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FINAL REPORT

REPP-Connectivity-Pulley Ridge
Connectivity of the Pulley Ridge-South Florida Coral Reef Ecosystem: Processes to Decision-Support Tools

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Executive Summary

This multi-PI and multi-institutional study, led by the University of Miami and coordinated through two NOAA Cooperative Institutes (CIMAS and CIOERT), investigated the role that the mesophotic coral ecosystems (MCEs) of Pulley Ridge (250 km west of Cape Sable, Florida) plays in replenishing key species in the downstream reefs of the Florida Keys and Dry Tortugas. This study included evaluating the processes and potential for population connectivity, assessing the community structure of the Pulley Ridge MCE, determining the value of the resource, and providing information to resource managers. The research activities included both field, laboratory, and modeling efforts across physical, biological, and socio-economic disciplines. Major findings included identification of potential dispersal pathways between Pulley Ridge MCE and the Dry Tortugas–Florida Keys reef ecosystem, species-specific capacity for utilizing such dispersal pathways, and evidence of potential for some species of a limited deep-shallow water larval subsidy. Remotely operated vehicle surveys of Pulley Ridge (inside and outside of the Habitat Area of Particular Concern [HAPC] boundaries) revealed both more spatially extensive mesophotic scleractinian coral communities than previously known, as well as evidence of a considerable decrease in coral cover on the Main Ridge in the last 10 years. Also, fish populations, while diverse, were primarily associated with red grouper pits, habitat that is also shared by the invasive lionfish (> 2 orders of magnitude increase over the last 6–8 yrs). Evidence suggests that bicolor damselfish populations at Pulley Ridge may grow more slowly, but they attain larger sizes than shallow-water fish, and may contribute up to 9% of the total reproductive output of fish within the entire Pulley Ridge–Dry Tortugas–FL Keys reef system. These data were shared with management stakeholders for consideration of boundary changes to both the HAPC and FKNMS. Economic modeling of impact of greater closure on the fishing community suggest minor (~3%) losses, though perceptions within the fishing community is that losses would be significant to very significant. As a result of our findings, the Pulley Ridge HAPC was expanded by the Gulf of Mexico Fishery Management Council in 2018.

Purpose

The overall goals of this project were to:

(1) Evaluate the potential connectivity of the Pulley Ridge (PR) mesophotic coral ecosystem (MCE) to other MCEs and shallow reef habitats of the West Florida shelf (i.e., Dry Tortugas [DT]) and the Florida keys (FLKeys);

(2) Describe the community composition and function of the PR MCE on the southwest Florida Shelf (Figure 1);

(3) Estimate ecosystem value of this system; and

(4) Place all data (population connectivity, community structure, and ecosystem value) into a framework to facilitate data access by managers.

Beyond the scientific goals, this project was also aimed at getting the most complete information into the hands of managers and stakeholders to inform current and future management decisions pertaining to the PR/DT/FLKeys mesophotic and shallow reef ecosystems.

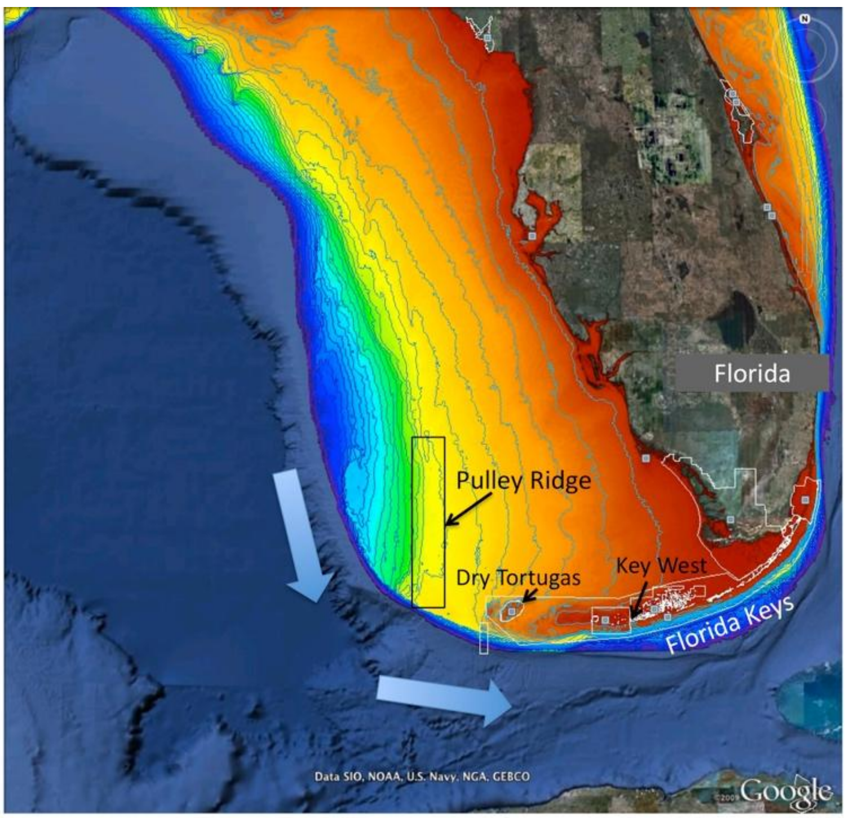


Figure 1. Full Study area showing PR in relationship to the DT and the FLKeys. Bathymetry is shown every 10 m from 0–200 m depth.

To meet these overall goals, we targeted the following objectives:

➢ **Identify the primary physical oceanographic drivers influencing larval dispersal pathways.** Specifically,

- Determine the influence of the Loop Current (LC) proximity to the southwest Florida Shelf (SWFS) on the circulation and water properties around the PR;
- Determine the influence of the Florida Current (FC) proximity to the Atlantic Florida Keys Shelf on the circulation and water properties around DT;
- Determine the influence of cyclonic eddies along the LC/FC system on cross-shelf and along-shelf processes determining the physical connectivity between PR and the DT.

➢ **Model likely connectivity pathways between PR, DT and the FLKeys, as well as other potential upstream sources along the western Florida shelf.** Specifically,

- Obtain (through analysis of existing data and collection of new data) empirical data critical for the initial conditions and parameterization of the biophysical model (spawning production, larval 3D distributions, pelagic larval durations [PLD], location-specific growth and mortality).
- Produce species-specific connectivity networks and connectivity matrices for targeted species, including under selected scenarios such as increased ocean temperatures, hurricane passage, and habitat fragmentation.
- Validate the model through comparison of model outputs to existing larval settlement records for the FLKeys and short comparative records of larval supply to PR, and spatial patterns of coral and fish genetic structure.

➢ **Validate inferred connectivity pathways (from above connectivity modeling) through genetic analyses.** Specifically,

- Assess genetic connectivity among subpopulations of each of 8 model species and characterize their comparative genetic diversity using microsatellite and/or SNP markers.
- Quantify the magnitude and direction of gene flow between subpopulations, with a focus on the role of the PR MCE as a refuge and source of recruits to the FLKeys.
- Assess potential constraints on connectivity and response to climate change by determining symbiont community structure (*Symbiodinium* spp.) in the PR coral species.

➢ **Evaluate spatially-explicit fish abundances and provide measures of reproductive output.** Specifically,

- Estimate the spatial distribution, abundance, and size structure of key economically and ecologically important reef-fish species in PR MCE, compared to those regionally located in upstream (west Florida shelf) and downstream (DT-FLKeys) areas.
- Link population abundance and size structure to spatially-explicit reproductive output of selected reef fish species in PR MCE.

➢ **Determine spatially-explicit habitat descriptors and community structure in and about PR and DT.** Specifically,

- To compile and assimilate existing data on community structure of MCEs from the entire study area into a comprehensive database.

- To locate, characterize, and determine the distribution of MCEs in the study area.
- To preliminarily quantify two key reef processes: benthic primary productivity and settlement/recruitment potential of corals.

➢ **Provide estimates of the economic value of ecosystem services of PR and evaluate costs-benefits of specific management option alternatives.** Specifically,

- Evaluate the economic connectivity of PR to users of the ridge and of those biological resources connected ecologically to PR.
- Evaluate the bio-economic ecosystem-level impacts of management options considered for PR.

Approach

Six separate research teams (Physical Oceanography, Bio-physical Modeling, Population Genetics, Population Dynamics, Community Structure, and Bio-economics) utilized a multi-faceted approach to address three overarching goals (connectivity, characterization, and bio-economics). Each team brought specific strengths and methods, and shared data outputs and findings to meet our overall goals. The Decision Support Tools team was responsible for providing a central collecting point for all data for archiving. Figure 2 provides a conceptual diagram of how the various teams interacted.

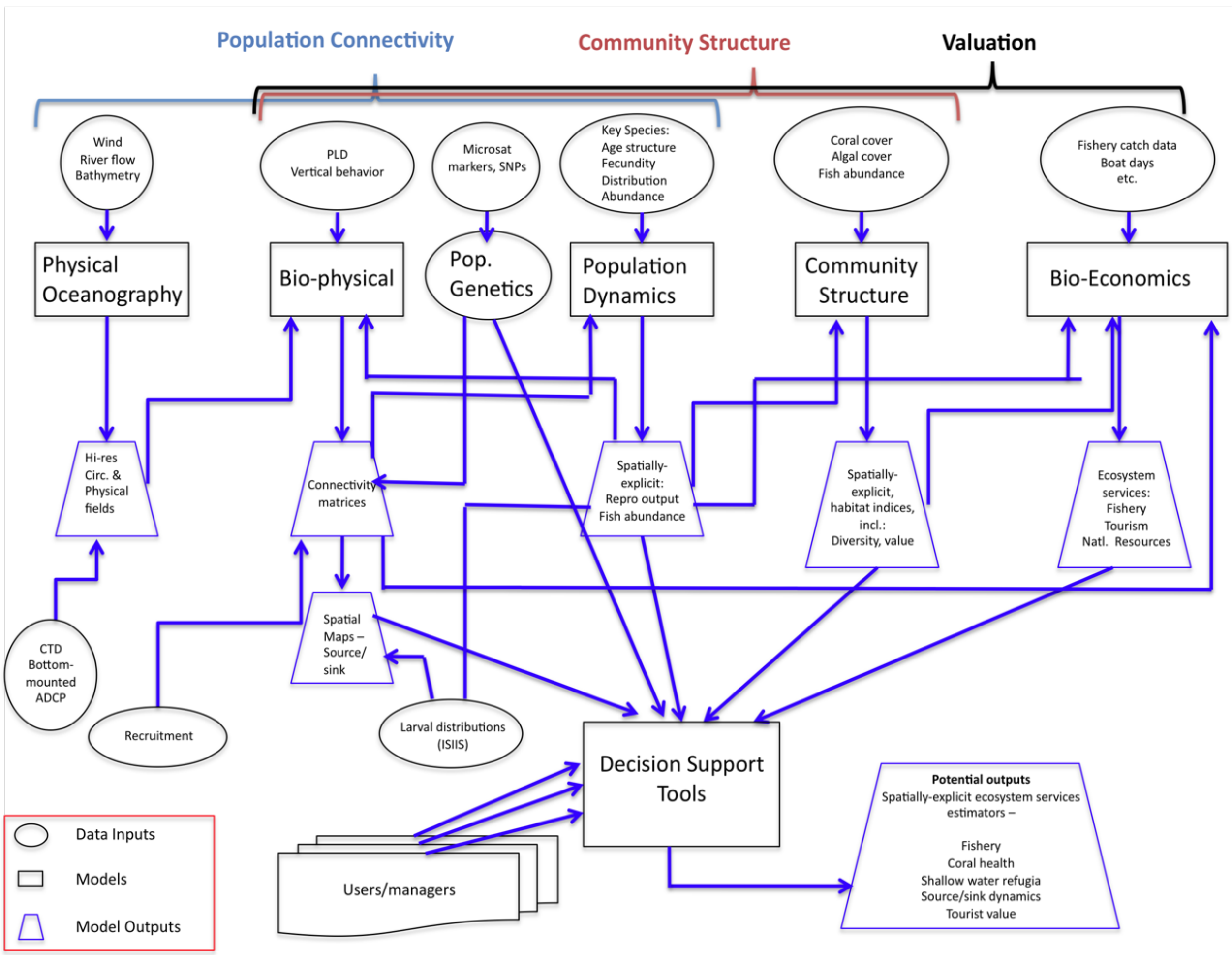


Figure 2. Conceptual project diagram demonstrating how the six research teams worked together to address the three overarching goals.

Data necessary to address the above goals were obtained by three primary means: fieldwork, laboratory-based studies, and modeling. Field data were gathered through a combination of deep technical diving for specimen collections (primarily for population genetics and population dynamics studies), remotely operated vehicle (ROV) transects, moorings [CTD, acoustic Doppler current profiler (ADCP), and light traps], satellite-tracked drifters, MOCNESS, in situ ichthyoplankton sampling, and fish traps. Laboratory data were primarily focused on genetic characterization and age/growth/fecundity studies, and modeling on physical oceanography, population connectivity, and ecosystem value estimation. Data mining was also utilized for model input and parameterization. A unique aspect of this project was a Stakeholder Advisory Board (consisting of federal, state, and non-governmental stakeholders) to help guide the outputs and ensure their utility for resource managers. More specific descriptors of each approach follows.

FIELDWORK

We had four field seasons during the project (2012–2015), with seven research cruises. During the first field season, only one research cruise occurred on the University of Miami's RV *Walton Smith* where both technical diving and ROV operations were conducted. During the 2nd–4th field seasons, we utilized two vessels (RV *Walton Smith* and the MV *Spree*—the latter was focused on technical diving operations including species collections and servicing the three Physical Oceanography (PO) moorings, while the former covered the ROV, fish traps, drifters, light traps, and plankton work).

Physical oceanographic moorings—(Ryan Smith and George Halliwell, NOAA-AOML; Arnoldo Valle-Levinson, University of Florida)

Subsurface PO moorings were deployed in August 2012 and March 2013 (Figures 3–4). One mooring was placed at PR (24°42.00'N, 83°40.47'W in 69.5 m of water) and another northwest of the Tortugas Ecological Reserve North (TERN) in the northern DT (NDT, 24°46.40'N, 83°05.74'W in 54.1 m of water) in August 2012, and in March 2013, one was placed west of the Tortugas Ecological Reserve South (TERS) in the southern DT (SDT, 24°28.54'N, 83°09.21'W in 66.7 m of water). Each mooring was designed to hold a bottom-mounted, upward-facing ADCP, which provided a time series of the current velocity profiles at the site, and a conductivity/temperature (CT) recorder, which provided a time series of bottom temperature and salinity. Instruments at each of the three moorings were maintained annually by technical divers until the instruments were removed in June 2015 (note: the moorings were retrieved in August 2015). Satellite-tracked surface drifters were also deployed 2012–2015 (Figures 5–8) off the R/V *Walton Smith* and in 2014 off the MV *Spree*.

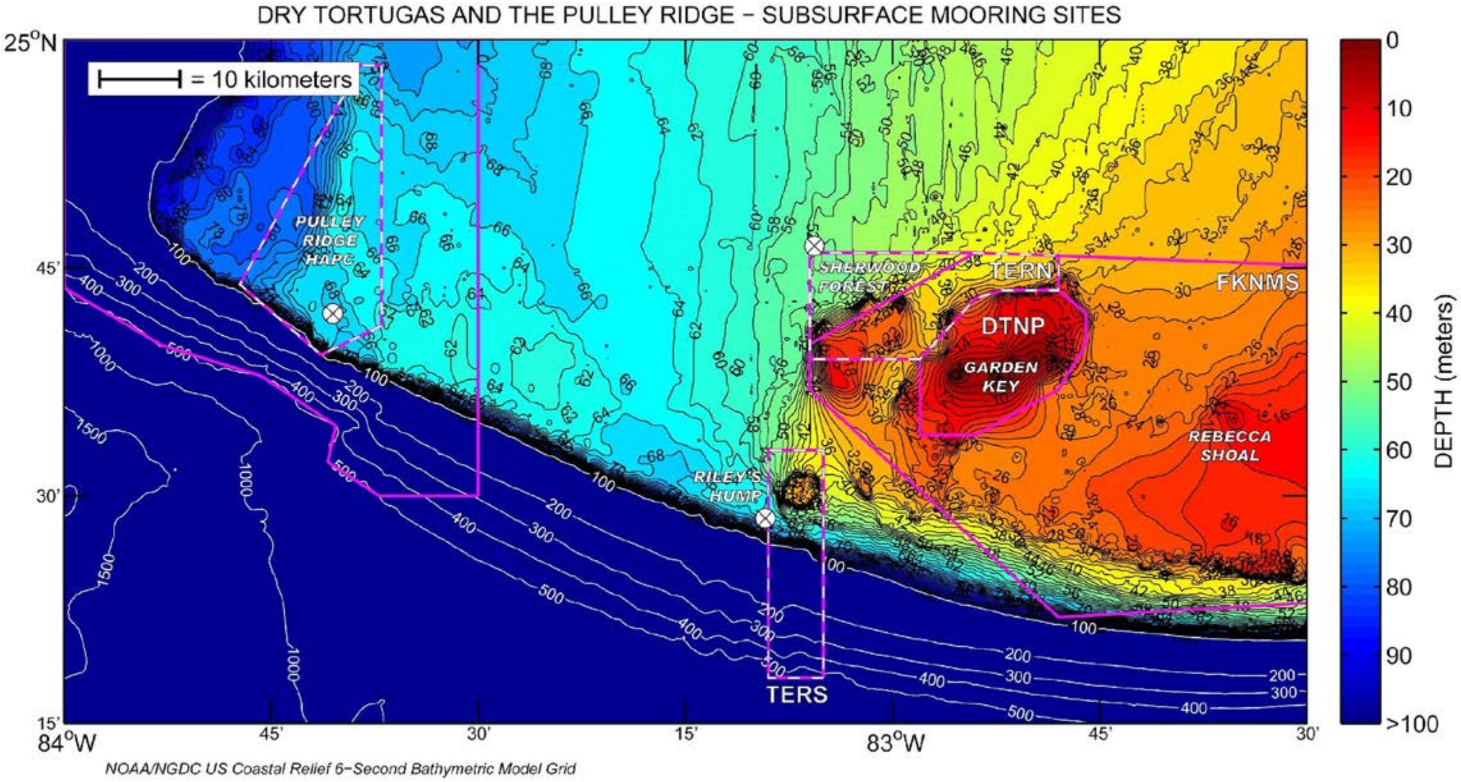
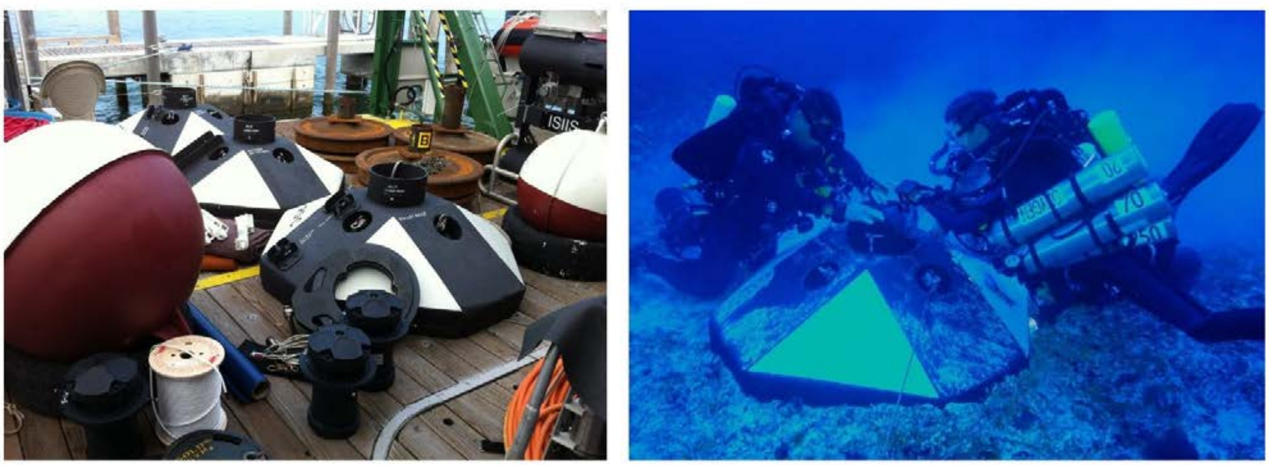


Figure 3. White markers indicate the location of project subsurface PO moorings in the Dry Tortugas (TERN/NDT and TERS/SDT) and at Pulley Ridge (PR). Instrument installations were conducted in August 2012 (PR and NDT) and



March 2013 (SDT).

Figure 4. (Left): PO moorings staged on the RV *F.G. Walton Smith* prior to departure in August 2012. (Right): University of Miami technical divers deploying a PO mooring at Pulley Ridge in August 2012.

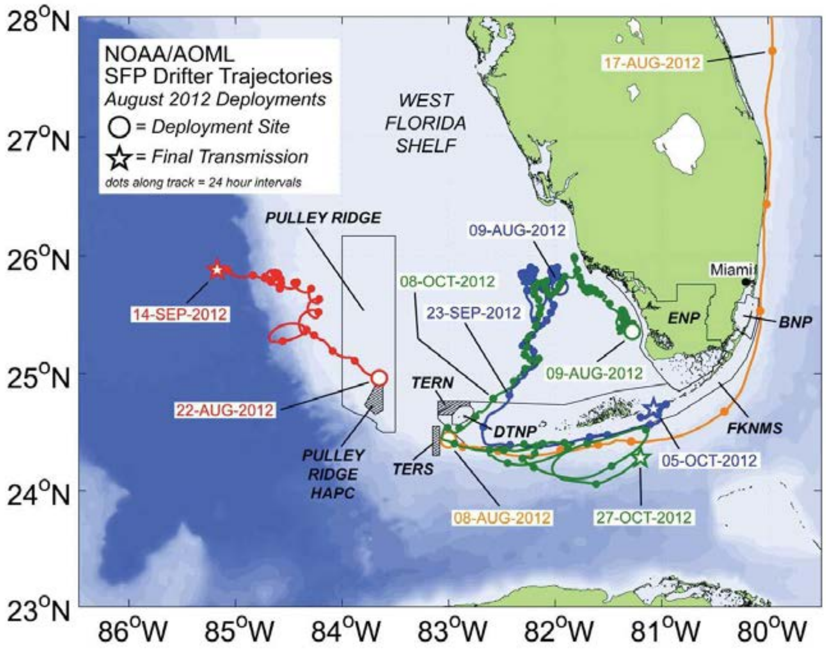


Figure 5. Trajectories of NOAA/AOML South Florida Program (SFP) drifters deployed in south Florida coastal waters during August 2012. The orange/red trajectories correspond to deployments at SDT/PR, respectively. Blue and green are from shelf deployments.

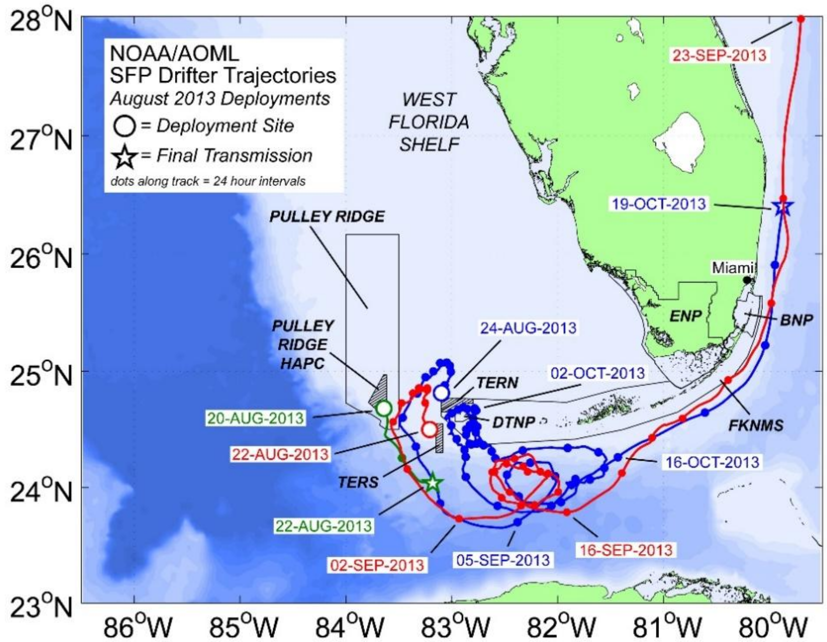


Figure 6. Trajectories of NOAA/AOML SFP drifters deployed in south Florida coastal waters during August 2013. Red/blue/green trajectories correspond to deployments at SDT/NDT/PR, respectively.

