Results *and* Impacts of the First Decade of the Florida RESTORE Act Centers of Excellence Program

EDITED BY | NICOLE A. RAINEAULT

JANUARY 2024

Mission

Engage a broad base of non-governmental participants, including institutions of higher education, with interest and expertise in science, technology, and monitoring to support a healthy Gulf of Mexico environment and economy.

Vision

Sustainable Gulf Coast Region ecosystem goods and services, including living resources, fisheries and wildlife habitats, beaches, wetlands and coastal communities.

Program Management Team

Anthony (Tony) DiLernia, Captain, Director Office of Maritime Technology, The City University of New York, ret.

Evelyn Fields, Rear Admiral, NOAA Commissioned Officer Corps, ret.

William (Monty) Graham, Director, Florida Institute of Oceanography

Holly Greening, Tampa Bay Estuary Program Director, ret.

Larry McKinney, Harte Research Institute Executive Director, ret.

Bonnie Ponwith, NOAA Fisheries Southeast Fisheries Science Center Director, ret.

Julien Lartigue, NOAA RESTORE Science Program Director

Publication design by
Jessica Brightman
www.DesignBrighter.com

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Celebrating Ten Years of Research that Illuminates the Gulf

NICOLE A. **RAINEAULT**

Thriving coastal and Gulf environments that support wild and human lives. Sustainable fisheries for recreation and sustenance. Knowing where (and how) juvenile sea turtles travel when they leave Florida beaches and how they are impacted by harmful algal blooms. Better built environments and fewer invasive species. Oil spill impacts on sharks, large fishes, and dolphins. These are some of the goals of research through the Florida RESTORE Act Centers of Excellence Program (FLRACEP) funded by the U.S. Department of the Treasury.

The beauty and inspiring sights that draw millions of people to Florida's coastal environments and waterways are now inextricably a combination of natural and human creation. Birds and beachcombers, fish and anglers, reefs both natural and artificial: communities on our Gulf coast intermingle people, wildlife, human construct, and the environment. Florida's economy depends on a pristine and healthy Gulf coast to draw and sustain inhabitants, tourists, and support recreational and commercial fisheries. When disasters suddenly impact the environment, people must work together and rapidly take stock of resources and losses to chart a path forward.

One of the stark realities that faced scientists, managers, and the Gulf community after the Deepwater Horizon oil spill in April 2010, was how little we knew about the ecosystems, wildlife, and resources that were impacted.

So many basic questions could not be answered by the experts, leading to frustration amongst the public and a call for support so that we would know more in the future.

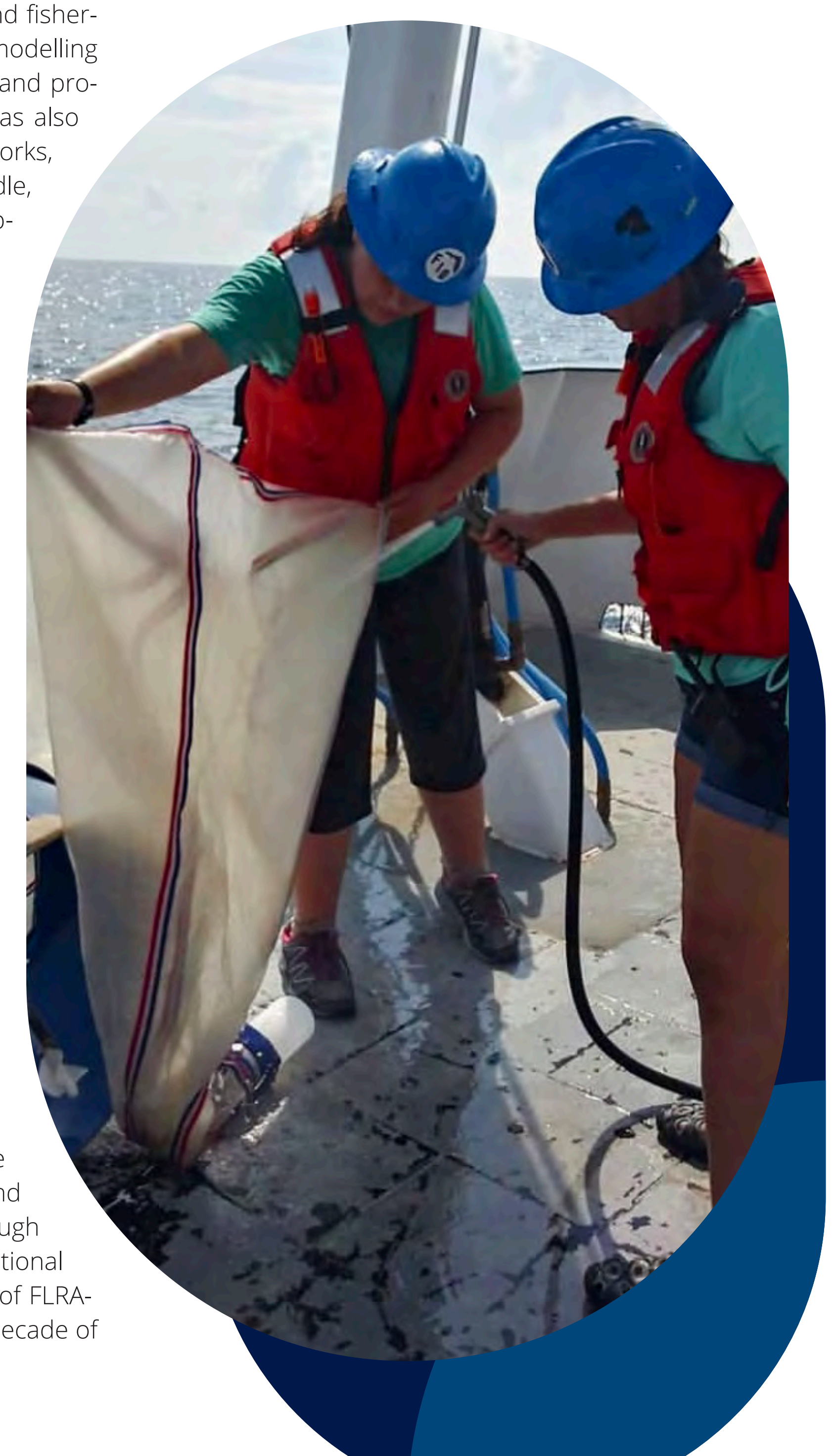
We are grateful that the call to action was met. Congress passed the Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States (RESTORE) Act, which was signed into law on July 6, 2012. RESTORE established the Gulf Coast Restoration Trust Fund in the U.S. Department of the Treasury and 80% of all civil penalties paid after July 6, are deposited into the Trust fund and invested. Programs, projects, and activities that restore and protect the environment and economy of the Gulf Coast region receive funding, including the establishment of the Centers of Excellence Research Grant Programs in each of the Gulf states. Florida Institute of Oceanography was selected to administer the funds for the state of Florida in August 2014 and reached out to the community to establish the program scope, rules, and policies. Key aspects of the program are a Program Management Team (PMT) to serve as an independent body and provide guidance and engage in the development of the program strategic plan, funding strategies, solicitation reviews, and funding approval. The seven-member PMT is comprised of highly engaged, successful Gulf coast experts with wide-ranging knowledge and experience. Public scoping elevated three out of five eligible research disciplines for the Florida RESTORE Act Centers of Excellence Program (FLRACEP) to focus competitive research grant requests on: 1. Coastal fisheries and wildlife ecosystem research and monitoring; 2. Comprehensive ecosystem observing, monitoring, and mapping; and 3. Coastal sustainability, restoration, and protection, including solutions and technology that allow citizens to live in a safe and sustainable manner in a coastal delta in the Gulf Coast Region.

To date, five externally peer-reviewed research proposal processes have selected 21 projects for funding. $10.8 million has been awarded to researchers at ten different Florida research institutions and non-profit organizations to lead Centers of Excellence. The research has focused on filling gaps and innovating new technologies to monitor economically and recreationally important fisheries, understanding the health and life histories of critical wildlife, particularly sea turtles, sharks and large fish, and dolphins, and mapping and understanding the role of habitat to wildlife and fisheries. Environmental observation, monitoring, and modelling from these projects has improved our knowledge and provided new tools to resource managers. Funding has also supported the development of scientific frameworks, including for new estuary programs in the Panhandle, and to support data collection and synthesis for habitat mapping. Our most recent cohort of projects funded in 2023 will study the impact of restoration projects. This is a timely pursuit, as the Gulf region is several years into RESTORE-funded restoration planning and project implementation and most RESTORE program components have funding available for perhaps another decade of projects.

Beyond the scientific results of the projects, many partnerships between academic, Federal, state, and local agencies and non-profits, and industry have formed as a result of the encouragement of multi-institutional teams. 39 different organizations have been named as co-investigators or collaborators on awarded projects. Engaging the broader community, particularly through the Panhandle estuary and restoration projects, raises awareness about the importance of and challenges facing the Gulf. Additionally, many undergraduate, graduate, and early career scientists were and continue to be supported through the grants, helping develop future generations of stewards of the Gulf environment.

We invite you to read about the many discoveries and accomplishments of the Florida Centers of Excellence to date. We are proud that the results of these projects improve our understanding of the Gulf of Mexico and the tools available to measure and monitor the environment. Active projects run through 2026, but you will see that there is plenty of additional work to be done. We are using this review as part of FLRACEP's strategic planning process to chart the next decade of RESTORE research-funded projects in Florida, with a goal of ensuring that we know more, so that collectively we can better manage and protect the Gulf of Mexico, which is so vital to our lives and livelihoods. If you are inspired, please email flracep@usf.edu with your thoughts.

Scan here to learn more!



Florida Centers of Excellence Research Grant Program *by the Numbers (2015-2023)*

$10.83M in research grants

53 publications to date

1 NEW species discovered

21 projects awarded

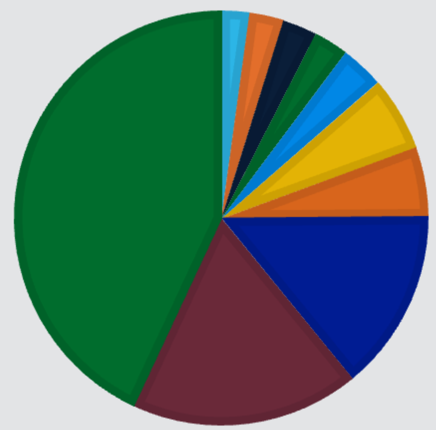
TEN FLORIDA Centers of Excellence

7 ICUN Red List of Threatened Species Reports

50 datasets archived

Centers of Excellence Lead Institutions

FLRACEP Funding to Lead Institutions



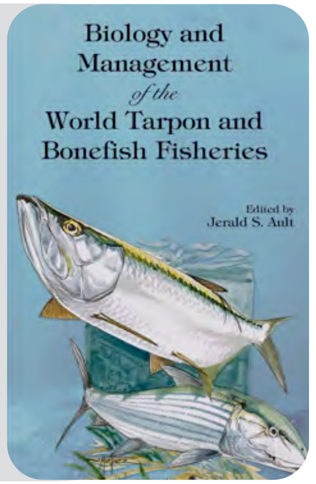
- Florida International University
- University of West Florida
- University of Central Florida
- University of Florida
- University of South Florida
- Sanibel-Captiva Conservation Foundation
- Nova Southeastern University
- Mote Marine Laboratory
- University of Miami
- Florida State University

Grants to support: Science, Technology, & Monitoring

- Coastal & deltaic sustainability, restoration and protection including solutions that allow citizens to live in a safe and sustainable manner in the Gulf Region
- Coastal fisheries & wildlife ecosystem research & monitoring in the Gulf Coast region
- Comprehensive observation, monitoring, and mapping of the Gulf of Mexico

Developing Biological and Economic Indicators to Sustain Florida's Valuable Marine Recreational Fisheries

JERALD S. **AULT**, STEVEN G. **SMITH**,
& DANIELLE **SCHWARZMANN**



Background

Florida's marine recreational fisheries are a world-class multibillion dollar enterprise, generating annual economic values an order of magnitude greater than commercial fishing, and even more than the Florida citrus industry. Recreational fisheries target hundreds of fish and shellfish species across Florida's seascape, such that their ecological dynamics and economic sustainability are primary conservation concerns. The principal management objective is to sustain these fisheries and their ecosystem services into the indefinite future. While landings and effort are reported by fishers to state and federal databases, less than 10% of these species have up-to-date stock assessments. Intensive fishing has fundamentally altered the ecological structure of Florida's fish communities through depletion of biomass to the extent that many primary fish stocks are unsustainable. Sustainability risks for multispecies recreational fisheries and their biological, economic and social optima are largely unknown. Because many exploited species lack biological-economic indicators, managers cannot accurately know if these stocks are fished sustainably or in an economically efficient manner. Our goal was to identify robust biological-economic indicators of stock status-economic efficiency that improve assessment capabilities to effectively balance sustainability risks from fishery production, overfishing likelihoods, and economic profitability.

Outcomes

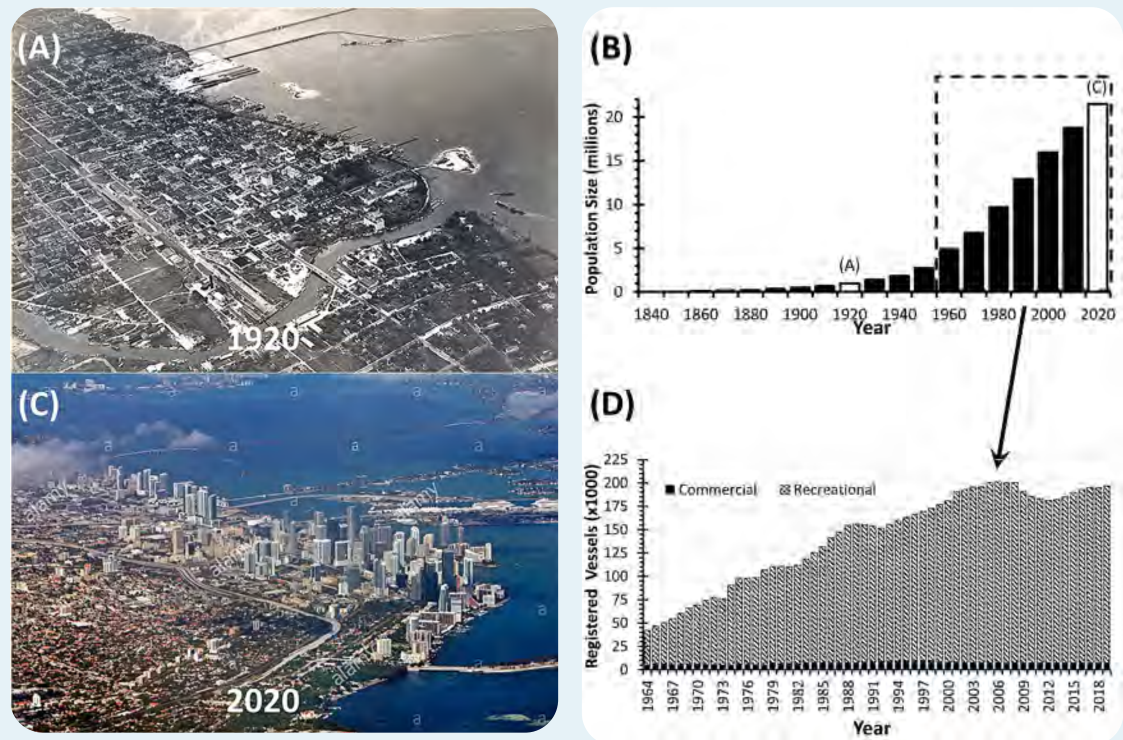
Our outputs were specifically aimed at decision-makers to improve the value of ecosystem goods and services of Florida Gulf coast recreational fisheries. For biological indicators, we employed a multi-decadal state-federal Marine Recreational Information Program (MRIP) timeseries database of catch, effort, and size-structured abundance. Our robust and novel biological stock sustainability indicator methodologies were applied to six key recreational species (spotted seatrout, red drum, red grouper, gag grouper, red snapper, gray snapper). Indicators were closely related to stock productivity via fisheries population dynamics theory, and were critical to the design and implementation of a "stated preference" economic survey. A valid stated-preference survey must include realistic scenarios, and this requires integration of biological-economic information in a way that minimizes resource risks and sustains fishery ecosystems. Our "choice-experiment" survey was focused on the primary regional recreational species, i.e., spotted seatrout. It was used to determine economic value to the recreational fishery of improving catch rates (and thus population sustainability) of spotted seatrout, by assessing how anglers valued combined changes in the existing bag limit and size limit. The biological component of the stated preference model deemed such changes necessary to ensure a sustainable stock. Using newly synthesized life history information for exploited species, we expanded the bioeconomic model's economic component for Florida's west coast spotted seatrout recreational fishery. These indicators were used in a novel length-based risk assessment framework to evaluate exploitation impacts and management options for species central to the recreational-commercial fisheries of Florida. Benchmarks were established from data-limited indicators which allowed cross-checks from other data-rich analyses. The estimation-simulation method used length frequencies as the principal data in lieu of catch and effort, and key developments were to: incorporate probabilistic mortality and growth dynamics into a numerical cohort model; employ a precautionary approach for setting sustainability reference points for fishing mortality and stock reproductive biomass; define sustainability risks in terms of probability distributions; and, evaluate exploitation status. The methodology allowed for a fairly comprehensive probabilistic evaluation of sustainability status, and also a frame of reference for exploring management options balancing sustainability risks and fishery production. This integrated biological-economic modeling determined the value recreational fishers give to changes in regulations (e.g., bag and size limits) that would support a more sustainable fishery.

Impact

This unique collaboration of economists and fishery stock assessment analysts greatly improved biological assessment and indicators for estimating the annual value of lost recreational services, and determining efficacy of management options. Since private boats had a lower probability of achieving the bag limit/size limit compared with those for professional guided fishing trips, a model was run to predict the probability of achieving the bag limit/size limit and the probability was interacted with the bag limit/size limit choice. This yielded a positive willingness to pay for the bag limit/size limit combination that was sustainable. Striking a "strategic balance" for marine recreational fishery resources involves multiple control methods to buffer uncertainty, mitigating environmental variability and chance. Linking angler's recreational preference directly to a decision variable(s) is a powerful and effective way to make management decisions. Integrating biological and economic indicators to inform resource assessment and management is good for fish, the ecosystem, fishermen, and Florida's economy!

Future Work

Looking forward, development of spatial stock ecosystem-wide management information systems to support informed decision-making for sustaining Florida fisheries is warranted. These models will integrate ocean-climate to spatial predator-prey dynamics to maximize the probability of sustainability and economic value. These new tools will greatly facilitate quantification of dynamic use of ocean habitats, migration processes, and responses to environmental changes by fishes. But this will also advance a central integrated methodology to determine the economic value to anglers of recreational fishery ecosystem services that could result from different management scenarios. Biophysical mechanisms surrounding spatially complex large-scale fish migratory behaviors, local movement patterns, and population connectivity, are critical to determining the natural processes and anthropogenic stressors that influence population dynamics and for developing effective conservation plans.



◄ (A) Southern Florida regional coastal development and fishery fleet growth: (A) downtown Miami circa 1920; (B) Florida's human population from 1840 to 2020 (Source: US Census), the open bars refer to panels (A) and (C); (C) downtown Miami 2020; and, (D) southern Florida registered commercial (black bars) and recreational (hatched bars) fishing vessels from 1964 to 2019 (Source: Florida Department of Motor Vehicles). Dashed rectangle in (B) corresponds to the time period shown in panel (D).

Demonstration of Fisheries Assessment Applications for Underwater Gliders

CHAD **LEMBKE**, SUSAN **LOWERRE-BARBIERI**, DAVID **MANN**, & J. CHRISTOPHER **TAYLOR**

Background

Autonomous underwater gliders are robust uncrewed systems initially designed to obtain physical characteristics of subsea coastal waters. They are routinely used to provide boundary conditions to circulation models, inform harmful algal bloom management, provide upper ocean heat content for hurricane strength forecasting, and numerous other research endeavors. This Center of Excellence project aimed to investigate the capabilities of these platforms to collect specific data sets in new ways to benefit fisheries management efforts. The lessons learned from this effort tested the feasibility of collecting detection data from acoustically tagged animals, passive acoustic recordings from soniferous organisms, and water column acoustic backscatter as indicators of plankton and fish as part of a comprehensive observing system.

