition collected at nine (9) sites throughout the extent of Florida Bay National Park.

We have completed five seasonal sampling trips to Florida Bay:  July and November 2006, as well as January, April and June of 2007.  These five sampling events have allowed us to capture seasonally variability in this system.  During each trip, we have concurrently conducted pelagic and benthic sampling and experiments to examine the role of zooplankton and sponges in affecting algal biomass in the Florida Bay ecosystem.  We also assessed the impact of the Fall 2007 blooms on survival of natural marked and transplanted sponges at our sites.

## PROMOTION OF CYANOBACTERIA BLOOMS IN FLORIDA BAY VIA ZOOPLANKTON GRAZING

**Christopher J. Gobler, Jennifer Goleski, Bradely J. Peterson, School of Marine and Atmospheric Sciences, Stony Brook University, Stony Brook, NY, 11794-5000; christopher.gobler@sunysb.edu**

Cyanobacteria are known to possess slow growth rates and do not require high levels of nutrients for growth (Kana and Glibert 1987; Sunda et al 2006). In contrast, picoplankton such as cyanobacteria are typically under tight top-down control via grazing (Calbet and Landry 2004). A loss of this control can cause cyanobacterial cells growth to outpace removal and can cause a subsequent algal bloom (Sunda et al 2006). The goal of this study was to determine the extent to which cyanobacteria and other phytoplankton in Florida Bay are under top-down control by zooplankton grazing. The spatial and temporal dynamics of phytoplankton (cyanobacteria, eukaryotes), zooplankton (mesozooplankton, microzooplankton, heterotrophic nanoflagellates) and heterotrophic bacteria were determined during winter, spring, summer, and fall throughout Florida Bay. In parallel, *in situ* meso- and microzooplankton grazing rates on eukaryotic algae, cyanobacteria, bacteria, and the total phytoplankton community were established. Comparisons of grazing rates on multiple prey items as well as to algal growth rates also were made.

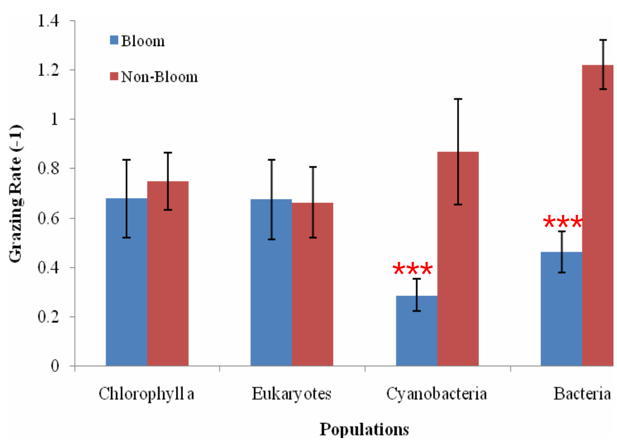



**Fig 1**. Microzooplankton grazing rates on the total phytoplankton community (chlorophyll a), eukaryotic algae (eukaryotes), cyanobacteriam and bacteria in Florida Bay during bloom and non-bloom conditions, 2006 – 2007/

During this study, we generally found high rates of microzooplankton grazing on all microbial prey items during non-bloom conditions (< 250,000 cells $ml^{-1}$), with grazing rates on prokaryotic prey (cyanobacteria and bacteria) being higher than grazing rates on eukaryotic algae and the total phytoplankton community, based on chlorophyll *a* (Fig 1). However, during dense cyanobacteria blooms (> 400,000 cells $ml^{-1}$) in Florida Bay's eastern, northern, and central regions, microzooplankton grazing rates on cyanobacteria were significantly lower than rates observed during non-bloom conditions and significantly lower than concurrent rates on other phytoplankton ($p < 0.05$; Fig 1). These results demonstrate that an absence of grazing control by zooplankton is likely a key factor in promoting cyanobacteria blooms in Florida Bay, a finding which supports with recent hypotheses about the development of these blooms (Sunda et al 2006).

A secondary objective of our study has been to characterize the organisms responsible for phytoplankton blooms in Florida Bay. Our preliminary data suggests that the cyanobacteria blooms in the eastern basin in the vicinity of Lake Surprise are distinct and separate events from the blooms which occur in the north-central basin. Our results show that the bloom species differ in their timing, intensity, pigment content, cell size, and their ability to form chains. These differences suggest there are likely substantial ecological differences among these bloom species.