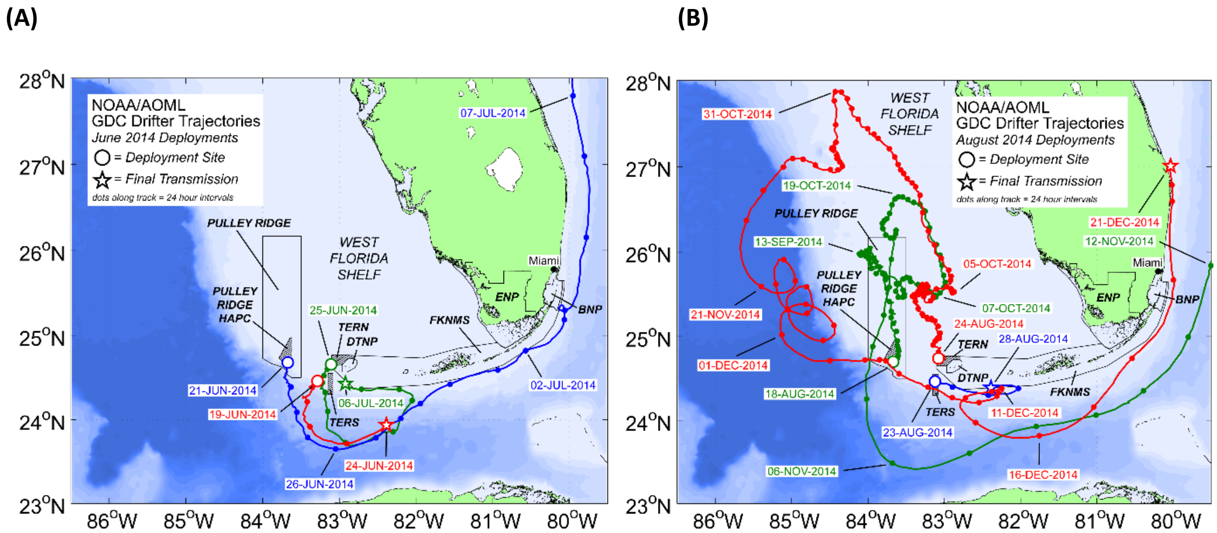


Figure 7. Trajectories of NOAA/AOML SFP drifters deployed in south Florida coastal waters during June 2014 (A) and August 2014 (B). For June 2014, blue (PR), red (SDT), and green (NDT); and for August 2014, green (PR), blue (SDT), and red (NDT).

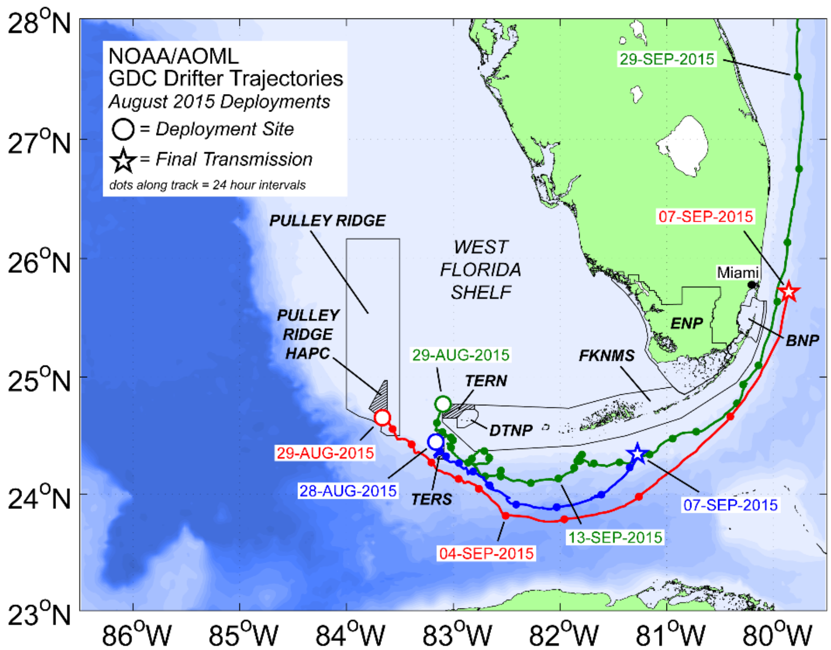


Figure 8. Trajectories of NOAA/AOML SFP drifters deployed in south Florida coastal waters during August 2015. The red trajectories correspond to deployments at PR. Blue and green are from SDT and NDT deployments, respectively.

ROV—(Dennis Hanisak, John Reed, and Stephanie Farrington, HBOI-FAU; Stacey Harter, Andy David, and Heather Moe, National Marine Fisheries Service/Southeast Fisheries Science Center)

ROV operations were conducted on four annual cruises (2012–2015) on the RV *Walton Smith* by the Underwater Vehicles Program of the University of North Carolina at Wilmington [ROV operators: Lance Horn, Glenn Taylor(2012–2013), and Jason White (2013–2015)]. In 2012 and 2013, the UNCW *Super Phantom S2* ROV was used, and in 2014 and 2015 the *Mohawk* ROV, owned by the NOAA National Marine Sanctuaries Foundation. In 2015, the ROV was outfitted with a collection skid making specimen collections possible. In 2012–2015, ROV data were collected at PR, and in 2013–2014, at the DT.

ROV video and photographic surveys were made at PR (to ground-truth multibeam sonar maps) and DT (based on bathymetric maps), to quantify and characterize the benthic habitats, benthic macrobiota, fish populations, and coral/sponge/algal cover. Prior to each ROV dive, georeferenced sonar maps were overlaid with random 1-km^2 blocks and uploaded to the ROV navigation software. Five 100-m radius circles were located within each random block for the quantitative transects. Typically, during one 4-hour ROV dive, five 100-m transects per block were completed, with two ROV dives each day, for a total of ~ten 100-m transects. Overall, 68 1-km^2 random blocks were surveyed over the four cruises at PR (2012–2015), and 23 Blocks in DT (2013 and 2014) (Figures 9 and 10). This totaled 237 hours of ROV video covering a distance of 150 km, and 16,071 still images for quantitative analyses.

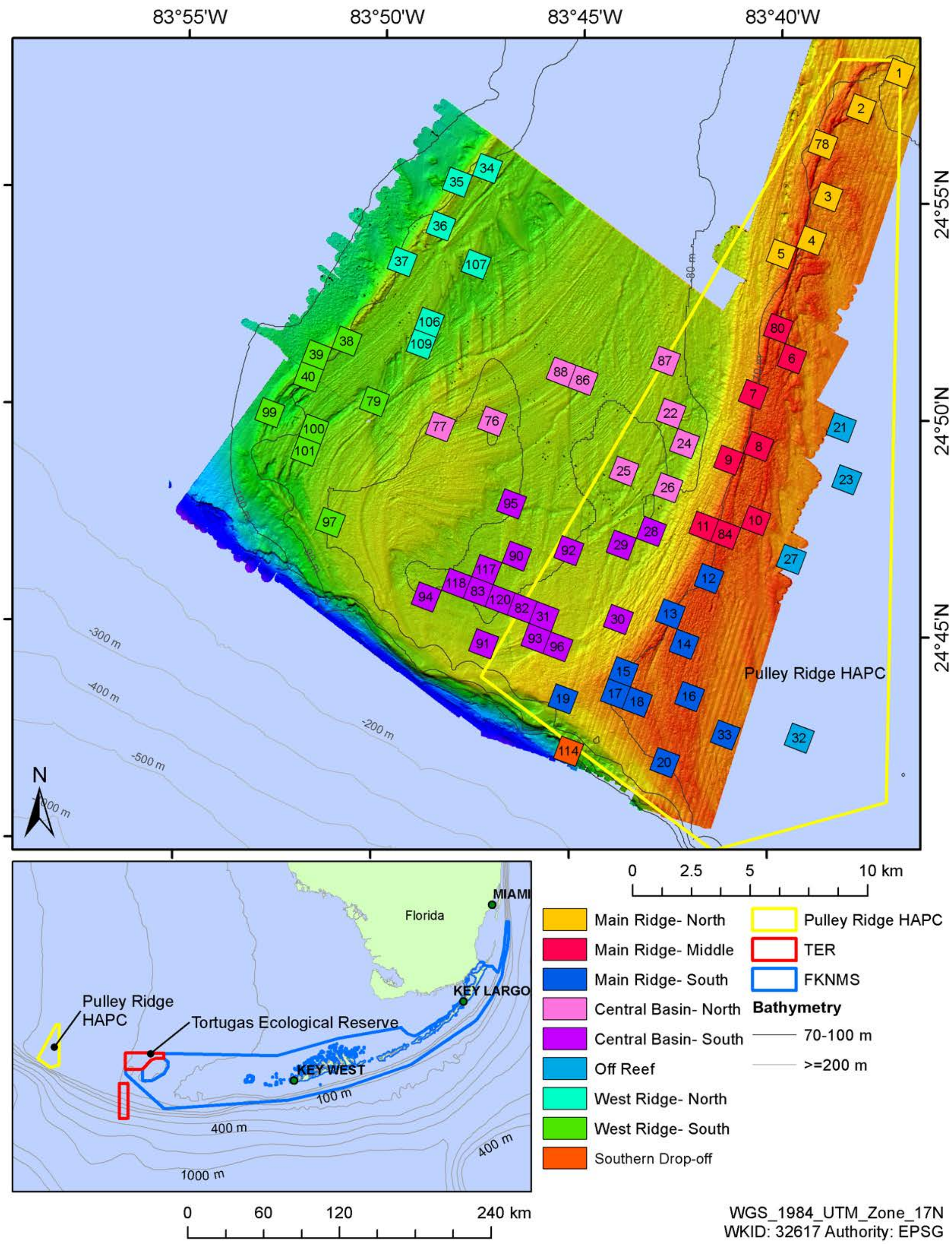


Figure 9. Random 1-km^2 blocks surveyed with ROVs during the 2012–2015 R/V *Walton Smith* cruises at PR. Habitat regions are color-coded: original 2005 PR Habitat Area of Particular Concern (HAPC) boundaries in yellow; Tortugas Ecological Reserves (TER) in red; Florida Keys National Marine Sanctuary (FKNMS) in blue. Background multibeam sonar map: Naar 1999, Cross et al. 2005, NOAA 2013.

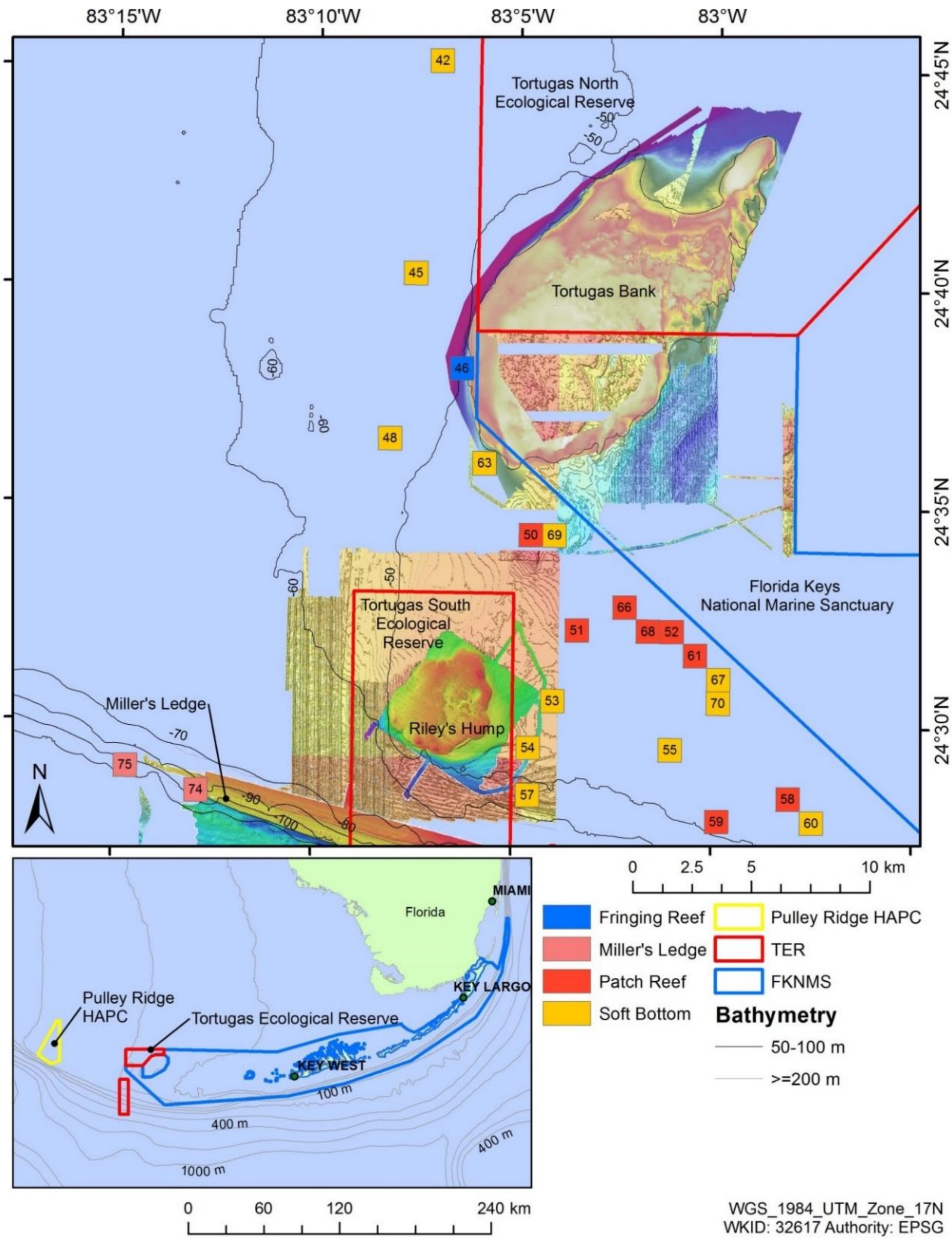


Figure 10. Random 1-km^2 blocks surveyed with ROVs during 2013–2014 R/V *Walton Smith* cruises at DT. Habitat zones are color-coded: Tortugas Ecological Reserves (TER) in red; Florida Keys National Marine Sanctuary (FKNMS) in blue. Background multibeam sonar map: Miller's Ledge - Multibeam Bathymetry Survey, Robertson 2002; TER - Multibeam Bathymetry Survey, NF-11-06-FKNMS, Donahue 2011.

Following the cruises, the FAU Harbor Branch team determined percent cover of substrate type and benthic macrobiota by analyzing the quantitative transect still images with Coral Point Count with Excel Extensions (CPCe 4.1©; Kohler and Gill 2006) and following protocols established in part by Vinick et al. (2012) for offshore, deep-water surveys in this region. For each random block, 120 images were randomly selected and overlaid in CPCe with 50 stratified random dots to identify the substrate and biota. The NMFS team used the video transects for analysis of fish populations and general habitat characterization. All fish within the 100-m transects were identified to the lowest taxonomic level possible from video. Fish species were counted within each transect, summed for the entire block and then divided by the total distance of all transects within a block. This resulted in the linear density of each species by block (# individuals/m). Fish densities per 1,000 m² were then calculated as: (linear density/5)*1000 (based on an average 5-m width field-of-view with the ROV).

Full details of all field ROV protocols and analyses are available in the final cruise report (Reed et al. 2017).

Fish Trapping—(Chris Koenig and Felicia Coleman, FSU)

Chevron fish traps were used by the FSU team during the RV *Walton Smith* cruises in 2013 and 2014 to collect red grouper and lionfish (and other species) to sample for genetics and age/growth analyses (Tables 1–2). To the extent possible, red groupers were released live after sampling. This team also collected samples separately of juvenile red grouper from sites downstream from PR in Florida Bay for comparison with the PR samples.

Table 1. Fish traps, light traps, and MOCNESS collection summary. AS = American Shoal, LK = Lower Keys.

Type	Year	Number/Sample No.	Location	Additional Info, Sensors
Fish Traps	2013	226 fish (incl. 62 red grouper, 4 Lionfish)	PR/DT	Species, Length, Photo, Fin Clip for Genetics, Gonads, Mercury
	2014	214 fish (incl. 25 red grouper, 1 black grouper, 3 red hind, 36 lionfish)	PR/DT	
Light Traps	2012	3 deployments *2 Sets of Traps (3 each) = 18	S PR	
		2 deployments *2 Sets of Traps (3 each) = 12	N PR	
	2013	4 deployments *2 Sets of Traps (3 each) = 24	PR	
		3 deployments *2 Sets of Traps (3 each) = 18	DT	
		2 deployments *2 Sets of Traps (3 each) = 12	AS/LK	
	2014	4 deployments *2 Sets of Traps (3 each) = 24	PR	
		3 deployments *2 Sets of Traps (3 each) = 18	DT	
MOCNESS	2012	3 Deployments *5 Nets/Tow = 15	PR	Plankton Taxonomy Sensors: Temperature, Salinity (PSU), Depth (m)
	2013	3 Deployments *5 Nets/Tow = 15	PR	
		2 Deployments *5 Nets/Tow = 10	DT	

Specimen Collection for Genetic Analyses—(Rick Gomez, UM Technical Diving Team Lead)

All other specimens for taxonomic and genetic studies (bicolor damselfish, corals, sponge, and algae) at PR and DT were obtained through the efforts of a technical dive team headed by Rick Gomez (UM), Table 2. In 2015, we obtained permission to dive within the TER. This normally is a no-take zone, but we were granted a collection permit based on the importance of the project to the FKNMS. In 2013–2015, two divers were added from the University of Puerto Rico (Milton Carlo and Evan Tuohy). We conducted a total of 270 rebreather, mixed-gas dives from 2012–2015: 56 in 2012, 71 in 2013, 77 in 2014, and 66 in 2015. Of these, the UPR divers conducted 76 in 2013–2015, helping us gather much needed data. In 2012, we had a team of four divers and for 2013–2015, we had six divers (including 2 from Puerto Rico).

Table 2. Total samples collected by technical divers and fish traps. Fish traps collected all listed fish species except *Stegastes partitus*.

	Pulley Ridge					Dry Tortugas				
Taxa	2012	2013	2014	2015	PR Total	2013	2014	2015	DT Total	Grand Total
Chlorophyta										
Halimeda spp.	15	33	36	-	84	22	20	44	86	170
Chordata										
*Epinephelus morio (red)**		28	16	-	44	34	14		48	92
M. phenax (Scamp)		8	1		9					9
M. bonaci (Black)		-	1		1					1
M. microlepis (Gag)						1			1	1
Holocentrus rufus		4		1	5	54	2	1	57	62
Pterois volitans		3	36	-	39	1			1	40
Stegastes partitus	36	35	60	12	143	26	27	5	58	201
Cnidaria										
Agaricia spp.	30	37	84	14	165	10	14	119	143	308
Montastraea cavernosa	13	28	26	-	67	10	35	55	100	167
Porites astreoides	-	-	-	-	0	-	-	55	55	55
Porifera										
Xestospongia muta	39	20	57	-	116	9	17	45	71	187
Grand total	**133**	**188**	**315**	**27**	**673**	**166**	**129**	**235**	**531**	**1204**

*Additional red grouper samples were obtained from Campeche Bank (n = 78), West Florida Shelf (n = 51), FLKeys (n = 35), and the Western Atlantic (n = 49).

Plankton Collections—(Robert Cowen and Su Sponaugle, OSU)

To complement existing plankton datasets for the Gulf of Mexico (GoM) and FLKeys region, and to evaluate any site-specific variation in vertical distributions, we utilized two plankton sampling systems: MOCNESS and ISIIS. The MOCNESS is a multiple opening-closing net and environmental sampling system. It was fished during 2012 and 2013 with three depth-discrete net samples taken at PR and 2013 with 2 tows at DT (Table 1). We also deployed ISIIS (In situ ichthyoplankton sampling system) three times during the 2014 cruise (two tows at PR and one at DT). Time availability for these deployments was very limited given the multitude of other activities demanding the science crews' time. ISIIS was towed across the PR study area at night (~2200-2400 hrs) while undulating from the surface to ca. 50 m deep. Given the very limited sampling, sample size was insufficient for a full quantitative assessment.

Light traps—(Su Sponaugle, OSU)

A novel series of light traps was designed to sample the zooplankton and ichthyoplankton above PR and DT (Table 1). On each of two cables (i.e., two replicates), a light trap was deployed at three depths: 6 m off the benthos, in mid-water, and 1 m below the surface. These light traps were identical to those deployed near the benthos and 1 m below the surface at two depths (shallow (<10 m) shelf and deep (20-30 m) shelf) in the FLKeys; the only difference being the anchor and deployment procedure (automatic vs. diver placed) given depth differences. These vertically discrete light traps were deployed for multiple nights on the 2012–2014 cruises to PR and DT (Table 1). Trap contents collected each morning were preserved for later identification and quantification of zooplankton and larval fishes in the laboratory. Use of the same sampling gear across depths at PR and DT allowed for the first comparison of zoo- and ichthyoplankton availability vertically through the water column over these mesophotic reefs, as well as among mesophotic and shallow and deep shelf reefs.

Characterization of diel migration—(Arnoldo Valle-Levinson, UF)

Analysis of field mooring data included time series of physical properties (which were combined with the respective time series from modeling, see next section) and acoustic analyses to characterize diel migration. The Received Signal Strength Indicator (RSSI), which is the raw signal received by the instrument when sending out acoustic pulses, was logarithmically transformed into echo intensity by using the following equations (Pleuddemann and Pinkel 1989; Rippeth and Simpson 1998):

$$I(z,t) = 10\log[RSSI(z,t)] \qquad \text{(Eq. 1)}$$

$$I'(\mathrm{z},\mathrm{t}) = \mathrm{I}(\mathrm{z},\mathrm{t}) - \bar{I}(z) \qquad \text{(Eq. 2)}$$

I' represents the echo intensity anomaly, which is the deviation of each measurement from the mean echo intensity ($\bar{I}(z)$) for that depth, from each deployment period. Since I' is derived from the RSSI, its value will be positive when there is a higher than average number of suspended solids above the instrument, and negative when below average; thus, it is a useful measurement in monitoring the migration patterns of organisms throughout the water column (Valle-Levinson et al. 2014).

LABORATORY-BASED STUDIES

Population genetics—(Mahmood Shivji, NSU; Margie Oleksiak and Andrew Baker, UM; Amy Baco-Taylor, FSU)

We assessed the population genetic connectivity of a mixture of vertebrates and invertebrates with different life histories, including foundational, invasive, and commercially valuable species (Table 3). Standard and state-of-the-art genetic methods were used in this study to evaluate population structure: microsatellites and SNPs. For assessing diversity of algal symbionts, Denaturing Gradient Gel Electrophoresis (DGGE) and quantitative real-time PCR was used. Details of these various techniques are reported in the relevant scientific publications reported below.

Table 3. Species selected for population genetic connectivity analyses.

<table>
<tr><th>Type</th><th>Common Name</th><th>Species</th><th>PI</th></tr>
<tr><td rowspan="4">Fishes</td><td rowspan="2">Red Grouper</td><td rowspan="2">Epinephelus morio</td><td>Mahmood Shivji (NSU)-microsatellite</td></tr>
<tr><td>Margie Oleksiak (UM)-GBS</td></tr>
<tr><td>Lionfish</td><td>Pterois spp.</td><td rowspan="2">Margie Oleksiak (UM)</td></tr>
<tr><td>Bicolor Damselfish</td><td>Stegastes partitus</td></tr>
<tr><td rowspan="4">Corals</td><td rowspan="2">Great Star Coral</td><td rowspan="2">Montastraea cavernosa</td><td>Andrew Baker (UM)</td></tr>
<tr><td>Josh Voss (UM)</td></tr>
<tr><td>Lettuce corals</td><td>Agaricia spp.</td><td rowspan="2">Andrew Baker (UM)</td></tr>
<tr><td>Mustard Hill Coral</td><td>Porites astreoides</td></tr>
<tr><td>Sponge</td><td>Giant Barrel Sponge</td><td>Xestospongia muta</td><td>Mahmood Shivji (NSU)</td></tr>
<tr><td>Algae</td><td>Calcified Green Algae</td><td>Halimeda spp.</td><td>Amy Baco-Taylor (FSU)</td></tr>
</table>

Population dynamics—(Chris Koenig and Felicia Coleman, FSU; Su Sponaugle, OSU and Esther Goldstein, UM)

The FSU team measured trap-captured fish length directly and used fin rays or otoliths to determine age–predominantly of Red Grouper. They derived reproductive data from previous studies (Coleman et al. 1996, Lombardi-Carleson 2008, Coleman et al. 2011, Nelson et al. 2011, Wall et al. 2011) because shipboard collection times (August) were outside of Red Grouper spawning season.