Outcomes

The gliders and sensors performed the research within specification. Gliders were deployed seasonally targeting a known habitat (Gulfstream Natural Gas Pipeline), including a region where 61 fish (red grouper and red snapper) had been acoustically tagged. A total of five 10–30-day glider operations were conducted between August 2016 and October 2017. The gliders were equipped with an acoustic receiver, passive acoustic recorder, and calibrated fisheries echosounder. Stationary receivers (n=5) with passive acoustic recorders were deployed in the location of the tagged fish in order to compare the glider data to that collected with traditional methods. All three technologies are still in use within the USF glider fleet based on lessons learned from this project. Updates on individual sensor performance during and following the project are detailed below.

Each glider deployment for this effort included an acoustic receiver. Detections were made in the four deployments that were able to traverse the tagging region. Through the duration, 70% of red grouper and 68% of red snapper were detected by the glider, while all but two fish were detected by the moored receivers. During the project, as the glider increased time spent within proximity of tagging locations from 24-48 hours detection rates improved. The mobile and periodic nature of the gliders reduces the detection success rate. However, some specimens were detected outside the immediate zone monitored by the moored receivers, showing that the glider provides the ability to detect fish outside areas where they might be monitored with more traditional (e.g., fixed) means.

Passive acoustic recordings were collected on all but one deployment. Data from these recordings and one of the moored sites were all analyzed for grouper calls. The tagging region with known grouper presence consistently recorded grouper sounds, while transits along the rest of the glider path detected sporadic calls. All detections can likely be attributed to the presence of grouper habitat. This was validated in one test case where grouper calls were detected and echosounder biomass was measured during a multibeam bathymetry survey of a region. In addition, this region was found to be populated with bottom features commonly associated with grouper habitat.

Fisheries echosounders were the newest sensor integration and suffered a transducer failure. System control and logging parameters were also refined during the missions. This is not unexpected when utilizing the prototype combination of two complex autonomous systems like the glider and an echosounder. All four deployments collected water column acoustic backscatter, which were analyzed for fish biomass. This was the first known fish biomass study conducted using gliders. Similar to the passive acoustic recordings of grouper, the echosounders provide a new tool to detect fish and plankton aggregations that could guide further fisheries studies.

Impacts and Future Work

The use of underwater gliders continues to expand their application toward biological sampling. This project demonstrated the value of combining three acoustic technologies on one platform and validated the technologies by confirming their utility, providing better understanding of the limitations of their use, and highlighting areas in need of refinement. To date, where possible all USF glider deployments continue to include attached acoustic receivers. All detection data is shared through two telemetry networks: the Integrated Tracking of Aquatic Animals in the Gulf of Mexico (iTAG) and Ocean Tracking Network (OTN). These data are viewed as opportunistic detections useful in augmenting existing studies. For many telemetry studies, limitations in spatial and temporal detection capability are imposed by costs of monitoring, so opportunistic platforms such as gliders that can sample varying spatial scales are viewed as complimentary to other monitoring techniques.

Passive acoustic recordings continue to be collected on most USF glider deployments. Efforts to collaborate with fisheries and marine mammal researchers is ongoing. The largest impediment to more expanded use of passive acoustic recordings is the automation of detection algorithms. For some species this has progressed (e.g., right whales), but it is expected that this technical impediment will be overcome in the near future.

Effort has expanded with USF collaborating with Florida International University, NOAA, and the University of Washington to integrate a second fisheries echosounder by a different manufacturer (Kongsberg). Efforts nationally have expanded to attempt use of these and other echosounders to obtain water column indicators of watercolumn fish or plankton biomass using gliders, with teams collectively approaching the challenges presented in data collection and dissemination. Water column acoustics can be analyzed with varying techniques depending on the target of the research, which will present challenges to the traditional view of observing system operations, but it is reasonable to expect that use will continue to expand and be refined.

Operational observing system robotic platforms that perform in a sustained and routine fashion will be a vital component to future fisheries research as the costs and reliability of autonomous systems continues to evolve favorably compared to shipboard and other traditional operations. Capitalizing on the reliability, versatility and efficiency of robotic systems to augment or even replace traditional fisheries data collection practices is essential to management practices.

► USF Slocum glider equipped with tag telemetry receiver, passive acoustic recorder, and echosounder launched in the eastern Gulf of Mexico *(Photo: Kevin Boswell).*

▼ USF glider preparing for departure from launch vessel *(Photo: Edmund Hughes, edited by Ben Prueitt).*

Spawning Habitat & Early-Life Linkages to Fisheries (SHELF)

CHRIS **STALLINGS**, MYA **BREITBART**,
STEVE **MURAWSKI**, & ERNST **PEEBLES**

Background

The project *Spawning Habitat & Early-life Linkages to Fisheries* (SHELF) was funded by the Florida RESTORE Act Centers of Excellence Program (FLRACEP) in 2017, following a previously FLRACEP-funded study in 2015 that showed fish eggs could be successfully DNA barcoded to identify the species that spawned them. SHELF applies novel approaches to long-term monitoring of living marine resources in the eastern Gulf of Mexico. Specifically, SHELF continues to identify the taxa of planktonic fish eggs collected across the West Florida Shelf (WFS) using DNA barcoding. A specific objective of the monitoring effort, in addition to locating important fish spawning areas, is to produce a time-series that will detect changes in the amount or location of spawning by individual fish species, and to detect changes in fish-egg community composition over time, which may be linked to climate change, fishing, or changes in habitat quality. The project is also interactive in the sense that it provides for "targeted studies," which are smaller, individual studies that are motivated by the findings of the monitoring program. So far, we have completed two phases of SHELF and recently began the third phase.

Outcomes

In 2017, a rather complex pilot project began, which involved a multi-ship approach (commercial fishing and FIO research vessels) and used plankton nets to collect eggs. Under microscopy, we picked individual fish eggs from the total plankton samples and used DNA barcoding (DNA extraction followed by amplification and sequencing of the mitochondrial cytochrome oxidase I gene) to identify each egg. Eggs from 62 species belonging to 42 families were identified, with an additional 20 taxa classified to genus or subfamily level. Our monitoring efforts revealed that fish eggs were generally most abundant near shore, with a possible "hot spot" near Cape San Blas, suggesting (1) increased spawning in high-retention areas, (2) increased drift convergence in high-retention areas, or (3) both processes acting together. We were able to explain part of the observed distribution of eggs using physical oceanography models. These models further suggested that eggs spawned on the inner and middle sections of the WFS tended to be retained, whereas those on the outer shelf tended to be exported. Finally, we applied the Daily Egg Production Method (DEPM) to estimate spawning stock biomass (SSB) of vermilion snapper. This method combines estimates of the total daily egg production with mean daily fecundity, which we were able to quantify through our egg collections and dissections of gravid vermillion snapper we sampled throughout the study region. Using DEPM, we produced an SSB value for this economically important species that was consistent with that from the most recent traditional stock assessment, suggesting that the approach was successful. At the conclusion of the first phase of SHELF, we decided to focus our efforts on building a monitoring program of fish eggs across the WFS so we could develop a long-term time-series, a product that has been shown to be valuable in other regions but is lacking in the eastern Gulf of Mexico.

In the second phase of SHELF (2019-2023), we explored the use of metabarcoding, in which DNA is extracted and amplified from a composited sample containing all the fish eggs collected at a given station. Metabarcoding is faster and far less expensive than individual egg barcoding, so it was an attractive approach for our long-term monitoring program. However, we found several shortcomings in the approach, including the inability to provide absolute taxon proportions, the inability to return to individual eggs with additional primers (to increase identification power), and a high prevalence of false positives and false negatives. Thus, for the long-term monitoring program, we decided to continue to use individual egg barcoding.

In 2020, the COVID-19 pandemic created novel challenges to conducting fieldwork aboard research vessels where scientists and crew members live and work in close quarters. We were able to overcome this challenge by collaborating with NOAA's Southeast Area Monitoring and Assessment Program (SEAMAP), which had been collecting fish eggs across the WFS for years. This collaboration is a "win-win" for SHELF and NOAA since we can barcode archived samples and provide the taxonomic data to this management body. An additional advantage to working with SEAMAP is that the fish eggs are collected using a continuous underway fish egg sampler (CUFES) instead of plankton nets, resulting in a much cleaner sample that lacks non-targeted materials such as zooplankton and jellyfish, which enhances egg preservation. Moreover, having such clean samples saves us a lot of processing time by not having to tediously pick the eggs from the other materials. During the second phase of SHELF, we successfully barcoded samples collected by SEAMAP from 2013, 2014, and 2019. We identified 163 taxa across 251 sampling stations and had an 80% barcoding success rate. The species we identified from the eggs displayed community structure along an inner-outer shelf gradient, and corresponded with where we expected them to exist based on known species distributions. We also identified spawning hotspots for species of economic concern, such as yellowedge grouper, a deepwater species for which we previously lacked information on spawning location.

Current Work

In 2023, we began the third phase of SHELF. During this phase, we will continue to barcode eggs collected by SEAMAP using the CUFES for the years 2022-2025. We also have four targeted studies planned, with the first two designed to better understand seasonal spawning dynamics on the WFS. SEAMAP makes their annual collections in the late summer, which overlaps with peak spawning of several snappers and mackerels, among other species. However, many other economically and ecologically important species such as groupers, jacks, and drums, spawn at different times of the year. We will therefore conduct two years of egg collections in the fall, winter, and spring aboard FIO's R/V Weatherbird II using the same equipment and methods used by SEAMAP. This targeted study will more fully describe year-round spawning dynamics on the WFS and may guide the sampling schedule for future phases of SHELF. In a second targeted study, we will collect eggs around artificial and natural reefs for which we have over 10 years of seasonal reef-fish survey data. This study will allow us to test whether we can link adult fish abundances to egg production. The other two targeted studies will examine key assumptions of our methods. Planktonic fish eggs are rich in lipids, so they are buoyant and float. One assumption in our methods is that eggs spawned at depth will ultimately float to the surface waters, which is where we make our collections. We will test this assumption by barcoding eggs collected across depths ranging from 0-120 meters. In another targeted study, we will determine the causes of barcoding failure, since we have been unable to barcode about 20% of the eggs that we attempt to identify. To do this, we have created contingency plans to improve our identification success rate, including quantifying DNA extracts, determining if PCR inhibitors are present, testing alternative primer sets for different genetic loci, and generating sequences for additional voucher specimens if necessary. Lastly, we are in the process of fully operationalizing the SHELF program by documenting our Standard Operating Procedures (SOPs) to maintain consistency in the methods as students, postdocs, and technicians cycle through our team.

◄ A sample of eggs collected by the CUFES.

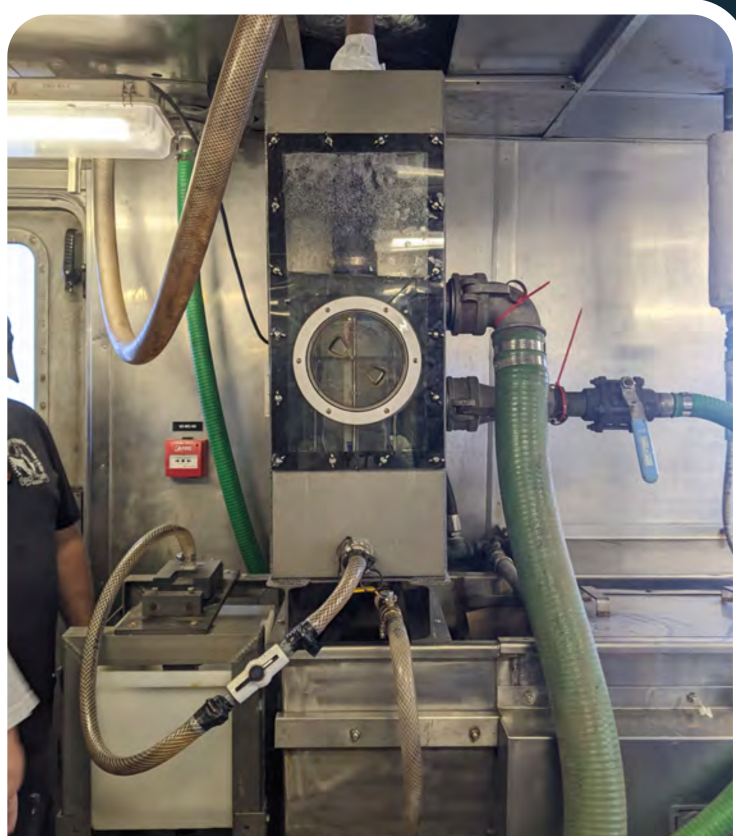
Impact

SHELF has basic and applied scientific implications as well as broader impacts. We have already learned how physical oceanography affects fish egg retention and transport in the region, that the emerging technique of DNA metabarcoding is powerful but has its limitations, and that multiple primers may be better to successfully barcode certain species, all findings that bolster basic research. The applied impacts are even more substantial. Our time-series will inform fisheries science and management on trends in adult biomass to determine how the populations respond to disturbances (e.g., oil spills, climate change), fishing, and policy (e.g., rebuilding plans). Moreover, since we barcode all eggs without prior knowledge about their identity, we will be able to detect community-level changes in the ecosystem, including those of ecologically critical forage fishes. Finally, our broader impacts include training and education of undergraduate and graduate students, creation of public outreach exhibits and activities, and dissemination of our findings to the scientific community and the public.

Future Work

After the third phase of SHELF has been completed, we will undergo another external science review to determine additional funding and scope. If fully funded, SHELF will continue through 2036 and allow us to barcode fish eggs across an almost 25-year time span. Such a timeseries would be unique to the WFS and is required for improved stock assessment and for understanding broader ecosystem changes.

► Locations SHELF has DNA barcoded eggs collected by NOAA SEAMAP in 2013 (gray), 2014 (yellow), 2019 (blue), and 2022 (red).



▼ The CUFES system aboard the NOAA Ship *Gordon Gunter*.

Evaluating Socioecological Benefits of Ecosystem Restoration on the West Florida Shelf Using the Atlantis End-to-End Ecosystem Model

CAMERON **AINSWORTH**, CHUANMIN **HU**, NATHAN **PUTMAN**, REBECCA **SCOTT**, YAO **YAO**, BEATRE **COMBS-HINTZ**, & HALLIE **REPETA**

Background

The Ainsworth laboratory has contributed to three Centers of Excellence (CoE) projects, including one that completed in 2023 and one that is just beginning. The overarching theme of these projects has been to better synthesize the available habitat data on the West Florida Shelf (WFS) and to examine and model the process of habitat restoration in a whole-ecosystem context. Our recently concluded CoE project explored how restoration of seagrass habitat on the West Florida Shelf would affect ecosystem carrying capacity for manatees (*Trichechus manatus latirostris*), green turtle (*Chelonia mydas*), Kemp's ridley turtle (*Lepidochelys kempii*) and birds. Up until now we have focused on seagrass restoration, but new efforts will consider mangrove, salt marsh, and other habitats.

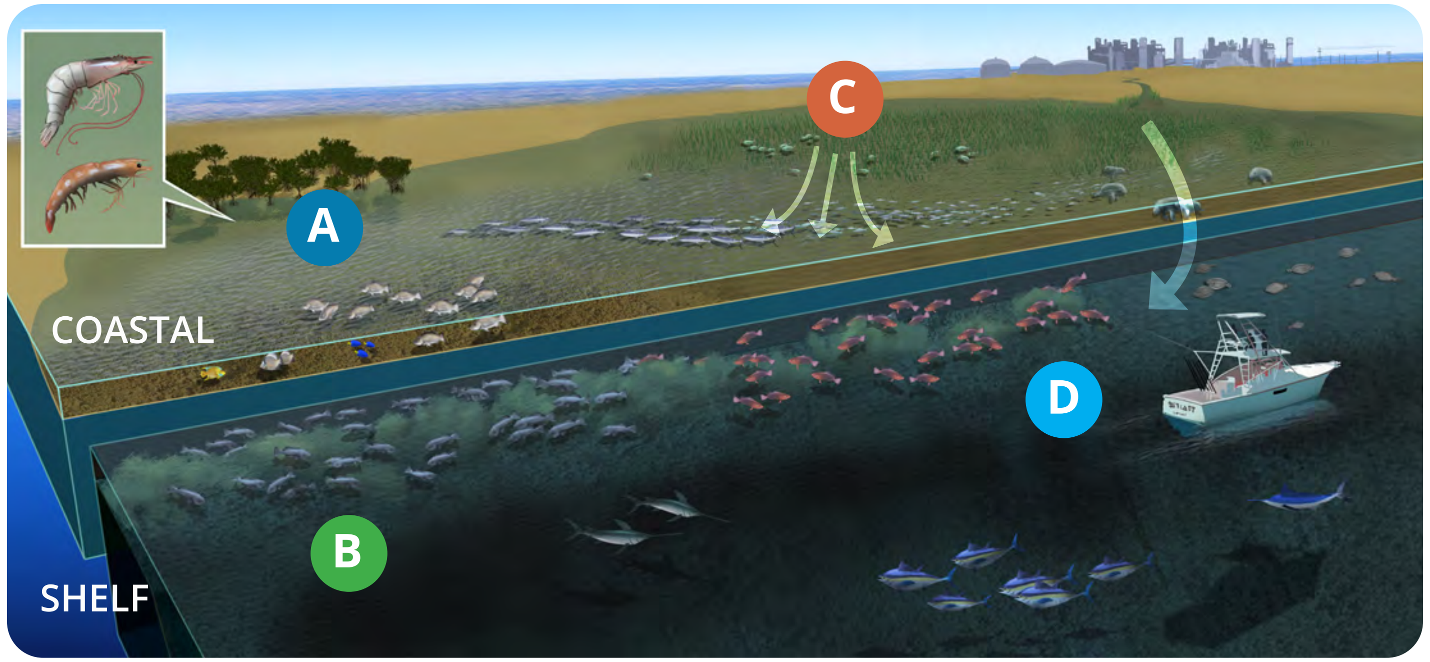
We employed an "end-to-end" ecosystem model, Atlantis. Atlantis straddles the worlds of nutrient-phytoplankton-zooplankton-detritus (NPZD) modeling and fisheries and food web modeling. In NPZD models, low trophic level components tend to be modeled at small spatial and temporal time scales and interaction rates are closely affected by physical variables like temperature and salinity. Fisheries and food web models are typically used to model top-down mortality influences (e.g., fishing, harmful algal blooms) and employ age structure to represent longer-lived species. Combining these qualities, Atlantis offers a useful tool for synthesizing bottom-up and top-down drivers. This is essential for modeling restoration activities. The programmatic goals of the Deepwater Horizon Trustees imply a combination of bottom-up and top-down effects on the ecosystem. These goals are to restore and conserve habitat, to restore water quality, to replenish living marine resources, and to enhance recreational opportunities.

This effort has built on the success of an early CoE project (see Babcock, et al.). In it, we built a spatial database of ecological data for fish, invertebrates, marine mammals, sea turtles, and seabirds to be used in Atlantis (Grüss et al. 2018a, 2018b, 2019). These data, now archived on GRIIDC, are foundational in the model in determining species interactions and limits to population growth. The spatial data informs 31 functional groups in the Atlantis model and allows us to differentiate behaviors between the Big Bend area, the Tampa/Charlotte Harbor area, Southeastern Florida, and the Florida Keys.

Outcomes

In this project, we relied on Florida Fish and Wildlife Conservation Commission (FWC) fisheries independent monitoring surveys to develop seagrass habitat affinity parameters for Atlantis for fish groups. These parameters fine-tune the effect of seagrass restoration at the species level and control how species arrange themselves spatially as seagrass coverage changes. One innovation made for this project was the development of new Atlantis code to better represent herbivory, and in particular the keystone role that manatees play as habitat organizers. The new code partitions seagrass habitat into slow-growth pools (roots and rhizomes) and fast growth pools (leaves and epiphytes). We model how manatees can consume slower growing parts of the plant like

What is the role of seagrass habitat in the marine food web?