Calbet, A. & Landry, M. R. 2004. *Limnol. Oceanogr*. 49:51-57;
Kana, T.M., and P.M. Glibert. 1987. Deep-Sea Res. 34: 497-516
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# THE IMPACT OF CATASTROPHIC ALGAL BLOOMS ON HARD-BOTTOM COMMUNITIES IN THE FLORIDA KEYS

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During the early 1990's, in what has been described as a "cascade of disturbances" in Florida Bay, drought and water management practices on the Florida mainland are thought to have instigated the large-scale die-off of seagrasses and the development of persistent phytoplankton blooms. Those blooms then decimated sponge communities, compromising the filtering capacity of the system and impacting species that use sponges as shelter. Periodic sponge die-offs have been recorded in south Florida since at least the mid 1800's, but the cascade of disturbances documented in the early 1990's highlighted the intricate and often unexpected inter-connectedness of marine ecosystems. These events energized the public and local politicians to action and helped initiate what has become one of the largest and most costly ecosystem restoration projects on the planet – the Comprehensive Everglades Restoration Project. In the summer and fall of 2007, the phytoplankton blooms returned and again left their destructive aftermath in the hard-bottom communities of Florida Bay and the middle Florida Keys.

Top: Healthy loggerhead sponge
Bottom: Post-bloom skeletal remains of loggerhead sponge

Surveys of the sessile hard-bottom community at 18 sites that we monitor annually revealed that, as before, the sponge community was particularly hard hit. At the seven most severely impacted sites, 22 of 24 species of sponges surveyed were killed, whereas all sponge species remained on "control" sites beyond the reach of the blooms. Sites on the periphery of the bloom had intermediate levels of sponge loss. The loss of large, structure forming sponges such as vase sponges (*Ircinia campana)* and loggerhead sponges (*Speciospongia vesparium*) was especially dramatic. On some impacted sites, very large loggerhead sponges (many approaching a meter in diameter) that had survived the 1990-91 blooms died in this most recent event. Large sponges are important filter feeders of the picoplankton (bacteria) in these shallow waters, so their demise must certainly diminish this critical ecosystem function. Large sponges also provide shelter for numerous organisms. Shortly after the sponge die-off, the spicule skeletons of sponges were all that was left of the once prominent sponge community at impacted sites, but most of those skeletons quickly disintegrated leaving little shelter for obligate sponge infauna (e.g., alpheid shrimps) and other species such as spiny lobsters (*Panulirus argus*) that utilize sponges opportunistically. The juvenile lobsters that remained on sites where sponge loss was particularly severe were highly aggregated in shelters that are not typically used, with possible ramifications for lobster growth and disease. Our investigations of the implications of this catastrophic repeat performance on sponges and lobsters are still in progress. In particular, we will soon have information on the impact of the sponge die-off on juvenile lobster abundance, nutritional condition, and disease once laboratory processing of samples is completed.

DOES SHELTER DISTRIBUTION INFLUENCE DISPERSAL SUCCESS IN JUVENILE SPINY LOBSTERS?

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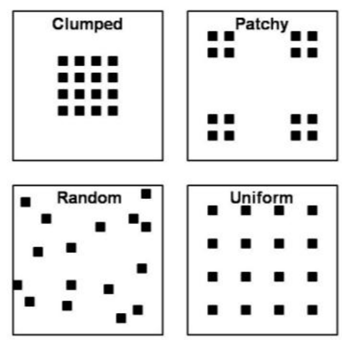
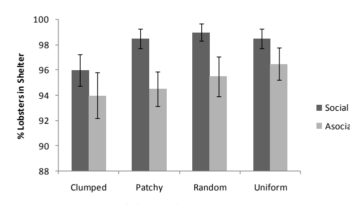
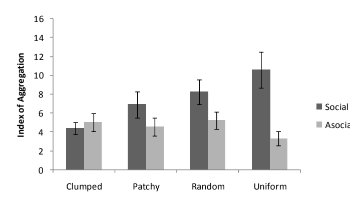
Caribbean spiny lobsters, *Panulirus argus*, settle in nearshore hardbottom habitats and undergo an ontogenetic habitat shift to coral reefs as they reach sexual maturity. In order to minimize the risk of predation, juvenile spiny lobsters are nocturnal and share crevice shelters with conspecifics during the day. Gregariousness may be favored through coordinated group defense, dilution of risk and/or a reduced time of exposure while searching for shelter (the guide effect). The relative importance of each mechanism is influenced by the density and distribution of predators and crevice shelters. Recent mass sponge mortality has decreased the total number of crevice shelters available while increasing the heterogeneity of shelter distribution in the Florida Bay spiny lobster nursery.