For more detailed studies comparing population demographics between mesophotic and shallow and deep shelf reefs, the OSU/UM team focused on a model fish species, the bicolor damselfish, *Stegastes partitus*. This species is a common planktivore that defends territories and lays benthic eggs on coral reef habitats. Populations exist across the entire depth range of interest, from shallow shelf reefs to mesophotic depths. Diver-collected adult fish were used from PR and shallow and deep shelf reefs to compare age, growth, and reproductive output for individuals and populations. Age and growth estimates were obtained through the interpretation of otolith (ear stone) increments. Multiple techniques were used to estimate reproductive output: gonosomatic index, batch fecundity, and oocyte area. For all computations, temperature was taken into consideration using field-deployed time series obtained from in situ temperature loggers. Additionally, recruitment of newly settled fish was monitored on monthly transects by divers at all shallow and deep shelf sites. Very few recruits were observed at PR throughout the study, thus transect quantification was not useful. For more details on methods see Goldstein et al. (2016a).

The OSU/UM team also examined mechanisms that could contribute to the observed depth-related differences in damselfish demography. They surveyed predator populations in shallow and deep shelf reefs and compared these to ROV surveys of predators at PR and DT. Bicolor damselfish behavior was filmed at shallow and deep shelf sites to compare how much time is apportioned to feeding, defense, sheltering, and reproduction, as well as the distances from shelter that fish travelled to feed in the plankton or exhibit aggressive behavior. Two techniques were used to measure diet—direct gut content of individual fish and stable isotope analysis. As noted above, light traps were used to examine differences in plankton availability at all sites. See Goldstein et al. (2017) for more details on methods.

The demographic data was applied to regional habitat-specific fish densities. ROV fish and habitat surveys from mesophotic depths and diver-based surveys from the shallow and deep shelf sites were used. In addition, publicly available (NOAA) diver-based densities across the wider region were used to compute bicolor damselfish reproductive output from different reef areas and estimate the proportion of regional reproduction potentially sourced from mesophotic depths. See Goldstein et al. (2016b) for more methodological details.

MODELING

Physical Oceanography—(Villy Kourafalou, UM)

A high-resolution (1/100°, ~900 m) numerical model was employed to study circulation processes and physical connectivity. Based on the Hybrid Coordinate Ocean Model (HYCOM), the Florida Straits, South Florida, and Florida Keys (FKEYS-HYCOM) model (Kourafalou and Kang 2012) was expanded to a larger area that covers the PR study site, in addition to the full Florida Straits and shelf areas around South Florida. Multi-year simulations were carried out and model fields were validated against observational data (Kourafalou et al. 2018). Model archives were provided to the biophysical modeling group to expand the physical connectivity findings to full estimates of biophysical connectivity among the reef areas under study (Vaz et al. 2016).

We also employed a new implementation of the HYCOM model covering the entire GoM at 1/50° (~1.8 km; GoM-HYCOM 1/50°) resolution and 32 vertical levels (developed through an ancillary NOAA project). This GoM-HYCOM 1/50° simulation resolves all major processes in both the deep interior (especially variability of LC/FC and eddies) and on shelf areas (especially river plume dynamics). The GoM-HYCOM 1/50° simulation is nested into the global HYCOM operational simulation run at the Navy Research Laboratory, using daily fields. Accurate simulation of Mississippi River pathways was made possible by this GoM model, the only GoM model that also incorporates realistic river forcing, using daily discharge values from the U.S. Geological Survey (USGS) and detailed plume dynamics based on Schiller and Kourafalou (2010) and Schiller et al. (2011). A data assimilation scheme (following Halliwell et al. 2014) constrains the LC/FC system variability.

Both FKEYS-HYCOM and GoM-HYCOM 1/50° have performed hindcast simulations that cover the study period and 7-day forecasts that are publicly disseminated in real time.

Empirical Oceanographic Data—(Josefina Olascoaga, Claire Paris, and Ana Vaz, UM)

Using historical (1994–2016) surface drifting buoy trajectory data, a probabilistic, Lagrangian circulation study was also conducted to further elucidate the oceanographic connectivity of PR with other locations in the GoM and adjacent areas.

Biophysical Modeling—(Claire Paris, Josefina Olascoaga, and Ana Vaz, UM)

The UM team developed a novel 3D module for the Connectivity Modeling System (CMS; Paris et al. 2013) coupled to 3D hydrodynamic fields (PO Group: Kourafalou) to estimate the levels of larval exchange and connectivity between PR, DT, the Marquesas, and the FLKeys for multi-species of corals (*Montastraea cavernosa*, *Porites astreoides*) and fishes (*Stegastes partitus, Pterois* spp.*, Epinephelus morio*). They also developed a new biological module of ontogenetic shift in buoyancy for coral planula larvae. In collaboration with the Population Genetics Group (Baker and Serrano), they explored possible sources of planulae within the wider GoM for *M. cavernosa,* and *P. astreoides*, a species not found in PR. Empirical data from *S. partitus* (Sponaugle and Goldstein) was incorporated into the biophysical dispersal model to refine estimates of connectivity between PR and the FLKeys.

Ecosystem Value—(Mahadev Bhat, FIU; David Die, UM)

To estimate the current levels of commercial fish production in the proposed PR HAPC expansion, the FKNMS expansion, the existing PR HAPC, and the Florida Gulf Coast, we worked with Dr. David R. Gloeckner, Chief of the Fishery Monitoring Branch, NMFS Southeast Fisheries Science Center, and NOAA contractor, Mr. Brett Pierce, who extracted fisheries data from the NOAA Unified Data Processing Logbook (UDP) and Accumulated Landings System (ALS) database. We queried the data from specific regions within and surrounding PR (see Figure 11 for the NMFS data reporting areas), and aggregated the data to protect confidentiality as per the NMFS's requirements**.** From these two datasets, we acquired information on (1) total fisher reported catches by gear, species, and NMFS statistical reporting area of the Florida Gulf Coast (2) total landings by county port and species, (3) average operating cost by NMFS area by aggregated counties and gear, and (4) price per pound by species group and county. The data used within the survey represents approximately 95% of the catch within the inquired region from the years 2012–2014. We computed annual average values of quantity and value of catches and landings and extrapolated to 100%. The above dataset also provided economic trip data from a sample of fishermen selected yearly to report costs per trip, as well as any economic data that was supplied voluntarily. The results of this analysis were further used in the regional input-output (IO) model explained below.

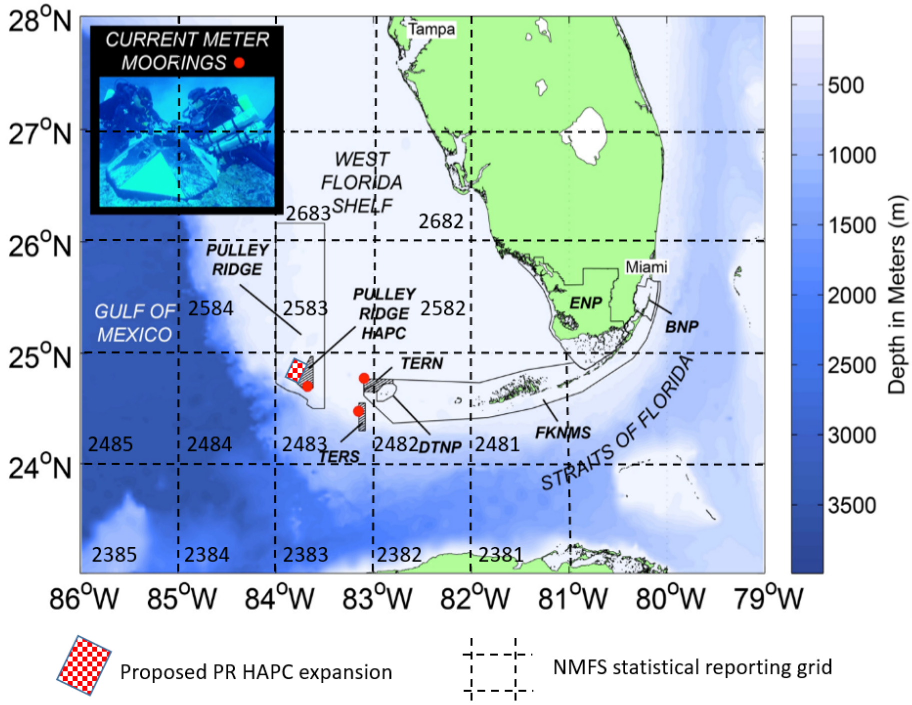


Figure 11. Proposed GMFMC expansion of the PR HAPC enforcement area

The second phase of this study involved developing a regional IO model to analyze the economic contributions of commercial fish harvested in the PR region and the potential economic losses from any restrictions in fishing under the proposed management changes. While many tools exist for regional policy impact assessment, IO methodologies have been commonly used to identify how potential changes within resource management may affect specific industry sectors, as well as the overall regional economy (Seung and Waters, 2006). An IO model consists of a set of equations that represent the interdependencies between different sectors of a regional or national economy. The model tracks the flow of goods and services (purchase and sales) between any two sectors in the economy, final sale to demand sectors (e.g., households, government, investments and exports) and value additions or payments to labor (wage), proprietors (income), taxes, and imports. The IO methodology allows us to track the impacts of changes in one or more economic sectors, such as commercial fisheries, on the rest of the economy in terms of changes in industry outputs, regional income, employment and taxes (Adams et al. 2002). Bhat and Bhatta (2006) characterize the fishery sector's interactions with the rest of the economy using multiple pathways. Dai and Yang (2013) formulate similar impact pathways in infrastructure development in terms of one direct impact and three types of indirect impacts as represented in Figure 12. Under this framework, the fishery-dependent economy is assumed to consist of three distinct groups of sectors, namely, primary fishery (PF) sector, backward linked (BL) sectors, and forward linked (FL). See Figure 12 for their definitions.

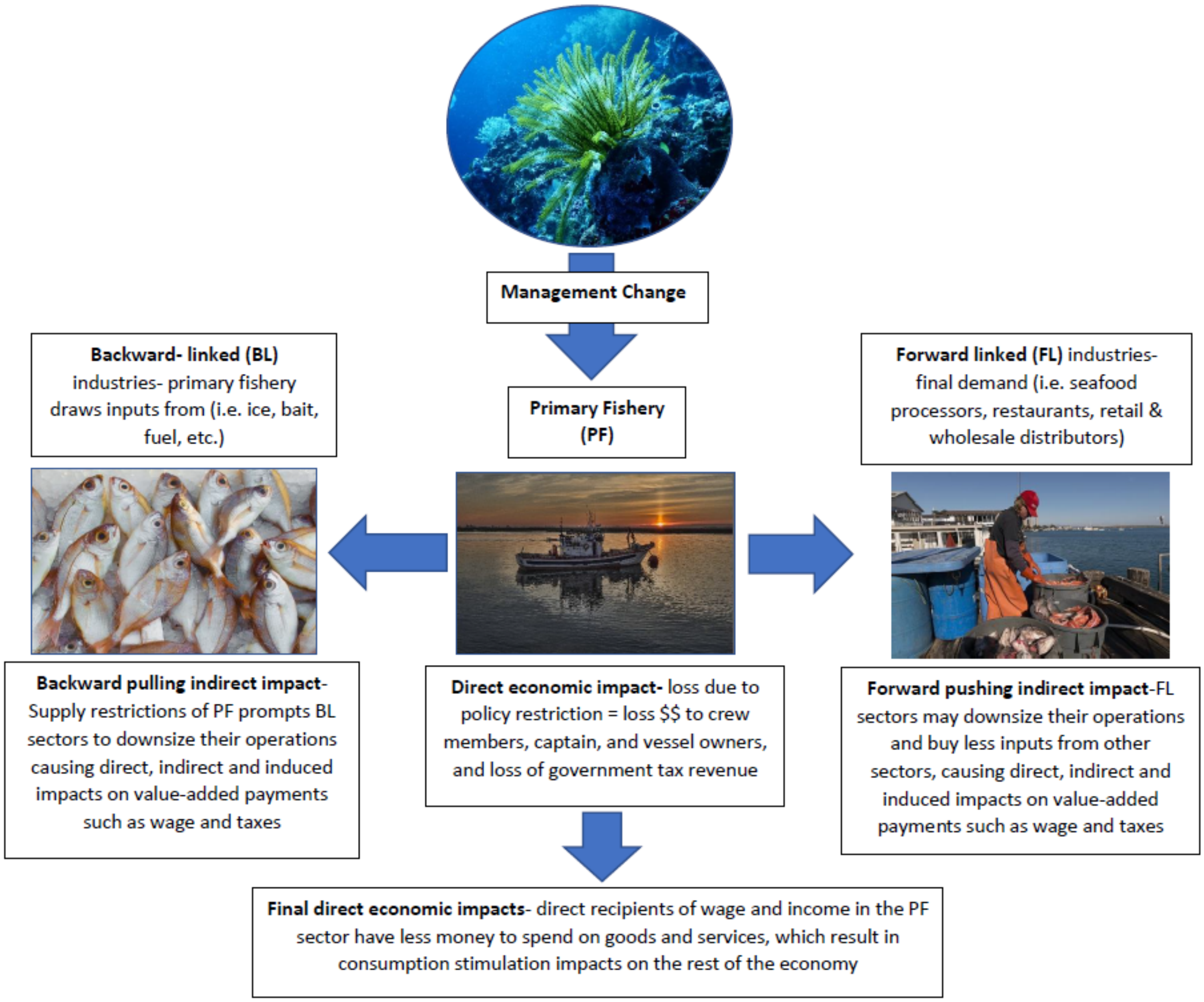


Figure 12. Visualizing how policy change affects commercial fishing and linked sectors

We used a commercially available regional IO economic modeling software along with the economic data, called IMPLAN (IMPact for PLANing) for developing the basic inter-industry economic framework. The original model for Florida counties come with more than 500 economic sectors. We had to aggregate this large number of sectors into a smaller and more manageable number of industry groups. We retained IMPLAN'S original primary commercial fishery sector, BL sectors (e.g., ice making, fuel, and bait) and FL sectors (e.g., seafood processing, restaurants, and retail) in our IO model, and combined the rest of the economic sectors into relevant groups. In total, we grouped the IMPLAN IO data of about 25 Florida Gulf

Coast counties into six geographically contiguous regional models to align the IO data with the NMFS fishery utilization data discussed earlier. We ran the final IO model to simulate various policy scenarios that roughly represented fishery management changes being proposed for the PR region.

Finally, in order to assess the opinions and perceptions of commercial fishermen who fish within Pulley Ridge and the surrounding regions, we created an approximately 50-question survey using the Qualtrics survey software for online distribution. For this survey, we contacted individuals who hold saltwater product licenses within the eight counties of the study area (Monroe, Manatee, Lee, Collier, Charlotte, Sarasota, Pinellas, and Hillsborough). We obtained the e-mail addresses for these individuals through public records. In total, nearly 1,600 individuals were e-mailed the survey through the Qualtrics platform in two separate distributions. Respondents whose answers were recorded in the first distribution were omitted from the email list in the second distribution to avoid repetition. The responses from the two survey distributions were combined and are featured in this survey representing 78 individuals.

MANAGEMENT-RELEVANCE

Stakeholder Advisory Board (Peter Ortner, UM)

The core of our continuing interaction with and focus upon management applications was engagement with and through our project Stakeholder Advisory Board (SAB; see Appendix A for membership list). This was established when the project was initiated and designed to be inclusive of the major state, regional and federal level agencies whose resource management might benefit from the projects findings, as well as the non-governmental organization community. At the beginning the agencies represented included: Bureau of Ocean Energy Management (BOEM), GoM Fishery Management Council (FMC), South Atlantic FMC, The Nature Conservancy, NOAA Office of National Marine Sanctuaries, NMFS SEFSC and Southeast Regional Office, Gulf Coast Ecosystem Restoration Task Force, NOAA OER, National Park Service Everglades National Park/Dry Tortugas National Park and Florida Fish and Wildlife Research Institute. Shortly thereafter, the FKNMS was added.

The group first met in person in November 2012 at the conclusion of an all-PI meeting to which the SAB were invited. They met again in person under similar circumstances in January 2014, December 2014, and October 2015. Ad hoc teleconferences and meetings with the SAB (or a subset of its members) were held by the PMC (Project Management Committee: Bob Cowen, Peter Ortner, and Shirley Pomponi) at irregular intervals to address specific issues. A final SAB meeting (open to other stakeholders) was held on February 28, 2018. This meeting presented the project's results and provided an opportunity for managers to discuss these results with the project scientists. (Note: this meeting, originally scheduled for January 24, had to be rescheduled due to the Federal Government Shutdown and as a result, attendance was less than originally expected.) See Appendix B for an Agenda and Attendance List.

Findings

a. High-level findings

i. Population connectivity

- *PR, DT, and FLKeys reefs are physically connected by oceanic currents.*

The Loop Current (LC) physically connects PR to the DT and FLKeys. Prior to this project, the LC was only known to release eddies that move westward. We documented that the LC also releases anticyclonic eddies that move eastward along the Cuban coast and northward along the shelf break of the southwest Florida shelf. These anticyclonic eddies have a direct impact on PR, DT, and the FLKeys by bringing warm waters over these reefs. Thus, based on physical oceanography, there is the potential for larvae to be transported between these reefs. Whether larvae are transported, though, is dependent on a species' biological (life history) characteristics.

The dominant flow direction between PR, DT, and the FLKeys can be interrupted (and even reversed) by periods of strong oceanic currents (e.g., LC). These variable flows, and resulting eddying motions could potentially also serve to foster retention mechanisms, which might contribute to occasional self-recruitment episodes at PR.

The strongest currents and warmest temperatures over PR are associated with a young LC near the southwest Florida Shelf. The water properties around South Florida reefs were documented to be influenced by remote riverine waters and associated materials, specifically from the Mississippi River.

- *Population connectivity between PR, DT, and FLKeys reefs is species-specific.*

Population connectivity between organisms living at PR to the downstream reefs of the DT and FLKeys is variable and species-specific. Most fish species (with multiple spawnings per year and relatively long larval durations > 15 d) are well connected as demonstrated by our genetic analysis and model predictions for the Red Grouper, Lionfish, and Bicolor Damselfish. There is also evidence that the great star coral, *Montastraea cavernosa*, is well dispersed throughout the system resulting in genetically connected populations between PR and > 15 m in the FLKeys. In contrast, the giant barrel sponge, which has a very short larval duration (< 1 week), showed evidence of very limited larval exchange or genetic connection between PR and DT, and no connectivity with the FLKeys. In this latter case, self-recruitment (vs. long-distance subsidy) dominates.

- *Connectivity between mesophotic and shallow coral ecosystems is physically possible, but limited biologically for some taxa*.

The 'deep-reef refugia' hypothesis posits that MCEs may be less vulnerable to disturbances in comparison to shallow reefs and serve as a source of larvae to replenish species on shallow reefs. While physical connectivity via oceanic currents exists between PR, DT, and FLKeys, various biological processes may restrict species exchange between mesophotic and shallow reefs. First, less than 50% of the species observed in the PR MCE have also been observed in shallow-water reefs of the FLKeys. For most species not present in both environments, the separation is likely tied to species-specific habitat requirements, rather than simple dispersal limits. Second, for species that do occur in both mesophotic and shallow reefs, dispersal between depths could still be limited for those species that brood their young or with very short larval durations (< 1 week). Further, for the great star coral, *Montastraea cavernosa*, genetics indicate depth-specific population structure (i.e., population connectivity between PR and reefs > 15 m in the FLKeys), suggesting limited exchange or habitat-specific selection. In contrast, we found for the bicolor damselfish, red grouper, and lionfish (i.e., fish with long PLDs) that populations are well mixed between mesophotic and shallow reefs.

Management Implication: The PR-DT-FLKeys system is physically connected by oceanic currents and therefore it is reasonable to be considered as a whole system, with some caveats as noted below. Most reef fish species studied from both mesophotic and shallow depths can be managed as single populations. In this regard, PR can be managed as part of a regional fisheries management plan. However, the relatively large number of species found in mesophotic reef habitats but not in shallow reef habitats in FLKeys suggest the uniqueness of this habitat for these species and thereby warrants special management of the MCE habitat. Further, though not universal, the potential for mesophotic habitat populations to subsidize certain shallow-water populations, adds further value to special management of this habitat.

ii. Community Structure/Population dynamics

- *PR has three unique geographically and biologically distinct habitat areas (Main Ridge, Central Basin, and West Ridge).*

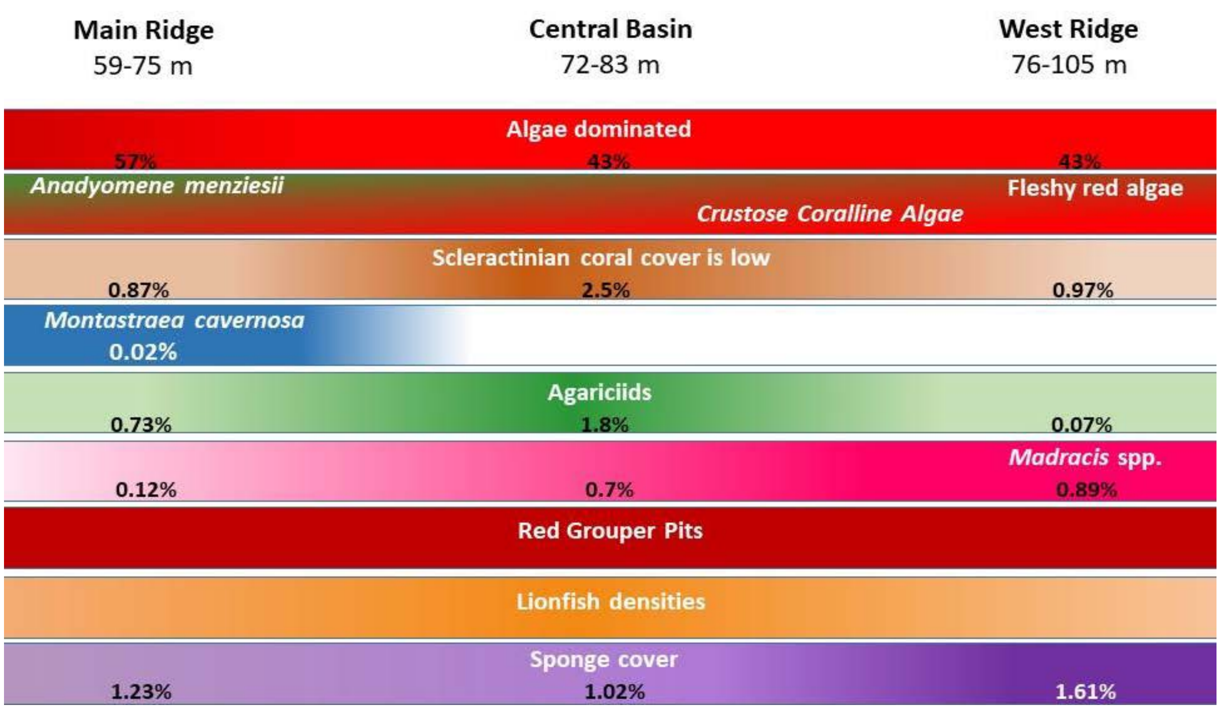


Figure 13. The patterns of major biota in three regions at Pulley Ridge: Main Ridge, Central Basin, and West Ridge.

The PR MCE community is highly diverse and more extensive in areal coverage than that outlined by the original 2005 HAPC boundaries. Extensive ROV surveys discovered previously unknown habitat to the west of the Main Ridge. Species diversity and dominance varies on PR resulting in an MCE with three distinct areas (Fig. 13): the Main Ridge, Central Basin, and West Ridge. In general, PR is a algal-dominated habitat (48%), with low scleractinian (1.4%) and sponge (1.3%) cover. Red grouper is one of the most abundant commercial species at PR, with an estimated 136,000 grouper pits within the original 2005 HAPC and ~155,000 grouper pits within the 2018 HAPC boundaries.

- *A 92% decline in hard coral cover occurred in the past decade. However, PR shows signs of recovery with new recruits.*

Comparison of our data (2012–2015) with data collected by USGS in 2003 on the Main Ridge showed a 92% decline in coral cover over 10 years. In contrast, the newly discovered Central Basin on PR had high densities of small plate corals (e.g., *Agaricia spp*.) suggesting a recent recruitment event.

- *Discovered several patch reefs and gray snapper spawning aggregation outside the TERs.*

Our ROV survey work discovered several previously unknown patch reef areas rich in benthic and fish diversity near, but outside the boundaries of the Tortugas Ecological Reserves (TERs). This included a spawning aggregation of grey snapper (*Lutjanus griseus*).

