FLORIDA KEYS NATIONAL MARINE SANCTUARY
Water Quality Protection Program Steering Committee
March 2026 Research Symposium

March 5, 2026

DRAFT NOTES

Steering Committee Members Present
Wade Lehmann, US Environmental Protection Agency (EPA), Region 4 (Co-Chair)
Lawrence Glenn, Florida Department of Environmental Protection (DEP) (Co-Chair)
Karen Bohnsack (Designee), Florida Keys National Marine Sanctuary (FKNMS)
Mark Shafer, U.S. Army Corps of Engineers (USACE) - *Online*
Heather Stewart, Florida Keys National Wildlife Refuges Complex (FKNWR)
Yazmin Valdez, Florida Commerce
Austin Sparber, South Florida Water Management District (SFWMD)
Gil McRae, Florida Fish and Wildlife Conservation Commission (FWC)
Philip Schwartz (Designee), Key Largo Wastewater Treatment District (KLWTD)
Alison Higgins, City of Key West - *Online*
George Garrett, City of Marathon
Marisa Carrozzo, FKNMS Sanctuary Advisory Council (SAC) - *Online*
Sandy Walters, Eco Legacy Solutions, LLC
Chris Bergh, Florida Keys Program, The Nature Conservancy (TNC)
Shelly Krueger, Florida Sea Grant/IFAS Extension Monroe County
Patience Cohn, Marine Industries Association of South Florida (MIASF)

I. Welcome and Opening Remarks

Dr. Wade Lehmann, Ocean and Estuarine Section Chief, EPA Region 4 called the meeting to order at 9:05 am and welcomed everyone. Lawrence Glenn, Division of Ecosystem Assessment and Restoration (DEAR) Director, DEP, and Dr. Lehmann are the meeting co-chairs.

Dr. Lehmann recognized Steering Committee members and other representatives from the WQPP and provided instructions for participating in the research symposium. The presentations and materials associated with the meeting will be available at the steering committee page on the Water Quality Protection Program website https://gis.myfwc.com/FKNMS_WQPP/steering.htm.

II. Development of a Sponge Restoration Strategy for Florida Bay: Integrating Ecological Research into Adaptive Management

William Sharp, Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute discussed changes observed in Florida Bay over the last few decades, including recent EPA-funded work and the sponge restoration strategy for this area.

Hardbottom communities of Florida Bay are shallow and typified by sponges not corals, and built on calcium carbonate bedrock overlain with unconsolidated sediment. These are ecologically important communities that promote nutrient cycling (making nitrogen available for other ecosystem components), perform filtration to remove organic matter, and provide habitat for a variety of species, including spiny lobsters. They also host infaunal communities that are important for soundscape ecology, and recruitment. There is connectivity between Florida Bay and the reef tract, with the bay serving as a nursery area for a number of species, including lobsters and reef fish.

Periodic cyanobacterial blooms have caused sponge die-offs throughout the bay since the early 1990s. Mostly observed along the west coast of Florida, these are a non-toxic, common species that blooms when conditions are right. Sponge mortality has been associated with dense blooms. In Mystery Basin, a 2013 cyanobacterial bloom led to a 95% loss of sponge biomass by 2014. Recovery was observed in 2015-2016, but was an order of magnitude less than pre-bloom conditions and included a different species composition. Central Florida Bay has been highly degraded by these blooms, including another experienced in 2022. Hurricanes and thermal events have also been a challenge. Data from pre and post Hurricane Irma showed a 95% loss of biomass, and an overall flattening of the substrate. The changes in Florida Bay are on a different scale, with a loss of architectural complexity that has been more profound than on the reef. The 2023 thermal event further affected sponges that had already been affected by the 2022 bloom.

Sponge restoration research began 15 years ago, with small scale experiments to determine the feasibility and timing of transplants, identify amenable species, and confirm sponges could be propagated. The first EPA funded study aimed to scale up restoration, establish a network of sponge nurseries in Florida Bay, and estimate the costs associated with this effort. A network of nurseries was established in Florida Bay with a focus on places that had not been affected by past cyanobacterial blooms. By 2020, 18,000 sponges of 6 species were in the nurseries. The largest scale transplant to date was attempted in 2020, with 15,000 sponges transplanted to four 0.25 hectare plots at locations that had been damaged by Hurricane Irma where there was good data on the community structure prior to the hurricane and little to no recovery since. Overall, this effort was affected by COVID in 2020, then hit by a cyanobacterial bloom in 2022 which was further west and toward the Keys than previously experienced. The 2023 thermal event further affected sponges at this site. Despite those numerous challenges and setbacks, in 2023 the site still hadn't been fully extirpated. One species was lost, but the site was still viable, which allowed for optimism with sponge restoration efforts.

DEP Coastal Zone Management Program is now supporting the development of a risk-averse sponge restoration strategy in Florida Bay. This includes four key components:

- Documenting Historic Blooms: Analysis of MODIS-Aqua satellite imagery (2003–2023) identified the most risk-averse restoration areas in Florida Bay, identified as Duck Key near Marathon and along the western side of the 7-mile bridge (33,346 hectares of hardbottom). This was based upon the duration of blooms observed historically across various portions of Florida Bay. This may allow success at least in the near term.
- Historic Surveys: Used mean sponge density across six species from 2002 surveys to identify a

restoration target of 2,210 sponges per hectare.
- Sponge Life History Characteristics: The restoration target is combined with an outplanting configuration to optimize recruitment of sexually-produced larvae, creating high-density outplant areas within a 1 hectare area to establish a self-sustaining community.
- Cost Analysis: The estimated cost is $27,360 per hectare at these targets.

Ongoing research is currently being funded by EPA and builds off of previous work. This effort will test different configurations of in-water nurseries to optimize sponge growth rates to support large scale restoration. Sponge nurseries are high density areas and have slow growth rates, thus nursery configuration makes a difference. There is also an effort to test species-specific filtration of planktonic communities in the water column. Generally, a diverse sponge community is more beneficial than a single species community, but this effort looked at singular species filtration considering challenges with potentially restoring a fully diverse sponge community. Filtration of cyanobacteria, Dissolved Organic Carbon and heterotrophic bacteria were analyzed across three species. Loggerhead sponges have shown to be better at removing cyanobacteria. This research is also assessing cyanobacterial tolerance of different species using controlled lab assays and cultured cyanobacterial cells from two decades of blooms in Florida Bay. Again, if only a less diverse community of sponges can be restored, it's good to know which are the most tolerant of this stressor. This work is ongoing but some early takeaways were that the two species of sponges tested (loggerhead and brown branching) could be kept alive for 5 days in an aquarium; cyanobacteria decreased and sponges were successfully feeding with no mortality. They also discovered that they can successfully culture cyanobacterial blooms. Next, these experiments will progressively be made more realistic.