A. Habitat Mosaic – A patchwork of different habitat types may increase predator diversity and ecosystem connectivity and accelerate uptake of seagrass production into the food web. **B. Exogenous & deep production** – Offshore reef associated and demersal communities may be resilient to changes in seagrass conditions because they derive much of their production from non-local sources. **C. Diffusion** – Land-based production is communicated through sedentary demersal and reef-associated fish populations via foraging and movement. **D. Ontogenetic migration** – Seagrass rearing habitat improves early life history survival of valuable pelagic predators. Ontogenetic migration acts as an express route for seagrass production to reach shelf.

roots and rhizomes, requiring longer regrowth time than other types of herbivores. In turn, the presence of seagrass affects the fish assemblage. This work has helped to advance our understanding of how seagrass restoration affects the marine ecosystem. When seagrass is abundant, there is increased fish production and more of the ecosystem's energy enters at the high trophic levels of fish. The restored ecosystem is characterized by longer trophic chains, increased ecosystem maturity, and increased biodiversity. Diets of most predator fish shift away from invertebrates and towards fish (Figures 1 and 2).

Another objective of this project was to use the Lagrangian model ICHTHYOP to simulate movement of passive oceanic-phase green and Kemp's ridley turtles. This is a collaborative effort with LGL (N. Putman) and the University of Central Florida (K. Mansfield, E. Senay). ICHTHYOP is calibrated to turtle satellite telemetry and makes use of data from another FLRACEP project (Mansfield). We coupled Atlantis and ICHTHYOP, using Atlantis to estimate how much and what types of prey items are encountered by the turtles. This work highlights the importance of hydrodynamic fronts and convergence features in providing foraging opportunities for turtles. This has implications for climate change, which will affect physical oceanographic processes. Finally, we estimated how much the turtles interacted with red tides from optical satellite data (Hu et al. 2022).

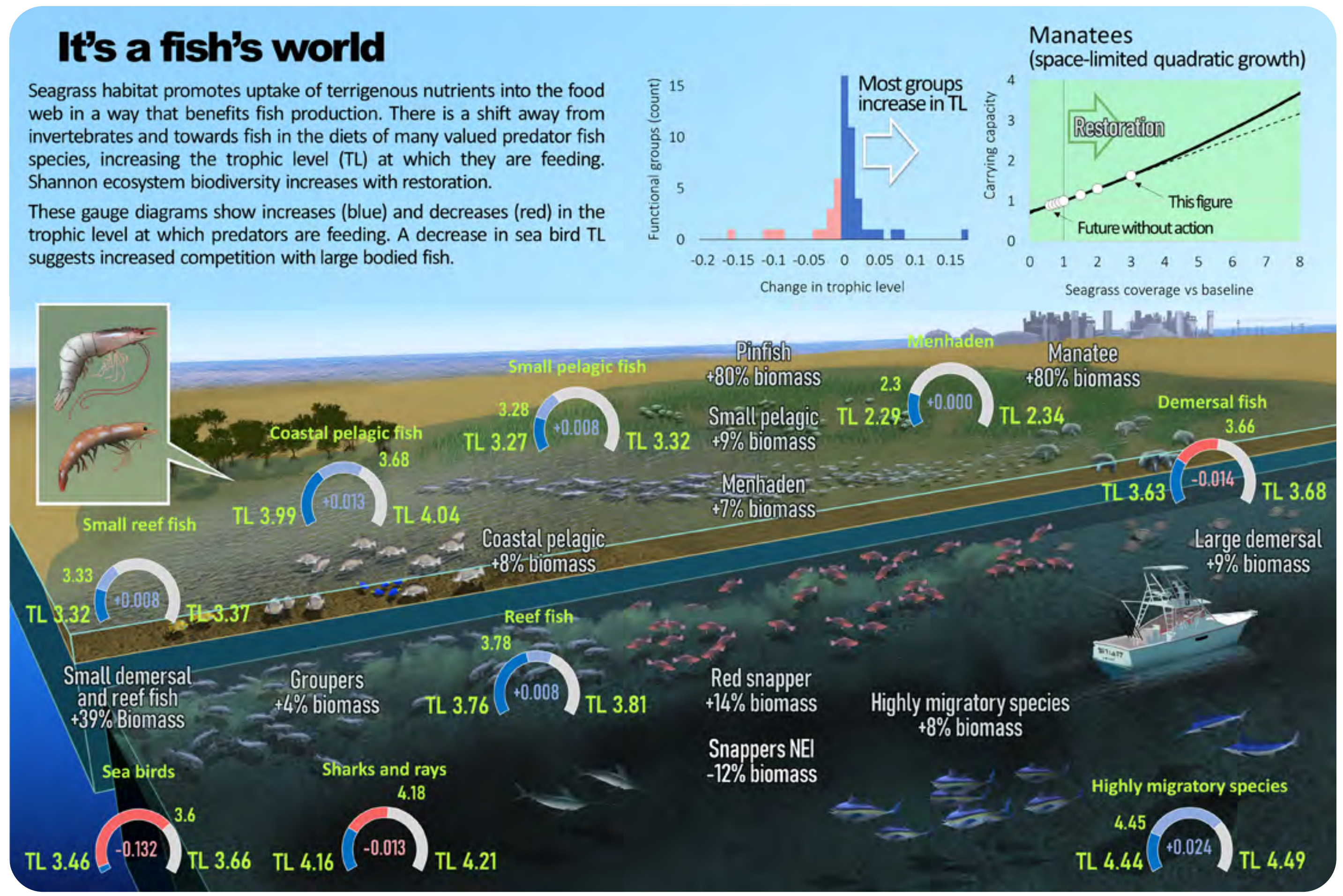
Impact

This work has contributed to three Ph.D. theses, two manuscripts in preparation, and a NOAA Technical Memorandum, which is being published in collaboration with NOAA end-users. We have already implemented the new habitat modeling capabilities in a Cooperative Institute for Marine and Atmospheric Studies (CIMAS) project funded by Southeast Fisheries Science Center (SEFSC-NOAA), which is focused on estimating shrimp production. Improvements to Atlantis made with FLRACEP funding (e.g., new species distributions, habitat affinities, and code updates) were reviewed by a Center of Independent Experts (CIE-NOAA) review panel in March 2023. The following agencies were represented: SEFSC-NOAA, the NOAA Southeast Regional Office (SERO), the Northwest Fisheries Science Center (NWFSC-NOAA), the Florida Fish and Wildlife Research Institute (FWRI), and the Centers of Independent Experts (CIE). Members of the Gulf of Mexico Fisheries Management Council and Ecosystem Science and Statistical Committee also participated. The FLRACEP innovations on seagrass were significant. This expert review is seen as qualifying work that makes Atlantis better-suited for supporting stock assessment. This follows a similar process on the West Coast at the NWFSC that validated the California Current Atlantis model and promoted its use within the Integrated Ecosystem Assessment program (Kaplan and Marshall 2016).

Ongoing and Future Work

FLRACEP has invested in Atlantis modeling once again with the project entitled, "Estimating combined effects of Florida Trustees Implementation Group (FL TIG) restoration projects in Florida using an end-to-end ecosystem model." The Deepwater Horizon Trustees have so far approved at least 157 restoration projects in Florida (FDEP 2022). The bottom-up and top-down ecosystem effects of restoration projects can be modeled and synthesized in Atlantis. The aim of this project is to better understand how different FL TIG restoration activities interact. Some of the restoration benefits that we expect to see include improved reproduction and rearing habitat for charismatic and valuable species, careful management of early life stage mortality, stimulated species production through mariculture, controlled nutrient loading, and increased fishing opportunities. These restoration activities are intended in the aggregate to shepherd the marine ecosystem towards a more desirable state. We will use Atlantis to help define that outcome and contrast it against a future without action. Through this we may understand what changes can be expected to the species assemblage as a result of restoration. This is an important step in vetting goals and describing tradeoffs between socioeconomic and cultural priorities (Ainsworth and Pitcher 2010; Ainsworth 2006). Recovery of charismatic animals and impacts on Florida fisheries will be emphasized. With over $245 million allocated in Florida for restoration (NOAA 2021), accounting for interactions could amount to significant cost-savings and more effective investments in restoration by DWH Trustees.

This work will expand habitat modeling from seagrass to include other habitats like mangrove, macroalgae, salt marsh, and oyster reef habitats. Statistical models will be used to account for fish and invertebrate community effects. A multivariate approach will evaluate the concept of the habitat mosaic, in which co-occurrence of different types of habitats increases predator diversity influencing population dynamics. This is an important second-generation question that we hope to answer through modeling and by exploring a spatially-expansive monitoring dataset of community composition sampled throughout the Big Bend (C. Stallings, unpublished data).



Improving the Use of Products Derived From Monitoring Data in Ecosystem Models of the Gulf of Mexico

ELIZABETH A. **BABCOCK**, ARNAUD **GRÜSS**,
CAMERON **AINSWORTH**, & TRACEY **SUTTON**

Background

The goals of this project were to review the use of monitoring data in ecosystem models for the Gulf of Mexico (GOM), compile these data into a comprehensive monitoring database, identify data gaps that limit ecosystem modeling efforts, improve statistical analysis tools for developing ecosystem model inputs from monitoring data, and apply these tools to the database to produce ecosystem model inputs. The inputs required by spatially-disaggregated ecosystem models such as Atlantis, OSMOSE, and Ecospace models include maps for each species and species group or age class (i.e. functional group) of either the spatial distribution of the group or spatial preference functions that define the group's habitat preferences.

The project began in January of 2016 with a meeting between ecosystem modelers and the leaders of monitoring programs to discuss the link between the data and the data needs of the models. We then compiled the data from more than 73 monitoring programs along with many environmental data sets. The project developed statistical methods to deal with the kinds of data that were available for all the functional groups needed for the ecosystem models. For fish and shellfish, we produced distribution maps for OSMOSE-WFS by fitting geostatistical generalized linear mixed models (GLMMs) to the large monitoring database. Preference functions for the West Florida Shelf reef fish in Ecospace were based on generalized additive models (GAMs) fitted to the large monitoring and environmental databases. For Atlantis-GOM, we developed a methodology that used the large monitoring and environmental databases and a combination of interpolation (geostatistical GLMM predictions) and extrapolation (GAM predictions) so that the data could be used to fill in distribution models for the parts of the GOM that were not covered by the monitoring dataset. For protected species, we developed multiple models specifically designed for the types of monitoring data that were available for each species (fish, invertebrates, marine mammals, sea turtles and seabirds). For manatee, we used sighting records along with habitat relationships based on previous studies. For sea turtles, we used MaxEnt models appropriate to presence-only data along with environmental data (Figure 1). For seabirds, we used binomial GAMs applied to presence/pseudo-absence and environmental data.

Outcomes

The compilation of monitoring and environmental data, along with the development of appropriate methods for each kind of data, allowed us to generate more accurate distribution maps and preference functions to input into the ecosystem models. This improved the quality of the outputs of spatially-explicit ecosystem models of the GOM, which is important because these models are used to inform fisheries stock assessments and fisheries management, to evaluate the impacts of the *Deepwater Horizon* oil spill, and to forecast potential impacts of habitat restoration.

The data compiled by this project and the generated data products were shared on the GRIIDC data portal (Gulf of Mexico Research Initiative, 2023), where they can be freely downloaded. Some of the species distribution models produced by this project were also shared via the Gulf of Mexico Data Atlas (Gulf of Mexico Data Atlas, 2023) and remain freely accessible to managers, scientists, and the general public (Figure 2).

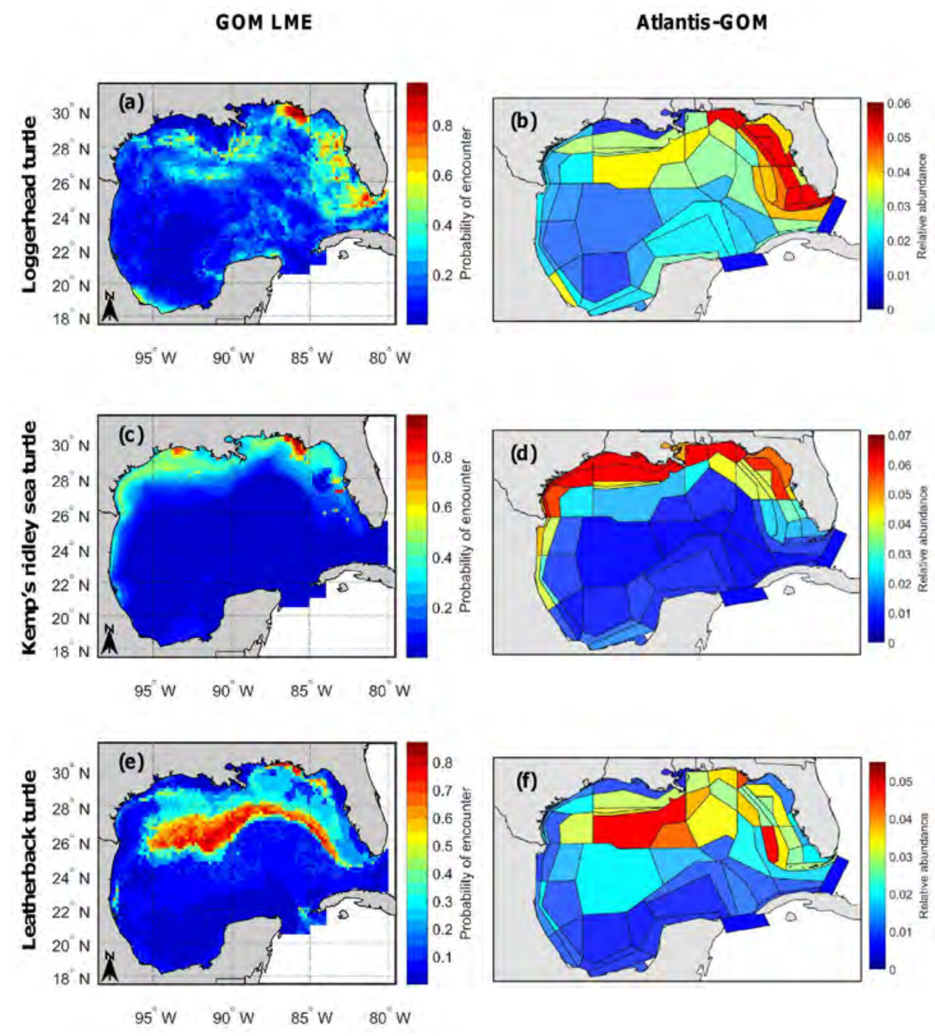
The project generated nine journal publications (Gruss et al. 2016, Gruss et al. 2017, Gruss et al. 2018a, Gruss et al. 2018b, Gruss et al. 2018c, Gruss et al. 2018d, Gruss et al. 2018e, Gruss et al. 2018f, Gruss et al. 2019). According to the Web of Science, these papers have been cited a total of 126 times, of which 52 of the papers refer to the Gulf of Mexico, and 11 refer to ecosystem models. The project co-Principal Investigators (P.I.s) have also continued building on this work. For example, the original project only used data from randomly chosen locations, because combining fixed-location and random-location data would not be consistent with the assumptions of the statistical models we were using. A later project by one of the co-PIs developed a solution to this problem that allowed the fixed station surveys to be included (Gruss et al. 2020).

Impact

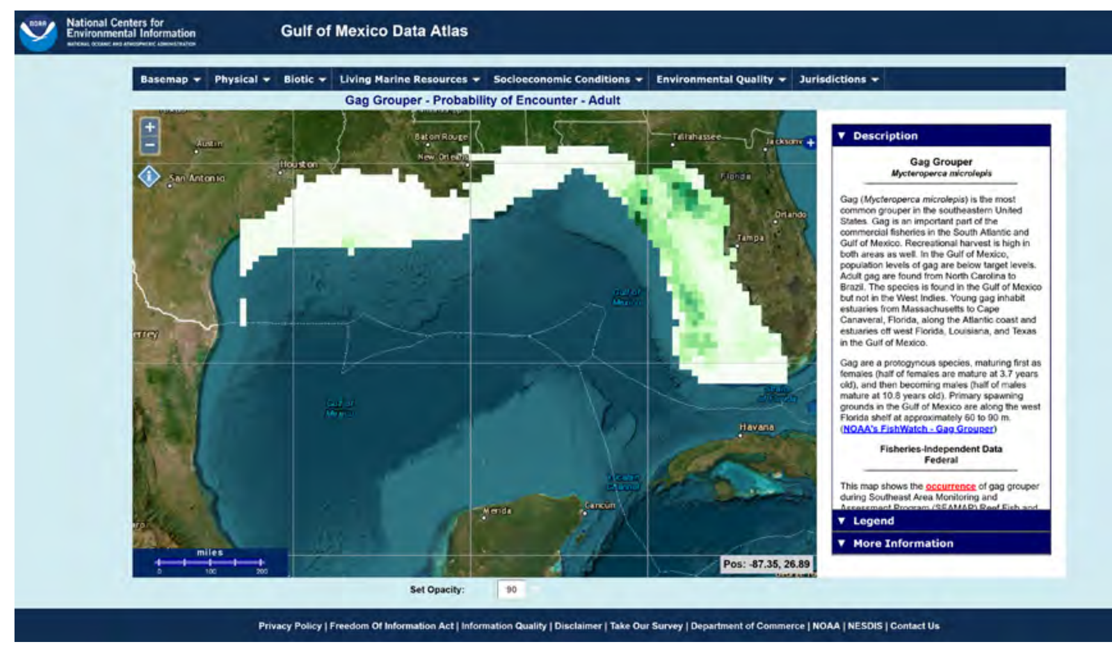
The ecosystem models that were improved using products from this project continue to be used to provide strategic and tactical advice on management in the Gulf of Mexico. For example, Dornberger et al. (2023) used the Atlantis model to simulation-test multiple mechanisms that might explain recent changes in the GOM benthic invertebrate community.

Future Work

One outcome of the project was the identification of data gaps in the GOM monitoring data. Critical gaps include the relative lack of monitoring data in deeper waters, inconsistent monitoring of protected species, and the lack of data from the Mexican and Cuban parts of the GOM, which would be useful for the Gulf-wide models such as Atlantis. Future work could update the databases, coordinate with monitoring outside the USA, and add more monitoring to the understudied parts of the GOM.



▲ Figure 1. Loggerhead, Kemp's ridley and leatherback sea turtle distribution maps (left) and Atlantis-GOM inputs (right), from Grüss et al. (2018d).



◄ Figure 2. Example species distribution map at the Gulf of Mexico Data Atlas (2023) for adult gag grouper, produced by this project.

Examining Impacts of Invasive Lionfish on Fisheries Resources and Ecosystems of the Northern Gulf of Mexico

DAVID **CHAGARIS**, WILLIAM F **PATTERSON** III,
MICHEAL **ALLEN**, KRISTEN **DAHL**, & HOLDEN **HARRIS**

Background

Invasive lionfish (*Pterois volitans/miles* complex) first appeared in the western Atlantic Ocean in the 1980s and expanded rapidly throughout the southeast U.S. and Caribbean during the late 1990s and early 2000s. Lionfish were first observed in the northern Gulf of Mexico (nGOM) in summer 2010, after which they expanded exponentially through 2016 leading to some of the highest densities in their invaded range on nGoM artificial reefs. This is of great concern given the devastating effects lionfish have had on reef fish communities in other invaded regions. In addition to lionfish, reef ecosystems of the nGoM are under pressure from overfishing, and more recently, the *Deepwater Horizon* oil spill (DwH). Negative consequences of these stressors on reef fishes may be compounded due to direct and indirect effects of invasive lionfish, and those effects could strongly influence food web structure and fishery resources in the region.

The goals of this project were to: 1) evaluate the impacts of lionfish on reef fish food webs in the nGoM, 2) assess the relative impacts of the *DwH* oil spill versus lionfish on reef fish communities, and 3) explore the benefits of mitigation strategies to reduce lionfish impacts (e.g., lionfish harvest). This project consisted of a video survey of lionfish and native reef fish densities on natural and artificial reefs in the nGoM, collection of lionfish age, stomach contents, and muscle stable isotope data, and development of a food web model.