- *Much of PR is dominated by red grouper pits, which support both an abundant assemblage of small (forage) fish species, as well as an increasing population of invasive lionfish*.

Red grouper pits are pervasive throughout all PR habitat, and are the primary source of overall fish diversity. While each pit is home to a single red grouper, large numbers of small and juvenile fishes are attracted to these pits. The invasive lionfish is also concentrated in these pits and their numbers have been increasing significantly; total counts of lionfish in 2006 vs. this study in 2012-2014 suggest a greater than two order of magnitude increase in their abundance at PR in just 6–8 years.

- *MCEs may support significant reproductive output of key fish species*.

A common fish species (i.e., *Stegastes partitus*) at PR (59–70 m) was found to grow slower but live longer and attain larger overall size, and invest more energy into reproduction than those from deep (20–30 m) or shallow (< 10m) shelf reef environments. When depth specific abundances across the whole PR-DT-FLKeys system are combined with these reproductive output measurements for *Stegastes partitus*, PR fish populations are estimated to contribute ~9% of the total system-wide reproduction, suggesting PR is a significant source population for the whole system.

Management Implication:

The finding of additional and highly diverse MCE habitat outside the PR HAPC is notable and warranted management action to expand protection boundaries. Thus, in 2018, the Gulf of

Mexico Fishery Management Council took action and expanded the HAPC boundary to include the Central Basin and West Ridge.

PR also supports diverse fish populations, which can contribute significant reproductive output to the greater PR-DT-FLKeys system. Management of fish populations in the larger region should consider the reproductive contributions of mesophotic populations. Specifically, closure of PR to fishing would allow Red Grouper populations in that area to reach greater densities and therefore provide greater reproductive output which would contribute to many other shelf and inshore areas. Management should also take steps to protect and reduce stress on mesophotic populations at PR as their inherent resiliency is low. This would include management measures to protect habitat damage from fishing or other extractive activities.

The catastrophic loss of coral at the HAPC is a matter of great concern. The cause and persistence of this decline is unknown. Periodic monitoring of coral distribution, abundance, and health would be desirable. Similarly, it is unknown what effects the Lionfish have on Red Grouper and other key fish species. Consequently, management should support research into the long-term effects of Lionfish on Red Grouper and their associated communities.

iii. Bio-economics

- *Stakeholders hold a negative view of closure impacts relative to modeled economic impacts*.

Economic evaluation of the expanded HAPC and FKNMS management options indicates that the policy-induced losses in the fishery-related income, taxes, and employment will be around *3%* of the total region-wide economic contributions attributed to fisheries. Nonetheless, almost 90% of survey respondents indicate the proposed management changes would affect their business either “Significantly” or “Very Significantly.” The perceived impacts of regulations seem to be larger than the model-based impacts predicts.

Management Implication: Creating an awareness among commercial fishers that the long-term benefits of the proposed management action outweigh the short-term costs is key to a successful implementation of the program.

b. Objectives-specific Findings

i. Identify the primary physical oceanographic drivers influencing larval dispersal pathways.

- *Determine the influence of the LC proximity to the southwest Florida Shelf on the circulation and water properties around PR*

<u>The Loop Current impacts local circulation on PR and DT reefs</u>

One of the major study findings is that the location and modulations of the LC system have a significant impact on the local circulation of the PR and DT regions. The LC system consists of the main LC body and the associated eddy field which has been known to include the large anticyclonic LC Eddy (LCE) or “ring”, and the cyclonic LC frontal eddies (LCFEs) that travel around the main LC body (Sturges and Leben 2000; Schmitz 2005; Le Hénaff et al. 2012). An important study finding is that, in addition to releasing LCEs that move westward in the Gulf interior, the LC releases previously not studied anticyclonic eddies that move a) eastward along the Cuban coast (Kourafalou et al. 2017) and b) northward along the shelf break of the West Florida Shelf (Kourafalou et al. 2018). These latter eddies, namely West Florida Anticyclones (WFA) have a direct effect on PR and DT, carrying warmer waters over the reef areas, thus potentially influencing reef resilience. An example is presented in Figure 14, which also serves as a comparison between model fields (Sea Surface Height: SSH and Sea Surface Temperature: SST) with data (AVISO Sea Level Anomaly and GHRSST - Global High Resolution SST, respectively). The release of the different kinds of anticyclonic eddies and the impact on sea level and surface temperature are well pronounced in both model and data. In particular, PR and DT are influenced both by the direct proximity of the LC and by the propagation of warm waters through the WFA shelf-break eddies over the reef area. Furthermore, they are indirectly influenced by the evolution of mesoscale anticyclonic eddies released from the main LC body along the northern Cuban coasts (example on Figure 14), which has implications on circulation across the Straits of Florida.

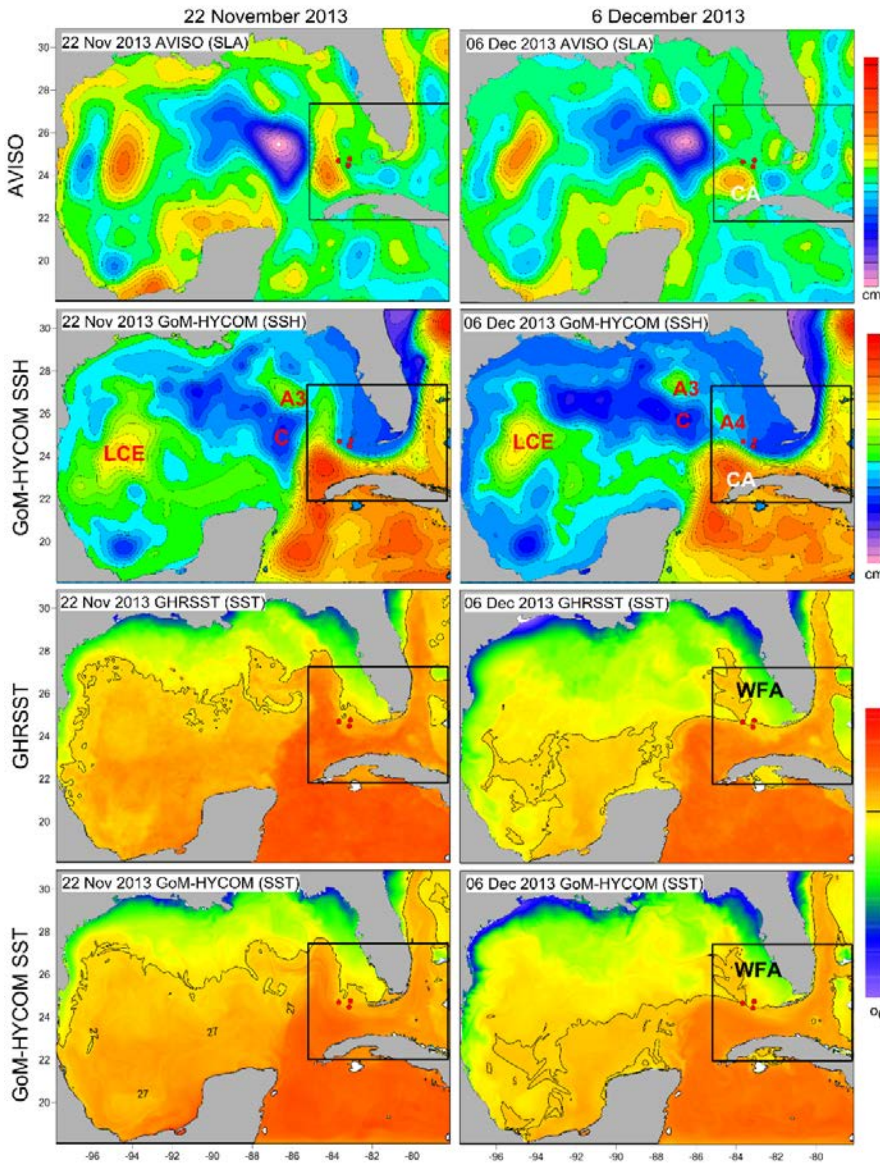
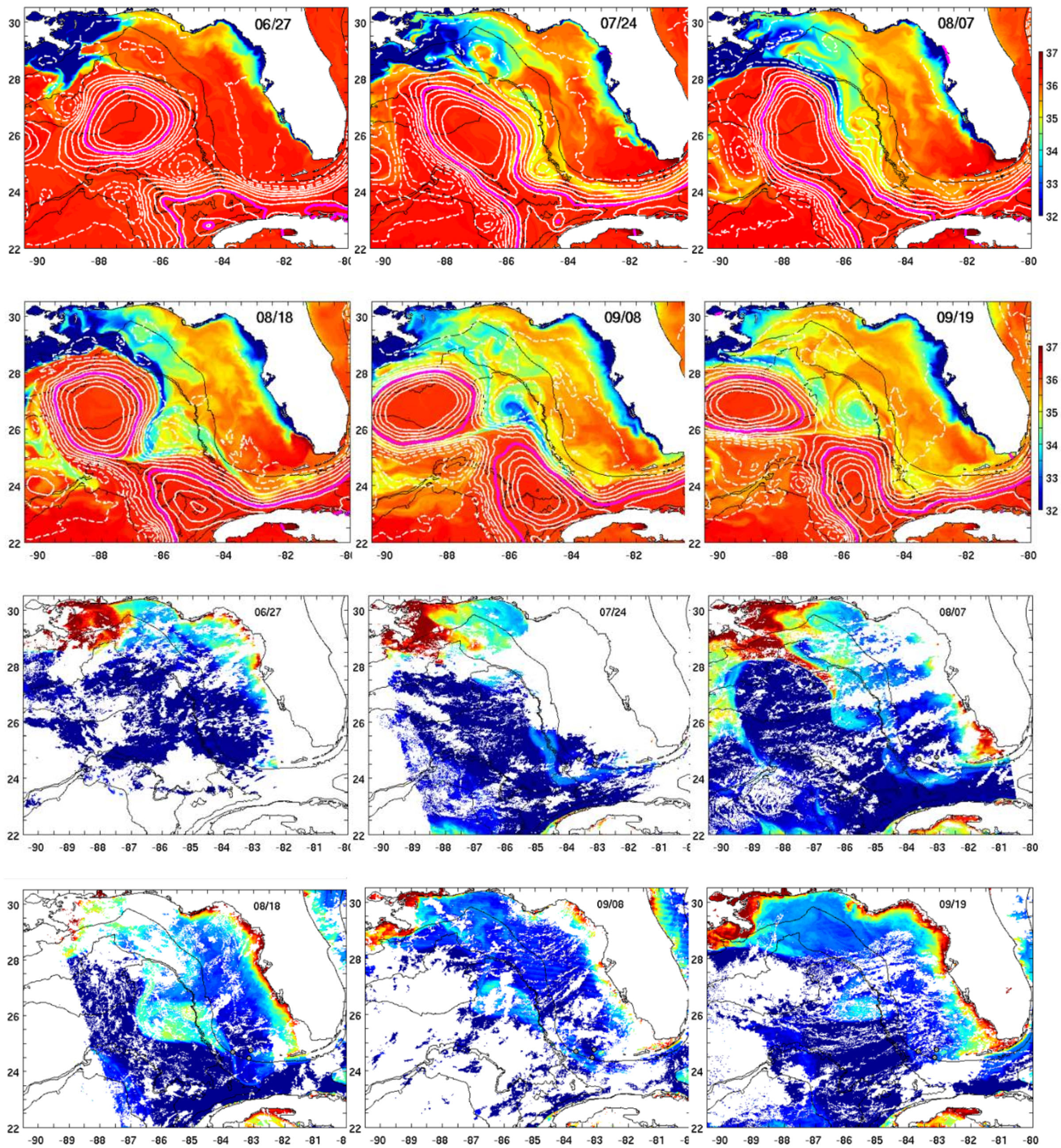


Figure 14. Spatial distribution of (top to bottom) AVISO Sea Level Anomaly (SLA), GoM-HYCOM 1/50 Sea Surface Height (SSH), GHRSST Sea Surface Temperature (SST), and GoM-HYCOM 1/50 SST on 22 November 2013 (left panels) and 6 December 2013 (right panels). The FKEYS-HYCOM region is indicated with a black box. Red dots indicate the positions of Pulley Ridge (PR), Northern Dry Tortugas (NDT), and Southern Dry Tortugas (SDT) moorings over the Southwest Florida Shelf. The Loop Current Eddy (LCE), the West Florida Anticylones (WFA: A3 and A4), the Cuba Anticyclone (CA), the major cyclonic eddy (C) and the 26°C isotherm are marked.

MS River discharge documented in situ to impact reefs on the SW Florida shelf



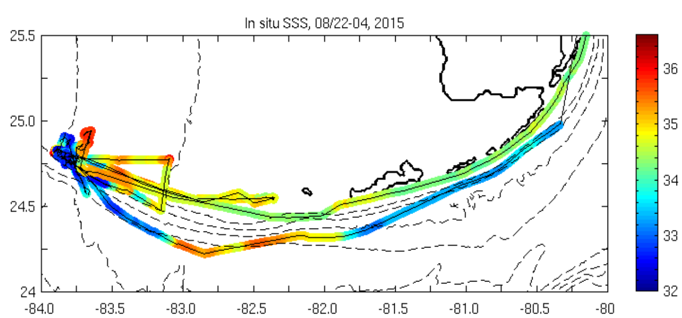


Figure 15 (Upper 6 panels): Sea Surface Salinity (colors, SSS) extracted from the assimilative GoM-HYCOM 1/50 simulation (zoom over the eastern GoM), from June 27 to August 18, 2015 (Middle 6 panels): Respective chlorophyll-a maps derived from ocean color satellite data. (Bottom panel): R/V Walton Smith *in situ* salinity data along the slope of the Southern Florida Shelf.

The proximity of the LC to the Southwest Florida Shelf facilitates the direct influence of anomalous waters that reach PR and DT reefs from remote areas, especially the Mississippi River. Events of Mississippi waters reaching the study area were documented during the 2014 and 2015 RV *Walton Smith* cruises and were simulated with our high-resolution GoM-HYCOM 1/50 model. The 2014 event has been discussed by Le Hénaff and Kourafalou (2015); we present herein highlights from the 2015 event. A remarkable aspect of the synthesis of observations and modeling in this project is that, for the first time, Mississippi River export toward the Straits of Florida were observed with in situ data and were also successfully modeled; previous studies (as Hu et al. 2005) relied solely on satellite data. Two of the project surveys documented the advection of low-salinity, high in nutrient content Mississippi waters to South Florida reefs, offering a unique in situ dataset. The model allows the understanding of regional and local conditions governing this type of connectivity.

Figure 15 shows a sequence of characteristic dates marking the onset, initial eastward spreading, and eventual southward advection of the Mississippi waters during the summer of 2015. We employ ocean color data (provided by Chuanmin Hu, University of South Florida), where the riverine water pathways are detected through their high pigment content, and model fields of Sea Surface Salinity (SSS) maps. SSH white contours (every 6 cm) are overlaid on SSS and outline the major mesoscale circulation features, namely LC and associated eddies, as well as in situ near-surface salinity data that document the significant changes in the water characteristics in the vicinity of the coral reefs at PR and DT. Positive SSH with respect to the basin mean is marked by continuous lines, negative SSH is marked by dashed lines. The LC is marked by the magenta SSH line of 17 cm over the basin mean, as defined by Leben (2005).

The 2015 Mississippi River event was overall stronger than the 2014 event. It was characterized by high Mississippi River discharge (~double of the long-term monthly mean for July), intense westerly winds for July-August that contributed to the eastward advection of the near-surface low-salinity riverine waters, which promoted the interaction with the extended LC. This was followed by southward advection toward the study area, along the LC front. The LCE detachment in early September 2015 interrupted the connection between the northern Gulf and the Straits of Florida, reducing the amount of low salinity waters over the study area. The cyclonic eddies around the LC participated on both the LCE detachment processes and the evolution of the brackish waters towards the South; significant quantities of low salinity waters were trapped in the cyclonic eddy that contributed in the LCE shedding in September 2015. The waters of Mississippi origin were measured and modeled to spread over the PR, DT, and FLKeys reefs, not only on the surface, but reaching 10-15 m deep around Pulley Ridge.

- *Determine the influence of the FC proximity to the Atlantic Florida Keys Shelf on the circulation and water properties around the DT*

FC location near the Atlantic Florida Keys Shelf supports offshore flows that move southward between PR and DT and FLKeys

The FC is an extension of the LC, flowing in the Straits of Florida between South Florida, Cuba, and the Bahamas. The variability of the FC frontal position as it enters the Straits of Florida was found to be important in determining the physical connectivity between the regional FC variability and the local shelf circulation over the PR and DT reefs. Following Kourafalou and Kang (2012), the zonal position of the 20^{o}C isotherm at the depth of 150 m along the 83.5^{o}W meridian was used to determine the FC frontal position. The northernmost position of the FC front along 83.5^{o}W that crosses between the three study moorings was found corresponding to the easternmost position of the LC, indicating the domination of the combined LC/FC system dynamics over the South Florida coral reef region. The FC frontal position was found relevant to the cross-shelf transport near the PR and DT moorings. The annual mean position of the FC front in 2013 was the highest (FC_{mean} = 24.22^{o}N) of the 4-year study period, staying persistently far north and almost over the shelf slope. This supported the long periods of offshore flows across the shelf-break, in agreement with the near-surface and near-bottom measurements at PR and SDT moorings, which showed prevailing southward flows during 2013.

- *Determine the influence of cyclonic eddies along the LC/FC system on cross-shelf and along-shelf processes determining the physical connectivity between PR and the DT.*

Cyclonic eddies physically connect PR and DT with the FLKeys

We employed drifter data (Figures 5–8) and model fields (Figure 16) to better understand the circulation around the study reefs and to determine the connectivity pathways. The good agreement of circulation features calculated by the model and depicted by the drifters also serves as additional model evaluation. The trajectories of the two drifters, deployed at the end of August 2013 at NDT (hereinafter NDT drifter) and SDT (hereinafter SDT drifter) locations are characterized by conditions when the FC is close to the DT (Figure 6). The FC curvature near the DT and westward coastal currents favored the local generation of a cyclonic eddy (Kourafalou and Kang 2012) prior to the drifter deployment. Both drifters were entrained in the FC southeastward flow along the shelf-break and were carried away from the moorings, following the southeastward displacement of the cyclonic eddy on 6 September. The cyclone enlarged over the 82.5^{o}W–24^{o}N area and entrained both drifters, spinning them cyclonically twice (e.g., 6 September and 13 September). The NDT drifter followed an extended cyclonic circulation and was involved in a second cyclone that was formed over the DT on 1 October (Figure 16d), while the SDT drifter was advected directly by the FC towards the Atlantic Ocean. Similarly, the NDT drifter moved towards the South and propagated more to the East, together with the cyclonic eddy and the FC along-shelf flow. Both drifters followed the offshore flow from the shelf towards the open sea and were involved in the FC meandering and in the evolution of the local cyclones north of the FC and along the southern Florida shelf. The drifters, combined with the modeled circulation, provided evidence of connectivity pathways between PR and DT (plus downstream Florida Keys reefs). We found that cyclonic eddies along the LC/FC system have a pronounced effect on the physical connectivity pathways, with implications on biophysical connectivity (especially as related to larval transport, Vaz et al. 2016).

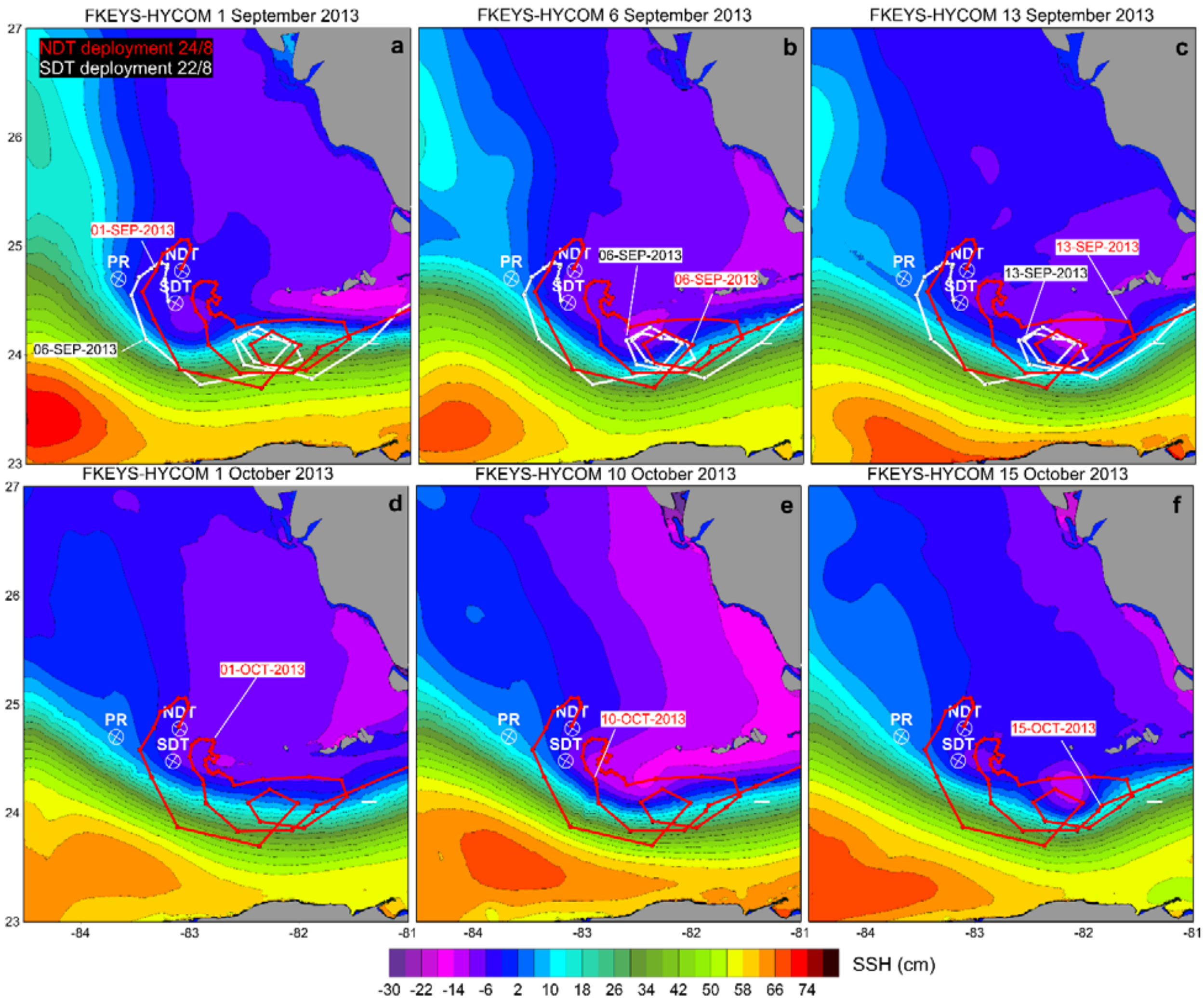


Figure 16. Snapshots of model-computed Sea Surface Height (SSH, cm) derived from the FKEYS-HYCOM simulation, over a subdomain from the western shelf-break of Florida shelf to the Middle Keys and NOAA/AOML drifter trajectories (dots along track at 24 hour interval) deployed in SDT (white track) and NDT (red track) on 22 August 2013 and 24 August 2013, respectively. The position of each drifter is indicated in the respective (a) 1 September 2013, (b) 6 September 2013, (c) 13 September 2013, (d) 1 October 2013, (e) 10 October 2013 and (f) 15 October 2013 SSH snapshot. White marks indicate the positions of PR, NDT and SDT moorings over the Southwest Florida Shelf.

- **Model likely connectivity pathways between PR, DT and the FLKeys, as well as other potential upstream sources along the west Florida shelf.**
  - *Obtain (through analysis of existing data and collection of new data) empirical data critical for the initial conditions and parameterization of the biophysical model (spawning production, larval 3D distributions, pelagic larval durations [PLD], location-specific growth and mortality).*

Results for this objective were compiled from existing data on larval distributions and PLDs. Some of these data were incorporated into the preliminary population connectivity modeling published in Vaz et al. (2016). Our intent was to also assess larval distribution through both MOCNESS net collections and using ISIIS (see methods), but available time on board the ship was too limiting to collect quantitatively meaningful data. Data on the growth and reproductive output of key fish species are reported below in the Population Dynamics objective.