The next steps in this effort are to complete the sponge restoration strategy document (targeting late 2026 as a target) and to continue the ecologically-based research to further refine practices. FWC is currently seeking EPA funding to test the strategy with a focus on determining environmental factors that maximize survival, planting in risk adverse areas, quantifying the return of ecosystem function, and evaluating if the restoration configuration affects sponge reproduction. To date sponge restoration efforts haven't scaled up to the extent hoped for ten years ago, but there is room for optimism.

Questions & Answers/Comments/Discussion:

- Heather Stewart: In the Keys sponges are often seen washed ashore during storm season. Do you have a sense of sponge mortality from wave energy and storms?
    - This is probably one of two species - vase sponges and brown branching sponges. These are high recruiting, fast growing species, so this is likely a natural process.
- Heather Stewart: Is there an effort to look beyond hardbottom communities for these sponge restoration efforts?
    - The system is dynamic in that some hardbottom sites are transitioning to seagrass communities; some of this is being assessed to determine the impact of this dynamic on outplanting.
- Lawrence Glenn: Has there been a change in dominant cyanobacteria species through time, and is there a tolerance based on the dominant type?
    - This can be verified by FWC's plankton specialist. In 1991-92, the species was identified as one that is very common. As far as we can tell, the dominant species appears to be

generally the same, but we've discovered there are a number of different strained or "tribes." This is largely unknown but efforts are underway to better understand this.

- Audience question: The focus of this work has been to reestablish larger numbers of sponges. Do the different species have any effect on each other? Imagine density would have an impact and would be important to consider for restoration planning.
    - Mixing species led to slower growth rates (which is the opposite of what was expected, which is that mixed species might reduce competition for food). Instead, they've observed that one species will dominate the others. Otherwise, no direct antagonistic effects were observed.
- James Douglas: What is the mechanism of mortality for sponges? The cyanobacteria is not toxic, how do they die?
    - The hypothesis is mechanical clogging from high cell counts. Bacteria in culture may not have the mucus sheath that causes this clogging. It may also be a behavioral response where the sponge shuts down the pump.
- Wade Lehmann: Regarding site selection and density, do you look at water flow in different areas?
    - Water flow is an important factor. The next steps include establishing current meters in the restoration areas to collect this information.

III. A Land-based Sponge Nursery to Restore Habitats and Improve Water Quality in Florida Bay

Dr. Andia Chaves Fonnegra shared information on developing a land-based sponge nursery to grow stocks from the larvae of brooding sponges. The project aims to increase genetic diversity in habitat restoration efforts, helping to offset losses from extreme weather, and to improve water quality. The three objectives of the project are:

1. Grow sponge juveniles from larvae, buds, and 3D sponge cell aggregates in a land-based sponge nursery.
2. Evaluate the efficiency of sponge juveniles in removing nutrients and harmful algal blooms from seawater and their survival after exposure.
3. Evaluate the success (survival and growth) of juvenile sponges obtained from larvae, buds, and 3D cell aggregates transplanted to FWC-FWRI sites in Florida Bay.

The project focuses on two of the six species initially considered: the glove sponge (*Spongia graminea*) and the yellow sponge (*S. Barbara*). The original six species considered were vase stinker, loggerhead, branching stinker, glove, yellow, and sheepswool. Glove and yellow sponges are commercial bath sponges, belonging to the Spongia and Hippospongia genera, which lack a mineral skeleton and appear black or dark in the water. The taxonomy of these species is complicated based on fibers, making identification difficult. Sponges have been a commercial commodity since Egyptian times and were mentioned by Aristotle and Plato. The sponge fishery is worldwide, and in Florida peaked in the 1930s and again in the 1980s after a mortality event in the Mediterranean shifted the industry to the lower quality sponges from the Caribbean. Sponge mortality has been associated with disease and overfishing, including an 80% decline, with a 60% reduction still observed ten years later. This decline has reduced habitat for species like the spiny lobster.

Previous sponge mariculture attempts in Florida Bay involved fragmenting and propagating sponges, which yielded 15,000 sponges at five in situ nurseries, but this technique does not increase genetic diversity. Thus, the first objective of this work is to grow sponge juveniles from larvae in a land-based nursery. The process involves collecting larvae, transporting and settling them, growing recruits, and then transplanting them to the field to increase genetic diversity. Larvae were collected from a wild population at Summerland Key during full moon peaks in June and July. A pantyhose trap with a funnel and bottle was attached to a sponge for collection. The 1mm larvae were counted and observed under microscope in the lab, with up to 10,000 larvae seen in a single slide image. Light microscopy images of the two species show that they are very similar looking, although S. graminea are darker. The yellow sponge (*S. Barbara*) produced substantially more larvae (10 to 1,000 per individual, sometimes over 1,000 in one night) compared to the Glove sponge (*S. graminea*), which had a maximum of a couple hundred. By size, medium and large sponges tend to produce higher amounts of larvae than small and extra-large sponges, suggesting that the youngest and oldest individuals are not reproductive.

Post-collection, larvae were placed on different substrates for settlement. After 24 hours, 30% of *S. Barbara* larvae and 20–25% of *S. graminea* larvae settled, with 33% total settlement for Spongia species after one week. Larvae showed a preference for plastic substrate (such as the sides of a Tupperware container); mineral-type substrate, such as plugs used for coral were also used. As recruits attach and spread, it changes the color of the plate; a microscope is used to track growth over time. Post-settlement, the larvae metamorphose into a pupa. The formation of the aquiferous system (the digestive and feeding system) is a crucial developmental timeline. A main research gap is how to grow sponges from a recruit to a juvenile, so the early development characteristics and times were studied. Results suggest that the aquiferous system is fully developed around week 7 for *S. Barbara* and week 8 for *S. graminea*. Recruit survival decreased over an 80 day period. The maximum survival time achieved in the nursery was 10 months, but with less than 5% survival. Efforts are underway to increase the survival time.