Outcomes

In total, 2,035 lionfish were collected from 185 natural and artificial reef sites that were also surveyed using a VideoRay Pro II Remotely Operated Vehicle (ROV) in 2016 and 2017. Lionfish ages ranged from 0 to 8 years, indicating lionfish were present in the Gulf of Mexico before their first detection in 2010. Male lionfish grew larger than females, and lionfish on artificial reefs were smaller than those of the same age at natural reefs. This appears to be evidence of density-dependent growth in lionfish, given consistently lower densities of lionfish on natural reefs compared to artificial reefs and significant negative relationships between lionfish density and size-at-age.

Those data were used in a food web model of reef ecosystems of the nGoM, that consisted of 63 biomass compartments including 39 fish groups, 19 invertebrate groups, 3 primary producers, and 2 detritus pools. Lionfish were included in the model as juveniles and adults to account for ontogenetic feeding, cannibalism by adults, and fishery selectivity. A forcing function was included to drive declines in reef fish abundance that was observed following *DwH*, and fishing effort time series were included to impose fishing mortality on target species. The ecosystem model was constructed to simulate reef fish dynamics under different combinations of lionfish, fishing, and *DwH* effects, and simulations demonstrated the potential for complex responses in disturbed nGoM reef ecosystems. The model made several key predictions. First, it demonstrated lionfish have had a major impact on nGoM reef ecosystems, leading to slower recoveries following *DWH* and lower fish biomass and diversity. Continued investment in monitoring and mitigation strategies is therefore warranted. Second, the model predicted some species or functional groups would have recovered to their pre-*DWH* biomass within 2–3 years in the absence of lionfish, while others would not have recovered at all, regardless of lionfish. This suggests the ecosystem may have experienced some level of reorganization, preventing it from returning to its pre-spill state. Lastly, the model predicted fishing to be the major driver for a suite of upper trophic level species, and cumulative effects of fishing with other stressors can result in further biomass declines.

Impact

This project quantified the relative impacts of two major stressors on reef fish communities (i.e., lionfish and oil spill) and assessed mitigation measures for improving reef fish communities in the NGoM. The results of this study can be used to guide future data collection and lionfish removal efforts. This work highlights the value of integrated ecosystem monitoring and modeling. Without the comprehensive collection of site-specific fish abundance, diet, and habitat information the model would not be able to reliably fit the observed trends. Absent the model, however, we would not be able to estimate ecosystem scale-effects of the lionfish invasion.

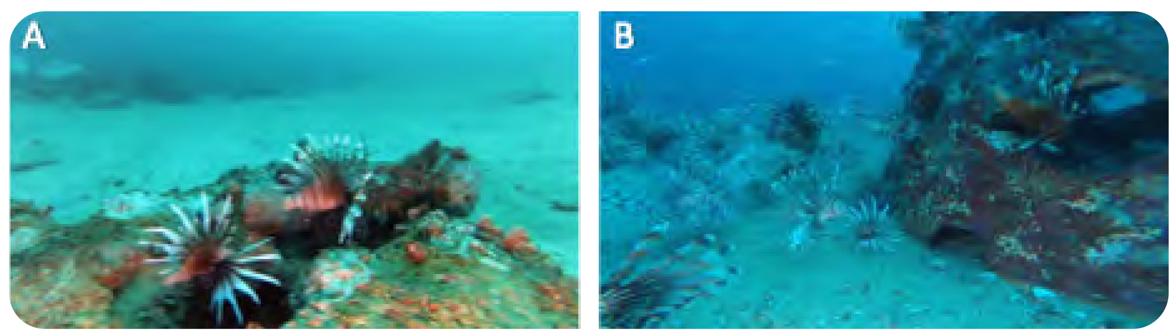
THIS WORK HIGHLIGHTS THE *VALUE* OF INTEGRATED ECOSYSTEM MONITORING AND MODELING.

When sampling lionfish for this study, we observed an ulcerative disease that has now been documented throughout the eastern Gulf of Mexico, U.S. Atlantic waters, and into the Caribbean Sea. Funding from the Florida Fish and Wildlife Conservation Commission (FWC) was provided to examine ulcerated fish and to diagnose the etiology of this disease and whether the potential pathogen is common among regions. Extensive analyses failed to reveal the disease's etiology, but lionfish populations declined 75-80% on natural or artificial reefs following the outbreak.

Future Work

We continue to monitor lionfish population trends and have developed new questions related to lionfish density at shelf-edge mesophotic reefs and the efforts required to control their populations at those depths. Lionfish and their prey exhibit extremely strong contrast in abundance trends over space and time. This presents an opportunity for learning more about predator-prey relationships in real world environments. Experiments of multiple scales, ranging from tanks to mesocosms to in situ manipulations of lionfish and prey densities could lead to one of the few real-world case studies that actually estimate functional responses between predator and prey populations.

The nGoM lionfish ecosystem model was presented to fishery managers at the FWC, who have been promoting lionfish harvest to mitigate impacts on reef ecosystems. Our results demonstrated the range of exploitation rates needed to suppress lionfish densities and protect native reef fish communities, but also highlighted the need for lionfish harvest from waters deeper than those accessible by recreational spear fishers. In response, an FWC-funded study was conducted to evaluate three trap designs on their ability to catch lionfish and minimize bycatch at mesophotic (>40 m) depths. Results indicated the amount of bycatch of native reef fishes was greater than the foregone consumption of them by captured lionfish. Therefore, traps designs tested were not feasible for controlling nGoM lionfish populations.



◀ Digital images from remotely operated vehicle video samples of lionfish on northern Gulf of Mexico A) natural and B) artificial reefs.

Fishery-Independent Surveys of Reef Fish Community, Size, and Age Structure off Northwest Florida

KEVIN M. **BOSWELL**
& WILLIAM F. **PATTERSON** III

Background

Reef fishes are iconic symbols of Florida's marine ecosystem. In addition to their ecological significance, reef fishes are exceedingly important to the state's economy. Marine fisheries are the second largest economic engine in the state behind tourism. Reef fishes support both recreational and commercial fisheries in the state, and also contribute to ecotourism by attracting SCUBA divers and snorkelers. However, reef ecosystems have been negatively impacted by numerous anthropogenic crises in recent years, such as sedimentation and hypoxia, red tide events, invasive lionfish populations, and the Deepwater Horizon oil spill. Unfortunately, spatially-resolved baseline data on reef fish community and trophic structure are lacking to evaluate the full impact of such events, and often we are left with only the coarse basin-scale or regional resolution of stock assessment models to attempt to estimate these impacts on reef fish population biomass or productivity in the northern Gulf of Mexico (nGOM). Traditional gears used to provide such baseline information, such as trawling, are limited at reef habitats due to their structural complexity. Recent events as well as advances in stock assessment modeling approaches have created an increased demand for reliable, inexpensive, non-extractive fishery-independent (FI) methods capable of examining reef fish communities across the nGOM shelf.

The goal of this Center of Excellence project was to apply advanced technologies in the nGOM off the Florida Panhandle to develop reliable, cost-effective FI survey methods to examine reef fish community structure, size distributions, and biomass across large areas (km^2) of reef habitat in a non-extractive manner. Sonar and remotely operated vehicles (ROVs) were employed to examine fish populations at natural and artificial reefs over two successive years in the nGOM. Stereo video data from ROV transects at each reef were used to address questions about differences in community, trophic, and size structure across the shelf. These data were also used to derive density estimates of fishery important species and invasive lionfish at the two reef habitats. Sonar surveys performed shortly before or after ROV transects covered a larger area (~2km^2) around the reefs and provided information on the fine-scale spatial distribution of fishes around artificial versus natural reefs and habitat-specific biomass of exploited reef fishes in the nGOM (Figure 1). The specific objectives of the surveys, which were conducted at natural and artificial reefs that were diverse in depth, area, and vertical height of structures, were to examine how artificial reefs of different size and location perform in replicating the fish communities, trophic structures, biomass, and habitat utilization present at natural reef habitats in the nGOM.

Outcomes

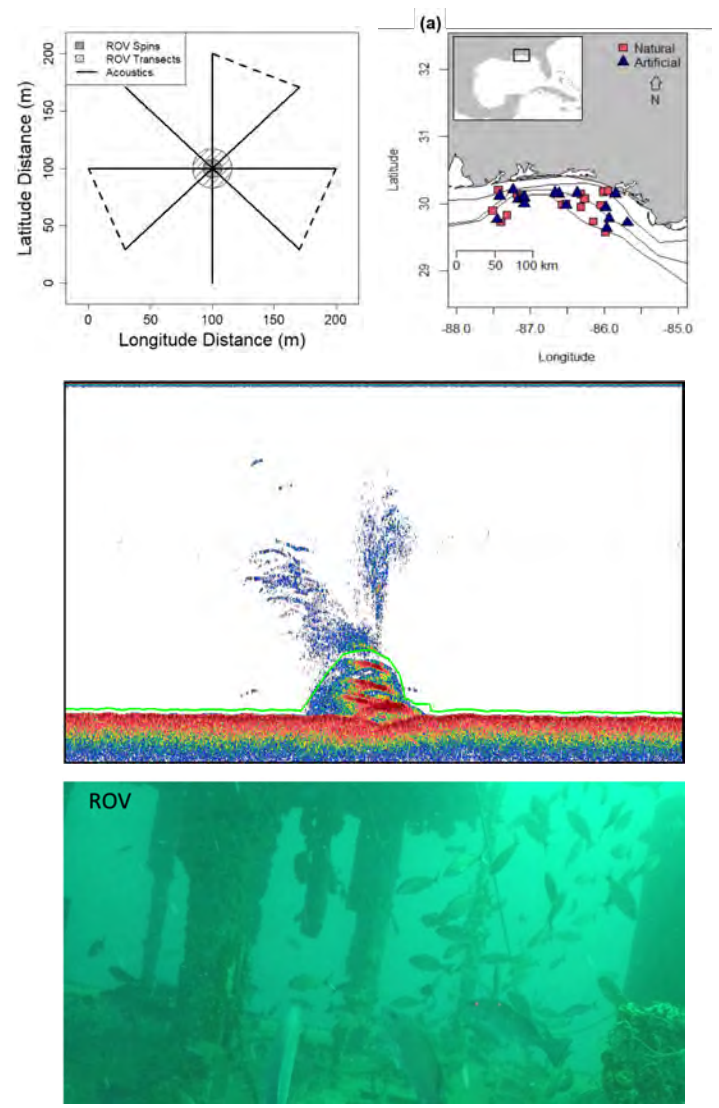
This study served to provide a proof-of-concept for employing these advanced technologies for future nGOM-wide surveys of reef fish communities, creating new baselines and approaches to assess impacts of future anthropogenic events while simultaneously filling important data gaps for resource assessment and management of recreationally and commercially important species.

Analyses of the data collected by ROV revealed that reef fish community structures and trophic guilds are significantly impacted by combinations of reef type, structure, and depth. Artificial reefs with simple structures were found to mimic the high densities of fishery important species found at complex natural reefs with high structure. Unlike at natural reefs, small, non-fishery important species occurred in low densities at these same artificial reefs. Split-beam sonar data revealed that fishes at natural reefs occur in low density patches dispersed across large areas, while fishes at artificial reefs occur in high densities only directly above the artificial structures. The area around the artificial structures utilized by fishes was found to be influenced by the area, height, and depth of the structure. Both technologies indicated that fish biomass is significantly higher on artificial structures than at natural reefs.

Impact

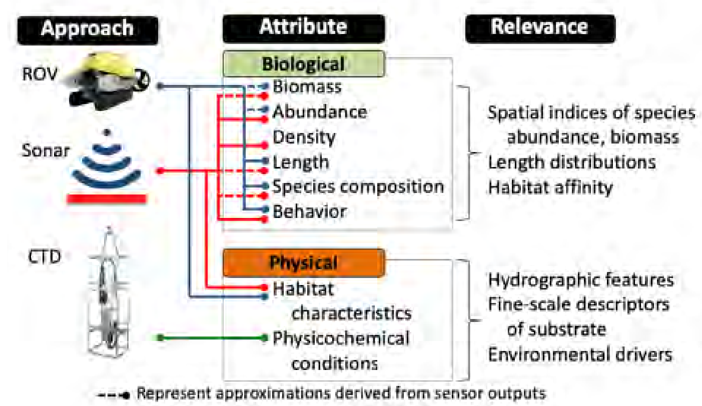
Combined, these results provide conservationists and resource managers with detailed information about how the structure and placement of artificial reefs can maximize their efficacy in replicating fish communities at natural reef habitats. This project also supplies baseline data on reef fishes in the nGOM against which scientists can assess the impacts and restoration timelines of future anthropogenic disturbances. The data provided by these technologies fills data gaps for resource assessment and management of recreationally and commercially important fishes. The data products may inform assessment modeling strategies and enhance studies focused on evaluating changes in stock structure of reef-associated species in the nGOM.

This work also serves as proof-of-concept for the concurrent application of remotely operated vehicles and cutting-edge acoustic instrumentation to rapidly and non-invasively examine patterns across multiple spatial scales. It has laid the groundwork for integrating these technologies to provide species-level information on fishery-important species at the spatial scales required to better understand their habitat utilization (Figure 2). We have worked closely with Fish and Wildlife Research Institute (FWRI-FWC) to help establish an active acoustics program following the lessons learned in this project. The outcomes of this project have also supplied information to develop statistically and spatially robust survey designs which can be applied across habitat types. Methodologies established in this project have already been used to inform Gulf-wide FI monitoring efforts targeting red snapper (*Lutjanus campechanus*) and greater amberjack (*Seriola dumerilii*), two highly utilized species which occupy natural reefs, artificial structures, and unconsolidated habitats comprised mostly of sand. FWRI-FWC is a collaborator on our existing greater amberjack count project across the northern Gulf of Mexico and South Atlantic. It is our hope that such efforts will continue to fill the data gap of highly valuable reef fishes in the nGOM and that this work will eventually serve as a blueprint for establishing spatially-explicit FI monitoring programs for reef fish communities in other regions of Florida and beyond.



◄ Figure 1. Project station locations (upper left) and sampling design at each station (upper right) illustrating the spatial survey extent of both technologies at a given habitat type. At artificial reefs, the ROV would perform spins in the water column and over natural reef it would perform transects. Bottom panels illustrate example data recorded for each technology type. Figure adapted from White et al. 2022.

▼ Figure 2. Schematic diagram of the linkages between parameters of interest and approaches employed. Solid lines represent direct estimation from sensor and broken lines represent those metrics approximated through analysis of sensor output.



Evaluating Fish Production and Ecosystem Impacts of Artificial Reefs

JANE M. **CAFFREY**, FLORIAN **CESBRON**, WILLIAM F. **PATTERSON** III, LISA A. **WAIDNER**, WADE H. **JEFFREY**, JOSEPH H. **TARNECKI**, STEVEN B. **GARNER**, & KENDRA K. **BABCOCK**

Background

Artificial reefs have been deployed throughout U.S. coastal waters since the late 1970s, primarily to enhance fisheries. Although numerous studies have examined their effects on fish communities, few have examined interactions between artificial reefs and primary producers or their effects on biogeochemistry of the surrounding water column. Understanding how reefs may alter primary production and biogeochemistry, particularly availability of nitrogen and phosphorus, is key to understanding overall reef productivity. Therefore, study goals were to examine how artificial reefs affect primary production, biogeochemical cycling, and fish production.

We studied nutrient dynamics, biogeochemical cycling, primary and secondary production, and fish community structure at replicate 1-km^2 areas (n = 9) on the shelf off Pensacola, Florida for one year (2015-2016) prior to reef deployment. At the beginning of year two of the study (September 2016), reefs were deployed in six of these areas, which were the impacted sites in our design. Three sites were without reefs and served as the control sites.

Outcomes

The fish community was dominated by small planktivores (scads and small carangids) in the year prior to artificial reef deployment. Following artificial reef deployment, juvenile reef fishes quickly recruited to reef structure (Figure 1). Reef species included snappers (Family: Lutjanidae), gray triggerfish (Balistes capriscus), and sheepshead (Archosargus probatocephalus).

The shallow continental shelf benthic habitats in the Northeastern Gulf of Mexico are influenced by coastal ocean upwelling from the Desoto Canyon, hurricanes, and estuarine outflow. These forces influence nutrient availability, light levels, and stratification, which ultimately control primary production on the shelf. The clear waters of this region support significant benthic production and production on artificial reefs, particularly at shallow reefs such as those used for this study.

Artificial reefs had little impact on production in the water column or sediments. The biomass and production of phytoplankton or benthic microalgae were most strongly influenced by seasonal changes in light and nutrients rather than installation of artificial reefs. Phytoplankton production was usually highest in the spring, while benthic production was highest in the summer (Cesbron et al. 2019). Benthic primary production represented about 24% of total primary production (water column plus benthic). Rates of primary production on the reef increased over time as organisms colonized the reefs. Artificial reefs were local sources of production, but low compared to benthic production.

Reefs are active sites of biogeochemical cycling and important sources of nutrients to the surrounding region. Epifauna colonizing the reefs are an important source of nutrients, particularly ammonium and phosphate. Experiments demonstrated that ammonium and phosphate fluxes increased as epifaunal biomass increased (Babcock et al. 2020). Nitrate was also released from the reefs, from the microbial process of nitrification, which is the conversion of ammonium to nitrate. Benthic invertebrates such as barnacles, crabs, amphipods, and tunicates on reef contained ammonium oxidizing bacteria and archaea (Babcock et al. 2020) (Figure 2).

Impacts

The project provided key baseline information about the shallow continental shelf environment in the northeastern Gulf of Mexico. This area is poorly studied compared to other continental shelves such as the South Atlantic Bight. Colonization of benthic invertebrates increased secondary production. This in turn supports higher trophic levels, particularly the commercially important reef fishes such as snapper, triggerfish and sheepshead. Results from this work represent one of the few studies of primary production, biogeochemical cycling, and the implications to fisheries production in the northeastern Gulf of Mexico. With the increasing deployment of artificial reefs in Florida, this provides key information for management of these habitats.

This study led to a thesis project examining the role of reef complexity on primary production and reef benthic invertebrate colonization. Diurnal changes in dissolved oxygen occurred on the reefs, along with higher gross production and respiration on complex reefs, compared to simple reefs (Sanders 2023). Respiration was higher than gross production at every site, indicating that the reefs were net heterotrophic (Sanders 2023). Tropical storms and major rain events led to declines in primary production and respiration. Both reef types had a similar benthic invertebrate community composition dominated by bivalves and crustaceans (Sanders 2023). Lessons learned from this work are now being applied to currently funded work comparing an impacted estuary that is experiencing severe seagrass decline (Indian River Lagoon) with the more pristine Santa Rosa Sound in the Florida Panhandle. Prokaryotic ammonium oxidizers are being enumerated in both. We hypothesized that ammonium oxidizers would be less abundant at Indian River Lagoon due to hypoxic conditions there, since molecular oxygen is required for this process.

Future Work

An important next step in this research is a better understanding of reef ecological function, particularly differences between natural and artificial reefs. Further studies examining food web interactions would be especially useful for understanding the role of artificial reefs and fish production. This FLRACEP project only examined the early stages of reef colonization by microbial and invertebrate communities. Long-term studies of primary production at artificial reefs are also needed, particularly to understand the spatial coupling between water column, the sandy bottom, and reefs.

► Figure 2. An artificial reef benthic community including barnacles, mussels, bryozoans, encrusting sponges, and red algae.

▼ Figure 1. Juvenile reef fishes (snappers, triggerfish, and grunts) that recruited to newly-deployed artificial reef sites in the first few months after deployment in September 2016.

Monitoring Oil Spill Effects & Recovery in Large Deep-Sea Fishes

R. DEAN **GRUBBS**,
JAMES **GELSLEICHTER**,
& CHARLES **COTTON**

▼ Holotype of a new species of deepwater shark described in the Gulf of Mexico (Pfleger et al. 2018) as part of this project. The species was named *Squalus clarkae*, Genie's Dogfish, in honor of the late Dr. Eugenie "Genie" Clark.