We did examine the vertical distribution of late-stage larvae (i.e., pre-settlement stage) using depth-discrete light traps. Light trap collections at three depths in mesophotic environments at PR and DT demonstrated that a greater abundance and diversity of zooplankton and settlement-stage fish occurs closest to the benthos (i.e., deepest trap) rather than near the surface (i.e., mid and shallow traps), but these collections were significantly lower than those collected over deep and shallow shelf reefs in the FLKeys. This greater supply of zooplankton at nearshore FLKeys sites is likely due to higher nearshore primary productivity. Together, primary and secondary production should contribute to an overall higher biomass of organisms closer to shore. Particularly for zooplanktivorous species such as the bicolor damselfish, patterns of zooplankton food availability underlie population distributions, demographics, and reproductive output.

Timing of the diel migration and relative abundance of organisms were verified to coincide with the day-night cycle. Figure 17 illustrates vertical excursions to the surface, beginning shortly after sundown (~18:00 EST), and return journeys to the reefs at sunrise (~6:00 EST). Light level as a cue for migration, and higher abundance in the water at night, is understood by how the bars of *I*´ (Figure 18) grow in the positive direction, hours just past sundown, and decrease until becoming negative at sunrise. Throughout the year, the cumulative abundance of *I'* through the water column is consistently higher at PR, as compared to both NDT and SDT.

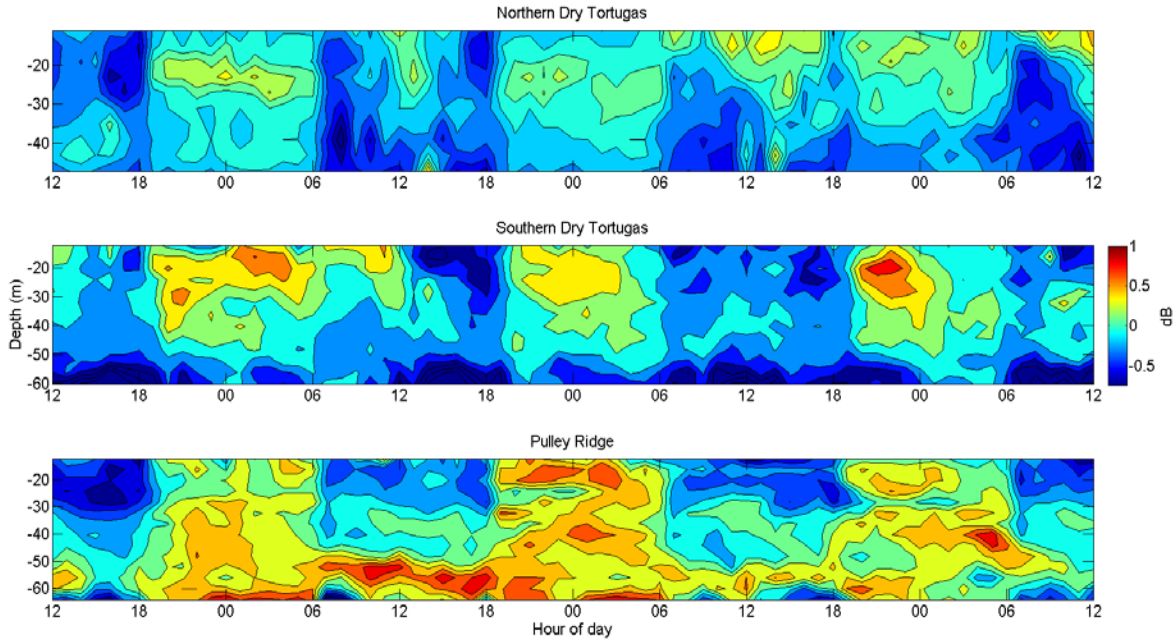


Figure 17. Three-day snapshot of vertical profiles of raw *I*′ at Northern Dry Tortugas (upper), Southern Dry Tortugas (middle), and Pulley Ridge (lower). Vertical ascensions begin at 18:00, where the organisms then reside in the water column throughout the night, and return to the reef at 6:00. Hours presented in EST.

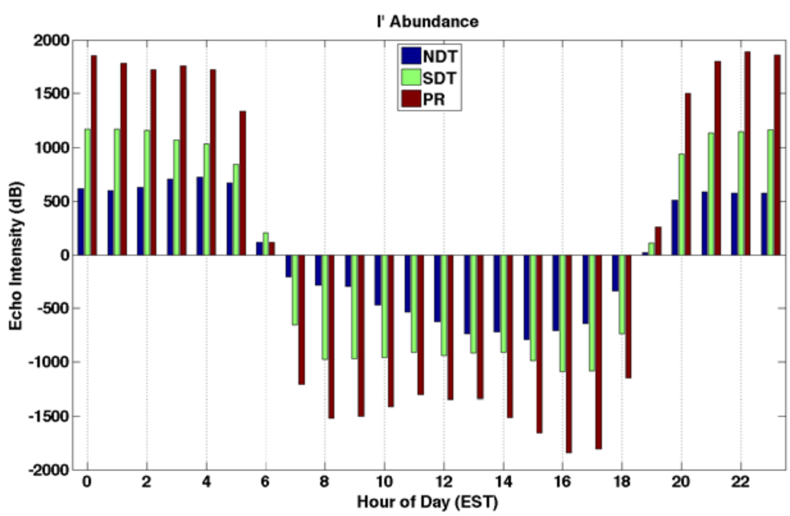


Figure 18. *I*′ abundance per hour of day. Vertically integrated *I*′ over water column and summed for every hour of the day at Pulley Ridge (PR; dark red), Northern Dry Tortugas (NDT; blue) and Southern Dry Tortugas (SDT; green). PR is consistently higher than the other reefs (NDT and SDT) during hours of darkness, indicating it as a possible upstream supplier.

Using historical (1994–2016) surface drifting buoy trajectory data, we conducted a probabilistic Lagrangian circulation study, which sheds light on the oceanographic connectivity of PR with other locations in the GoM and adjacent areas. The surface pathways uncovered by the drifter trajectories constitute a first order constraint for any surface ocean pollutant (e.g. spilled oil, toxic algae bloom), as well as larval motion for species that have buoyant egg masses, such as lionfish (Morris et al. 2009), and broadcast spawners for which a fraction of larvae may reach the surface, such as the great star corals (Holstein et al. 2016) and red grouper (Brulé et al., 1999).

Based solely on observed drifter trajectories, PR could be a source for neighboring regions, such as DT, FLKeys, Campeche Bank, and the east Florida coast, for species with short settlement times. The drifter data have also suggested that PR could be connected with most of the GoM (except the Louisiana–Texas shelf) and the Caribbean Sea but because the larval settlement time is in general smaller than the connecting time, only the reefs in the Caribbean Sea, DT, Western Keys, and the West Florida Shelf could potentially be a source of larvae to PR, indicating the importance of Pulley Ridge as a central refugium for species in the Gulf of Mexico (Olascoaga et al. 2018).

- *Produce species-specific connectivity networks, and connectivity matrices for targeted species, including under selected scenarios such as increased ocean temperatures, hurricane passage, and habitat fragmentation.*
- *Validate the model through comparison of model outputs to existing larval settlement records for the FK and short comparative records of larval supply to PR, and spatial patterns of coral and fish genetic structure.*

Based on biophysical simulations, PR populations are primarily connected to the DT, secondarily to the Marquesas, and replenish to lesser extent the FLKeys (Figure 19).

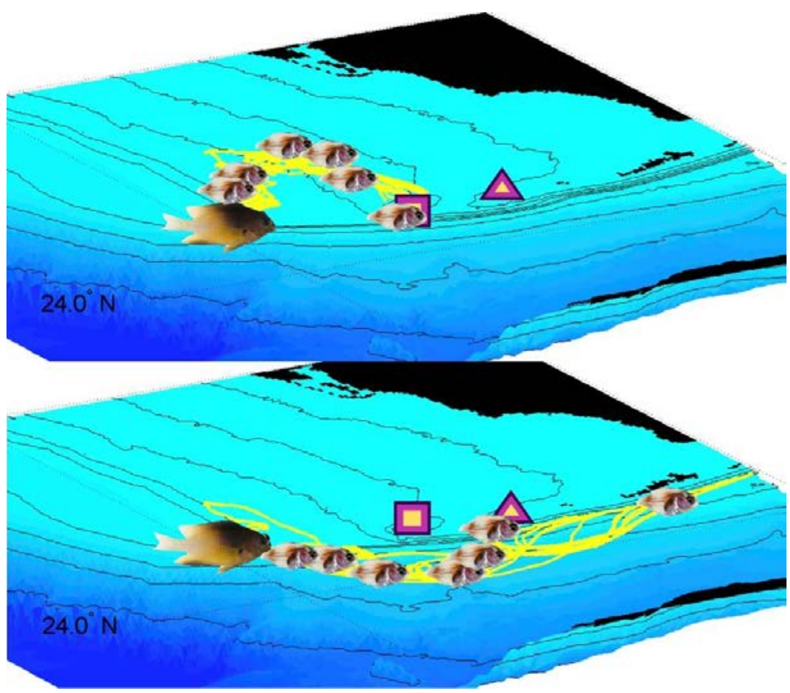


Figure 19. Simulated larval dispersal routes for *Stegastes partitus* from PR to primary dispersal location (DT-top) and secondary dispersal locations (FLKeys - bottom).

Fish species: Mesosphotic fish populations (based on the bicolor damselfish, lionfish, and red grouper models: Figures 20–22) are self-seeded and provide larval subsidies to downstream sites, from shallow to deep depths. However, subsidies are intermittent. Largely, there are two pathways: 1) FC position North, gyre over DT; and 2) FC position South, remotely generated eddies propagate along FLKeys reef tract. These two pathways are necessary, but not sufficient for successful exchange. Species-specific: Life history data is critical to assess connectivity. In addition, populations of PR can have very different demographics. The circulation patterns enable exchange through the GoM, with strong dependency on life history of the various species examined.

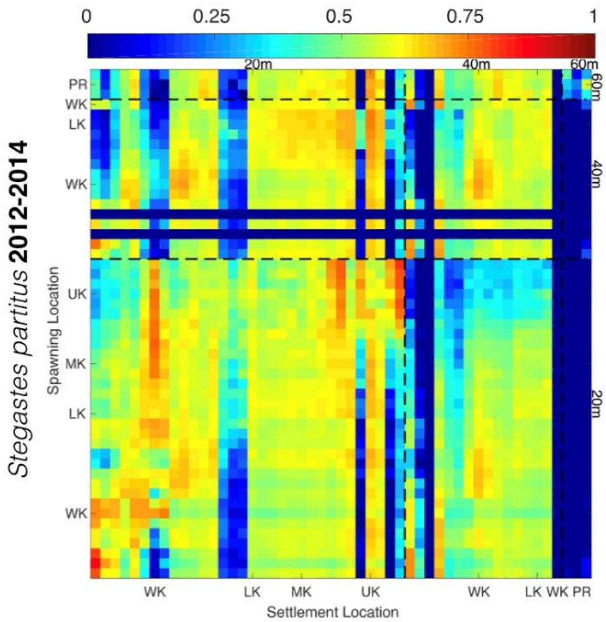


Figure 20. Connectivity matrix from biophysical modeling for *Stegastes partitus,* bicolor damselfish.

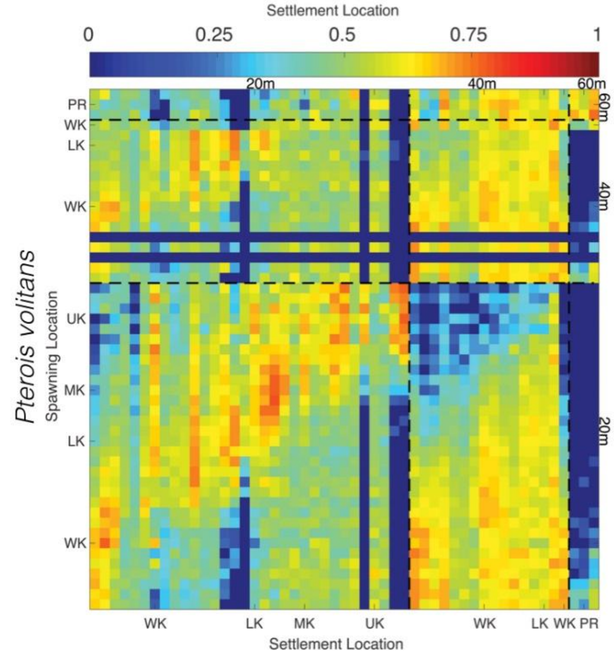


Figure 21. Connectivity matrix from biophysical modeling for *Pterosis* spp. *(volitans*?), lionfish.

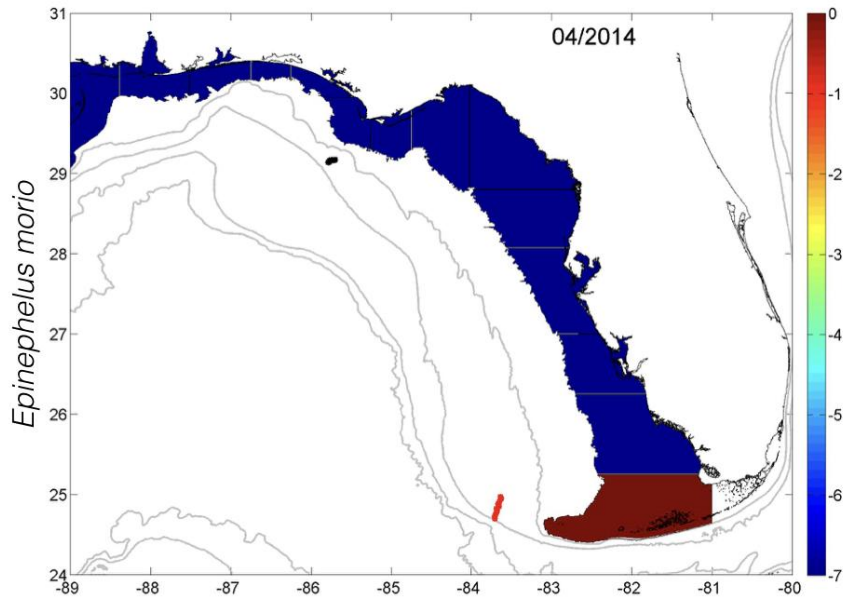


Figure 22. Simulation of expected larval dispersal of *Epinephelus morio*, red grouper, from PR to locations throughout the eastern GOM and FLKeys. Scale is $\log_{10}$ scale of expected concentration of successful dispersers (note the negative exponents).

Coral species: Biophysical simulations suggest that mesophotic corals from PR are highly self-retained, yet they exchange planulae between different reefs and depth strata. Notably, the number of connections increase when ontogenetic shifts on buoyancy are represented in the model. The higher export of *M. cavernosa* planulae, a broadcast spawner, can lead to the panmixia of populations on shorter time scales (< 2 generation), independently of other parameters, such as mortality, depth of fecundity, or pelagic larval duration (Figure 23). On the other hand, *P. astreoides*, a brooder, exhibit less connections between reefs and depth strata, and most of its planula settles at the depth strata of origin (Figure 24). When comparing connectivity model results with genetic Fst, we find that the model presents a good predictive capability for *M. cavernosa,* with significant relationship between predicted and realized connectivity for planulae presenting 30 days pelagic dispersal, explaining about 20% of the genetic variance.

Network connectivity analyses: *M. cavernosa* populations from PR are connected to both shallow- and deep-water reefs, particularly exporting larvae to other reefs. Most transport to the same depth strata is upstream (from PR towards Upper Keys), following the FC. However, mesophotic-shallow larval transport does not have predominant directionality and contributes to mixing of the populations.

Resiliency of the network is maintained by additional larval sourcing from the deep (20–30 m) reefs of DT and Middle Keys, and the shallow reefs for the Middle Keys for *M. cavernosa*. For *P.*

astreoides, reef resilience is maintained by both deep and shallow reefs of the DT and by the shallow reefs of the Upper Keys (Note: *P. asteroides* is not present at PR).

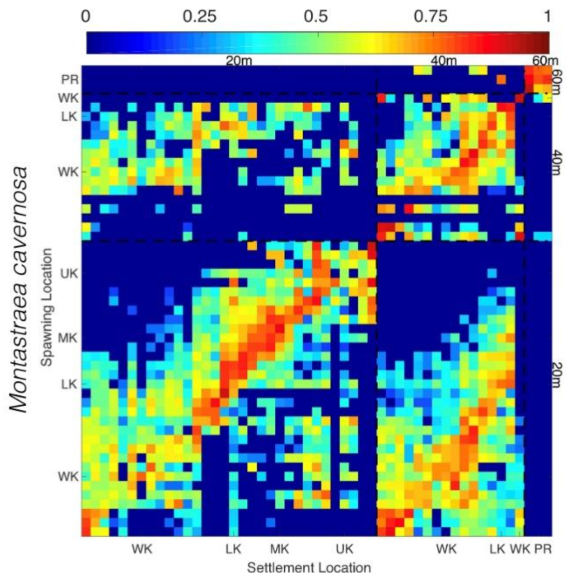


Figure 23. Connectivity matrix from biophysical modeling for *Montastraea cavernosa.*

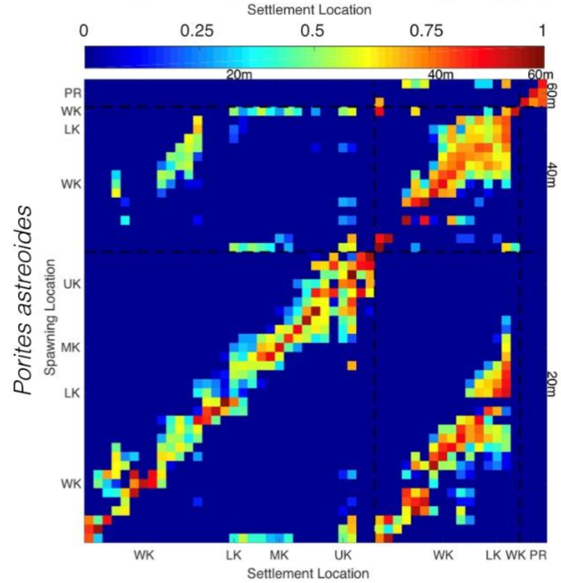


Figure 24. Connectivity matrix from biophysical modeling for *Porites asteroides.*

➢ **Validate inferred connectivity pathways (from above connectivity modeling) through genetic analyses.**

- *Assess genetic connectivity among subpopulations of each of eight model species and characterize their comparative genetic diversity using microsatellite and/or SNP markers.*

- *Quantify the magnitude and direction of gene flow between subpopulations, with a focus on the role of the PR MCE as a refuge and source of recruits to the FLKeys.*

The first two objectives were to assess genetic connectivity dynamics among subpopulations of each of eight model species: Fishes: *Stegastes partitus, Thalassoma bifasciatum, Epinephelus morio, and Mycteroperca bonaci or M. phenax; Corals: M. cavernosa,* Lettuce corals (Scleractinia: Agariciidae)*; Sponge: Xestospongia muta: Alga: Halimeda tuna.* Details on each species are provided below.

Fishes: *T. bifaciatum* ended up being very rare at PR, so *Pterois volitans* (lionfish) were assessed instead. No *Mycteroperca bonaci or M. phenax* groupers were obtained from PR, so these species were dropped from our analyses.

Fish species from MCEs sampled as part of this program are well connected (i.e., do not show genetic differentiation from) to fish from shallow reefs. This high genetic connectivity is likely due to long pelagic larval durations for the studied fish species [i.e., red grouper (*E. morio*): Figure 25*,* lionfish (*P. volitans*): Figure 26, and bicolor damselfish: Figure 27], in addition to strong Gulf of Mexico circulation patterns (LC). This high genetic connectivity suggests that these fish species can be managed as a single population. Assuming these findings apply for most fish species inhabiting Pulley Ridge, this MCE can be managed as part of a regional management plan.

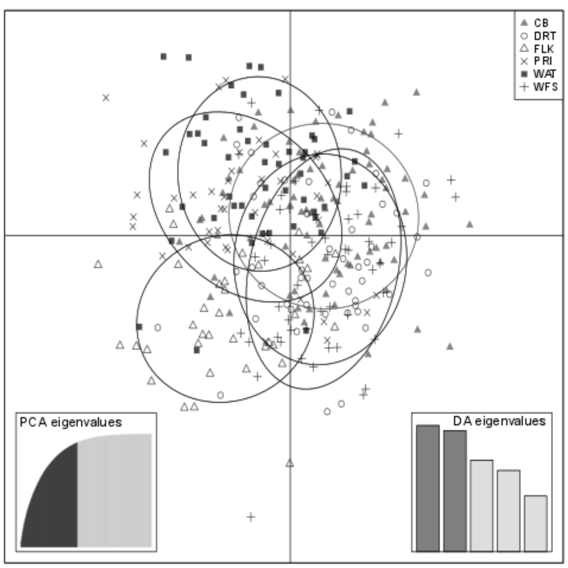


Figure 25. Discriminant Analysis of Principal Components (DAPC) analysis results of the red grouper. Only populations in the West Florida Shelf (WF) appear to be separated from the other populations (CB = Campeche Banks, DRT = Dry Tortugas, FLK = Florida Keys, PRI = Pulley Ridge WFS = West Florida Shelf, WAT = West Atlantic/Eastern Florida).

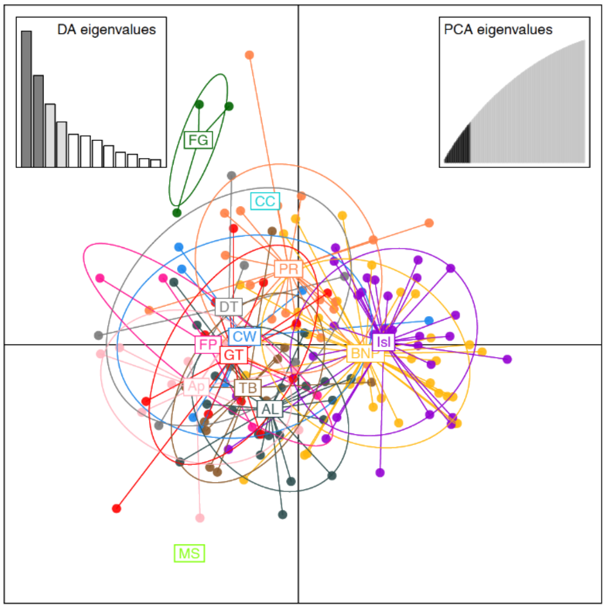


Figure 26. DAPC results for lionfish for samples collected in the NW Atlantic and the Gulf of Mexico. Our fine-scale genomic analyses of lionfish demonstrate lack of current genetic break between the first and last invaded areas in US waters, the NW Atlantic and Gulf of Mexico, respectively.

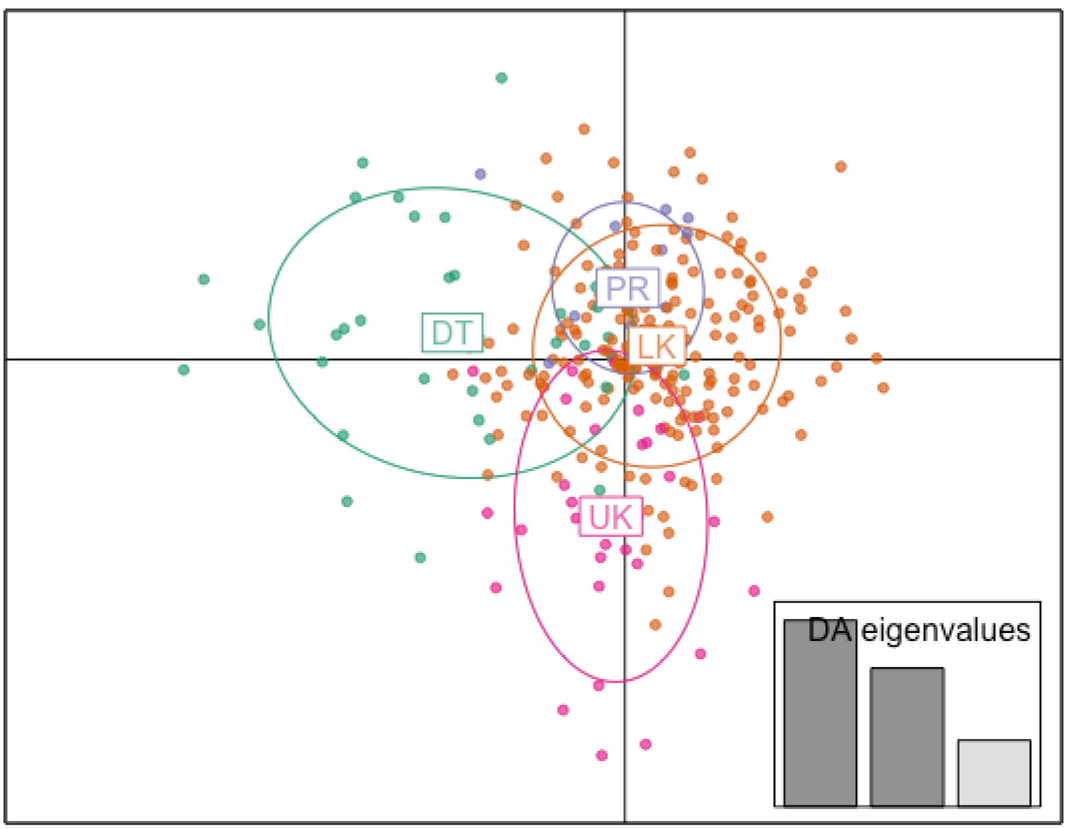


Figure 27. DAPC results for bicolor damselfish for samples collected at PR, DT and FLKeys (UK = Upper Keys, LK = Lower Keys), showing little genetic separation among populations.