Objective 2 evaluated the efficiency of sponge juveniles in removing nutrients and harmful algal blooms (HABs) from seawater and their survival after exposure. Settled recruits were used for this work, as they were a bit larger and had survived. An external *Synechococcus* strain was used to simulate the Florida Bay HAB, as a strain from the bay was unavailable. HAB concentrations were measured in several treatments (just sponge, sponge + algal bloom, just algal bloom, nothing). Bloom concentrations were higher in treatments with no sponge (HAB alone), and decreased by week three in the presence of sponges. Buds with the algal bloom grew significantly between day 0 and 10 compared to the control, suggesting they might be feeding from the bloom. The survival of *S. Barbara* recruits was not affected by the simulated HAB exposure

Objective 3 evaluated the survival and growth of juvenile sponges transplanted to Florida Bay. Recruits were transplanted onto plates. The first trial in December 2023, using 80 recruits, resulted in no survival after one month and two days. A subsequent 2024 trial was more successful after acclimating the recruits in the land-based nursery to Florida Bay temperature (24°C). This resulted in 44% success after three weeks. Growth across various locations on the plate were measured (outside up, outside side, inside down, inside side, etc.), with the outside side configuration being unsuccessful and the best growth occurring on the inside. Growth was difficult to quantify precisely due to sedimentation complicating the observation of recruit boundaries, but a general trend of increasing recruit size was observed

In summary, this project successfully created the first land-based sponge nursery using larvae from two commercial bath sponges, effectively closing the production cycle. Ongoing efforts must focus on improving protocols for larval settlement and growth, as well as the transport of juveniles back to the field. The overall goal is to conserve and restore damaged sponge populations. This work has the potential to support broader conservation efforts, larger-scale commercialization for Florida fishermen via aquaculture, and even microplastic reduction

Questions & Answers/Comments/Discussion:

- N/A

IV. Florida Keys Water Watch Sponge Restoration Aquaculture

Shelly Krueger, University of Florida/IFAS Extension Monroe County, discussed sponge restoration aquaculture efforts in Florida. Restoration aquaculture is defined by FL Admin Code FAC § 18-21.003 as the cultivation of plants and animals to increase declining wild populations and improve the health of coastal ecosystems. FDEP has established a sponge density target of 2,210 sponges per hectare. Sponge restoration serves as a nature-based solution to improve water quality, biodiversity, and essential fish habitat.

Vase sponge propagules (cuttings) in the FWC nursery showed transformed morphology after two years, and after four years, recruitment from other species was observed inside the nursery. The morphology of the transplanted vase sponges is identical to native, natural sponges. Histology studies have confirmed gametogenesis in several species, including Sheepswool, Loggerhead, and other Spongiid sponges. Specifically, sheepswool sponge reproduction occurred in April and May. For loggerhead sponges, an iconic dominant species in the backcountry, over 250 individuals were monitored but only one was found with eggs, suggesting that these sponges may reproduce synchronously but infrequently and thus was not captured during the 1.5 years these sponges were monitored. A survey of four Spongiid species (Sheepswool, Glove, Yellow, and Key West Grass sponge) in the FWC nursery from April to June found that 90% of the 95 sampled sponges were actively in gametogenesis, though reproduction was highly skewed toward males.

In 2023, extended record high temperatures associated with an unprecedented marine heatwave affected the coral reef and backcountry areas from Niles Channel to Boca Grande. Massive sponge die-offs were reported, including over 99% die off in the Waltz Key Basin study area. Sponges, including old, massive individuals, died in place, but macroalgae and coral appeared unaffected. The area visually recovered within six months to a year, despite the significant sponge loss.

Restoration efforts in the FWC nursery in the Lower Keys are documented using Before-After-Control-Impact (BACI) design. A total of 1, 138 sponges were planted in 2025, and only 4.6% mortality was observed through November. Research has compared the traditional horizontal cutting method with a new vertical cutting method, with the goal of enhancing survival for both the donor and the propagule in the nursery. Commercial harvest has traditionally occurred at the base to maximize the sponge for sale, and this method has also been adopted in early sponge restoration aquaculture efforts. As an alternative, the vertical cutting took up to half of the sponge and left more intact with an oscula for expelling water. When cut horizontally, sponges have to reform their aquiferous system. Survival was identical for both the propagules and donors, although the vertical cut propagules reformed their morphology faster and grew fuller. The horizontal cut propagules remained flatter/ of lower relief.

Traditionally, sponge cuttings are zip tied to the top of a brick. Efforts were also made to experiment with a sideways configuration to enhance sediment contact. Overall, the sideways configuration with sediment contact was successful; sponges grew into the sediment in a few months, making them more secure and less vulnerable to being rolled by storms.

New EPA-funded research is expanding sponge restoration into Biscayne National Park. Over 2,500 sponges were added to meet the FDEP density target of ~2,210 sponges per hectare. Genetics are being used to resolve species taxonomy issues, and additional research is planned on ecosystem services including filtration rates and effects on nutrient cycles. Florida Sea Grant will also host two sponge restoration workshops to include federal and state agency partners and restoration practitioners. These are planned in Summerland Key in 2027 and Biscayne National Park in 2028..

Questions & Answers/Comments/Discussion:

- Chris Bergh: Regarding the density targets from FDEP, what are those, why were they established, and how were they set?
    - The Florida Administrative Code has a definition of restoration aquaculture. DEP is working on priority sponge restoration zones and has established a target of 2,210 sponges per hectare.
- Brian Walker: Regarding the 2023 heat wave impacts, 2024 and 2025 were also some of the warmest years on record, but those high levels of mortality were not observed. Is there an idea about temperature thresholds for sponges, or what caused the mortality?
    - The mortality in 2023 may have been caused by a brownwater event combined with high temperatures. In August, temperatures reached 30.5°C, though the area frequently hits 32°C. Sponges in good current survived better than those in stagnant water, and the survivors of 2023 constituted the population in 2024.

Break

V. Modeling Water Quality and Phytoplankton Blooms in Florida Bay and the Florida Keys

Dr. Mingshun Jiang, Florida Atlantic University, discussed efforts to model water quality and phytoplankton blooms in Florida Bay and the Florida Keys. Florida Bay is a complex system influenced by a number of external forces, including the Everglades, the southwest Florida shelf, coastal current, and the Florida Current. The dynamics of the bay, including major cyanobacteria blooms, are important to the downstream Florida Reef Tract. This project aimed to answer three questions:

Q1: What drives the cyanobacterial blooms and why the focus in Central Florida Bay? These blooms have reached the Keys
Q2: What are the potential effects on seagrass and corals?

Q3: Where are the nutrients from? The distribution of nutrients creates contrasting gradients that drive bloom dynamics. Western Florida Bay has high leachable phosphorus (P). The eastern bay has a lot of calcium carbonate sediments and less P, and the northeastern bay provides iron and nitrogen inputs. High P also comes from upstream coastal waters. While the eastern Bay is N-limited, the Western Bay is P-limited. These various inputs meet in central Florida Bay, favoring blooms.