In order to predict how these changes in shelter abundance and distribution might influence the dispersal success of juvenile spiny lobsters I constructed a spatially-explicit individual-based model of lobster shelter selection behavior. First I measured the shelter fidelity, shelter sharing and dispersal distance of 140 marked juvenile lobsters in order to observe the natural range of shelter selection behaviors. Then I compared the relative success of two alternate behavioral strategies in a computer simulation of lobster dispersal. SOCIAL is a strategy of dispersal where orientation angle at each time step is directed toward nearby conspecifics. ASOCIAL is a strategy of dispersal where the orientation angle at each time step is random with respect to nearby conspecifics.




When shelters were abundant in the model, both SOCIAL and ASOCIAL strategies were nearly equal in dispersal success regardless of shelter distribution. However, the index of aggregation for the SOCIAL strategy increased from random to significantly non-random as shelter distribution changed from clumped to uniform. When shelters were rare in the model, SOCIAL had significantly higher dispersal success than ASOCIAL regardless of shelter distribution pattern. Furthermore, the index of aggregation for SOCIAL was significantly non-random regardless of shelter distribution. These results suggest that benefits due to the guide effect increase as the abundance of shelter decreases whereas group defense benefits remain constant.



# EFFECTS OF MASSIVE SPONGE MORTALITY ON HARDBOTTOM COMMUNITIES IN FLORIDA BAY

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Throughout Florida Bay, large sponges in nearshore hardbottom habitat play an important ecological role by providing shelter for scores of crevice-dwelling residents. Occasional mass sponge mortality, usually mediated by disturbances such as long-lasting algal blooms, can rapidly change the abundance and distribution of shelters for these crevice-dwelling animals. Despite several sponge die-offs in the 1990s, we still know little about how many members of the hardbottom community respond to changes in shelter availability after sponge shelters are lost. In the of Fall 2007, an algal bloom again impacted a large area of FL Keys hardbottom. Here we examine how the hardbottom community has changed after the sponge kill.

The algal bloom impacted four of eight long-term sampling locations, setting up an ideal Before-After Control-Impact (BACI) sampling design. Each sampling site was a square (625 $m^2$) permanently marked on all for corners, with ten artificial shelters. Artificial and natural shelters were searched for den residents on SCUBA in June and November 2007. Sponge abundances were assessed in June 2006 and November 2007.

Large sponges on impacted sites were wiped out. Within the spiny lobster population, the most abundant resident on our sites, the smallest lobsters decreased on impacted areas, slightly larger post-algal juveniles increased, and the largest lobsters decreased on all sites in November. Octopus and several crab species declined on impacted sites, while toadfish showed no change in abundance. Residents also shifted from using sponge shelters to artificial and other structures. These results indicate a strong impact on the community from sponge losses, even in areas where abundant artificial shelters were available.


**Figure 1: Sponges on impacted sites in June and November 2007.**

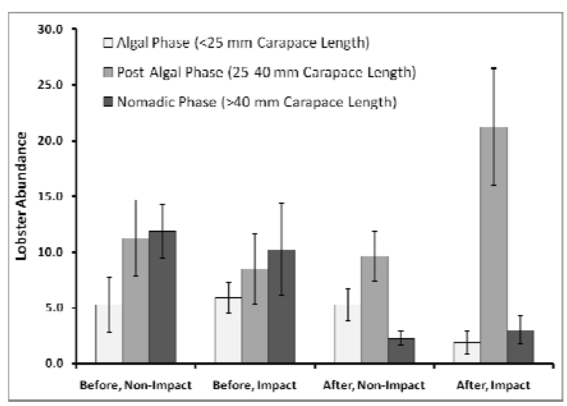


**Figure 2: Abundances of three size classes of lobsters, the most common hardbottom resident, on impacted and non-impacted sites before and after sponge losses.**

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