Corals: For the great star coral (*M. cavernosa*), there was strong evidence for different populations at deep (20–30 m) and shallow (< 10 m) sites in the FLKeys (Serrano et al. 2014). PR belongs to the same population as deeper sites (> 15 m) in the Lower FLKeys, but is different from the Flower Gardens population, which belongs to the same population as shallow sites in the FLKeys (Figure 28).

Corals from deep (20–30 m) sites in the DT represent a third population, which may also be present in the Upper Keys at intermediate (10–20 m) and deeper depths (Serrano et al. in prep.). High resolution molecular methods also revealed additional fine-scale differentiation among some deep DT sites and mesophotic sites, such as the northern and southern sites of PR (Drury et al. in prep.).

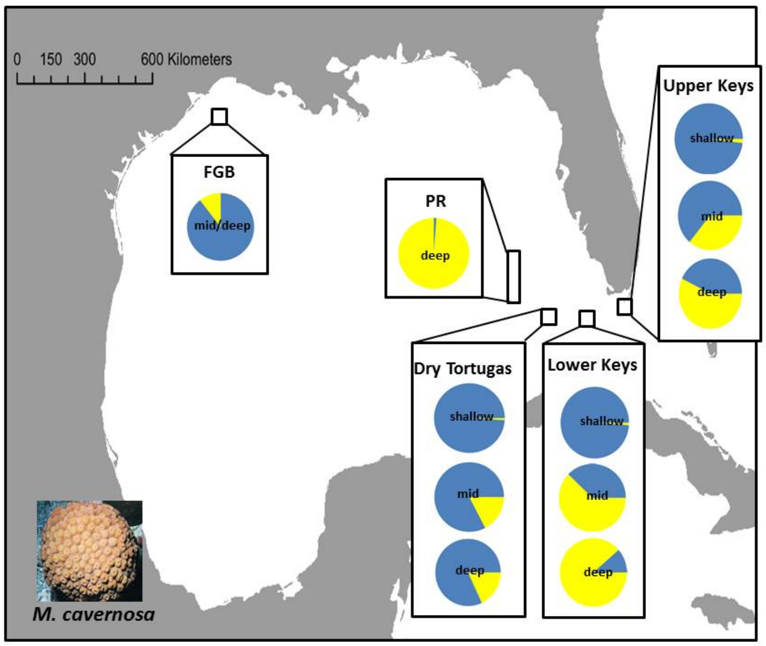


Figure 28. Graphical representation of STRUCTURE analysis of *M. cavernosa* samples. Pie charts represent the proportion of membership to either of the two genetic clusters (shallow depicted in blue, deep depicted in yellow) for each region and depth.

The mustard hill coral (*Porites astreoides*) also has different populations at deep and shallow shelf sites throughout the FLKeys (Serrano et al. 2016), and although not present at PR is nevertheless instructive in lending support to the *P. astreoides* findings (Figure 29). For example, *P. astreoides* at Flower Garden Banks belongs to the same population as shallow sites in the FLKeys, but deep DT samples appear to be a completely separate population not present anywhere else in the FLKeys (Serrano et al. in prep.).

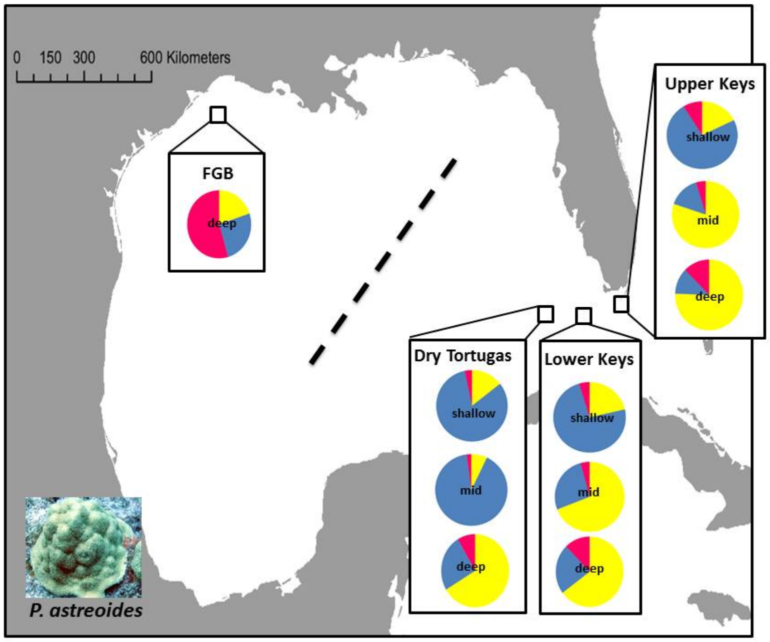


Figure 29. Graphical representation of STRUCTURE analysis of *P. astreoides* samples. Pie charts represent the proportion of membership to one of the three genetic clusters (shallow depicted in blue, deep depicted in yellow, FGB depicted in pink) for each region and depth.

Lettuce corals (family Agariciidae) are dominant members of the coral community at PR, but their taxonomy and systematics are complex, and these deep-water species are not typically found in shallow water (hence no connectivity). We developed next generation molecular methods to investigate species boundaries in these taxa from PR (Perez-Portela et al. in prep.; see Figure 30), but there were not enough samples for a connectivity analysis once the data had been grouped into taxonomic units.

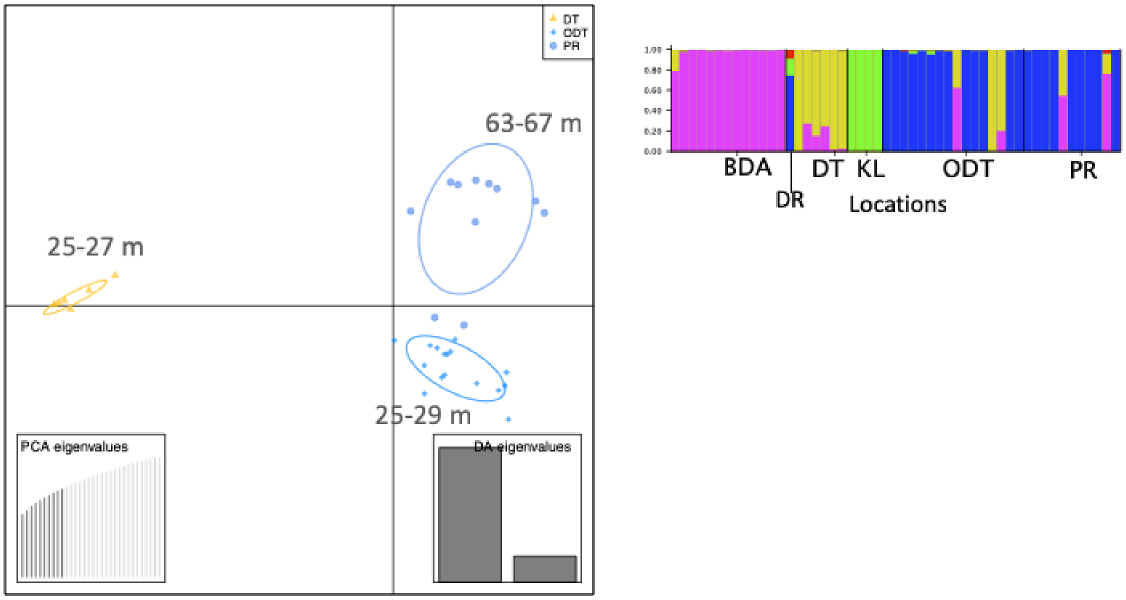


Figure 30. Maximum Likelihood tree (left) and Results of STRUCTURE analysis (right) of *Agaricia* spp. samples based on 1,253 SNPs and 51 samples. Different colors represent different clades (species). BDA - Bermuda, DR - Dominican Republic, DT - Dry Tortugas, KL- Key Largo, ODT – Outside Dry Tortugas Boundary, PR - Pulley Ridge.

Sponges: The giant barrel sponge (*Xestospongia muta*) demonstrated genetic connectivity between mesophotic and shallow communities across only relatively small spatial scales (Figure 31). While giant barrel sponges inhabiting PR were well connected genetically to those sponges occupying the geographically proximal DT, little genetic connectivity was observed between PR and the more geographically distant middle and upper FLKeys. Genetic connectivity across limited spatial scales is likely due to the presumed short larval duration of this species (~3 days) and sponges in general. Based on these results, PR sponge species may have a higher likelihood of representing distinct genetic populations which do not serve as a source of recruits to the upper FLKeys.

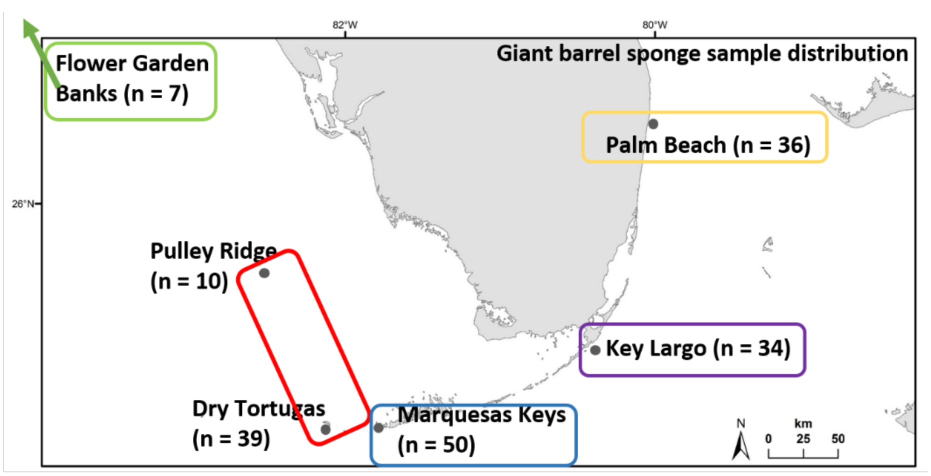


Figure 31. The Giant barrel sponge samples show five separate genetic populations.

Calcareous algae: The target species,*Halimeda tuna*, were not obtained from PR. Instead, a total of nine morphotypes of *Halimeda* were obtained instead plus one morphotype from DT.

The *Halimeda* obtained from PR corresponded to seven haplotypes (Figure 32), with one of these also present on DT. Since we collected *H. tuna* from shallow water for our genetic comparisons, we did not have adequate sample coverage for population connectivity studies. Instead we redirected our efforts to documenting and describing the diversity of *Halimeda* species found on PR. We are waiting on the morphological identifications (samples supplied to taxonomist in May 2017) of our morphotypes to be able to complete this work.

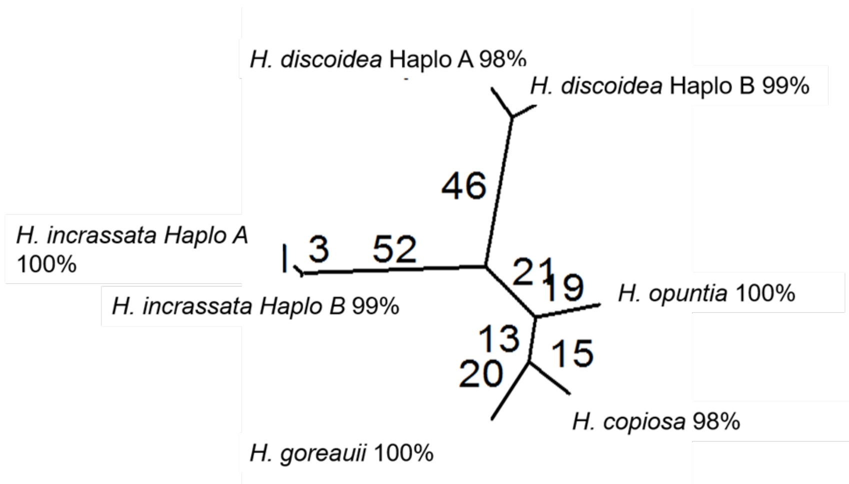


Figure 32. The *Halimeda* samples collected at Pulley Ridge likely represent four species and five haplotypes with *H. copiosa* and *H. discoidea* being the most abundant.

- *Assess potential constraints on connectivity and response to climate change by determining symbiont community structure (*Symbiodinium *spp.) in the PR coral species.*

Algal symbionts (family Symbiodiniaceae) do not constrain the connectivity of *M. cavernosa* because the same symbionts are found in both deep (20–30m) and shallow (< 10 m) water in the FLKeys (Serrano et al. 2014) and are similar to those at PR (unpubl. data). Similarly, they do not constrain the vertical connectivity of lettuce corals (*Agaricia* spp.), because deep-water lettuce corals are not found at shallow sites. Algal symbionts do differ between deep and shallow populations of *P. astreoides*, which match patterns of population structure in Florida, but not in other areas (e.g., Bermuda, USVI) suggesting corals can acquire appropriate symbionts depending on their recruitment site (Serrano et al. 2016). However, since *P. astreoides* is not present at PR this is a moot finding. We conclude that algal symbionts are not generally a limiting factor for the two PR corals we examined, *M. cavernosa* and *Agaricia* spp.

- **Evaluate spatially-explicit fish abundances and provide measures of reproductive output.**
    - *Estimate the spatial distribution, abundance, and size structure of key economically and ecologically important reef-fish species in PR MCE, compared to those regionally located in upstream (west Florida shelf) and downstream (DT-FLKeys) areas.*

We captured 62 Red Grouper in traps on PR. All these fish were mature (Lombardi-Carleson et al. 2008) and varied in age from 5 to 17 years and size from 39 to 75 cm total length. All Red Grouper sampled on PR by ROV lasers were also mature (50–80 cm total length; Harter et al. 2016). In addition to Red Grouper, we also caught 1 Gag (74 cm), 9 Scamp (73–79 cm TL), 4 Mutton Snapper (42–61 cm TL), 1 Dog Snapper (66 cm TL), 1 Yellowtail Snapper (39 cm TL), 1 Greater Amberjack (112 cm TL) and 1 Almaco Jack (58 cm TL). All these fish were mature.

Bicolor damselfish on MCEs grow more slowly, but live longer and attain larger maximum sizes. These populations also invest more energy into reproduction than shallow-water populations. Thus, mesophotic populations have the potential to serve as a valuable source of reproduction for the entire region. However, because populations are skewed towards older ages and recruitment rates are low, persistence relies on long-lived individuals, suggesting that long term resiliency of these populations may be low.

Predation risk for bicolor damselfish is highest at deep shelf (20–30 m) sites, resulting in higher rates of fish sheltering behaviors and lower fish access to zooplankton prey. Growth rates are higher for shallow shelf (fish who can feed high in the water column with a lower threat of mortality). Diet and stable isotope analyses of mesophotic fish indicate that they have a variable, lipid-rich diet and feed at a higher trophic position than shallower reef fish. Combined, these data demonstrate that PR is a suitable habitat for bicolor damselfish populations.

- *Link population abundance and size structure to spatially-explicit reproductive output of selected reef fish species in PR MCE.*

Red Grouper have a protracted spawning season (Coleman et al. 1996) extending from January through July, but peaking in April-May. Thus, environmental conditions during their density independent state—the planktonic larval stage—may vary seasonally, but larvae are distributed broadly depending on current patterns. Small juveniles may occur inshore or in depths as great as 30 m (Koenig, personal observation). Excavating behavior, which is well known for adults (Coleman et al. 1996), begins immediately after metamorphosis, and provides significant protection to juveniles regardless of settlement habitat.

Red Grouper do not migrate to spawning sites as most other large groupers do, but instead exhibit polygynous pair mating in their home excavations (Coleman et al. 1996, Nelson et al. 2011) which they dig and maintain (Coleman et al. 2010), apparently for life. Thus, protection of an area means protection of the reproductive adults—i.e., they do not migrate. Population densities can be very high at shelf-edge depths, especially if the populations are protected from fishing (demonstrated by Wall et al. 2011).

We estimated the density of Red Grouper pits (and therefore the density of Red Grouper because only one Red Grouper occupies one pit) within the PR sampling area using the line transect method of estimating density (Krebs 1999). The densest grouping of Red Grouper pits was observed in the southern region of PR (2012) and the lowest in the western region (2013). The central and northern areas were intermediate in pit density (summarized in Figure 33).

Lionfish were abundant in Red Grouper pits and rather sparse elsewhere on PR (Figure 33). Lionfish were also most abundant in Red Grouper pits with high numbers of small fish (i.e., fish that are relatively small as adults, like damselfish, blennies, gobies, cardinal fish, etc.; Figure 34). While this result seems counter intuitive (i.e., that Lionfish would consume all the small fish so that a negative relationship would exist as shown by Albins 2015), counter explanations exist. One explanation is that small fish attract Lionfish, so pits with a large abundance of small fish would also have a large number of Lionfish. But if the attraction is for feeding on them, they would seemingly deplete the small fish. Another explanation is that the presence of Red Grouper ameliorates predation upon small fish (shown experimentally by Ellis and Faletti 2016).

Figure 33. Map of area sampled on Pulley Ridge in 2015. The figure shows Lionfish density as represented by a black circle with a fish inside (diameter of the circle proportional to density in numbers per m). Red Grouper pit density represented by a circle—the diameter of which indicates pit density. The green portion indicates density of active pits and the white indicates density of abandoned pits.

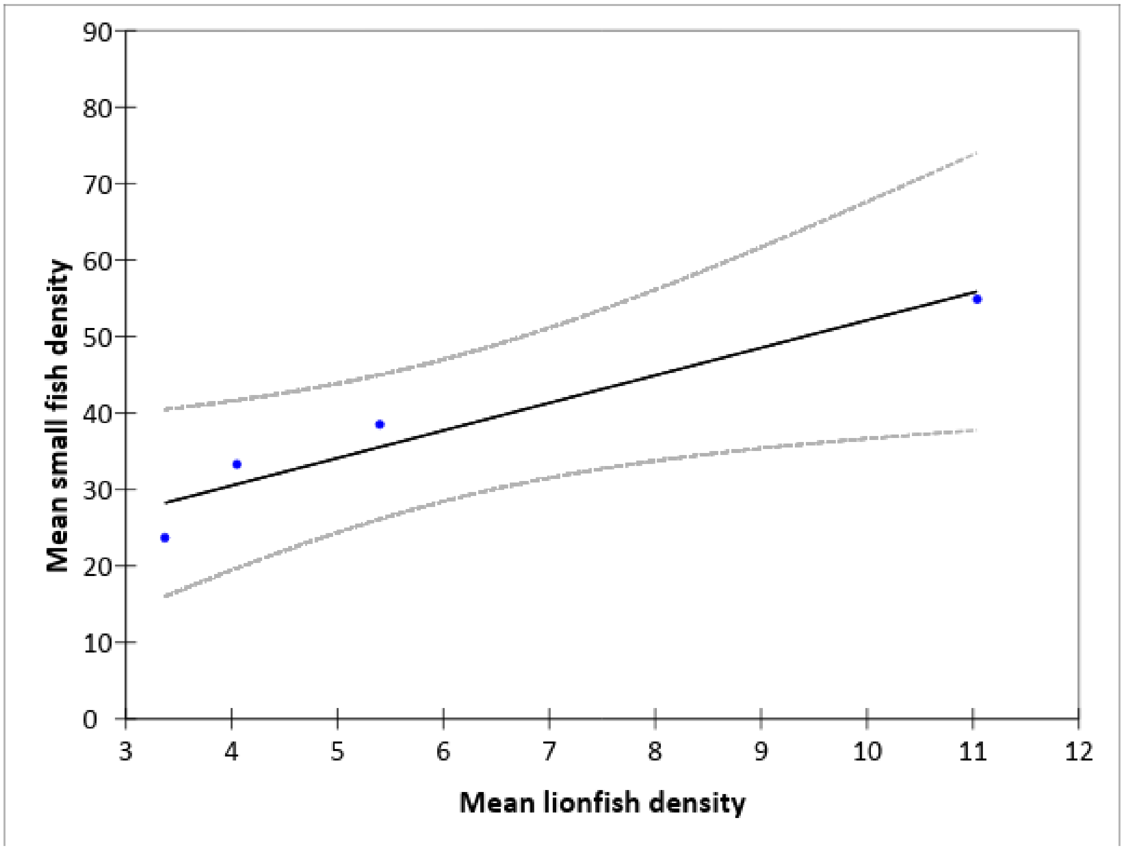


Figure 34. Linear regression showing relationship between annual mean Lionfish density (number per pit) in Red Grouper pits on PR and annual mean density (number per pit) of small fish (i.e., small as adults) ($r^2 = 0.93$, $P < 0.05$). Dashed lines are 95% confidence limits. Sample sizes: 2012 – 75 Red Grouper (RG) pits; 2013 – 43 RG pits; 2014 – 51 RG pits; 2015 – 57 RG pits.

For our model reef fish species, bicolor damselfish, approximately 9% of regional egg production is sourced from PR populations. This value is heavily influenced by the total area of habitat at PR available to support fish populations. Combining fish distribution, size, and abundance data with depth-specific reproductive output estimates resulted in a conservative (minimum) estimate of the total contribution of PR populations to the wider FLKeys region. Consideration of the higher egg quality produced by mesophotic bicolor damselfish (as outlined above) would increase this estimate. (These data are being incorporated into the biophysical dispersal model to refine estimates of connectivity between PR and the FLKeys). While bicolor damselfish densities are low at mesophotic depths, the vast area of habitat contributes significantly to this estimate, highlighting the necessity of maintaining intact mesophotic habitat. Figure 35 summarizes these life history patterns by depth.

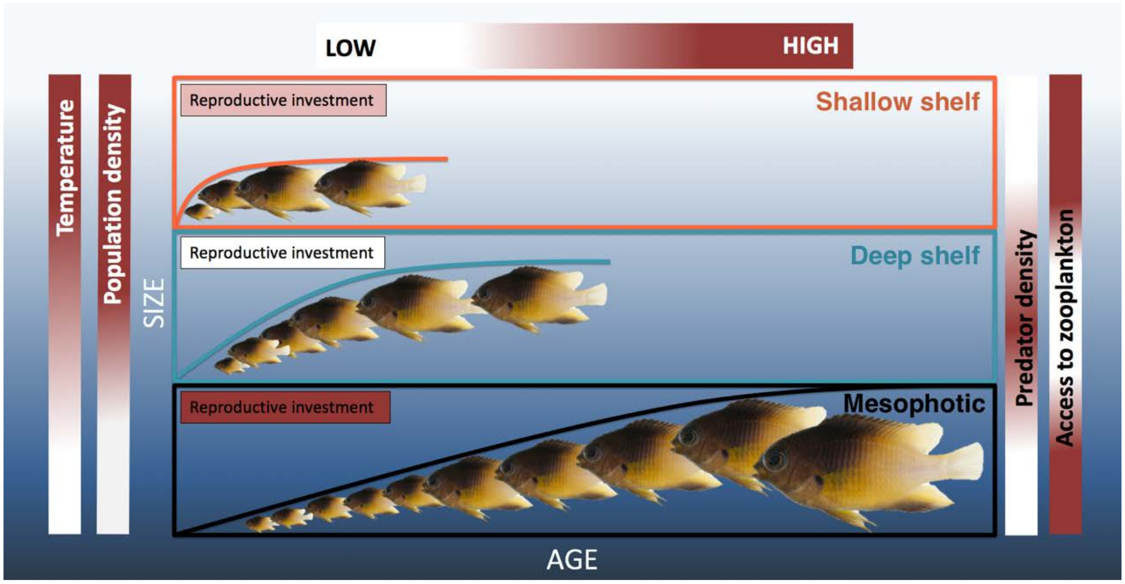


Figure 35. Schematic of model fish *Stegastes partitus* (bicolor damselfish) demography differences with depth. Bicolor damselfish at PR grow more slowly, but attain larger asymptotic sizes and live significantly longer than shallow shelf fish. Higher predator densities in deep shelf reefs cause more sheltering behavior by these planktivorous fish and reduce their access to zooplankton prey. In comparison, despite low population densities of bicolor damselfish at mesophotic depths, access to higher quality prey leads to significantly higher investment in reproduction. Schematic based on data from Goldstein et al. (2016a, 2016b, 2017). Sponaugle and Cowen (*in press*).