Background

Prior to the oil spill in the northern Gulf of Mexico (GoM), knowledge was limited concerning continental slope fish communities in the region below 200 meters, particularly for large (20-500 cm), mobile, bottom-dwelling fishes that are not adequately sampled using typical sampling gear (grabs, sleds, and trawls). Deep edge habitats at these depths, such as submarine canyons and the continental shelf-slope transition, are areas of high biomass and biodiversity. Given that the oil spill occurred at 1,500 meters, these communities were directly affected by the oil exposure. The goal of this project was to collect large deep demersal sharks and bony fishes to monitor abundance patterns, toxicological responses, and changes in community structure due to oil. Oceanographic sampling was conducted annually at the same stations (200-2,000 m depth) in spring of 2016 and 2017 that were sampled following the oil spill from 2011 to 2015 (funded by FIO and GoMRI). These additional data provided a 7-year time series to examine trends in the oil spill responses of these deep-sea species and communities.

Outcomes

Following the oil spill, we used novel fishery-independent survey methods to capture and sample the larger, more mobile fishes in the northern GoM at depths of 200 to 2,000 m from west of the spill site near Louisiana, east across DeSoto Canyon to the continental slope offshore of Florida's panhandle (Figure 1). Substituting space for time, sites along the continental slope off Tampa, Florida were sampled as a control. Our approach used a fixed station survey design where the same 50 stations were sampled across years, allowing for the assessment of changes in community structure, biodiversity, relative abundance, and toxicological responses to oil over space (e.g., regions or distance from the oil spill) and time since the spill.

Over the course of 15 cruises conducted between 2011 and 2017, more than 5,500 fishes from 108 species (3 species of hagfish, 36 species of sharks and skates, 69 species of bony fishes) were sampled. Thus, this project greatly advanced the limited knowledge pertaining to deep demersal fishes, facilitating descriptions of the patterns of abundance and community structure of large demersal teleosts, elasmobranchs, and hagfishes of this region. The samples collected supported the work of more than 20 graduate students as well as colleagues from more than a dozen institutions.

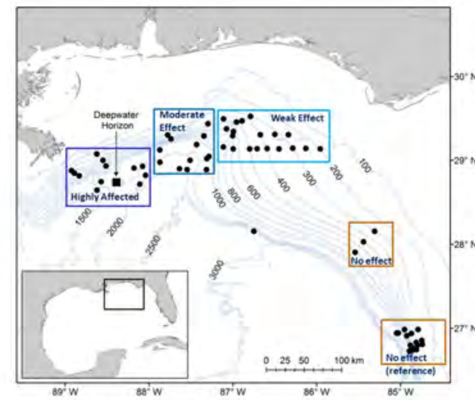
A surprising finding of this study was that community composition of large deep-sea fishes varied significantly over relatively small spatial scales. For example, the continental slope fish communities differ between the east and west sides of DeSoto Canyon and these assemblages differed from those of the West Florida Slope. Toxicological results showed that some species experienced physiological effects from oil exposure that correlated with distance from the well site. In deep-water shark species, effects didn't show up until three years after the spill, likely reflecting time required for such effects to transfer up the food chain. Our data following seven years of sampling suggested that by 2017, these effects had perhaps dissipated for some species but persisted and even increased in others.

Impact

We used catch-rate data to assess changes in population-relative abundance, community structure, and diversity relative to time since and distance from the DwH oil spill. Polycyclic aromatic hydrocarbon (PAH) exposure and metabolism were determined by examining levels of hepatic biotransformation enzymes associated with PAH's in the liver as well as biliary fluorescent aromatic compounds (FACs), which reflect the levels of PAH metabolites in ile. These biomarkers provided an essment of the relative quantities 'AH toxins being filtered by the liv- ı addition, studies of movements ration were conducted using satellite telemetry for large shark species such as the Bluntnose Sixgill Shark (Figure 2). Life history samples were also collected to conduct age, growth, and reproduction research on poorly studied taxa (Figure 3). This project led to the publication of 27 peer-reviewed papers to date. Among these were the description of one new species of deep-sea shark (*Squalus clarkae*, Pfleger et al. 2018, see sidebar) in the Gulf of Mexico, the resurrection of a sixgill shark species (*Hexanchus vitulus*, Daly-Engel et al. 2018) as well as range extensions for multiple species (e.g., the Greenland Shark, Walter et al. 2017). Collected samples were also used to examine patterns of mercury bioaccumulation in economically important tilefish as a function of the oil spill (Perrot et al. 2019). Ultimately, our work contributed to efforts to assess petrochemical risk (Polidoro et al. 2021) and develop a petrochemical vulnerability index (Woodyard et al. 2022) for hundreds of marine species in the Gulf of Mexico.

Future Work

The *Deepwater Horizon* oil spill brought into focus the lack of knowledge concerning the biology and ecology of deep-sea communities in the Gulf of Mexico, particularly for large fishes. It was apparent that a basic understanding of what species were present in the region deeper than 200 m was lacking and therefore no baseline data concerning species abundance, distribution, community structure, or oil exposure were available to assess the effects of the DwH spill. Our findings suggest that seven years after the oil spill, some deep-sea fishes were still being affected by the oil, illustrating the need for continued long-term monitoring of the effects of the oil spill on this ecosystem and also highlighting the need for baseline research on deep-sea fish communities in other parts of the Gulf of Mexico where deep-water oil drilling occurs. A majority of active oil drilling leases in the Gulf are deeper than 500 meters and the *Deepwater Horizon* oil rig was on the eastern edge of those active deep-sea drilling sites. Should another deepwater oil release occur, availability of baseline data for deep-sea fish communities to the west remains low. Given the extreme regional heterogeneity we found in these communities in the eastern GoM, it is likely that very different communities occur to the west.



◄ Figure 1. Stations 200-2000 m deep were sampled from 2011 through 2017 to examine the effects of the *Deepwater Horizon* oil spill on large deep-sea bony fish, sharks, and hagfish.

► Figure 2. Tagging and releasing a Bluntnose Sixgill Shark (*Hexanchus griseus*) aboard the R/V *Apalachee* in 2016.

▼ Figure 3. FSU Graduate students Bianca Prohaska and Brian Moe collect blood samples from a Little Gulper Shark (*Centrophorus uyato*) to assess reproductive hormones and chronic physiological stress.

Tissue clocks: New Methods for Aging Sea Turtles

HANNAH **VANDER ZANDEN**, AMY **WALLACE**,
JENNA **BENNETT**, & WILLIAM **PATTERSON**, III

Background

Sea turtles are long-lived creatures that regularly navigate among feeding and breeding sites as adults. Prior to adulthood, sea turtles occupy many habitats during their complex life cycles. For most of the seven species across the globe, hatchlings move offshore and then remain in the open ocean for several years before returning to coastal sites as large juveniles, where they continue to forage and grow until they reach a reproductive age, often between 15-30 years old.

The timing of these transitions, the age of sexual maturity, and their overall reproductive lifespan has important consequences for population dynamics and may affect the trajectory of population recovery. The status of all sea turtle species ranges from data-deficient to critically endangered, and despite signs of recovery for many populations over the last few decades, there are other populations that have continued to decrease. Therefore, predicting the future trends in population growth or decline requires good estimations of age and timing of life stage transitions. Particularly for Gulf of Mexico sea turtle populations, our knowledge is limited. Whereas most studies have been conducted on sea turtles in the Atlantic, we do not know if these critical population metrics differ for sea turtles in the Gulf of Mexico because of differing factors such as environmental conditions or genetic diversity. These knowledge gaps motivated our study to evaluate eye lenses as a new method to age sea turtles and to develop region-specific parameters for updating Gulf of Mexico sea turtle population models.

To date, the only reliable method to determine the age of sea turtles uses their bones. This aging method (known as skeletochronology) requires a cross-section of a flipper bone (the humerus). After processing and staining the bone cross-section, it is possible to count visible growth lines under a microscope, which represent annual rings, similar to tree rings (Figure 1). With the growth rings, it is possible to assess the timing of the transition from the open ocean to coastal waters as well as when individuals reach sexual maturity. Unfortunately, as turtles get older, two characteristics of bone growth make counting the growth lines more difficult. First, the growth lines tend to get compressed, and it becomes challenging to distinguish unique lines, even under the microscope. Second, the center of the bone is subject to resorption, and the youngest rings are often lost. Based on the turtle size, it is possible estimate the number of lost rings, but the precision of the aging approach is decreased by both of these challenges. An emerging alternative to aging fish with the ear structures known as otoliths, is to use the core of the eye lens. Measurements of radiocarbon in this tissue that was formed early in the animal's life provides an accurate aging approach that does not rely on interpreting growth rings (Figure 2).

The radiocarbon method has never been used for sea turtles, so one of our project goals was to apply this method for the first time. The first step in doing so was to verify that the approach works in turtles of a known age. We sought hatchling eye lenses for the verification process. We had a mix of loggerhead and green sea turtle hatchlings that did not survive the trip to the open ocean and washed back to shore where they were found near the University of Florida Whitney Marine Laboratory in St. Augustine, Florida. In addition to hatchlings that were collected between 2019 and 2021, we also had one hatchling from a prior study that had been stored in the freezer since 1992.

Outcomes

Of the 17 hatchlings tested, 15 fell within the expected range of radiocarbon values based on their year of collection. We suspect the two that fell outside of the range may have been occupying areas with upwelling of deep, older water, based on preliminary results from other studies. Our verification turtles were from the east coast of Florida, but we expect that upwelling is less likely to affect sea turtles from the Gulf of Mexico, where the radiocarbon method was validated for fish. Ongoing research along the east coast of the U.S. will likely aid comparisons and the interpretation of radiocarbon results between the two ocean basins.

Impact

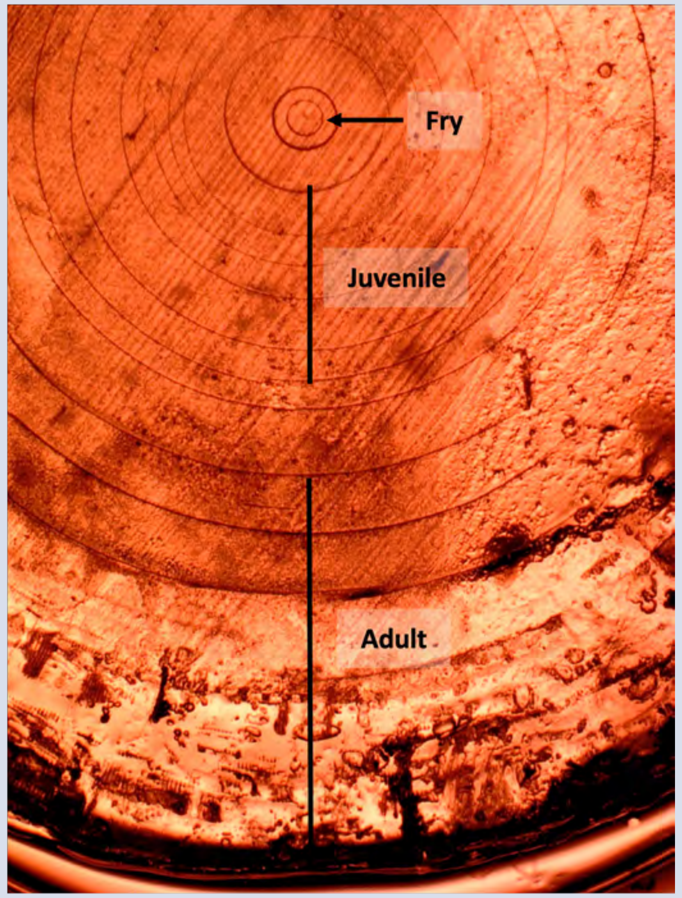
In summary, we have found that using the bomb radiocarbon method is promising for sea turtle eye lenses. Aging sea turtles using the bone method is extremely labor-intensive and requires trained individuals. Whereas radiocarbon dating is expensive, the time needed to process samples is greatly reduced. A less laborious and reliable aging method would provide valuable information for sea turtle populations in order to fill demographic data gaps.

Future Work

The next steps in our project are to compare sea turtle eye lens and bone aging methods and determine if the radiocarbon approach is reliable for larger, older turtles. The structure in sea turtle eye lenses is proving more challenging to work with than that of fish, but if we can overcome the limitations, the method may provide important information about sea turtle life history characteristics and contribute to improving future population trajectories.

▲ Figure 1. A cross-section of a juvenile sea turtle humerus bone (top) with a magnified image of the visible growth rings (yellow lines) (middle left). A cross section of an adult sea turtle humerus with resorption in the center (yellow ellipse) (bottom) and a magnified image of compressed growth rings near the outer edge (middle right).

▼ Figure 2. A cross-section of a fish eye lens where the core represents the early life stage as a fry, and then successive layers represent juvenile and adult portions of the life. *(Photo from: Tzadik et al. 2017)*



Finding the Sea Turtle "Lost Years" in the Gulf of Mexico

KATHERINE L. **MANSFIELD**
& KATRINA F. **PHILLIPS**

Background

Successful species conservation and management requires an understanding of an animal's spatial distribution and how this distribution may vary over time and in response to changing environmental conditions (Guisan et al. 2005). Marine turtles inhabit geographically diverse habitats during different stages of their lives. Very little is known about sea turtles during their first years at sea—from the time they leave their nesting beaches as hatchlings through their early years living in the open ocean. Juvenile oceanic developmental habitats are not well defined for any sea turtle species, nor are their in-water behavior and risk potential relative to anthropogenic activities (e.g., oil spills, fishery activities, etc.). Further, the timing and locations of sea turtles' ontogenetic or age-driven habitat shifts (e.g., from oceanic stage to coastal stage juveniles) are poorly understood.

Sea turtles are long-lived, late-maturing, and highly migratory animals, making their management a challenge; many species use the Gulf of Mexico during different periods of their long lives. Sea turtles were among the many organisms affected by the 2010 *Deepwater Horizon (DWH)* oil spill in the northern Gulf of Mexico. In the offshore areas most affected by the *DWH* spill, assessment efforts estimated that upwards of 150,000 oceanic stage turtles died due to the spill (Wallace et al. 2015). Data gaps surrounding this sea turtle life stage made it challenging to both assess the populations affected by the disaster, as well as determine restoration needs. Key unanswered questions included: Are the turtles transient or resident in the northern or eastern Gulf of Mexico? Are oceanic turtles active swimmers or passive drifters (as assumed from long-held hypotheses)? Funding from the Florida Restore Act Centers of Excellence Program (FLRACEP) first funding cycle helped tackle some of these questions while also supporting the first of its kind study to cohesively examine the health, diet, movements, behavior, and stock of origin for four species of wild-caught oceanic-stage sea turtles in the Gulf of Mexico. Subsequent funding from the FLRACEP third funding cycle built on our initial results, allowing us to take a deeper look at the mechanisms driving the movements and behavior, diet, and genetic stock structure of the turtles found in the northern Gulf of Mexico and West Florida Shelf.

Impact

Our ongoing work, supported in part by the FLRACEP, continues to address the data and technology gaps identified by the National Marine Fisheries Service, the U.S. Fish and Wildlife Service, and the International Union for Conservation of Nature (IUCN). Our research has resulted in the largest dataset for wild-caught oceanic stage turtles in the world. Our novel satellite tracking data has shown us that there are species-specific differences in orientation, and that the West Florida Shelf is an important juvenile developmental habitat for oceanic-stage turtles transitioning to coastal habitats (Phillips 2022). Many turtles encountered in our study area originate from international rookeries, including Mexico (Phillips et al. 2022). Tracking data coupled with passive oceanographic drifter data (Figure 1) shows us that these young turtles are not 100% passive drifters as previously assumed. Development and use of integrative and novel methods have helped revolutionize sea turtle in-water work by improving life-history models, identifying nursery and development habitats, and providing an understanding of the dispersal and behavior of small oceanic sea turtles. Our findings are helping the National Marine Fisheries Service designate Critical Habitat for green sea turtles (*Chelonia mydas*) under the U.S. Endangered Species Act, and are helping determine locations of management concern, while bridging the gaps in our understanding of early sea turtle life history.

▲ Figure 1. Two satellite-tagged green sea turtles released with an oceanographic drifter. *(Photo: K. Mansfield, Permit: National Marine Fisheries Service #19508)*

◄ Figure 2. Oceanic-stage hawksbill sea turtle in habitat. *(Photo: K. Phillips, Permit: National Marine Fisheries Service #19508)*

Future Work

The more we learn, the more questions we have about this early sea turtle life stage and we are actively searching for additional funding support to continue our ground-breaking work. While we now know that these little animals are active swimmers, we don't know when or why they would choose to swim. Perhaps the answer lies in their association with *Sargassum*, a brown, floating macroalgae on which these little turtles are known to associate (Figure 2). *Sargassum* provides protection from predators and young turtles find plenty of prey items to feed on while perched on this floating habitat. However, *Sargassum* is transient and may raft up in large mats, or scatter when the winds and seas rise. What does association with *Sargassum* mean for these little turtles' long-term survival and fitness? Are they actively searching for this habitat or opportunistically encountering it? How do ocean currents influence where and when these little turtles and *Sargassum* co-occur? What we do know is that these currents vary a little each year, so a long-term perspective on the movements, dispersal, and habitat availability is needed to best predict how future threats such as changes in the climate, *Sargassum* blooms or die-offs, or oil spills will impact sea turtle populations in the Gulf.

We are still learning about the ontogenetic shift that young turtles make from offshore to nearshore habitats and what our FLRACEP-funded work has illustrated is that this transition is not as well-defined as previously assumed. Turtles may still behave as surface-dwelling oceanic stage turtles, but they may occupy what we had traditionally consider coastal (neritic) habitat (Phillips 2022). These findings have us questioning our life history models for sea turtles and redefining these little oceanic-stage turtles as perhaps dispersal-stage turtles (Phillips 2022). And as we expand our research to other parts of the world, we are realizing that what these young turtles may be doing in the North Atlantic and Gulf of Mexico may not be representative of dispersal stage turtles in other ocean basins.

Health and Reproductive Impacts of Brevetoxin Exposure on Nesting Loggerhead Sea Turtles *(Caretta caretta)* and their Offspring

▼ Measurements are taken on a nesting loggerhead after collecting blood. *(Photo: Shane Antalick)*

KELLY **SLOAN**,
NICOLE **STACY**,
PAUL **JULIAN**,
ANDREW **GLINSKY**,
JACK **BRZOZA**,
SIMONA **CERIANI**,
& JUSTIN **PERRAULT**

Background

Blooms of the harmful algae *Karenia brevis* are a significant and intensifying threat to sea turtles that use the Gulf of Mexico as foraging, migrating, breeding, and nesting grounds. These dinoflagellates release a suite of potent neurotoxins, collectively termed brevetoxins, that can result in mortality of wildlife species including fish, sea turtles, sea birds, and marine mammals. Since 2000, red tide conditions (>100,000 *K. brevis* cells/L) have been documented annually in at least one county on Florida's west coast.

The 2018 *K. brevis* bloom was the most environmentally destructive harmful algal bloom (HAB) on Florida's west coast since 2005. Between October 2017 and January 2019, *K. brevis* cell counts averaged 443,000 cells/L at 156 sample sites in the watershed surrounding Sanibel and Captiva Islands. The highest concentration recorded at these sites during this event was 50,200,000 cells/L on November 19, 2018 in a sample collected near Captiva Island. Nearly two million kg of dead marine life were collected between July and December 2018 on Lee County beaches (Figure 1).

Marine turtles can be exposed to brevetoxins through inhalation of aerosolized toxins and drinking contaminated water, but the primary route of exposure is through ingestion of contaminated prey. Brevetoxins can persist in the environment and sea turtle prey items for more than one year, which can result in continued exposure through trophic transfer after a bloom has dissipated. The acute impacts of brevetoxicosis in stranded and rehabilitated turtles with clinical evidence of toxin exposure are well documented, but few characterize the long-term effects of brevetoxins on wildlife health.

Our objectives were to: (1) quantify brevetoxin concentrations in plasma for loggerhead sea turtles (*Caretta caretta*) nesting on Sanibel Island, Florida, USA, following an intense and prolonged red tide bloom, (2) establish correlations with brevetoxin exposure and blood analytes, (3) determine brevetoxin concentrations in unhatched egg contents and dead-in-nest hatchling livers, and (4) identify impacts of brevetoxin exposure on hatching success.