A coupled hydrodynamic-biogeochemical-Submerged Aquatic Vegetation (SAV) model was developed using the Regional Ocean Modeling System (ROMS) to simulate water quality and phytoplankton blooms. The model includes temperature, salinity, circulation; and Florida Bay is shallow so dynamics from seagrass were also included, and the nested modeling allows better resolution of complex bathymetry, including narrow channels and banks in Florida Bay.

The multi-functional biogeochemical model includes two nutrients (N, P), two phytoplankton groups (including cyanobacteria), two zooplankton groups, and bacteria to simulate the microbial loop. The SAV module incorporates an additional nutrient (Si), additional phytoplankton groups, and includes epiphytes, which both take up nutrients and create a shading effect for seagrass, and SAV, which is split into above-ground and below-ground biomass. The model also accounts for winds and river inputs with 2011 and 2012 considered "normal" years. Inputs in the summer vs. fall vary, which is an important distinction considering cyanobacteria blooms often start in the fall or late summer. Upstream sources generally carry more P than N, while freshwater flow from the Everglades carries more N than P.

Model outputs were compared to actual water quality and seagrass data, and it was found that the model effectively simulates tides and circulation, showing consistent seasonal patterns and that overall flow in central Florida Bay is weak and stagnant. Salinity has a gradient between late spring when there is a lack of flow/inputs and the fall, when a lot of freshwater inputs lower salinity. The downstream impact on the Keys depends on wind, discharge, and coastal currents. The model showed that the bay exports both Chlorophyll-*a* (Chl*a*) and nutrients to the Keys. Seasonal effects include little water movement toward the south during the summer (winds from the southeast, low discharge); in the fall (winds from the northeast, strong discharge) conditions favor water movement south and nutrient transport out of the bay to the Keys. The ultimate fate of these waters depend on circulation. The Florida Current usually moves to the north east, which brings particles to Miami; however in the last summer and early fall, there is a nearshore return flow to the Keys.

In summary, central Florida Bay's stagnant flow and convergent N/P inputs favor blooms. Seagrass and epiphytes are critical in controlling phytoplankton by keeping nutrients low. Grazing also likely controls phytoplankton blooms. The model also requires improvements, particularly the inclusion of sediment diagenesis.

Questions & Answers/Comments/Discussion:

- It was noted that the north-south coastal current brings P from the West Florida Shelf. Is there a lot of variability in nutrient inputs and currents from year to year?
  - We have a lot of information about nutrients and what is coming from the West coast; less is known about the currents. USF has monitoring stations in Tampa and Charlotte Harbor, but further south we may not have the same long term monitoring information. We believe the current in this area to be generally consistent and southward, although

some particles will go north.

- Henry Briceno: This is a complex system. Water and sediment matter. In the Ten Thousand Islands, the sediments are P rich. This is a main source of P that interacts with water from the eastern portion of the bay and creates a dynamic mixing zone.
- Brian Walker: Was this just looking at the 2012 timeframe? Is this a normal or anomalous pattern?
  - Simulations were run for 2011 and 2012; have longer simulations but most time has been spent modeling these years. It's uncertain if this is normal, but it's believed that this is the general pattern. Freshwater flow is mostly from NE Taylor Creek but there is not much coming to central Florida Bay. Everglades Restoration is trying to move more flow to the center of the Bay to reduce high salinity conditions; this could potentially affect the nutrient balance and impact seagrass dynamics.
  - The stagnation in Central Florida Bay is key, allowing N from the east and P from the west to meet, creating optimal conditions for blooms. External factors like rainfall create disturbances that can affect this balance.

VI. Impacts of Caloosahatchee Discharge and Hurricane Ian on Southwest Florida Shelf Water Quality, Epibenthic Life, and Microbial Communities

Dr. James Douglass, Florida Gulf Coast University, provided an overview of a study on water quality, epibenthic life and microbial communities on the Southwest Florida Shelf, and impacts associated with Hurricane Ian and Caloosahatchee discharge. The research was primarily supported by EPA funding.

The Southwest Florida Shelf is vast, understudied, ecologically and economically important and impacted by a variety of threats. The shelf is a mosaic of sand and hardbottom habitats. While areas further north have been well characterized by remote sensing and scuba surveys, there are a lot of unknowns between Sarasota and the Florida Keys. Only 5% of the area has been scanned, and sand covered over 90% of the surveyed area. The Caloosahatchee is a major conveyor of freshwater and pollution from Lake Okeechobee and coastal watersheds into estuaries and the Gulf of Mexico.The impacts are obvious from aerial imagery, but less well understood when it comes to water quality and sea life impacts.

The study included bimonthly sampling from June 2022 through August 2023 across two transects (North, in the Caloosahatchee plume, and South, near Naples) to examine the influence of the plume, depth (5-20 m), substrate type, and seasonal changes. Hardbottom was not present at all sites. Work was primarily conducted from small vessels at a research station in Estero Bay and with larger research vessel/cruise support following Hurricane Ian.

Water Quality included YSI sonde measurements, grab samples at the surface, middle depth and bottom, and bulk water sampling. Water quality data showed inshore-offshore gradients. Nutrients, Chlorophyll *a*, and Dissolved Organic Matter (DOM) generally decreased with distance from shore and from the Caloosahatchee. The salinity gradient was from 31 ppt nearshore to marine salinity offshore. DOM correlates with salinity with more organic matter inshore and declining offshore. DOM is important as it's the most abundant form of organic matter in the ocean and affects a number of ecosystem processes including HABs. The different molecular components were characterized as terrestrial in origin near shore (such as from seepage and agricultural inputs), or marine origin (phytoplankton/ reprocessed by microbes) offshore. Oxygen stratification/low dissolved oxygen, was observed at the deepest depth. Overall, the system experiences chronic water quality stress compounded by acute disturbances like blooms and storms. Isotope data indicates that submarine groundwater discharge was a patchy but significant source of nutrients to the nearshore shelf.

Microbial communities: were assessed across different parts of shelf and habitat and characterized as water column, particle-attached, or sediment microbes. Genetics were run to determine types and diversity of microbes, what ecosystem processes they are involved in, and how they differ across space and time.Water column microbes are more diverse offshore and in the wet season. Coastal inputs of nutrients are reprocessed on their way offshore, which leads to a lot of microbial activity. Particle-attached microbes had the opposite pattern and were most diverse inshore, during dry season with a lot of interaction while sediment was stirred up during dry season storms. Sediment communities were more diverse than water column communities, and sediment and particle-attached microbes were highly similar, suggesting strong benthic-pelagic coupling (associated with sediment resuspension). Water column microbes were dominated by cyanobacteria while sediment communities and particle-attached microbes were dominated by sulfate reducing bacteria and ammonia-oxidizing archaea. Certain microbes could be good indicators of freshwater influence from the Caloosahatchee plume. An influx of decaying algal materials drives wet season microbial changes.