- *Assimilate and Synthesize Regional Ecosystem Databases*
- *Link abundance and size structure to spatially-explicit reproductive output of selected reef fish species in PR MCE to the SCEs*

These tasks were deleted in Year 2 due to budget cuts.

➢ **Determine spatially-explicit habitat descriptors and community structure in and about PR and DT.**

- *To compile and assimilate existing data on community structure of MCEs from the entire study area into a comprehensive database*
- *To locate, characterize, and determine the distribution of MCEs in the study area*

All data from the four cruises have been provided in our last cruise report (Reed et al. 2017a) and are available to the public on the NOAA website: https://data.nodc.noaa.gov/coris/library/NOAA/Non-CRCP/Corals/Reed2017a_Pulley_Ridge_ROV_Cruise_Report.pdf.

In summary, a total of 199 benthic macrobiota were identified from the quantitative image analysis at PR (see Appendix 2 in Reed et al. 2017). The most diverse taxa by far were sponges (92 taxa). The other sessile benthic taxa included 29 macroalgae, 12 Scleractinia (hard corals), 15 gorgonian octocorals, and 7 Antipatharia. A total of 153 benthic macrobiota were found at the DT sites (see Appendix 3 in Reed et al. 2017), which were dominated by sponges (57 taxa), macroalgae (32), corals (19), and gorgonians (16).

The benthic communities and habitats were quite different between PR and DT. The PR sites were at mesophotic depths of 59–105 m, whereas the patch reefs and fringing reef sites at DT were comparatively shallow (23–55 m). A total of 12 scleractinian species were identified at PR. The most common species at PR included *Agaricia fragilis, A. lamarcki/grahamae, A. undata, Helioseris cucullata, Madracis brueggemanni, M. formosa, M. decactis,* and *Oculina diffusa*. *Montastraea cavernosa* was also present but in relatively low abundances. DT had 19 scleractinian species with the most common being *M. cavernosa* and *Agaricia agaricites*, with low abundance.

All fishes were identified, counted, and densities determined for each ROV dive. A total of 86 fish taxa were identified from PR (see Appendix 4 in Reed et al. 2017) and 96 taxa from DT (see Appendix 5 in Reed et al. 2017). The fish assemblages of PR and DT were also significantly different, primarily due to higher densities of yellowtail reeffish (*Chromis enchrysurus*), chalk bass (*Serranus tortugarum*), purple reeffish (*Chromis scotti*), greenblotch parrotfish (*Sparisoma atomarium*), sunshinefish (*Chromis insolatus*), and lionfish (*Pterois volitans*) at PR. A total of 29 managed species were observed; 20 at PR and 17 at DT (see Table 12 in Reed et al. 2017). The most abundant species at PR were almaco jack (*Seriola rivoliana*), vermilion snapper (*Rhomboplites aurorubens*), and red grouper (*Epinephelus morio*). We observed a total of 1,885 lionfish during the course of this project; 1,814 of these were observed at PR, while only 71 were observed at DT. Most of these at PR were associated with active red grouper pits in close proximity to the resident large red grouper and numerous small reef fish that assembled in masses in these holes and used them as oases. Using all the ROV data, both on and off transect times, 66 fish taxa were observed in the grouper pits, 16 of which were managed species.

Although the project officially ended in February 2018, we have been working on further characterizing certain aspects of the benthic community: specifically the sponge and algal communities. The sponge effort is led by Cris Diaz (FAU Harbor Branch). A total of 149 sponge specimens collected during PR cruises (2010, 2011, 2015) were studied taxonomically. From these, 103 species have been identified, with new regional reports, and approximately 20% of species are considered new to science. Compared with photographic survey analyses from ROV dives, the collection and taxonomic determination of samples have increased our estimates of the species richness by at least 10% (92 species originally listed from visual characterization of ROV videos), and have revealed novel species. The algal effort is being led by Dennis Hanisak (FAU Harbor Branch). In addition to the 2015 cruise (the only one that included ROV collection capability), he has gathered samples from cruises that date back to the 1990s from the PR area. Preliminary examination of all previous samples and photo samples reveals at least 95 species (vs. 32 reported above from image analyses): Rhodophyta - 60 species, Chlorophyta - 25 species, and Ochrophyta - 10 species. These additional results on sponges and algae underline the importance of sampling and taxonomic determinations to grasp the true nature of the biodiversity that exists in these unique MCEs.

Pulley Ridge

PR is primarily rock rubble and rock/coral pavement/substrate. It consists of a Main Ridge and a West Ridge separated by a basin (known herein as Central Basin), and an area of predominately sediment east of the Main Ridge (known herein as Off Reef). These regions were further divided into North and South sub-regions. Random blocks were overlaid on these regions (Fig. 9). All sites studied (Fig. 9) were of low rugosity, low relief (< 1–2 m), and low slope (0–10^{o}).

Only the Main Ridge had been surveyed previously (Halley et al. 2013) and is entirely within the original 2005 PR HAPC. Our surveys added for the first time, data for the Central Basin and West Ridge, which were discovered to have MCE habitat at depths ranging from 72 to 105 m. The majority of the Central Basin and all of the West Ridge are outside of the original PR HAPC boundaries. Information on these areas was provided to the Gulf of Mexico Fishery Management Council (Reed and Farrington 2014b) and the HAPC boundaries were expanded in June 2018.

The depth range of all the blocks surveyed at PR was 59 to 105 m (Table 4). The Main Ridge was generally the shallowest region ranging from 59 m on top of the ridge to 76 m at the base; the Central Basin ranged from 72 to 83 m, and the West Ridge was the deepest of the mesophotic reef regions at 77 m on top of the ridge to 105 m at the base. The Off Reef blocks were at depths of 63 to 69 m, but were predominantly soft sediment habitat (88% soft bottom), and will not be discussed further. The percent cover (CPCe Point Count substrate notes) of hard-bottom substrate ranged from 80 to 98% (including both bare substrate and substrate underlying the biota). The Main Ridge averaged 94% hard bottom, Central Basin was 91%, and West Ridge was 88%.

The most important discovery of the Community Structure group was the finding of extensive mesophotic coral habitat outside the original PR HAPC. As noted above, previous exploration of PR had focused on the Main Ridge, which is within the original HAPC. We discovered significant MCE habitat present to the west of the original HAPC boundaries, including the relatively flat Central Basin and the deeper West Ridge.

There is a distinct pattern of biota among these the Main Ridge, Central Basin, and West Ridge (Fig. 13). Overall, algae are the most abundant organisms (25–50% cover). On the Main Ridge, the community is dominated by the endemic green alga *Anadyomene menziesii* and transitions to one dominated by crustose coralline algae and fleshy rhodophytes on the West Ridge. For corals, *Montastraea cavernosa* is restricted to the Main Ridge; several species of agariciids are most abundant on the Main Ridge and Central Basin, and *Madracis* spp. are most abundant on the West Ridge. A diverse sponge community is also present throughout out all regions of PR. Red grouper is the most dominant commercially important fish at PR and found in all regions of PR.

Table 4. Habitat characterization by region from ROV surveys at PR and DT during 2012 to 2015 RV *Walton Smith* cruises. Percent cover of benthic macrobiota from CPCe Point Count. HB = % cover of hard-bottom substrate (rock, coral, rubble) and % SB = soft bottom cover from CPCe Point Count notes. The deepest site was block 114 (105 m: low rugosity, low relief, cobble bottom, 8% biota, 90% hard bottom, 10% soft bottom) and it is not reflected in this table.

General Area/Region	Rugosity	Relief	Slope	Habitat Type	Biota	%HB/ %SB	Depth Range (m)
Pulley Ridge (All Sites)					49.88%	87/13	59.3-93.9
Main Ridge	Low	LR	0-10°	Rubble/Pavement	60.03%	94/6	59.3-75.5
Main Ridge- North	Low	LR	0-10°	Soft/Rubble	45.38%	87/13	59.3-73.2
Main Ridge- Middle	Low	LR	0-10°	Rubble	55.47%	97/3	61-72.2
Main Ridge- South	Low	LR	0-10°	Rubble/Pavement	72.52%	97/3	63.5-75.5
Central Basin	Low	LR	0-10°	Rubble/Pavement	46.93%	91/9	72.4-83
Central Basin- North	Low	LR	0-10°	Soft/Rubble	34.44%	80/20	76.5-83
Central Basin- South	Low	LR	0-10°	Rubble/Pavement	53.96%	98/2	72.4-82.1
West Ridge	Low	LR	0-10°	Rubble/Pavement	46.67%	88/12	76.8-93.9
West Ridge- North	Low	LR	0-10°	Rubble	47.35%	91/9	76.8-85.7
West Ridge- South	Low	LR	0-10°	Rubble/Pavement	46.08%	84/16	78.5-93.9
Off Reef	Low	LR	0-10°	Soft	19.79%	12/88	63.1-68.9
Tortugas (All Sites)					26.55%	21/79	22.9-114.4
Fringing Reef	High	MR	10-60°	Rock Ledge	58.06%	98/2	26-31.5
Patch Reef	Low	LR	0-10°	Rock Ledge	26.26%	27/73	22.9-55.3
Soft Bottom	Low	LR	0-10°	Soft	27.76%	0/100	27.3-56.8
Miller's Ledge	Low	LR	0-10°	Pavement	4.69%	63/37	79.7-114.4

In a previous survey on the Main Ridge an average coral cover of 12.83% (USGS 2005; data collected in 2003) was reported, whereas we found 0.82% coral cover (2012–2015 data). This is a 93.6% loss of coral cover in 10 years within the original PR HAPC (Fig. 36).

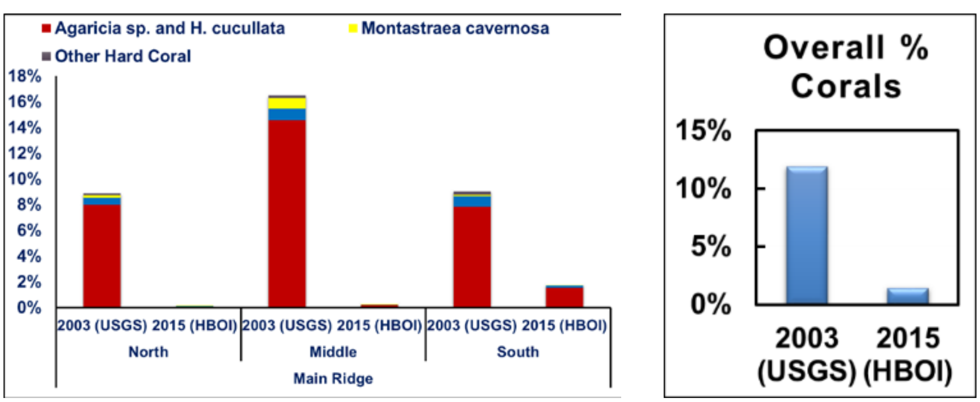


Figure 36. Comparison of coral coverage from our 2012–2015 cruises with a 2003 USGS cruise revealed large losses of coral in the original PR HAPC.

In contrast with the loss of coral on the Main Ridge, during our 2014, we discovered an area of high coral coverage in the previously unexplored Central Basin (Fig. 37), which we investigated further in 2015. A total of 51,814 living scleractinian corals were counted. The density of all scleractinian coral species was 6.83 colonies m^{-2}; platelike coral density (*Agaricia* spp. and *H. cucullata*) was 4.89 colonies m^{-2}. The Central Basin-South region which is outside the original PR HAPC had the greatest coral density overall (15.82 m^{-2}), and Block 120 (Fig. 9) had the greatest density of agariciid corals (30.3 colonies m^{-2}). A great majority of the *Agaricia* were < 5 cm in diameter, indicating they were likely recent recruits and may be recovering from the die-off that occurred after 2003 (for unknown reasons).

Figure 37. A major discovery was large patches of nearly continuous platelike coral (*Agaricia* spp.) in the Central Basin.

Red grouper pits provide the only habitat of relatively high rugosity, moderate relief (1–2 m deep, 8–15 m wide), and moderate slope (10–30^{o}) at PR. Only when the pits are maintained by a red grouper does this rugosity exist, which provides essential habitat for a variety of fishes (Coleman et al. 2010). Once the grouper leaves a pit (fished off or dies), the pit fills in with sediment which covers the exposed rock ledges.

The pits built by red grouper provide habitat to a large variety and density of small reef fish, and the exposed rock provides habitat for sessile benthic biota. Overall, 66 fish taxa were observed in the grouper pits of PR, 16 of which are managed species. Unfortunately, lionfish were observed in 72.5% to 91.4% of grouper pits during 2012 and 2014, respectively. While the maximum number of lionfish observed in a single pit was 74, the average abundance per grouper pit ranged from 3.1 in 2012 to 13.8 in 2014. Lionfish are native to the Indo-Pacific, but in recent years they have become established along the southeast coast of the U.S., the Caribbean, and the Gulf of Mexico. Lionfish (*Pterois volitans*/*miles*) were first discovered on PR during submersible dives conducted by FAU-HBOI in 2010 when six lionfish were observed. The lionfish population has significantly increased since then. We observed a total of 1,885 lionfish during the course of four cruises; 1,814 of these were observed at PR and 71 at DT. Most of the lionfish at PR were associated with active red grouper pits in close proximity to the resident large red grouper and numerous small reef fish (Fig. 38).

Figure 38. Most lionfish (left) at Pulley Ridge are located in pits excavated by the commercially important red grouper (right).

Dry Tortugas

Since we did not have multibeam maps of the DT region for the ROV surveys, we could not pinpoint sites that showed potential hard-bottom, or rocky habitat (Fig. 10). The majority of random blocks selected were primarily soft-bottom habitat (12 blocks, 100% soft bottom). Two blocks were placed on Miller's Ledge, which had never been surveyed outside of the South TER. Within the TER, both Miller's Ledge and Riley's Hump had been extensively characterized by Weaver et al. (2006). These two blocks were placed to see the extent of the Miller's Ledge to the west of the TER. These blocks were predominately hard bottom (63%), but were deeper (to 114 m) than the other reef blocks, and were deep-sea coral habitat and not a MCE. One block was on the west slope of the Tortugas Bank (Block 46), but outside of the FKNMS and TER boundaries. This site was at depths of 26–31.5 m, and is the deep fore-reef of the bank. The base of the reef flattens out into flat sand at 31 m. This reef was primarily hard bottom, reef habitat (98% hard bottom). The remaining 8 blocks were discovered to be low relief, patch reef habitat at depths of 23–57 m, just to the west of the FKNMS boundary (red blocks in Fig. 10).

Since there were limited multibeam maps of the DT outside of the TERs, we categorized the blocks by habitat type after the ROV surveys were conducted (Fig. 10). The blocks were randomly selected from areas outside of the TERs and FKNMS that appeared to be within mesophotic depths (> 30 to 100 m) based on available bathymetric contour charts. Four habitat types were found from the ROV dives: Soft Bottom (12 blocks), Fringing Reef (1 block), Patch Reefs (8 blocks), and Hard bottom (Miller's Ledge, 2 blocks). These are color-coded in Figure 10. The MCE sites include the newly discovered patch reefs west of FKNMS, and the fringing reef which is the west slope of the Tortugas Bank. Information on these areas was provided to the FKNMS (Reed and Farrington 2014a) along with a recommendation from the project scientists to be included within the Sanctuary boundaries.

Our ROV dives in the DT and resulting analyses resulted in a rich set of new data characterizing the benthic communities and fish populations at reef sites in the region of the TERs. These sites are located outside the protection of either the TERs or the FKNMS. On one of the patch reefs, we observed a large spawning aggregation of grey snapper (*Lutjanus griseus*; Fig. 39).

Figure 39. A goliath grouper (*Epinephelus itajara*) with a large spawning aggregation of grey snapper (*Lutjanus griseus*) on a newly discovered patch reef outside of FKNMS.

- *To preliminarily quantify two key reef processes: benthic primary productivity and settlement/recruitment potential of corals.*

These objectives were deleted in Year 2 due to budget cuts.

➢ **Provide estimates of the economic value of ecosystem services of the PR and evaluate costs-benefits of specific management option alternatives.** Specifically,
  - *Evaluate the economic connectivity of the PR to users of the ridge and of those biological resources connected ecologically to PR*

The commercial fishery sector in the study region did have significant linkage effects on the economy. However, the proposed expansions of the HAPC in the PR region and jurisdiction of FKNMS was determined to have minimal economic impacts on the regional income, tax revenue, and employment (< 3%) in the short run, particularly resulting primarily from restricted grouper fishing. However, these income and employment losses might very well be offset by economic gains following improved fish stocks downstream in the DT area and effort reallocation into areas north of PR.

- *Evaluate the bio-economic ecosystem-level impacts of management options considered for the PR*

Based on the commercial fishers' survey, their reactions to both the HAPC expansion and the FKNMS expansion were negative. An overwhelming majority of the respondents said the proposed PR HAPC regulations would either very significantly (31.6%) or somewhat significantly

(57.9%) affect their operations. About 53.5% of respondents indicated that they would not support an expansion of the PR HAPC, because 66.7% of this group contend that the extension of the HAPC would hinder their current fishing operations. 23.3% of those who opposed expansion did so even if the proposed management action did not hurt their business. Of the 16 respondents who indicated support for the HAPC extension, only 37.5% of those respondents indicated they would support a larger expansion of around 500 sq. miles. Response to the FKNMS expansion was similar to that of the HAPC expansion in that 63.2% of respondents did not support the expansion, with 56.4% of respondents indicating that an expansion would not protect coral reef health in PR. When respondents were asked which proposal would be most effective in improving coral reef health in PR, 58.5% of respondents indicated that they "said 'no' to either proposal earlier," but the next majority (18.9%) suggested that they thought a combination of both proposals would be most effective.

For the success of the future fishery programs in the region, fishery management agencies should incorporate the opinions of stakeholders into management design. However, the agencies dealing with fishery resources located in PR HAPC and FKNMS currently face steep challenges, including a prominent disparity between the stakeholders' perceived economic losses and real estimated losses. The real estimated losses that fishery sector and the regional economy will suffer appear to be minimal, although distributed slightly unevenly regionally. Furthermore, these losses diminish in the medium and long term due to ecological stock improvements and behavioral adjustment within the fishery sector. Yet, based on the primary survey, commercial fishermen appear to be jaded by past fishery management experiences in the region, and have little incentive to invest in the future as they continue to age. Reconciling the gap between the stakeholders' perception and reality puts additional responsibility on the part of management agencies, scientists, and community organizations. The fishery agencies should provide educational opportunities for fishermen and backward- and forward-linked businesses in the region that highlight past management success stories. The survey results suggest that a portion of fishermen are uncertain about the effectiveness of protected area changes. Targeted education of past success stories and negotiation may garner broad-based support for the proposed management programs.

c. Description of need, if any, for additional work.

- Observations of significant loss of coral cover suggests the need for both continued monitoring of coral distribution, abundance, and health, as well as research as to the cause and persistence of this decline.
- Given the expanding population and distribution of Lionfish throughout the Caribbean and GOM, and the current observations of Lionfish presence in Red Grouper pits, research is needed to assess the long-term effects of Lionfish on Red Grouper and their associated communities.
- Speciose groups such as the agariciid corals, sponges, and *Halimeda* algae warrant further study to better resolve the taxonomy and ecology of individual species, as well as assess their connectivity.

Outputs

i. New fundamental or applied knowledge

- PR, DT, and FLKeys are interconnected physically by oceanic currents and water properties are controlled by both local and regional circulation. NDT is under the influence of shelf circulation, while PR, SDT, and FLKeys are strongly influenced by oceanic currents (LC and FC) (Kourafalou et al. 2018).
- Discovered that the LC releases anticyclonic eddies that move eastward along the Cuban coast and northward along the shelf break of the southwest Florida shelf(SWFS) bringing warm water over the reefs (Kourafalou et al. 2017, 2018).
- Documented that the strongest currents and warmest temperatures over PR are associated with a young LC near the SWFS, after the shedding of an anticyclonic LC ring (central GoM) or northward release of an anticyclonic eddy (West Florida Shelf) (Kourafalou et al. 2017, 2018).
- Documented in situ that Mississippi River water influences the water property around South Florida reefs (Le Hénaff and Kourafalou 2016).
- Biophysical models for the bicolor damselfish demonstrated that PR can self-seed and provide larval subsidies to downstream shallow and mesophotic reefs. Subsidies are intermittent via two primary pathways: (1) northeast with northern FC position, mesoscale eddy over DT, and (2) southeast path with southern FC position, propagation of remotely generated eddies (Fig. 40; Vaz et al. 2016; Olascoaga et al. 2018).

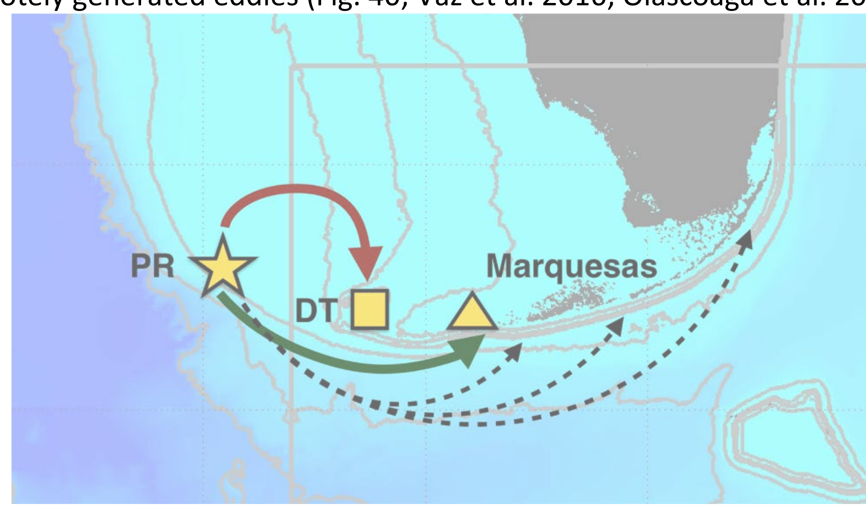


Figure 40. Biophysical modeling demonstrates that bicolor damselfish populations at PR, DT, and FLKeys are connected by two pathways: (1) northeast (green) and (2) southeast (red).

- Found that the bicolor damselfish populations on PR are older and larger than downstream shallow reefs in FLKeys. PR populations rely on older females investing in and producing high quality offspring, which have a better chance of survival. When combining this information with the knowledge that bicolor damselfish in the Western Atlantic are genetically similar, PR may serve as potential refuge for bicolor damselfish and as a possible source of stock for shallower populations (Goldstein et al. 2016a, 2016b, 2017).

- Estimated that PR bicolor damselfish population generates 9% of regional (PR, DT, FLKeys) production based on combining information on growth, reproductive output, density, and habitat availability (Goldstein et al. 2016a, 2016b, 2017).
- Fishes (bicolor damselfish, red grouper, and lionfish) studied generally have long pelagic larval durations (3–7 weeks) and showed high connectivity among sites and depths. PR has the potential to act as a refuge for these species. For each species, shallow and mesophotic populations should be managed as a single population under regional management plans.
- The coral (*M. cavernosa*) and sponge (*X. muta*) studied both have shorter pelagic larval durations (~days to weeks) and showed higher population structure. *M. cavernosa* showed strong population structure by depth, with high connectivity between PR and reefs > 15 m in the FLKeys, with very little connectivity between PR and DT. *X. muta* showed connectivity only between PR and DT, the nearest downstream reef.
- Discovered a new coral area in 2014 in the PR's Central Basin. The area is extensive and has the densest cover of plate corals (*Agaricia* spp.) known in the Gulf of Mexico.
- Documented a 93% decline of hard corals at PR on the Main Ridge that occurred over a 10-year period.
- Documented that lionfish populations have significantly increased on PR since 2010, when the first six lionfish were recorded.
- Discovered a snowy grouper aggregation outside, but near the TER boundary.
- Cessation of commercial fishing at PR HAPC will not lead to large declines in fishery revenue at the fleet level. However, these declines can possibly be significant for individual operators for whom PR is an especially valuable fishing ground.
- It was not possible to precisely estimate economic benefits of the cessation of commercial fishing from the HAPC to downstream reef areas (DT, FLKeys). These benefits likely exist and can be estimated based on recent studies done in Hawaiʻi and other places. Also, these benefits are diffused over a larger area.
- The majority of fishermen responding to the economics survey did not support changes in regulation in the PR.