To answer these questions, we collected samples across four nesting seasons to assess the impacts of red tide bloom exposure on nesting loggerheads. When a sea turtle was encountered during the nesting process, blood was collected during the egg-laying process (see photo to left). Nests from the sampled females were excavated and inventoried and unhatched eggs from each clutch were collected for brevetoxin analysis (Figure 2). When available, we also collected dead-in-nest hatchlings during nest inventories. Plasma, egg contents, and hatchling livers were analyzed for total brevetoxin concentrations. To evaluate impacts of brevetoxins on embryonic development, loggerhead hatchlings were also subjected to complete histological examination.

Outcomes

Between 2019 and 2022, we sampled blood from 428 seemingly clinically normal nesting loggerheads (none of study turtles had clinical evidence of brevetoxicosis). We also collected 276 unhatched eggs and 1,593 eggs from the nests laid by these females. Our results indicated that maternal plasma brevetoxin concentrations were relatively low and similar to previous studies of clinically normal nesting loggerheads. Several correlations of brevetoxins with blood analytes provided evidence of subclinical effects on immune functions and overall health, similar to findings in marine mammals.

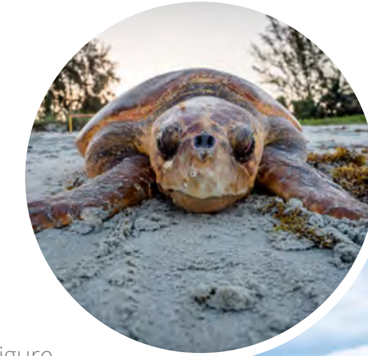
Egg and hatchling liver concentrations were low in 2019 but were higher than previously reported in 2020 and 2021. These results confirm that toxin transfer is occurring from nesting female to the egg, with high values reported in many hatchling liver tissues.

We also learned that 141 turtles used foraging grounds in the Gulf of Mexico while 74 foraged in the subtropical Northwest Atlantic (Caribbean region). Turtles that were from the Gulf of Mexico had significantly higher brevetoxin loads than those using foraging grounds in the Caribbean.

Histopathologic evaluation of hatchling tissues revealed a large percentage of animals with lesions on the eyelids and skin of the head. Assessment of brevetoxin tissue concentrations in these animals did not show a link with disease severity, so other factors are likely at play in relation to the changes seen in the eyes and skin.

Impacts

Our results provide evidence that even when HABs do not cause direct mortality of exposed wildlife, they can potentially act as a physiological stressor that continuously impacts the health of sea turtles with potential downstream effects that need to be further assessed. Prior to this study, there was a significant data gap on this topic in the policy realm and the lack of known impacts has effectively slowed federal protection. Understanding the full effects on sea turtle health and reproductive success could affect "take" permits related to the water management decisions that affect growth of HABs.



▲ Figure 1. A live adult male loggerhead suffering from brevetoxicosis during the 2018 red tide event *(Photo: Alexis Horn)*

► Figure 2. An inventory is conducted to evaluate success and collect samples. *(Photo: Shane Antalick)*

The combination of global climate change and increasing eutrophication will likely increase the incidence and intensity of HABs. It is important to consider the impacts of these blooms on threatened and endangered sea turtle health and reproduction when evaluating stressors on the population and developing management strategies.

Future Work

The low plasma concentrations in this study were not surprising given that blood reflects relatively recent exposure to toxins, and toxins likely distribute into the fat or liver after weeks of circulation in the blood. Future studies may focus on collecting fat samples, although sampling these tissues from live animals presents logistical and ethical challenges. Learning more about the impacts of brevetoxins on hatchling fitness and survival is another remaining research area. *All research was permitted under FWC MTP-047.*

Health and Movements of Florida's Gulf Dolphins

RANDALL **WELLS**

Background

Cetaceans, as apex predators, are important components of Gulf of Mexico ecosystems and can act as sentinels for ocean health. However, outside of research in bays, sounds, estuaries and associated coastal waters, where they were found to have serious, and in some cases chronic health conditions consistent with exposure to pollutants that have impacted population trajectories, dolphins have received very little research attention. Gaps in our understanding limit innovations in conservation and management for both coastal and continental shelf dolphins – some of which might have been exposed to *Deepwater Horizon* oil and products. We have been addressing important research gaps regarding movement patterns, habitat use, and health for the two dolphin species that regularly inhabit the continental shelf waters off Florida's west coast, bottlenose (*Tursiops truncatus*) and Atlantic spotted (*Stenella frontalis*). With the overarching goal of providing requisite information for conservation and management, our objectives included: 1) improving understanding of dolphin stock structure and habitat use through tagging, tracking, and genetic sampling, 2) establishing baseline data on environmental contaminant concentrations in dolphin tissues, 3) obtaining baseline dolphin health data, 4) evaluating potential relationships between lung disease and respiration and diving patterns, 5) investigating feeding patterns through stable isotope and fatty acid analyses, and 6) maintaining and expanding the long-term Gulf of Mexico Dolphin Identification System (GoMDIS).

We have been using catch-and-release health assessments to establish baselines and serve as the basis for comparison to inshore dolphins to assess health status, providing opportunities for collection of samples for genetic, environmental contaminant, and diet analyses, as well as for attaching satellite-linked location and dive data tags (Figure 1). These tags provide information on ranging and habitat use patterns, along with dive patterns. Relationships between dive patterns and health are being investigated as potential behavioral proxies for assessing health of dolphins tagged without capture. Continuation of our long-term collaborative photo-identification matching system and repository, GoMDIS, has facilitated identification of sources of stranded dolphins, and range shifts in response to environmental changes.

Outcomes

To date, we have completed three of four planned field sessions. Four Atlantic spotted dolphins, four bottlenose dolphins, and one rough-toothed dolphin have been tagged and tracked for ~3 months each, on average. Results from tracking are the first data of their kind available for helping to refine understanding of dolphin stock structure. In contrast to NOAA's published stock assessment reports, which show the stocks ranging through continental shelf waters across the entire northern Gulf of Mexico, movements of the nine tagged dolphins have been consistently concentrated off the west central coast of Florida (Figures 2-3). While there were a few excursions to the north or south, most of the locations were concentrated in the eastern half of the West Florida Shelf, within about 10-50 nm of shore, and at least 75 nm from the shelf edge, roughly ranging from offshore of the mouth of Tampa Bay to offshore of Sanibel Island. If ranging patterns have not changed since the *Deepwater Horizon* disaster, then it is likely that the portions of the stocks using waters off Sarasota were not exposed to oil from the spill. Initial analyses suggest seasonal east-west movements, with dolphins moving farther offshore during warmer months. Bottlenose and Atlantic spotted dolphins moved through waters of similar depth ranges (15-74 m), and preliminary analyses of dive data indicate that they are using the entire water column. Digital acoustic archival tag (DTAG) data show that the animals are feeding at or near the seafloor. For the first time in the Gulf of Mexico, dolphins were tracked during passing hurricanes, and the movements seen for the 8 animals were generally consistent with wind and wave directions. Health, lung function, environmental contaminant, and feeding pattern analyses are in progress.

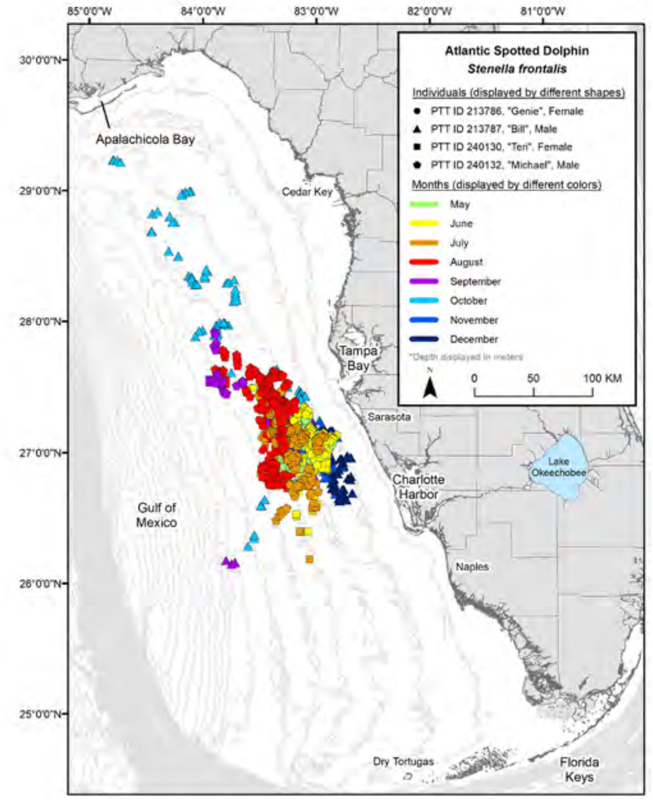
Impact

Our project is still underway, with the final session of field work remaining, as well as analyses of samples and data. Upon completion of the project, findings will be provided to the National Marine Fisheries Service (NMFS), for consideration for management action, and for incorporation into their congressionally-mandated Marine Mammal Stock Assessment Reports. Our initial tracking data lend support to recent NMFS genetic findings (based on only a few samples) that dolphin stock structure over the West Florida Shelf needs to be reconsidered and refined in order to bring designations of stocks into better alignment relative to threat exposures.

Future Work

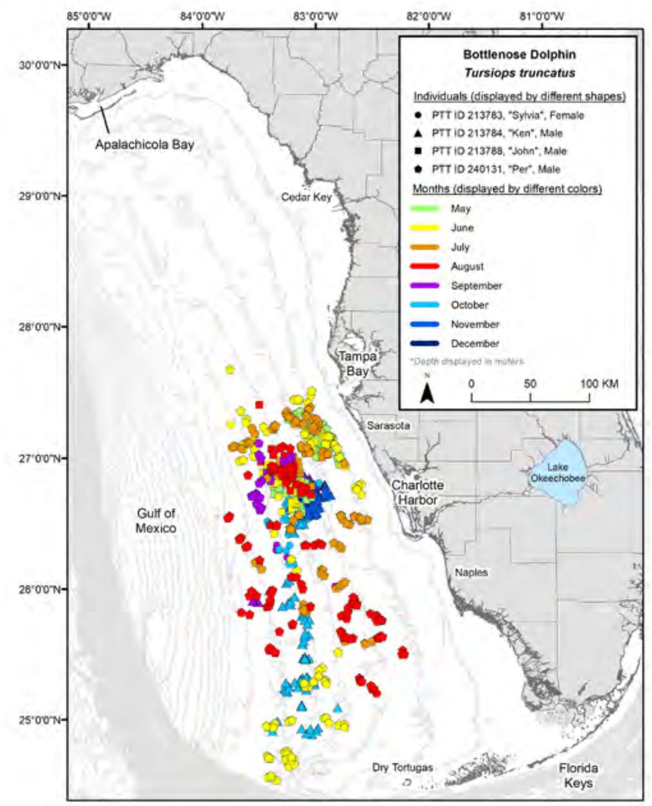
The preliminary tracking data raise myriad questions about the factors (e.g., physiographic, oceanographic, biological, ecological), that define the ranges and stock structure of dolphins over the West Florida Shelf. Were the east-west movements during the summer of 2023 related to extreme heating of the Gulf of Mexico, or are these movements typical? What drove these movements to deeper water? Further analyses of data from the current project, as well as an increased sample size of tag deployments and samples will be necessary to address these questions. Over the course of this project, we have developed and refined the approach of safely catching dolphins in deep water through hoop-netting, providing opportunities for sampling and tagging. In addition, through a parallel project, we have developed a tool to deploy satellite-linked tags to bow-riding dolphins. As this tool is perfected through a recently funded project, it could become a cost-effective means of deploying large numbers of tags without the need to catch dolphins.

▼ Figure 1. The Atlantic spotted dolphin nick-named "Eugenie Clark," was the first dolphin tagged over the West Florida Shelf, on June 1st, 2022. The dolphin has a satellite-linked tag on its dorsal fin, and a short-term digital acoustic archival tag (DTAG) attached by suction cups to its back.



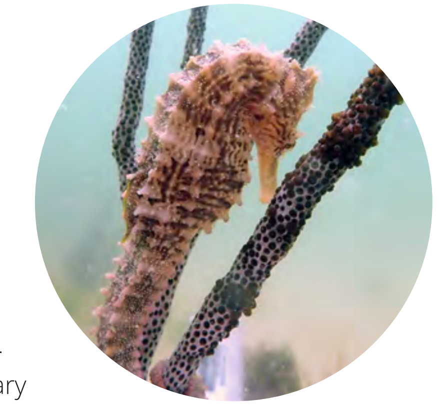
▲ Figure 2. High-quality Argos locations from satellite-linked transmitters on four Atlantic spotted dolphins tagged during 2022-2023.

▼ Figure 3. High-quality Argos locations from satellite-linked transmitters on four bottlenose dolphins tagged during 2022-2023.



Hardbottom Mapping and Community Characterization of the West-Central Florida Gulf Coast

BRIAN K **WALKER**, SHELBY **EAGAN**, CORY **AMES**, SANDRA **BROOKE**, SEAN **KEENAN**, & RENÈ **BAUMSTARK**



Background

The continental shelf off Florida's west coast is a wide shallow carbonate platform with a mosaic of hard and soft bottom habitats hosting a variety of ecologically important sea life including seagrasses, hard and soft corals, sponges, crabs, shrimp, lobsters, and fishes. The distribution and biological composition of these habitats are poorly understood. Habitat maps and community baseline data are scarce or nonexistent for a majority of the West Florida Shelf (WFS). There is a long-recognized climate gradient along the Florida peninsula ranging from warm-temperate in the north to sub-tropical in the south, causing latitudinal changes in marine benthic communities. The lack of seafloor maps and community data have led to inconsistencies in placement of biogeographic transitions. Understanding regional biogeography has become critical as the climate continues to warm and tropical species are moving into historically temperate areas, a process called tropicalization. This redistribution of species has serious consequences for economic development, livelihoods, food security, human health and culture, and therefore must be incorporated into local, regional and global assessments as standard practice. Community biogeographic baseline data are essential in order to detect these changes and understand how climate change affects the ecosystems that support human populations.

Our Center of Excellence objectives were to: (1) construct a benthic habitat map of approximately 1,200 km^2 of shallow-water seafloor north and south of Tampa Bay, (2) collect quantitative survey data to characterize hardbottom benthic communities within the mapped area, and (3) investigate coastal benthic community spatial patterns in a biogeographic context. This was a collaborative effort between Nova Southeastern University, Florida Fish and Wildlife Conservation Commission, NOAA National Marine Fisheries Service, and other scientists. Team members mapped and characterized two large nearshore areas that are popular with recreational fishermen off of Clearwater and Sarasota. These represented the first seafloor habitat maps and community characterization for the study areas. This inventory of Florida's west-central coast hardbottom communities provided information on the composition, condition, and extent of the understudied economically-important benthic biological resources and how they vary spatially. This information provides a baseline for future change in a warming climate. Not only is this information essential for optimizing fishery survey designs, advancing ecosystem management capabilities, and estimating stock abundances, but it is also a valuable public resource as a guide for recreational activities (e.g. fishing, diving).

Study areas were chosen based on locations where archived satellite imagery was suitable for visual image interpretation. Detailed habitat mapping of the imagery was accomplished by visual interpretation at a 1:3,000 scale with a minimum mapping unit of 0.4 ha (1 acre) following similar methodologies used by other regional mapping efforts. Features were classified to the Florida Unified Reef Map following the Federal Coastal and Marine Ecological Classification Standard (CMECS). CMECS was used for habitat categorization and was modified where necessary to better define habitats. Digital video data were collected at 258 locations throughout the study area using drop cameras to ground-truth the mapped habitats. The video data were used to inform the image interpretation process in GIS.

Twenty-nine haphazardly chosen, shallow-water (<20 m) hardbottom quantitative survey sites were visited over a 6-day period; 15 in the north section and 9 in the south. At each site, four non-overlapping 20 m transect tapes parallel to each other were extended without crossing into a different habitat. Photographs were collected 52 cm above the surface at 1-m intervals along the length of each transect. Simultaneously, a 1-m belt survey was conducted along 15 m of the two middle transects (30 m^2 total) to document coral demographic and condition data. Along each of the middle transects, scleractinian corals greater than 4 cm were identified, counted, and measured (maximum length, width, and height) to calculate density. Gorgonian coral density was binned into height size classes (4–10, 11–25, 26–50, 50+ cm) and by individual morpho-type (Rod, Plume, and Fan). Percent mortality and the presence and severity of bleaching and disease were documented for each coral surveyed.

Outcomes

Baseline mapping and satellite image interpretation of two large areas between 4 and 16 m depth off Clearwater and Sarasota, Florida yielded 294 km² of hardbottom within the 1,263 km² total mapped area (Figure 1). A total of 4,079 individuals from nine stony coral species and 1,918 gorgonian corals were measured. Populations were dominated by four stony coral species: *Siderastrea radians* (4.9 m²), *Oculina robusta* (3.3 m²), *Solenastrea hyades* (2.5 m²), and *Cladacora arbuscula* (0.7 m²). Most corals were less than 10 cm in length (73%), width (85%), and height (80%). Bleaching prevalence was high but mostly specific to *O. robusta* (52%) and *S. hyades* (17%). Pooled soft coral density across all sites was 5.4 m².

Impacts

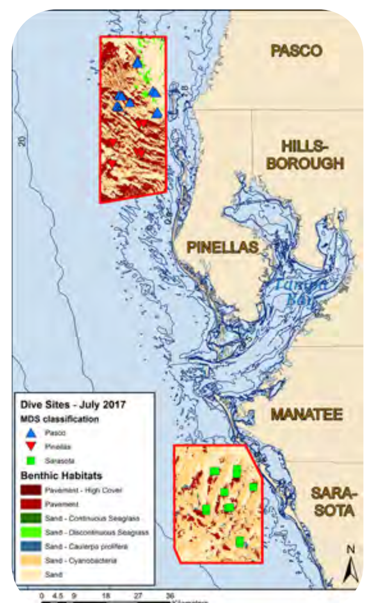
Effective place-based management strategies need to be informed by spatial context. Understanding the spatial distribution of marine organisms is critical for making informed management decisions. The outputs of this work provided the first detailed benthic habitat map of the area and a detailed survey of the composition of hardbottom benthic communities in the region. Further, results identified Tampa Bay as a coastal benthic biogeographic transition and illustrated the influence of the Bahamas Fracture Zone on coastal communities (Figure 2). This is critical management information to scale community and stock estimates, model populations, and run prediction scenarios on management actions and climate change expectations.

Future Work

The WFS is an expansive area making it challenging and expensive to map. Presently bathymetry is being collected for the State of Florida out to 20 m depth at a cost of about $100 M. Unifying new and existing seafloor data while concurrently collecting targeted, benthic community data over broad scales will facilitate the development of benthic habitat maps to refine community biogeographic zonation. This is a necessary precursor to detecting spatial shifts in communities and for population modeling. We continue to look for opportunities to further this important research.

This project was the focus of Shelby Eagan's Master's thesis work at Nova Southeastern University. It was succeeded by more nearshore community biogeography research as part of Nicole Blank's Master's thesis project led by Sandra Brooke at Florida State University. Both works were published in the peer-reviewed literature and further highlight the need for detail habitat maps and characterization of Florida's west coast.

▼ Figure 1. The final map with the characterization survey site location symbolized by biogeographic communities. Biogeographic patterns were evident between counties where the densities of corals and gorgonians decreased from south to north between Pasco, Pinellas, and Sarasota counties. The main community shift indicated an ecoregion boundary at, or very near, the mouth of Tampa Bay. Another shift associated with the Bahamas Fracture Zone (BFZ) occurred at the Pinellas and Pasco County border (Figure 2) through the shelf. This study identified additional potential ecoregion boundaries near Port Richey north of Tampa Bay and somewhere between Port Richey and St. Teresa to the north.