Benthic community data were collected across two 50-m transects that ran north and west from a common point; abiotic characteristics (hard bottom, shell hash, and sand/mud) and benthic cover (fleshy macroalgae, calcareous green algae, seagrass, sponge, soft coral, stony coral and other invertebrates) were classified across the transects including with quadrats and video. Overall, the epibenthic community composition was strongly influenced by substrate type, depth, and proximity to the Caloosahatchee. The site nearest the Caloosahatchee (N5) was the most distinct with less diversity and more cyanobacteria. The presence of hard substrate was especially important; where exposed limestone was limited, biogenic structure (e.g., dead soft coral skeletons overgrown by coralline algae) was crucial for habitat formation. The site near Naples (S5) was more diverse with abundant *Sargassum filipendula*. Corals (*Siderastrea*, *Solenastrea*) and red macroalgae were found even in murky, inshore waters. Some species of hard corals, soft corals, macroalgae and fish were found exclusively offshore and away from the plume (e.g., *Stephanocoenia intersepta* hard corals), while others were found everywhere (*Solenastrea hyades*, *S. bournoni*).

Hurricane Ian passed almost directly over the transects, causing severe physical disturbance. Satellite imagery showed turbid water from sediment stirring and coffee-colored freshwater discharge. The primary disturbance mechanisms were scouring and burial, resulting in large amounts of sediment movement and the disappearance of hardbottom in some areas. Sediment composition also changed, with a tendency for soft mud accumulation. Although some recovery was observed, complete recovery is expected to take years.

There is more to study regarding the half life of hardbottom habitat on the southwest Florida Shelf, as it is periodically covered with new hardbottom habitats being revealed elsewhere.

Future work will include expanded mapping and species range delineation, especially for corals, and assessing whether the southwest Florida shelf could be a refuge habitat for species declining in the

Florida Keys National Marine Sanctuary (FKNMS). There will also be comparisons between artificial reefs and natural hard bottom and an attempt to evaluate the impacts of trawling, which stirs up sediment and may contribute to why certain areas are sand and rubble. Genetic-assisted assessments to better understand eukaryotic biodiversity will also be conducted. There are a lot of tunicates but no good guidebook for shelf biota.

Questions & Answers/Comments/Discussion:

- Chris Bergh: What is the linear nature of trawling patterns to the north? Is there a topographic feature?
  - This NOAA trawl layer extends to the whole Gulf. If superimposed on artificial reefs, the tracks often form a halo around those to avoid snags. The tracks are color coded by how many times a single 100m x 100m pixel has been trawled that year (with the map only showing pixels that had been trawled at least three times in a year, so this is an underrepresentation).
  - Chris also noted that trawling activity is believed to stir up sediment, contributing to murkier water as more sediment is available to be stirred up by natural sources.
- Regarding a question on groundwater, Dr. Douglass noted that groundwater provides an episodic source of freshwater, nutrients, and organic matter to the shelf that seeps out versus flows out like a river at a constant rate. There are experts at FGCU's water school. Essentially the springs turn on when the landscape is laden with water but there is uncertainty about the time lag before that happens. Groundwater is an important source of freshwater, nutrients, and organic matter to areas of the shelf and is also a potential route for pollution and excess nutrients to get on the shelf. To that end, there is concern about the impacts of shallow injection wells in this area and where that water comes out.
- Heather Stewart, USFWS: Regarding the benthic surveys and the use of coral point counts, how is that analyzed where there are multiple layers of organisms growing on top of each other?
  - Only the top layer is categorized for each pixel. For example, a frond of macroalgae above coral would be categorized as macroalgae.

Lunch

VII. Modeling Biscayne Bay Circulation and Microplastic Fate and Transport: Applications for Improving Canal Conditions

Dr. Reinaldo Garcia, Hydronia LLC, and Dr. Henry Briceño, Florida International University, presented an overview of their 5–6 year effort to model the dispersion of microplastics and other pollutants in Biscayne Bay (BB). While not highly visible, microplastics account for 60-80% of total marine debris and behave as a vector for transporting toxic chemicals. The goal is to create a tool that anyone can use to assess and simulate pollutant dispersion in the bay.

The project utilizes the RiverFlow2D [Hydronia] model, which is a 2D shallow water equation model featuring GPU parallelization, which allows it to run on a desktop computer and up to 1000x faster than a one processor model. Available modules include Water Quality, Sediment transport, Oil Spills, Urban Drainage (SWMM), and Plastic Transport.

The research effort encompasses two EPA-funded projects, the BBOM and BBLAST models which were both collaborative efforts between FIU, government and the private sector.

BBOM (Biscayne Bay Operational Model) was funded by EPA from 2019–2023. The goal of this effort was to develop an operational hydrodynamic, sediment transport, and water quality model for Biscayne Bay. The model was calibrated and validated, starting with circulation and a series of instruments FIU installed to obtain data at different locations. This was implemented across Biscayne Bay, and used a flexible mesh with different sizes and resolutions from 5-500 m (even finer in canals), which can account for various factors that may alter hydrology. A second validation occurred against an independent dataset from the South Florida Water Management District, using depths and salinities collected at 41 stations over a one-year period (Jan–Dec 2019). The model produces detailed circulation patterns that accurately reproduce water elevations and salinity in the bay. Accurate simulations required accounting for freshwater inflows from canals and rivers, groundwater, tidal forcing, and wind stress for accurate simulations.

BBLAST (Biscayne Bay Plastic Transport Model) was funded from 2023–2025, with a goal to enhance BBOM by including a specialized module for simulating the transport and fate of plastics by using particle transfer to track trajectories of particles with different sizes and densities. This model incorporated updated bathymetric data and an improved model mesh to increase resolution. An intense effort was made to gather velocity and depth information across the bay. Drifters tracked by satellite GPS were deployed to revalidate the model's ability to reproduce plastic trajectories for particles originating in different locations. Microplastics were also sampled at different inflow locations, especially in northern Biscayne Bay to help calibrate the concentration of microplastics in different parts of the Bay. This allows an assessment of the fate of plastics. Trajectories are driven by tidal currents and wind, with the release time affecting the end location of particles. The model successfully reproduced large-scale circulation patterns and supported microplastic transport analysis. Models showed limitations in shallow coastal areas and fine-scale variability due to limited wind data. FIU has an ongoing project to extend the model's use for nutrients (N+P) and other pollutants. NBC/Telemundo developed five different videos to share this project.

Potential Applications in the Florida Keys: The high-resolution capabilities of the model make it valuable for simulating water quality and pollutant dispersion in the canals of the Florida Keys. It can be used to investigate the complex exchange of water and pollutants between canals and open waters. The model can also be used to assess pollutant occurrence and evaluate how specific remediation measures—such as implementing culverts or other hydraulic structures—could improve canal water quality and circulation patterns.

Questions & Answers/Comments/Discussion:

- N/A

VIII. Linking Environmental, Ecological, Anthropogenic, and Host-Specific Drivers to Stony Coral Condition on Florida's Coral Reef

Dr. Brian Walker, NSU, presented on an EPA and DEP-funded study to link environmental, ecological, anthropogenic, and host-specific drivers to the condition of stony coral on Florida's Coral Reef (FCR). This work has focused on southeast Florida, but will be extended to the Keys. Today's presentation will show the value of the approach. More information is available at: https://www.int-res.com/journals/meps/articles/meps14988 and https://www.nova-ncri.org/news/How-Inland-Waters-Shape-Coral-Reef-Health-in-Southeast-Florida.

FCR provides rich biodiversity and vital ecosystem services like coastal protection, as stony corals reduce up to 97% of wave energy. Corals thrive in oligotrophic (low nutrient) waters. Stony coral is the backbone of the reef system, growing the structure that other organisms inhabit. Major stressors include global heat events, which are increasing in frequency and magnitude.The unprecedented 2023 thermal event resulted in the "functional extinction" of *Acroporid* species in the Keys. Local Stressors include Land-Based Sources of Pollution (LBSP) from coastal development, stormwater runoff, and septic/sewage systems, which degrade water quality, and contribute to disease, mortality and affect other coral functions. Stony Coral Tissue Loss Disease (SCTLD) was one of the most impactful local stressors in recent years, which originated in Southeast Florida in 2014 and spread both north and south over six years.

This study looked at inland water connections to improve understanding about what may be driving stressors on the reef and how we can control them. A challenge with ecological and water quality data is the periodicity of data collection and the misleading trends, false signals, failed detection of extreme events, and misinterpretation that result from undersampling. This study attempts to address this issue of "aliasing" in undersampled water quality data with a three-component workflow:

1) Modeling water quality Drivers (Component A): Used machine learning to model the relationship between monthly reef water quality samples and more continuous terrestrial environmental data (rainfall, inlet flow, wind speed).
2) Nutrient Hydrographic Modeling (Component B): Input these relationships into a hydrographic model (SLIM model) to understand circulation patterns and generate continuous nutrient exposure data across the reef (exposure maps), significantly improving spatial and temporal resolution of nutrient exposure.
3) Linking to Coral Health (Component C): Used the continuous modeled nutrient data to quantify the relationship with coral health metrics like SCTLD lesions and bleaching.

<u>Component A:</u> This framework was applied to 4 Inlet Contributing Areas (ICAs), from Government Cut to the south to Hillsboro Inlet to the north. Rainfall and canal flow across the ICAs were associated with monthly DEP water quality sampling data. Environmental data was summarized at each location to get a historical accumulation of a metric; then statistical analyses were conducted to look at correlations and help explain water quality variation at each site.

The models successfully explained 41–79% of the variation in key water quality analytes (Nitrate, Nitrite, Orthophosphate, Silicate, and TSS). Terrestrial water sources (flow rate in the past 7 days, rainfall) and Year were key predictors of water quality variation. Overall, annual increases were observed in nitrogen, phosphorus, and silicate over time, indicating that water quality is getting worse. This may be due to population growth and associated increases in nutrient loading over the past 10-15 years in Miami Dade and Broward Counties. However, mitigation efforts like Miami-Dade County's septic-to-sewer and 2021 fertilizer ordinances may be slowing the rate of increase, which were observed in the data in 2021.

Large coral monitoring has been ongoing for eight years, and has included active disease interventions to keep them alive. This dataset allows an opportunity to study disease recurrence over time. The coral colonies were assessed by location, number of disease treatments and the percentage of disease by month, with similar modeling conducted to understand what environmental variables contribute to disease over time. Water quality data didn't come out as a statistical factor, although that may be due to a lack of resolution in the data. Overall, temperature, inlet flow, and rainfall explained up to 66% of the variation.

Component B: The relationships between terrestrial and coral reef water quality data were input into ocean circulation models to estimate continuous nutrient exposure on the reef. Reefs northward of their adjacent inlet are the most exposed to water from that inlet. There were interesting patterns observed during wet and dry seasons. This also showed that Government Cut is one of the biggest influencers for the whole region, and acts as a major transition in water quality seascapes. Specifically, Biscayne water quality sites were significantly different than other areas in the study region, and corals in the Biscayne area were found to harbor very different symbionts.

Temperatures and nutrients north of Government Cut increased the incidence of SCTLD. Corals south of Government Cut experienced major bleaching during the 2023 heat wave, while those north of the cut did not, creating a refuge. Corals north of Government Cut also showed faster healing and higher fecundity than corals off of Biscayne and the Lower Keys.

Component C: Relationships were modeled between the modeled continuous nutrient data and ecological data (coral disease and bleaching). At the time of this talk, areas south of Government Cut could not be included in the model; this work is underway and the analysis will be redone in the future.

For SCTLD, 46% variation was explained, mostly accounted for by colony effect (the location along the coast and inlet exposure). Modeled silicate was a strong indicator of terrestrial water sources contributing to disease. Increased exposure to inlet water (Government Cut was the most important source of exposure) and higher temperatures increased disease severity, although corals experienced a decline in disease once they bleached.

Environmental drivers for bleaching included colony location, calm conditions (low landward wind), high temperatures, and year. These factors explained 92% of variance. No nutrient model was available for bleaching.

In summary, LBSP is degrading water quality along Florida's Coral Reef, with annual increases in nitrogen, phosphorus, and silicate observed on the reefs. Reefs northward of their adjacent inlet are most exposed to water from that inlet, and Government Cut is a major transition point between water quality seascapes. Disease increased with more exposure to inlet water and higher temperatures, while colony location, calm conditions, high temperatures and year contributed most to bleaching. Efforts to mitigate LBSP may be slowing the rate of increasing nutrients, having a positive effect.

Future work aims to expand the model to include the entire FCR, Dry Tortugas, and Keys and expand the time frame to include 2018 through 2024. As funding allows, the model may also seek to integrate with the Biological Condition Gradient scores, integrate additional data (like sewage outflow and tourism), and use new bathymetric data to upgrade to a 3D hydrodynamic model. Workflows can also be developed to analyze ocean acidification, carbonate chemistry, enterococci and beach closures, etc. The results of this effort may help identify microrefugia for restoration, as well as identify probable sources for water quality stress.