► Figure 2. A map of Florida coastal benthic ecoregions adapted from Walker et al. (2020) updated with recent study sites by region. Lines extending from the shelf represent ecoregion or potential ecoregion transitions for the nearshore areas. The Bahamas Fracture Zone (FZ) is represented by the diagonal dotted lines through the shelf. This study identified additional potential ecoregion boundaries near Port Richey north of Tampa Bay and somewhere between Port Richey and St. Teresa to the north.

Facilitating the Development of a Standardized Mapping Framework for the West Florida Shelf

ANNA **BRASWELL**, VINCENT **LECOURS**,
& XIAOHUI **QIAO**

Background

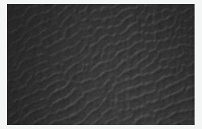
Seafloor habitat mapping provides foundational contextual information for research as well as conservation, management, and decision-making. Habitat mapping efforts require the integration of multiple types of data such as seafloor geomorphology and substrate, chemical properties of the water, and species occurrences, to name only a few examples. Because they are discipline-specific, these data often have different forms (e.g., localized points or polygons, continuous data) and formats, making it difficult to integrate them into a common geographic framework. This may prevent an optimal integration of the data, which, if standardized, could be used for many different purposes, thus increasing the cost-benefit of collecting them and improving our knowledge of the environment and subsequent decision-making.

Our Center of Excellence (CoE) aims to better understand the current practices in the collection, processing, interpretation, and management of oceanographic, biological, geological, chemical, and bathymetric data for the West Florida Shelf (Figure 1). Based on the analysis of current practices, we aimed to make expert recommendations for a framework of standardized practices that will benefit everyone interacting with seafloor data in Florida and ensure the future usability of collected data.

Our evaluation of current practices was two-fold: we first performed a meta-analysis of how different communities handle seafloor data internationally and elsewhere in the United States, and then we surveyed the stakeholder community in Florida (102 respondents from the following sectors: 32% academic, 55% government, 13% private or non-profit). The meta-analysis taught us that such a standardized framework is extremely challenging to implement because it requires buy-in from various institutional levels and stakeholders with different backgrounds and expertise. Hosting a standardized data repository requires abundant financial, technical, and support resources. For example, the European Marine Observation and Data Network (EMODnet), the gold standard for such a standardized framework, cost between 5.4 and 13.7 million euros per year between 2014 and 2020. We also learned that data is everywhere, from the many public repositories to the innumerable personal hard drives that hold them. In addition, repositories and institutions have varied degrees of rigor in their data collection and management standards, making synthesis across projects difficult. Through our survey of Florida-based stakeholders, we learned that disciplines vary on their degree of data collection and metadata standards and on the level of disciplinary engagement on consistent data standardization. Survey results also point to a lack of knowledge and use of standards for metadata: 61% of survey respondents either do not use standards or do not know about standards. We also found that 39% of survey respondents do not openly share their data but only release them upon request. This number is surprising considering the directives from academic journals and funding agencies on data release.

With these results in mind, we brought together a panel of disciplinary experts in each data type to find potential solutions to some of these issues (Figure 2). This team has produced the most significant result of our CoE research to date, namely clear recommendations to guide decisions about data collection and metadata standard requirements for data collected within the West Florida Shelf and beyond. Our next step is to solicit community buy-in through a survey of stakeholders and interested parties to give feedback on the recommendations from the expert panel. This will allow us to quantify the level of agreement with these recommendations, the likelihood that they will be adopted by the community of stakeholders, and the tools needed by the community to facilitate a widespread adoption. Our future work will develop some of these tools and if needed, amend the framework based on community feedback to increase the likelihood of widespread adoption.

BATHYMETRY & BACKSCATTER
Bathymetric data represent the depth of the seafloor and can be collected using acoustic remote sensing (e.g., multibeam echosounders), optical remote sensing (e.g., bathymetric lidar), or by direct measurements (e.g., ead lines). Backscatter data represent the intensity of the acoustic ofoptical returns and have been linked to substrate patterns.

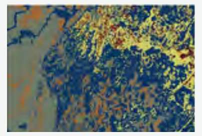


GEOLOGY & GEOMORPHOLOGY
Marine geological data represent the nature and structure of the seafloor and sub-sea-floor. Geomorphological data represent the morphology, or shape, of the seafloor, which is influenced by geological processes.

BIOLOGY
Marine biological data can represent for example species presence and absence, abundance, and density. Observations can be made for example from physical samples or video data.

PHYSICS & OCEANOGRAPHY
Marine physical data characterize the currents, waves, and other dynamic processes that govern the motion of water and the oceans.

CHEMISTRY
Marine chemistry deals with the properties, composition, structure, and interactionor substances in the oceans. Marine chemistry data are often measured using sensors that can measure a wide range of ocean water or sediment characteristics.



OTHER DATA
The study of benthic environments involve many other data types, such as data on human activities, seabed habitats, marine litter and pollution, and infrastructure.

▲ Figure 1. Definition of the types of data investigated through this Center of Excellence.

► Figure 2. Our expert panel helped us identify common issues and potential solutions pertaining to data collection and management standards, or the lack thereof.

Outcomes

We see the impact of our CoE in the changing mindset of the community. Through community surveys, presentations, and online presence, we work to influence the way that other researchers and data managers think about their data. Our message invites people to consider the opportunities in open data and how to collect and release their data in a way that allows them to be interoperable and reusable for others. We anticipate that our CoE will directly impact the state recommendations on data collection and metadata standards. Representatives from the Florida Fish and Wildlife Conservation Commission, Gulf of Mexico Alliance, and the National Oceanic and Atmospheric Administration, along with research community representatives, are involved in the review of all standards, making sure that recommendations align with state, regional, and national efforts, and promoting the framework. Through state buy-in, we hope to add momentum to the project, increasing the number of people that are openly releasing standardized and accessible data and metadata. Through increasing data accessibility, our project will ultimately influence the number of synthetic scientific works and management decisions in the state and therefore benefit all Floridians.

Future Work

Over the course of our project, we discovered that institutional support and community buy-in is key for creating a culture of open data. Our work improves data reuse through informing agencies on data standards and providing them with guidelines and geospatial tools to implement with their research and funding efforts. We see the follow-up to this project as funding for implementation of the proposed data framework, which would include a statewide data repository with explicitly-defined data standards or guidelines and tools to support the integration of data into the repository. To ensure adequate funding and regulatory power, we envision this as a top-down approach that produces both regulations and tools to facilitate scientific data sharing (e.g., EMODnet). Our project sets the groundwork and highlights the hurdles in such an ambitious but necessary effort.

Developing Partnerships to Support Estuary Programs in Northwest Florida

MATTHEW **DEITCH**, JANE **CAFFREY**, AMANDA **CROTEAU**, TESFAY **GEBREMICAEL**, & HALEY **GANCEL**

Background

Nonregulatory basin-scale management frameworks provide a unique opportunity to incorporate rigorous science and stakeholder input to develop novel mechanisms for watershed management. Over the past three years, participants representing federal, state, and local agencies, elected officials, local conservation groups, researchers, and other stakeholder collaborators in northwest Florida and south Alabama have worked to develop the Pensacola and Perdido Bays Estuary Program (PPBEP), the Choctawhatchee Bay Estuary Program (CBEP), and the St. Andrew and St. Joseph Bays Estuary Program (SASJBEP). These programs were established following the U.S. Environmental Protection Agency (EPA) National Estuary Program model, with each program having a goal of developing strategies to enhance water quality, habitat, and community resilience in the estuary and surrounding region. The goal of our Florida Panhandle Center of Excellence project was to provide meaningful scientific input and rigor in identifying and implementing methods to assess impacts and reduce stressors that affect water quality, habitat, and community resilience in each system in the context of social-ecological adaptive management frameworks (Figure 1).

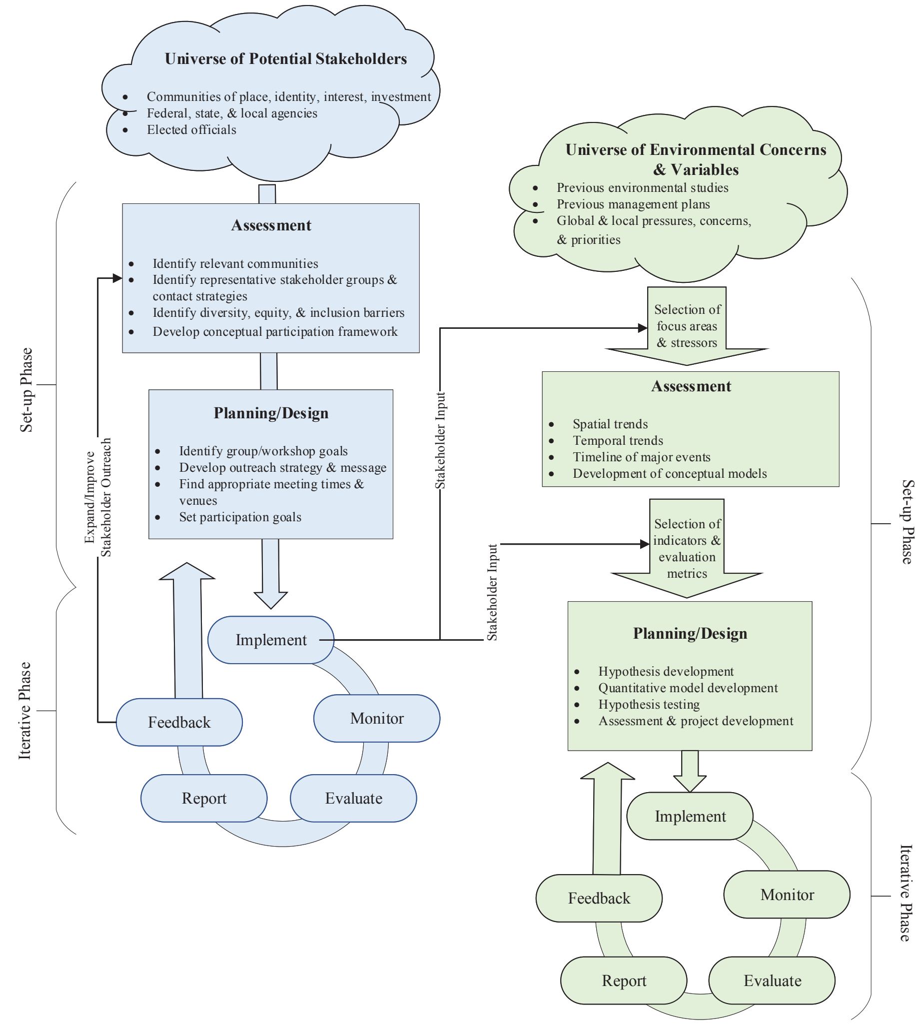
Our project consisted of two phases: (1) stakeholder engagement, which included preparing for and implementing a series of workshops focused on reaching consensus among participants on key indicators, stressors, and root causes of impacts to water quality, sediment quality, habitat, and community resilience in each Estuary Program region, and preparing and implementing a community survey for broader public input; and (2) conducting research to examine issues related to stressors and impacts that were identified in workshops. For workshop preparation, we developed an online bibliography of all published research on each watershed and comprehensive datasets characterizing water quality and habitat characteristics. Summaries were presented in a preliminary planning workshop. Then a series of topic-based workshops were held using interactive group activities to solicit input from participants on stressors, indicators, and root causes, as well as data gaps and possible actions to improve conditions. The project began in March 2020, when concerns over COVID-19 led agencies and other organizations to reduce in-person activities; all workshops were implemented virtually and utilized an online real-time collaboration program, which provided a framework for workshop participants to share input via text boxes and vote on priority issues and concerns presented during the workshops. In total, we conducted 15 workshops to solicit input and establish priorities on topics including water and sediment quality, water quantity, habitat, fish and wildlife, and community resilience. Typically, each workshop had 35 to 50 participants. Online real-time collaborations proved to be a powerful mechanism for participants to share information and voice opinions on priority needs and actions for each Estuary Program. Post-workshop surveys indicated that participants were overwhelmingly satisfied with the workshops, likely a result of activities that were well-organized and efficiently facilitated by the project team.

Outcomes

A community survey tool was developed that examined participants' values and perceptions around water quality, habitat quality, environmental change, and management, and how they interact with and utilize natural resources locally. This survey was distributed via social media, email, and advertisement within the Choctawhatchee, St. Andrew, and St. Joseph Bay watersheds.

The stakeholder engagement phase of the project concluded with the Center of Excellence team providing detailed summaries of workshop content to each Estuary Program. Summaries provided a foundation for each Estuary Program's Comprehensive Conservation and Management Plan (CCMP), based on stakeholder inputs. They included major stressors and root causes threatening ecosystems and communities in each Program region, and data and knowledge gaps. Priority regions for future conservation work and a list of current and future projects addressing these issues over the near- and long-term were identified. Each Panhandle Estuary Program has taken a different approach to incorporating workshop outputs into their CCMP, with PPBEP using the workshop and analysis results as supporting content to develop a CCMP draft, and SASJBEP using the workshop output to prioritize goals and actions that will be central to developing their CCMP.

While each Panhandle Estuary Program worked to develop their CCMP, the Center of Excellence team conducted new research building on our initial data analysis addressing major concerns raised by participants over the course of the workshop series. Our research focused on examining relationships between land cover and water quality, and trends in water quality in watersheds and estuaries over time. Preliminary results indicated that land cover change is not one-directional: for example, land cover data in 2001 and 2019 indicate that 740 km2 of the 14,000 km2 Choctawhatchee Bay watershed converted from evergreen forest to hay/pasture or shrub/scrub, but 840 km2 of hay/pasture or shrub/scrub converted to evergreen forest. Land cover-water quality relationships have not been clear: no changes in water quality consistently correlated with changes in land cover in our project area. Analysis of estuarine water quality and watershed hydrology indicated that measured salinity generally declined and water clarity increased through the project region (Croteau et al. 2023), which was a surprising trend, considering that freshwater inputs from stream discharge were generally less or the same over time and other research has indicated increasing sea level in the Gulf of Mexico region.



▲ Figure 1. Adaptive Management Framework integrating participatory and ecological cycles, from Deitch et al. 2021.

Future Work

As our project concludes, we will continue to conduct research that advances the goals of the Panhandle Estuary Programs. Land cover-water quality relationships can be analyzed through several methods, and given the interest in understanding the topic, this will likely continue to be a subject of research in the future. Estuary Programs are also interested in understanding how management actions could affect water quality, habitat, or fish and wildlife communities; we are developing models to investigate these relationships as well. We will continue to leverage the partnerships developed through Estuary Program collaboration to conduct meaningful research supporting CCMP objectives over the duration of their operation.

Collaborative Science to Assess Restoration Success (C-STARS)

JESSICA **GRAHAM**, RYANN **ROSSI**, WHITNEY **SCHEFFEL**, & HALEY **GANCEL**

Background

C-STARS is a multidisciplinary research project that will study the success of living shoreline restoration efforts and ecosystem services across three Florida Panhandle estuaries (Pensacola, Choctawhatchee, St. Andrew Bay) (Figure 1). Living shoreline projects work to create coastal habitats, reduce shoreline erosion, and provide protection to critical infrastructure. This Center of Excellence will compile existing and new data to better understand the full range of value these projects provide to the region.

Outcomes

Results from this research will provide a better understanding of the local ecosystem services that living shorelines can provide, determine project-specific dynamics, and determine the timeline of when these services are provided. Many interested landowners ask when they can expect to see results of restoration efforts. This project will provide a general timeline of when results have been realized in the past and give landowners more information than we currently can provide, which will also help to inform the development of restoration targets for each of our estuaries and aid in future project designs and management decisions. Living shoreline projects have been installed across these estuaries since the early 2000s (Figure 2). As practitioners gained knowledge from various projects, many transitioned from using bagged oyster shell to limestone rock for breakwater structures (Figure 3). Developing restoration targets will provide each program with goals related to the return on investment both environmentally and economically when the information resulting from this effort is combined with suitability assessments respective to each estuary.

Impact

This project brings together over 11 partners from across the region. Many of the partners represent end users that were involved in siting the living shoreline projects, which were based directly on resource management needs, and these same partners will be responsible for applying resulting information into management application. C-STARS will provide information on habitat creation, fish and oyster production, nitrogen removal, and shoreline protection associated with living shorelines at a regional and temporal scale. The translation of these metrics to localized ecosystem services will allow end users to promote and understand the value of living shorelines and increase implementation at a public and commercial scale.

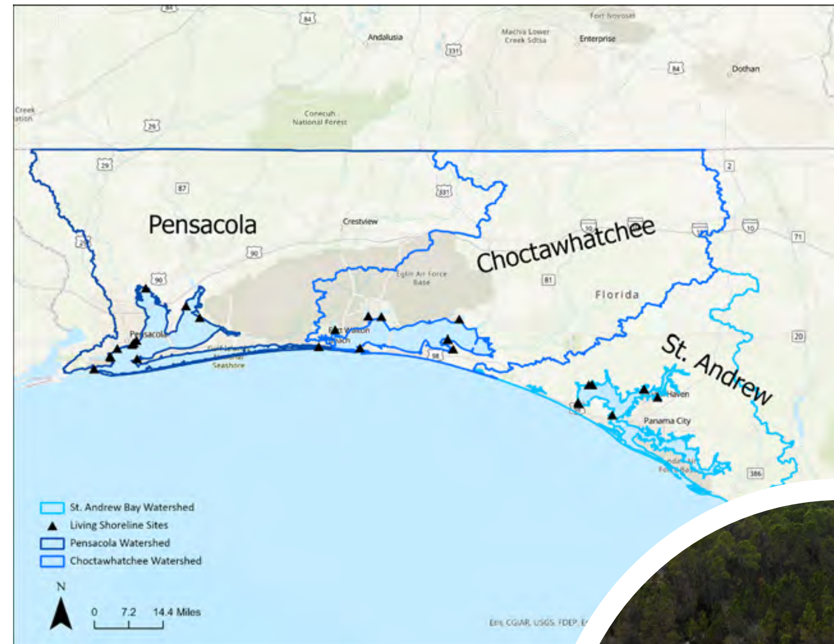
Estuary Programs, local municipalities, state and federal agencies, and NGOs benefit from this research. The Estuary Program can use the resultant information in combination with existing or future living shoreline suitability models to determine realistic restoration targets. This information will also allow entities like the Estuary Programs and other NGOs such as Choctawhatchee Basin Alliance and St. Andrew Bay Watch to communicate the benefits to local municipalities to increase adoption on public lands. The transfer of this information to our partners and state and federal agencies will also help these entities to message the benefits of living shorelines and ecosystem services, which can be used in various ways to help meet their missions.

Many of our partners have a limited capacity to analyze their data and share with public and technical audiences, which results in data gaps. Consequently, much of our partners' existing data is left out of analyses and their true regional impact is undervalued. The online platform aims to alleviate some of these demands by making data more readily available and allow information to be kept up-to-date as new projects come online. This platform will be similar to that of ArcGIS Hub, where geographic information can be accessed and data downloaded by other entities. We anticipate that the results will be used to message the value of living shorelines, increase and streamline implementation, inform research, and provide a synthesized, regional dataset of living shoreline monitoring data and ecosystem service values.

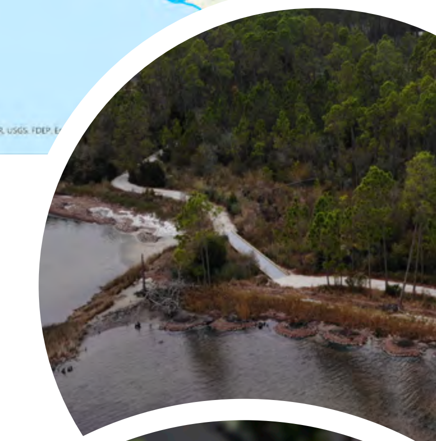
This project will be executed through a diverse partnership across the Florida Panhandle from Escambia to Bay County. Following the Deepwater Horizon oil spill disaster, The Nature Conservancy (TNC) brought numerous stakeholders together based on watershed boundaries to determine the driving issues and how to address these issues to proactively plan for the allocation of potentially billions of dollars toward improving our environment. Ultimately, these communities devoted funds, including those that resulted from the RESTORE Act, to establish three Estuary Programs that would be locally driven. These three Estuary Programs have been working across their local communities to build and maintain partnerships and effectively implement actions that have been identified to have positive impacts on both local communities and natural resources. The partnership working to execute this project is the result of over a decade of work by these partners and many others. Partners both direct and indirect include: St. Andrew and St. Joseph Bays Estuary Program, Choctawhatchee Bay Estuary Program, Pensacola and Perdido Bays Estuary Program, Choctawhatchee Basin Alliance, St. Andrew Bay Watch, Florida State University RIDER Center, Rowan University, The Nature Conservancy, Northwest Florida Water Management District, Florida Department of Environmental Protection, Florida Fish and Wildlife Conservation Commission, and the U.S. Environmental Protection Agency.