Questions & Answers/Comments/Discussion:

- N/A

IX. Updates on the Hypothetical Linkages Between Toxigenic Benthic Dinoflagellates, Spinning Fish, and Sawfish Mortalities

Dr. Michael Parsons, Florida Gulf Coast University, and Dr. Alison Robertson, University of South Alabama, presented an update on the investigation into benthic dinoflagellates and algal toxins as potential causes for the unusual fish behavior and sawfish mortalities observed in the Florida Keys.

Part 1: What We (Think We) Know

Research focused on benthic dinoflagellates as potential stressors, as the event affected many species and appeared water-borne rather than diet-related. Common stressors like red tide (brevetoxins), low oxygen, low salinity/temperature, disease, and typical pollutants were ruled out. Elevated levels of the benthic dinoflagellate *Gambierdiscus* (1000 cells/liter) were observed in the water column and gut contents of affected fish, with concentrations significantly higher than the 10+ year baseline. This called to mind an incident at the Pittsburgh Zoo aquarium in 1984, where a cold event shut down a wetland component of the exhibit, which resulted in murky water, upside down fish, and samples with *Gambierdiscus*.

Benthic dinoflagellates were the focus of this investigation because many produce toxins and toxin precursors. This is mainly known from ciguatera poisoning, although in that case the toxins are internal to the fish with exposure by ingestion. Benthic dinoflagellates can produce other compounds, including maitotoxins that are water soluble and could thus be introduced via fish gills. Sampling for benthic dinoflagellates was underway in the lower Keys and Long Key since mid-2010, so good baseline data was available. Most of the spinning fish were in this vicinity, between Sugarloaf and Big Pine Key. Sampling requires special care and the use of scuba as they are epiphytic benthic dinoflagellates located on seagrass and algae, which are prevalent and allow comparison across sites. Water is also collected for nutrient and toxin analyses.

Spinning fish were first noticed in October 2023 after a hot summer. Dr. Parsons' team joined in February 2024 with sampling conducted into May. The focus was on *Thalassia* and *Halimeda*, which were sampled and investigated for different species of *Gambierdiscus*. These were statistically compared to unaffected sites in the Middle Keys. Comparisons between the Lower and Middle Keys during the event showed elevated *Gambierdiscus* densities in the water column in the Lower Keys. No other sampled taxon popped out, except that some were more significant on *Halimeda* at the normal sites. *Thalassia* sites had more significant spinning concentrations for some species, which was consistent with elevated *Gambierdiscus* at these sites as well. Sampling after the event largely subsided (summer 2024) showed similar reduced concentrations of *Gambierdiscus* on *Thalassia*, which has remained low since. The baseline for comparison is an 8-year average of every month. Elevated concentrations were observed again at the "normal" sites in the Middle Keys in 2025, but less than observed previously. Spinning fish hotspots were centered around Big Pine Key with flare ups in Islamorada, although with a lower intensity and frequency of reports).

The summer 2023 heat wave was an impactful event, and *Gambierdiscus* and Ciguatera are known to flare up after big environmental disturbances (including hurricanes, shipwrecks, and as seen at the

Pittsburgh Zoo exhibit). This is the “superbug hypothesis” in which a really toxic *Gambierdiscus* species becomes prominent enough to notice following a big event. Often people notice this when Ciguatera rises, but that has not been reported during this event. Fluorescent in-situ hybridization (FISH) probe analysis identified multiple species and strains (70-80% of which were unknown), suggesting cryptic diversity within *Gambierdiscus* populations may play a role in the event.

In conclusion, *Gambierdiscus* cells were elevated in the lower Keys in February 2024, primarily evident on *Thalassia* and in the water column. At this point, we don’t know how to define a bloom of these benthic dinoflagellates. Gambierdiscus densities decreased in the summer months of 2025, as expected. Higher densities were observed in the Middle Keys in early 2025 with some spinning fish reported in the vicinity, although it’s unknown if that was coincidental or connected. It’s possible that multiple species may be involved and that cryptic diversity plays a role.

<u>Part 2: Benthic Algal Toxins, Unusual Fish Behavior, & Sawfish Mortalities</u>

This was a significant event with stories picked up by National Geographic. Less than 6 months into the event, some stories appeared that the event had been solved; that is not the case and it remains unsolved today. We need to be careful not to mistakenly assume the answer, as this is a multifaceted, complex problem.

Dr. Robertson showed examples of the spinning behavior. Reported fish behaviors included spinning, loss of equilibrium (swimming upside down), vertical breaching, reduced fight/flight response, and impaired gill movement. Behavioral symptoms typically ceased after 30-40 minutes when fish were moved to clean water. Spinning is a normal stress response, including to other stress events such as low dissolved oxygen, dietary changes, exposure to neuroactive contaminants, etc. For example, 6-PPD Quinone is a compound in tires which, when broken down, biotransforms and can cause this activity. However, this compound would be unlikely to be in the water during a time of less rainfall. Algal neurotoxins were the primary focus of the investigation, given the observed increase in *Gambierdiscus*. Other clues included the many different types of fish affected (80+) and the elevated benthic algal cells on macroalgae. A number of other potential causes were ruled out, including Karenia brevis, low oxygen and salinity, disease/parasites, and the suite of typical pollutants of concern, among others

Of the dinoflagellates in the samples, Gambierdiscus alone is capable of producing a variety of Caribbean ciguatoxins, as well as Maltotoxins, Gambierones, and derivatives of those. Using assay-guided fractionation researchers analyzed surface waters, benthic algae, and fish tissues to analyze fractionations of compounds and capture all the potential contaminants. Bioassays allow us to look at composite toxicity and mechanisms of marine biotoxins to understand the class of a compound, even if we don’t know the exact compound. These have been assessed for hundreds of fractions across a number of samples.

Water and sediment were collected across 19 sites. On the map presented, red = ciguatoxin detected in sediment and water, pink = no detectable natural toxins, orange = a variety of different toxins were detected. Over 60 species and 538 cultures were screened to look for different algae, then isolated and assayed to determine if a bioactive neurotoxin producing strain was present in the Keys at the time of the incident. In looking at benthic algal toxins in symptomatic sawfish, ciguatoxins were found in most samples, including 30% of muscle samples, 58% of liver samples, and 60% of gill samples. Other algal toxins were also found at high levels in gill tissue, which reaffirms the hypothesis of something being present in the water and impacting gills. At a minimum, this level of exposure could make these sawfish susceptible to something else in the environment. Exposure tests showed that combined algal extracts could replicate the behavioral effects observed in fish, confirming a potential link.

Overall, a complex profile of benthic algal toxins was detected, including Caribbean ciguatoxins, maitotoxins, gambierones, portimines, pinnatoxin-G, gymnodimine, and okadaic acid. Findings suggest a multifaceted problem involving a complex mixture of benthic algal toxins. Future work will continue to investigate these linkages and their spatiotemporal trends.

Questions & Answers/Comments/Discussion:

- Heather Stewart: Noted that there were certain fish species that were more impacted; have the researchers looked into physiological response and metabolism impacts from neurotoxins?
    - Yes, we are trying to understand how marine biotoxins affect different species. We mostly see phase 2 biotransformation in fish, where any addition to the molecule makes it more water soluble. Several species were tested to see if metabolism differs, and findings were fairly similar across species (parrotfish, lionfish, snapper; also looked at Atlantic salmon, though they aren't here). All responded similarly in biotransformation and metabolism, though there are species not tested yet that may differ. The biotransformation and metabolism of other compounds that bioaccumulate in shellfish has not been tested, which is a large task. We are also considering how diet plays a role; ciguatoxin is an issue, and exposure via ventral gills over seagrass or site fidelity around seagrass beds may be factors. However, we must take caution with anecdotes, as these are human observations and other species (e.g., barracuda or tarpon) had few observations. We need to determine the cause before definitively looking across species.
- Audience question: Could a cold event create similar conditions as the elevated dinoflagellate levels seen in extreme heat events?
    - It is possible. There are two main hypotheses: Cryptic diversity (could this stress event cause something to be more prominent or express toxins more?) and environmental effects (top-down control). The heat spell may have knocked out micro-grazers for Gambierdiscus, and micro-grazer samples are being collected to investigate this further.

X. Shallow Injection Well Research Update

Dr. Rachel Housego, Pennsylvania State University, shared findings from a multi-year research project on shallow wastewater injection (SIW) in Marathon, Florida. The project aims to understand the fate, transport, and geochemical transformation of treated wastewater effluent injected into SIW, with a focus on physical hydrology.

Marathon is an island within the Florida Keys National Marine Sanctuary and adjacent to sensitive coral ecosystems in the Keys. The island itself is a historical reef structure, and the subsurface is composed of Key Largo limestone. The Key Largo Limestone aquifer exhibits complex, high-porosity karst features—including matrix conduits and caves—that create preferential flow paths for discharge into surface waters. Tidal forcing also interacts with groundwater.

The City of Marathon operates the largest SIW system in the Florida Keys, injecting approximately 642,000–720,000 m^3/day of treated effluent (freshwater, 2–3 PSU) into an aquifer characterized by saline groundwater (35 PSU) at depths of 18–27 meters. This effluent contains nitrogen, phosphorus and pharmaceuticals, which all vary depending on injection flow rate. A system of monitoring wells were installed adjacent to the Area 3 SIW well; these are vertical clusters ranging in depth from 3 to 27 meters to capture the structure of the wastewater plume. Two transects (N-S and E-W orientation) were analyzed.

Key Research Findings

- Dye tracer experiments confirmed that the injected effluent is buoyant and creates a dynamic, spreading plume. Flow is preferential, with dye appearing almost immediately in adjacent monitoring wells and showing dominant movement to the north and east. The system is heavily influenced by tidal forcing, which modulates the hydraulic gradient and the position of the plume interface.
- Monitoring using continuous sensors (CTDs) showed that while plume morphology is consistent over time, the interface between fresh and saline water is dynamic, fluctuating with tidal cycles. While there is no clear temperature signal associated with the injectate, temperatures in the shallow wells flux with tides (as cooler water moves in and out) and seasonally. Temperature readings in the deeper wells are consistent through time. Similarly, salinities are consistent in deep wells and fluctuate with tides in the shallowest well.
- Research indicates that both nitrogen and phosphorus are removed along the flow path from the injection well to surface waters through processes such as adsorption to limestone (for phosphorus) and denitrification (for nitrogen). However, this removal is not total, and anthropogenic markers (such as sucralose) and wastewater-derived nutrients were detected in wells adjacent to Florida Bay. Measurable quantities of these anthropogenic pollutants are likely discharging from the subsurface into adjacent surface waters, including Florida Bay and Boot Key Harbor. Travel time through the subsurface is important for determining the amount of removal before discharge into surface waters.

The study is now evaluating the transition to deep injection wells to determine the possible consequences for water quality and the time scale for recovery to a traditional freshwater lens configuration. Higher salinity water can drive desorption of phosphorus, especially if mineralization is non-stable. Researchers are analyzing carbonate cores from the plume area to determine the stability of adsorbed phosphorus and assess the risk of remobilization and the vulnerability of discharge into nearshore waters (how much phosphorus is in the limestone?). Additionally, numerical modeling (FEFLOW) is underway to characterize recovery times and evaluate best management practices for shallow injection, such as variable injection rates and whether blending effluent to increase density and residence time can increase the system's effectiveness.

In conclusion, shallow injection creates a buoyant plume that transports nitrate, phosphate, and other anthropogenic pollutants to adjacent surface waters. Transport rates and interface positions are dynamic and linked to tidal forcing. Ongoing geochemistry and modeling will help understand how water quality will evolve over the transition from a SIW to a deep injection well. More information is available in the following research papers:

https://www.ingallslab.com/uploads/1/2/4/3/124385792/acs_es_t_-_2024_-_meyers.pdf

Fate of wastewater nitrogen upon injection into a coastal saline groundwater system, Florida Keys, USA

Questions & Answers/Comments/Discussion:

- Audience question: How deep are the deep injection wells?
    - They are approximately 3,500 feet deep, extending well below the boulder zone.
- Chris Bergh, TNC: This scientific effort was really the result of a request by citizen activists; thank you for bridging this forward and to EPA for funding the research. The science says the concern was likely well-founded, and the City of Marathon is now taking action. This is a testament to the value of the WQPP.
    - George, City of Marathon, noted that the research originated from concerns regarding sucralose detections north of the island. While initial monitoring and TAC input questioned the validity of those findings, the committee supported the need for scientific rigor, leading to the installation of monitoring wells and the current comprehensive geochemical study.
- Sandy Walters, Eco-Legacy Solutions: Regarding the recent cold weather (worst since 2010), was there an impact on corals?
    - Gil McRae, FWC, responded that assessment is ongoing, but there has been no indication of impacts comparable to 2010, nor were any associated fish kills observed.

Meeting Wrap-Up and Adjourn
Wade Lehmann thanked everyone for participating in the WQPP mini-research symposium.

The meeting adjourned at 4:30 pm.