Future Work

This information could be used to help prioritize green infrastructure and natural buffers in coastal areas to trap sediments and pollutants, and prevent erosion. Lessons learned could also be incorporated into Land Development codes and update language in permitting to streamline installation for coastal property owners. The data resulting from this project could also be combined with a number of other datasets to better understand best practices based on environmental characteristics, including size and number of reefs, angle of installation, and recommended project size to realize benefits.



▲ Figure 1. Map of the living shorelines project sites across Pensacola, Choctawhatchee, and St. Andrew Bay estuaries.



► Figure 2. RiverCamps living shoreline includes bagged oyster reef and grass planting project in St. Andrew Bay, completed in 2017 by St. Andrew Baywatch. *(Photo: Darryl Boudreau)*

► Figure 3. Jenna Kilpatrick and Chad Perko of Choctawhatchee Basin Alliance remove a mature oyster shell bag, that was placed two years ago, from a constructed reef to measure size and abundance of oysters, and observe and record associated algae, invertebrates, and fish. *(Photo: Choctawhatchee Basin Alliance)*

Comparative Study of Carbon Storage in Restored Versus Natural Florida Gulf Coast Mangrove Ecosystems

BRAD **ROSENHEIM**, ISABEL **ROMERO**, DONNY **SMOAK**, KARA **RADABAUGH**, & JOSH **BREITHAUPT**

Background

Mangroves are important ecosystems along the Florida Gulf Coast, providing diverse services related to habitat, storm surge protection, and carbon sequestration. Our project, funded in 2023, aims to compare restored and natural Gulf Coast mangrove systems to determine success and resilience of restored systems on the decadal time scale. We will compare natural mangrove forests in Naples and Tampa Bay to adjacent mangroves that were created through restoration projects twenty to forty years ago. Comparing the carbon stock in these systems along with other measurements will isolate the key variables that affect aboveground biomass and belowground carbon sequestration.

Field work for this project began in July 2023 with site selection aided by end users Florida Fish and Wildlife Conservation Commission (FWC) and TerraCarbon LLC. We selected sites based on scouting data, and data collection began in September 2023.

Outcomes

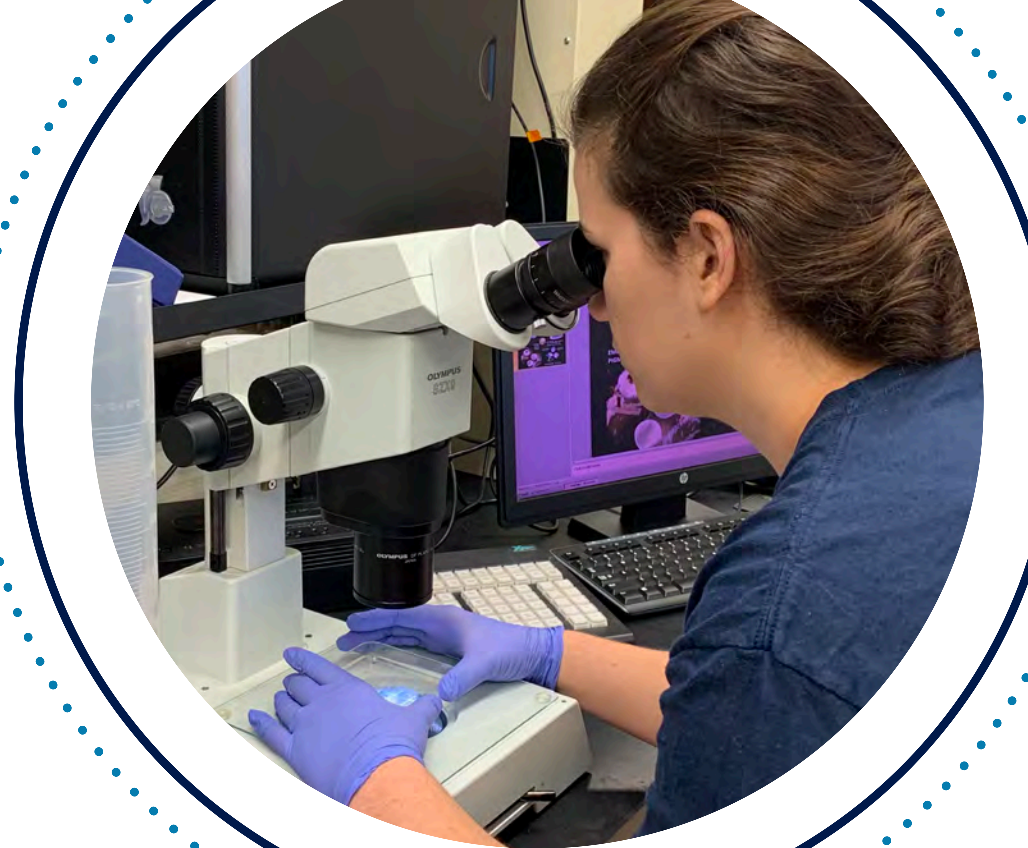
Initial site evaluation has indicated the presence of mangrove peat at the restored sites. Mangrove peat accumulates because organic matter decomposes slowly in the naturally anoxic and saturated soil after establishment of a healthy mangrove forest. Peat production constitutes an effective carbon sink as carbon dioxide from the atmosphere is removed by plants during photosynthesis, and much of the resulting plant organic matter is stored belowground as peat. This observation alone indicates that restored mangroves along the Gulf Coast of Florida can serve as carbon sinks in addition to natural mangroves. Our study will determine how long after creation of the restored forests peat started to accumulate and how well these restored systems are sequestering carbon compared to adjacent natural sites.

Impact

Monitoring at restoration sites varies widely and is rarely conducted for more than two to five years following project completion. Because this study focuses on sites that are twenty to forty years old, this offers a unique opportunity to quantify the characteristics of restored mangroves on a longer timescale. The results of this comparative study will not only provide guidance on the long-term success of restoration projects, but they will also inform the capacity for Florida mangrove restoration projects to serve as natural climate solutions by removing carbon from the atmosphere and long-term storage as peat belowground. Such information directly informs the development of carbon removal and offset projects that are required for nations to meet Paris Agreement commitments, and for corporations to meet voluntary commitments to emissions reductions. As our research progresses, we also anticipate interest from the academic community towards isolating the key variables that affect carbon sequestration in mangrove ecosystems globally. Identification of the variables that lead to maximized forest biomass, carbon sequestration, and soil accretion (e.g., elevation, nutrient concentration, salinity, etc.) will enable this project to provide guidance for future restoration projects on how to maximize carbon sequestration and forest resilience in the face of sea-level rise.

► Mangrove crab perched on a mangrove leaf. *(Photo: H. Stewart, FWRI)*

▲ Ph.D. student B. Alejandra Aguilar (USF) crosses a tidal creek in a Tampa Bay natural mangrove site. *(Photo: B. Rosenheim, USF)*



CONCLUSION

Science, research, and monitoring projects tackled over the last decade through the Florida RESTORE Act Centers of Excellence Program (FLRACEP) generated 53 publications to date. Projects ranged from basic life history studies, technology and methods development, simulation modeling for scenario analysis, and a longitudinal evaluation of restoration methodologies. Each publication contributes to our growing understanding of the Gulf of Mexico ecosystem and equips scientists, managers, and policy makers with the knowledge required for sound stewardship of this remarkable ecosystem. This summary, however, is unique in that it provides a comprehensive view across the body of work accomplished thus far, enabling us to evaluate the collective contribution to the stated goals and objectives of the RESTORE Act and the FLRACEP.

However beautiful the strategy, you should occasionally look at the results.

–SIR WINSTON CHURCHILL

Each project summary outlined the research question, key findings, a description of project impacts, and proposed future work, but embedded within and among them are advances less obvious to the eye. Nearly-annual all hands meetings with our researchers stimulated new ideas, innovative approaches, and unique partnerships. Technologies were modified for expansion to new taxa or habitats. Fieldwork constraints imposed by the COVID pandemic catalyzed the use of new approaches to analyzing archived tissues, increasing the return on investment of the original collection. Proposal processes incentivized engagement of early career researchers as an investment into the scientific mentors of the future. Means of increasing the awareness and transfer of research and findings to other Gulf of Mexico Centers of Excellence were tapped. These outcomes, though less tangible, represent a significant contribution to the collective impact of the FLRACEP.

Determined to be responsible stewards of the resources entrusted to the FLRACEP, this comprehensive look at the research conducted over the last decade serves as the launching point for our strategic planning process to guide our work over the next decade. We will use what we have learned thus far to evaluate and refine our program focus, to harvest and prioritize second-generation research questions, and evaluate knowledge gaps germane to our mission, all toward bolstering the relevance and impact of the FLRACEP. Now that you have studied our work thus far, we would reiterate our invitation to you. If you are so inspired, you are encouraged to provide your thoughts on our work thus far and our plans going forward via email at flracep@usf.edu.

The Program Management Team

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AUTHOR INFORMATION

Center of Excellence Lead/Principal Investigator **in bold**

Cameron Ainsworth, Ph.D., Associate Professor of Physical & Fisheries Oceanography, University of South Florida, St. Petersburg, FL

Michael Allen, Ph.D., Professor of Fisheries & Aquatic Science, University of Florida, Gainesville, FL

Cory Ames, Graduate Research Assistant, Nova Southeastern University, Dania Beach, FL

Jerald S. Ault, Ph.D., Professor of Fishery Management Science & Policy, University of Miami, Miami, FL

Elizabeth Babcock, Ph.D., Associate Professor of Marine Biology & Ecology, University of Miami, Miami, FL

Kendra K. Badcock, Graduate Student, University of West Florida, Pensacola, FL

Susan Lowerre-Barbieri, Ph.D., Research Scientist, Florida Fish and Wildlife Research Institute, St. Petersburg, FL

René Baumstark, Ph.D., Section Leader, Florida Fish and Wildlife Research Institute, St. Petersburg, FL

Jenna Bennett, Undergraduate Researcher, University of Florida, Gainesville, FL

Kevin M. Boswell, Ph.D., Associate Professor & Director of Marine Biology, Florida International University, Miami, FL

Anna Braswell, Ph.D., Assistant Professor of Coastal Ecosystems & Watersheds, University of Florida, Gainesville, FL

Mya Breitbart, Ph.D., Distinguished University Professor, University of South Florida, St. Petersburg, FL

Josh Breithaupt, Ph.D., Assistant Research Scientist, Florida State University, St. Teresa, FL

Sandra Brooke, Ph.D., Full Research Faculty, Florida State University, St. Teresa, FL

Jack Brzoza, Biologist, Sanibel Captiva Conservation Foundation, Sanibel, FL

Jane M. Caffrey, Ph.D., Professor of Estuarine & Coastal Ecology, University of West Florida, Pensacola, FL

Simona Ceriani, Ph.D., Research Scientist, Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission, St. Petersburg, FL

Florian Cesbron, Ph.D., Associate Professor, National Institute of Marine Sciences and Techniques ((Cnam Intechmer)/Caen University (LUSAC)), Cherbourg-en-Cotentin, France

David Chagaris, Ph.D., Nature Coast Biological Station, University of Florida, Cedar Key, FL

Charles Cotton, Ph.D., Associate Professor, State University of New York, Cobleskill, NY

Amanda Croteau, Ph.D., Center for Environmental Diagnostics and Bioremediation, University of West Florida, Pensacola, FL

Kristen Dahl, Ph.D., School of Forestry, Fisheries and Geomatic Sciences, University of Florida, Gainesville, FL

Matthew Deitch, Ph.D., Assistant Professor of Watershed Management & Sustainability, University of Florida, Gainesville, FL

Shelby Eagan, Graduate Research Assistant, Nova Southeastern University, Dania Beach, FL

Haley Gancel, Ph.D., Staff Scientist, Pensacola and Perdido Bays Estuary Program, Pensacola, FL

Steven B. Garner, Ph.D., University of Florida, Gainesville, FL

Tesfay Gebremicael, Ph.D., IFAS West Florida Research and Education Center, University of Florida, Milton, FL

James Gelsleichter, Ph.D., Professor, University of North Florida, Jacksonville, FL

Andrew Glinsky, NOAA, Honolulu, HI

Jessica Graham, Ph.D., Director, St. Andrew & St. Joseph Bays Estuary Program, Florida State University, Tallahassee, FL

R. Dean Grubbs, Ph.D., Associate Director of Research, Florida State University Coastal and Marine Laboratory, St. Teresa, Florida

Arnaud Grüss, Ph.D., Fisheries Population Modeler, National Institute of Water and Atmospheric Research, Wellington, New Zealand

Holden Harris, Ph.D., School of Natural Resources and Environment, University of Florida, Gainesville, FL

Beatre Combs-Hintz, Ph.D. Student, College of Marine Science, University of South Florida, St. Petersburg, FL

Chuanmin Hu, Ph.D., Professor, College of Marine Science, University of South Florida, St. Petersburg, FL

Wade H. Jeffrey, Ph.D., University of West Florida, Pensacola, FL

Paul Julian, Ph.D., Biogeochemist, Everglades Foundation, Fort Meyers, FL

Sean Keenan, Assistant Reseach Scientist, Florida Fish and Wildlife Research Institute, St. Petersburg, FL

Vincent Lecours, Ph.D., Courtesy Assistant Professor, University of Florida, Gainesville, FL

Chad Lembke, Research Faculty, Project Engineer, University of South Florida, St. Petersburg, FL

David Mann, Ph.D., President, Loggerhead Instruments, Sarasota, FL

Katherine L. Mansfield, Ph.D., Professor & Director of the Marine Turtle Research Group, University of Central Florida, Orlando, FL

Steve Murawski, Ph.D., Research Professor, University of South Florida, St. Petersburg, FL

William F. Patterson III, Ph.D., Professor, School of Forestry, Fisheries and Geomatic Sciences, University of Florida, Gainesville, FL

Ernst Peebles, Ph.D., Associate Professor, University of South Florida, St. Petersburg, FL

Justin Perrault, Ph.D., Vice President of Research, Loggerhead Marinelife Center, Juno Beach, FL

Katrina Phillips, Ph.D., National Science Foundation Postdoctoral Fellow, University of Massachusetts, Amherst, MA

Nathan Putman, Ph.D., Scientist, LGL Ecological Associates Ltd., Bryan, TX

Xiaohui Qiao, Ph.D., Research Assistant Professor, University of Florida, Gainesville, FL

Kara Radabaugh, Ph.D., Research Scientist, Florida Fish and Wildlife Research Institute, St. Petersburg, FL

Nicole Raineault, Ph.D., Chief Scientist, Florida Institute of Oceanography, St. Petersburg, FL

Hallie Repeta, Ph.D. Student, College of Marine Science, University of South Florida, St. Petersburg, FL

Isabel Romero, Ph.D., Associate Research Professor, College of Marine Science, University of South Florida, St. Petersburg, FL

Brad Rosenheim, Ph.D., Professor of Geological Oceanography, University of South Florida, St. Petersburg, FL

Ryann Rossi, Ph.D., Estuary Scientist, St. Andrew and St. Joseph Bays Estuary Program, Panama City, FL

Whitney Scheffel, Lead Scientist, Pensacola and Perdido Bays Estuary Program, Pensacola, FL

Danielle Schwarzmann, Ph.D., Chief Economist, NOAA National Marine Sanctuaries, Silver Spring, MD

Rebecca Scott, Ph.D. Student, College of Marine Science, University of South Florida, St. Petersburg, FL

Kelly Sloan, Coastal Wildlife Director & Sea Turtle Program Coordinator, Sanibel Captiva Conservation Foundation, Sanibel, FL

Steven G. Smith, Ph.D., Senior Research Scientist, CIMAS, University of Miami, Miami, FL

Donny Smoak, Ph.D., Professor, University of South Florida, St. Petersburg, FL

Nicole Stacey, Ph.D., Clinical Associate Professor, University of Florida, Gainesville, FL

Chris Stallings, Ph.D., Associate Professor of Biological Oceanography, University of South Florida, St. Petersburg, FL

Tracey Sutton, Ph.D., Professor, NOVA Southeastern University, Fort Lauderdale, FL

Joseph H. Tarnecki, Research Scientist, University of Florida, Gainesville, FL

J. Christopher Taylor, Ph.D., Ecologist, NOAA, Beaufort, NC

Lisa A. Waidner, Ph.D., Assistant Professor, University of West Florida, Pensacola, FL

Brian K. Walker, Ph.D., Research Program Director, GIS & Spatial Ecology, NOVA Southeastern University, Fort Lauderdale, FL

Amy Wallace, Ph.D., Postdoctoral Researcher, University of Florida, Gainesville, FL

Randall Wells, Ph.D., Director, Sarasota Dolphin Research Program, Mote Marine Laboratory, Sarasota, FL

Yao Yao, Ph.D. Student, College of Marine Science, University of South Florida, St. Petersburg, FL

Hannah Vander Zanden, Ph.D., Assistant Professor of the Department of Biology & Archie Carr Center for Sea Turtle Research, University of Florida, Gainesville, FL

COMMON ACRONYMS

CBEP • Choctawhatchee Bay Estuary Program

CCMP • Comprehensive Conservation and Management Plan

CIE-NOAA • Centers of Independent Experts

CIMAS-NOAA • Cooperative Institute for Marine and Atmospheric Studies

CMECS • Coastal and Marine Ecological Classification Standard

CoE • Center of Excellence

CUFES • Continuous underway fish egg sampler

DEPM • Daily Egg Production Method

DwH • Deepwater Horizon

DTAG • Digital acoustic archival tag

iTAG • Integrated Tracking of Aquatic Animals in the Gulf of Mexico

EPA • Environmental Protection Agency

FAC • Fluorescent aromatic compounds

FIO • Florida Institute of Oceanography

FL TIG • Florida Trustees Implementation Group

FLRACEP • Florida RESTORE Act Centers of Excellence Program

FWC • Florida Fish and Wildlife Conservation Commission

FWRI • Fish and Wildlife Research Institute

GOM • Gulf of Mexico

GoMRI • Gulf of Mexico Research Initiative

GoMDIS • Gulf of Mexico Dolphin Identification System

IUCN • International Union for Conservation of Nature

NMFS-NOAA • National Marine Fisheries Service

NOAA • National Oceanic and Atmospheric Administration

NPZD • Nutrient-phytoplankton-zooplankton-detritus

nGOM • Northern Gulf of Mexico

NWFSC-NOAA • Northwest Fisheries Science Center

OTN • Ocean Tracking Network

PPBEP • Pensacola and Perdido Bays Estuary Program

PAH • Polycyclic aromatic hydrocarbon

ROV • Remotely operated vehicle

SASJBEP • St. Andrew and St. Joseph Bays Estuary Program

SEAMAP-NMFS • Southeast Area Monitoring and Assessment Program

SEFSC-NOAA • Southeast Fisheries Science Center

SERO-NOAA • Southeast Regional Office

SHELF • Spawning Habitat & Early-life Linkages to Fisheries

SSP • Spawning Stock Biomass

TNC • The Nature Conservancy

WFS • West Florida Shelf

The FLRACEP and FIO leadership greatly appreciate the important work of the founding team and key personnel who have made the program a success.

Current FLRACEP Staff

Kristin Erickson
William (Monty) Graham
Nicole Raineault
Lauren Taylor
Kelsey Wilkinson

Past Program Management Team

James Holbrook
George Morgan
Dennis Nixon
Keith Overton

Past FLRACEP Staff

Elizabeth Fetherston-Resch
James Garey
William (Bill) Hogarth
Lieu Huynh
Phillip Kramer
Nicole Mendez
Cam Ngo
Andy Shepard
Kristy Tavano