Project activities stimulated related projects:

1. Building upon the connectivity concepts which the PR project was based, a joint cruise (employing the same ROV technologies pioneered during the PR project and supported by many of the PR project principals) circumnavigated Cuba in 30 days in 2017. This project was done under the Sister Sanctuary Agreement between the U.S. and Cuba, which established a working relationship between two of our project sites (the FKNMS and the Flower Garden Banks National Marine Sanctuary) and two marine protected areas in Cuba (Banco de San Antonio and Guanahacabibes).

2. Based on preliminary analyses of the cruise data, Cuban colleagues are proposing four additional sites as marine protected areas.

ii. Scientific publications

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Seeteram, N., M.G. Bhat, B. Pierce, K. Cavasos, and D. Die. (In review). Reconciling economic reality and stakeholder perception: A management challenge in Florida Gulf Coast fisheries. Marine Policy

Sponaugle S., J. Ivory, E.D. Goldstein, E.K. D'Alessandro (In prep*)* Patterns of larval fish and invertebrate supply to mesophotic, deep, and shallow reefs in the Florida Straits.

Sponaugle S., J. Ivory, E.D. Goldstein, K. Doering, E.K. D'Alessandro (In prep) Zooplankton assemblages across a depth gradient on a mesophotic coral reef.

Voss, J., J. Reed, S. Farrington, and M.D. Hanisak (In prep) Decadal changes in benthic community composition at Pulley Ridge.

<u>Theses</u>

Bedell, Z. 2017. The Connectivity of Pulley Ridge and the Dry Tortugas Based on Echo Intensity and Current Measurements. M.S. Thesis. University of Florida. 57 p

Doering, K. 2014. Comparison of invertebrate zooplankton assemblages near coral reef habitats across depth strata. Undergraduate Honors Thesis. University of Miami

Goldstein, E.D. 2015. Comparative demography of a coral reef fish: vertical and horizontal spatial variability in bicolor damselfish traits and survival across the Florida Shelf. Ph.D. dissertation. University of Miami

Mignard, C. 2014. Characterizing biodiversity of fish communities in support of the evaluation of new marine management alternatives for the Pulley Ridge. MSc Thesis. Université Pierre et Marie Curie, Paris, France

Serrano, X.M. 2013. Horizontal vs. vertical connectivity in Caribbean reef corals: identifying potential sources of recruitment following disturbance. Ph.D. dissertation. University of Miami. 153 p

Starnes, E.D. 2017. Effects of fishing gear area restriction and catch share programs on effort distribution in Pulley Ridge, Eastern Gulf of Mexico. M.S. Thesis. University of Miami. 182 p

Reports

Reed, J., D. Hanisak, S. Farrington and K.R. Rademacher. 2012a. Preliminary cruise report: 2012 Pulley Ridge Cruise, August 14-25, 2012, R/V *Walton Smith* and UNCW *Superphantom* ROV. NOAA Cooperative Institute for Ocean Exploration, Research and Technology, Miami, FL. HBOI Miscellaneous Contribution Number 824, 63 p

Reed, J., S. Farrington, D. Hanisak and K. Rademacher. 2012b. NOAA SEADESC I Report: 2012 Pulley Ridge Cruise, August 14-25, 2012, R/V *Walton Smith* and UNCW *Superphantom* ROV. NOAA Cooperative Institute for Ocean Exploration, Research and Technology, Miami, FL, 57 p

Reed, J. and S. Farrington. 2014a. Proposal to Gulf of Mexico Fishery Management Council and FKNMS: Mesophotic reefs outside of the Tortugas Ecological Reserves. HBOI Technical Report Number 165. 9 pp.

Reed, J. and S. Farrington. 2014b. Proposal to Gulf of Mexico Fishery Management Council: Proposed Pulley Ridge HAPC Extension. HBOI Technical Report Number 164. 51pp.

Reed, J., S. Farrington, H. Moe, S. Harter, D. Hanisak, and A. David. 2014c. Characterization of the mesophotic benthic habitat and fish assemblages from ROV Dives on Pulley Ridge and Tortugas during 2012 and 2013 R/V *Walton Smith* Cruises. NOAA Cooperative Institute for Ocean Exploration, Research and Technology, Miami, FL. HBOI Technical Report Number 147, 51 p

Reed J.K., S. Farrington, S. Harter, H. Moe, D. Hanisak and A. David. 2015. Characterization of the mesophotic benthic habitat and fish assemblages from ROV dives on Pulley Ridge and Tortugas during 2014 R/V *Walton Smith* cruise. NOAA Cooperative Institute for Ocean Exploration, Research and Technology, Miami, FL. HBOI Technical Report Number 157, 133 p

Reed, J., S. Farrington and D. Hanisak. 2016. Characterization of mesophotic coral/sponge ecosystem habitats in the region of the Tortugas Ecological Reserves from ROV Dives during 2013 and 2014 R/V *Walton Smith* cruises. NOAA Cooperative Institute for Ocean Exploration, Research and Technology, Miami, FL. Harbor Branch Oceanographic Technical Report Number 176, 138 p

Reed J.K., S. Farrington, A. David, S. Harter, H. Moe, L. Horn, G. Taylor, J. White, J. Voss, S. Pomponi, D. Hanisak. 2017a. Characterization of Mesophotic Coral/Sponge Habitats and Fish Assemblages in the Regions of Pulley Ridge and Tortugas from ROV Dives during R/V *Walton Smith* Cruises of 2012 to 2015. NOAA CIOERT Cruise Report. Submitted to NOAA-NOS-NCCOS, NOAA Office of Ocean Exploration and Research. Harbor Branch Oceanographic Technical Report Number 178, 76 p

Reed J.K., S. Farrington, S. Harter, A. David, H. Moe, D. Hanisak. 2017b. Characterization of the Mesophotic Benthic Habitat and Fish Assemblages from ROV Dives on Pulley Ridge during 2015 R/V *Walton Smith* Cruise. NOAA CIOERT Report. Report to NOAA-NOS-NCCOS, NOAA Office of Ocean Exploration and Research. Harbor Branch Oceanographic Technical Report Number 177, 221 p

iii. Patents

N/A

iv. New methods or technology

See v. below

v. New or advanced tools (e.g., models, biomarkers)

- The high resolution ($1/100^0$, ~900m) FKEYS-HYCOM model was expanded to cover the Pulley Ridge area (in addition to covering coastal seas around South Florida and the full Straits of Florida).
- Algorithm development for the open-source Connectivity Modeling System developed and maintained in the Paris Lab: (1) Habitat Module: 3D settlement choice, (2) Biological Module: ontogenetic buoyancy for coral planula larvae.

- This research resulted in the development of next generation population genetic tools and databases (SNP genotypes) for a variety of important taxa that can be applied to future studies of connectivity and population structure in the region.

vi. Workshops/Conference Sessions

- *Annual PI meetings*: We held annual 'All-PI' meetings (2011–2016) with our NCCOS Program Manager to coordinate research activities and report on results. Additionally, we invited Stakeholder Advisory Board (SAB) Members to attend.
- *Stakeholder Advisory Board meetings*: We held annual meetings with our SAB immediately following the 'All-PI' meetings to update them on each year's work and to obtain input to research directions and outputs that would be of help.
- *Pulley Ridge Ecosystem Project Briefing for Stakeholders*: On February 27, 2018, we held an in-person meeting (available via webinar) for interested stakeholders including the SAB, to present the project's results and how they might be useful in addressing resource management issues. The meeting originally scheduled for January 24, 2018 had to be cancelled due to the Federal Government Shutdown. As the project officially ended on February 28, 2018, we had to run the meeting before this date. Thus, many folks that were planning on attending couldn't make the new date. See Appendix B for the agenda and attendance list.

- *All PI Collaboration Workshop*: May 1-2, 2017, we held an all PI workshop to improve collaboration among the projects groups and identify cross-group papers to be developed. The meeting resulted in the identification of five papers that are now either in press, in review, or in prep: (1) Comparison of organisms/habitat of three Pulley Ridge locations (Western Ridge, Main Ridge and Central Basin); (2) Changes in benthic communities at Pulley Ridge over 30 years; (3) Multi-species integration of biophysical and genetic approaches to understanding connectivity between Pulley Ridge and Florida Keys, USA; (4) Description of Pulley Ridge for Springer's MCE Book; and a (5) Bioeconomic study of economic value of fishery and non-use benefits.
- *Special Session at ICRS*: We organized and led Session: *Connectivity, recruitment and isolation among coral reef populations* at 13th International Coral Reef Symposium (ICRS), Honolulu, Hawaii, USA, June 2016. See Presentations for list of oral presentations and posters. ICRS is the premier meeting for coral reef scientists and managers and held once every four years. This is the best way to make the scientific community aware of the project and its results, outside of peer-reviewed publications.
- Individual PIs participated in a variety of conference/workshops (per presentations Sec. vii)

vii. Presentations

2012

Cowen, R. and P. Ortner (2012) Gulf of Mexico mesophotic reef species connectivity to FKNMS shallow and deeper reefs (the Pulley Ridge Project). Florida Keys National Marine Sanctuary Advisory Council Meeting, December 11, 2012, Key West, Florida (oral presentation)

2013

Cowen, R. (2013) Understanding coral ecosystem connectivity in the Gulf of Mexico: Pulley Ridge to the Florida Keys. Gulf of Mexico Fishery Management Council Workshop on Interrelationship between Coral Reefs and Fisheries, May 21, 2013, Tampa, Florida (oral presentation)

Doering, K. (2013) Invertebrate zooplankton assemblages collected with light traps at Pulley Ridge, a mesophotic reef. Summer Internship Presentation. University of Miami (poster)

Goldstein, E.D. (2013) Comparative demography of a coral reef fish across vertical spatial scales. RSMAS Division of Marine Biology and Fisheries Student Seminar (oral presentation)

Goldstein, E.D., S. Sponaugle (2013) Spatial variation in the early life history traits of a coral reef fish. 37th Annual larval Fish Conference, Miami, Florida (poster)

Goldstein, E.D., S. Sponaugle (2013) Spatial variation in the early life history traits of a coral reef fish. Gulf of Mexico Fishery Management Council Workshop on Interrelationship between Coral Reefs and Fisheries, Tampa, FL (poster)

<u>2014</u>

Doering K., E.D. Goldstein, S. Sponaugle (2014) Comparison of invertebrate zooplankton assemblages near coral reef habitats across depth strata. Honors Thesis Presentation. University of Miami (poster)

Farrington, S., J. Reed (2014) Deepwater and mesophotic reef surveys and conservations efforts. Graduate Studies Program, November 25, 2014, NOVA University, Ft. Lauderdale, Florida (oral presentation)

Goldstein, E.D. (2014) Population demographics of a coral reef fish across vertical spatial scales. RSMAS Department of Marine Ecology and Biology Student Seminar (oral presentation)

Karnauskas M, Walter JF, Paris CB (2014) Improving estimates of recruitment strength in stock assessments via a biophysical modeling framework. AFS 144 Annual Meeting, August 17-21, Quebec (oral presentation)

Koenig, C. (2014) Gulf of Mexico: A Case Study for Gag Grouper, Natural Mortality, and Recruitment, AFS 144 Annual Meeting, August 17-21, Quebec (Abstract)

Holstein, D., A.C Vaz, T.B. Smith, C.B. Paris (2014) Mesophotic reefs as critical components of coral reproductive networks. Ocean Sciences Meeting, Honolulu, Hawaii (poster)

Ortner, P. (2014) Coral Ecosystem Connectivity: Pulley Ridge to the Florida Keys. Update on ecosystem activities. South Atlantic Fishery Management Council Meeting, Point Vedra Beach, FL, June 9, 2014 (oral presentation)

Paris, C.B. (2014) Biophysical Models: Tracking Invisible Larval Pathways from Spawning to Recruitment, AFS 144 Annual Meeting, August 17-21, Quebec (oral presentation)

Reed, J. (2014) Proposal for expansion of the Pulley Ridge mesophotic coral reef HAPC protected area and proposal for new deepwater *Lophelia* coral HAPC off the west Florida shelf. Gulf of Mexico Fishery Management Council, Coral Working Group, December 4-5, 2014, St. Petersburg, Florida (oral presentation)

Sagarese, S., J. Tetzlaff, M. Bryan, M.J. Schirripa, M. Karnauskas, A. Gruss, C.B. Paris, G. Zapfe (2014) Incorporating Integrated Ecosystem Assessment Products into Stock Assessments for the Gulf of Mexico: a case study for gag grouper, natural mortality, and recruitment. AFS 144 Annual Meeting, August 17-21, Quebec (oral presentation)

Sponaugle, S., C.B. Paris, K.D. Walter, V.H. Kourafalou, E. D'Alessandro (2014) Observed and modeled larval settlement of a reef fish to the Florida Keys. Ocean Sciences Meeting, Honolulu, Hawaii (oral presentation)

Vaz, A. C., C.B. Paris, D.M. Holstein, M.J. Olascoaga (2014) Simulating mesophotic to shallow reefs connectivity considering three-dimension coral reef habitats, Ocean Sciences Meeting, Honolulu, Hawaii (poster)

2015

Baker A.C.; X. Serrano (2015) Patterns of deep-shallow connectivity of reef corals in the Florida Keys, Pulley Ridge, and Flower Garden Banks: Implications and opportunities for studies of transnational coral reef connectivity between Cuba and the USA. 10th Congress of Marine Sciences, MARCUBA 2015, November 16-20, 2015, Havana Cuba (oral presentation)

Goldstein, E.D. (2015) Variable reproductive investment of a coral reef fish across vertical spatial scales. RSMAS Department of Marine Biology and Ecology Student Seminar

Goldstein, E.D. (2015) PhD Defense, RSMAS, University of Miami

Goldstein E.D.; E.K. D'Alessandro; S. Sponaugle (2015) Variable population demographics of a coral reef fish across vertical spatial scales. American Fisheries Society Meeting, Portland, OR

Kourafalou, V.H., H. Kang, N. Perlin and M. Le Hénaff (2015) A real-time, high resolution forecast system of connectivity between South Florida, Cuba and the Bahamas. 10th Congress of Marine Sciences, MARCUBA 2015, November 16-20, 2015, Havana, Cuba.

Lindo-Atichati D.; A.C. Vaz; M. Karnauskas; C.B. Paris (2015) Estimating oil exposure of red snapper and gag grouper during the DWH blowout, Oil Spill and Ecosystems Science Conference, Feb 16-19, Houston

Paris, C.B. (2015) Modeling larval life in moving fluids: hydrodynamics, cues, and navigation, Physics/Ecosystems Interactions, Gordon Research Conference, June 7-12, Biddeford, ME

Pomponi, S. (2015) Florida Keys National Marine Sanctuary Advisory Council, Annual Meeting, Marathon, FL, August 18, 2015; Pulley Ridge and Tortugas characterization: proposals for expansion of FKNMS (oral presentation)

Smith, R.H., A. Valle-Levinson, V.H. Kourafalou (2015) Current observations at Pulley Ridge mesophotic reef: results from a three-year time-series of moored ADCP data. 10th Congress of Marine Sciences, MARCUBA 2015, November 16-20, 2015, Havana Cuba

Vaz, A.C., C.B. Paris, M.J. Olascoaga, V.H. Kourafalou, H. Kang. 2016. Connectivity between Pulley Ridge mesophotic reefs and the Floridas Keys. Ocean Sciences, New Orleans, LA. (Invited oral presentation)

<u>2016</u>

Cavasos, K.; M. G. Bhat. (2016) Bioeconomic evaluation of marine reserve size: Protecting restored coral reefs while maximizing fishery value. 13th International Coral Reef Symposium, Honolulu, Hawaii, USA, June 2016 (poster)

Johnston, M.W., A.M. Bernard; M.S. Shivji; (2016) Genetic and biophysical modeling assessment of red grouper (*Epinephelus morio*) connectivity in the Gulf of Mexico and Southeastern USA. Oral Presentation at the 2016 Annual Gulf and Caribbean Fisheries Institute Conference, Cayman Islands. November 2016.

Luzader, R; A.R. Baco; (2016) Assessing the diversity of *Halimeda* spp. on Pulley Ridge Mesophotic Reefs. Poster presentation at the 2016 Ocean Sciences Meeting, New Orleans, Louisiana, February 2016.

Paris, C.B.; A.C. Vaz; S. Wood (2016) Modeling of Physical-Biological Interactions using the Open-Source Connectivity Modeling System. 2016 Ocean Sciences, New Orleans, LA (tutorial).

Vaz, A.C.; C.B. Paris; M.J. Olascoaga; V. Kourafalou; H. Kang (2016) The perfect storm: match-mismatch of bio-physical events drives larval reef fish connectivity between Pulley Ridge and the Florida Keys. 2016 Ocean Sciences, New Orleans, LA (poster presentation)

Special Session #15 at the 13th International Coral Reef Symposium, Honolulu, HI:

Bhat, M. G; N. Seteram; B. Pierce; and D. Die. (2016) Socio-economic impacts of expanded habitat protection in Pulley Ridge, Florida Gulf Coast (oral presentation)

Cowen, R.K.; P.B. Ortner; S.A. Pomponi (2016) Connectivity of the Pulley Ridge-South Florida coral reef ecosystem: processes to decision-support resources (oral presentation)

Goldstein, E.D.; E.K. D’Alessandro; S. Sponaugle (2016) Refugia and resilience: population demographics and reproduction of a coral reef fish across vertical spatial scales (oral presentation)

Harter, S.; H.L. Moe; J.K. Reed; A.W. David. (2016) Fish assemblages associated with red grouper pits at Pulley Ridge, the deepest photosynthetic coral reef in the continental U.S. (poster)

Johnston, M.W., A.M. Bernard; M.J. Reichert; M.S. Shivji. (2016) Genetic and biophysical modeling assessment of connectivity in the red grouper, *Epinephelus morio* (oral presentation)

Kourafalou, V. H.; R. H. Smith; A. Valle-Levinson; M. Le Hénaff; H. Kang; Y. Androulidakis (2016) Physical processes controlling connectivity among South Florida coral reefs and pathways of upstream river influence (oral presentation)

Luzader, R.K.; A.R. Baco-Taylor (2016) Assessing the genetic connectivity of *Halimeda* spp. on Pulley Ridge mesophotic reefs (oral presentation)

Mader, C.; J. Perez; C. Scott; T. Norris; N. Datar (2016) The Pulley Ridge interactive decision support resource (DSR) (poster)

Olascoaga, M. J.; A. C. Vaz; C. B. Paris; R. H. Smith (2016) Historical Analysis of Oceanographic Connectivity in the Pulley Ridge (oral presentation)

Pérez-Portela, R.; J. Reed; S. Cairns; M. Oleksiak; A.C. Baker (2016) Investigating species boundaries in Caribbean agariciid corals by combining whole genome scanning and morphological analysis (oral presentation)

Reed, J.K.; S. Farrington; J. Voss; K. Spring; A. Hine; V. Kourafalou; R. Smith; A.C. Vaz; C.B. Paris; D. Hanisak (2016) Resilience of a unique mesophotic reef in the Gulf of Mexico, USA: A 30-year historical perspective of the coral communities at Pulley Ridge reef (oral presentation)

Sponaugle, S.; E. Goldstein; E.K. D'Alessandro (2016) Habitat availability and depth driven population demographics regulate regional reproductive output of a common coral reef fish (poster)

Studivan, M.S.; J.D. Voss (2016) Comparing genetic connectivity and gene expression across shallow and mesophotic reef corals in the Gulf of Mexico (oral presentation)

Vaz, A.C.; C.B. Paris; M.J. Olascoaga; V. Kourafalou; H. Kang; J.K. Reed (2016) The perfect storm: match-mismatch of bio-physical events drives larval reef fish connectivity between Pulley Ridge mesophotic reef and the Florida Keys (Oral presentation)

<u>2017</u>

Hanisak, M.D. (2017) Exploring Pulley Ridge: The deepest mesophotic coral reef on the U.S. continental shelf. Vetlesen Lecture, University of Rhode Island, Naragansett, RI, November 1, 2017 (Invited oral presentation)

Hanisak, M.D. A peek at the macroalgae of Pulley Ridge: The deepest mesophotic coral reef on the U.S. continental shelf. 39th Annual Southeastern Phycological Colloquy, University of North Carolina Wilmington, Wilmington, NC, October 28, 2017 (oral presentation)

Hanisak, M.D.; J. Reed; S. Farrington. Macroalgae at Pulley Ridge: The deepest mesophotic coral reef on the U.S. continental shelf. International Phycological Congress 11, August 13-19, 2017, Szczecin, Poland (oral presentation)

2018

Diaz, C.; S. Pomponi; J. Reed; S. Farrington; D. Hanisak (2018) Porifera biodiversity of Pulley Ridge mesophotic reef: the importance of sampling and classifying organisms to truly understand and manage mesophotic coral reefs. Mesophotic Coral Reef Ecosystems Gordon Research Conference. Bates College, Lewiston, ME. June 17-22, 2018 (poster)

Hanisak, M.D.; J. Reed; S. Farrington; J. Voss (2018) The benthic community of the mesophotic coral reef ecosystem at Pulley Ridge. MarCuba, 11th Congress on Marine Sciences, October 2018, Havana, Cuba (oral presentation)

Kang, H.; V. H. Kourafalou; Y. Androulidakis; R. H. Smith; and A. Valle-Levinson (2018) Modeling and monitoring the impact of the Loop Current/Florida Current System on the physical connectivity among South Florida coral reefs [OM14A-2031]. 2018 Ocean Sciences Meeting, Portland, OR, 12-16 Feb (oral presentation)

Olascoaga, M. J.; P. Miron; C.B. Paris; P. Perez-Brunius; R. Perez-Portela; R.H. Smith; A.C. Vaz. (2018) Connectivity of Pulley Ridge with remote locations as inferred by satellite-tracked drifter trajectories. 2018 Ocean Sciences Meeting, Portland, OR, 12-16 Feb (oral presentation)

Pérez-Portela R. et al. (2018) Population genomics of the lionfish invasion across the Northwestern Atlantic and the Gulf of Mexico, Marine Evolution Stromstad, Sweden.

Pomponi, S., C. Diaz; M. Garcia-Hernandez; L. Busutil. (2018) Biodiversity and connectivity of sponges from Cuba and southwest Florida mesophotic coral ecosystems, MarCuba, 11th Congress on Marine Sciences, October 2018, Havana, Cuba (oral presentation)

Voss, J. (2018) Coral connectivity and symbiosis among mesophotic coral reefs in the Gulf of Mexico and Northwestern Caribbean, Mesophotic Coral Reef Ecosystems Gordon Research Conference. Bates College, Lewiston, ME. June 17-22, 2018 (oral presentation)

viii. Outreach activities/products (e.g., website, newsletter articles)

- For the 2013–2015 field seasons, we collaborated with NOAA’s Office of Ocean Exploration and Research (OER) to create a web presence (as an OER signature cruise) and highlight the two research cruises that occurred each year aboard the R/V *F.G. Walton Smith* and M/V *Spree*. This effort consisted of constructing a series of essays for the NOAA Ocean Explorer website including a *Mission Intro*, *Mission Plan*, *Project Overview*, *About PR*, *About MCEs*, *Management Interest in PR by FKNMS Staff*, *Understanding the physical connectivity of reef systems*, *Understanding coral reef connectivity*, *Benthic communities of PR, Biophysical Modeling*, and annual Mission Summaries. All essays were written at an 11th grade science level. In addition to essays, we wrote 11 (2013), 10 (2014), and 12 (2015) mission logs discussing our activities while at sea. The 2013–2015 field seasons websites can be accessed at:

- 2013: http://oceanexplorer.noaa.gov/explorations/13pulleyridge/welcome.html
- 2014: http://oceanexplorer.noaa.gov/explorations/14pulleyridge/welcome.html
- 2015: http://oceanexplorer.noaa.gov/explorations/15pulleyridge/welcome.html

- We provided information to NCCOS to maintain our project website (https://coastalscience.noaa.gov/project/coral-ecosystem-connectivity-gulf-florida-keys/). This included providing information for 14 separate News stories for the NCCOS website.
- We are also working with NCCOS to archive all of the project data, as appropriate, with the National Center for Environmental Information (NCEI) or National Center for Biotechnology Information (NCBI). Data once archived will be accessible on our data collection page on the NCCOS website: (https://products.coastalscience.noaa.gov/collections/regional/pulleyridge/).
- All data is also accessible through the project sponsored Decision Support System at the University of Miami, RSMAS (http://mesophotic.ccs.miami.edu).
- Physical Oceanographic Model 7-day forecasts were publicly disseminated in real time: http://coastalmodeling.rsmas.miami.edu
- Class undergraduate lectures (Sponaugle): Oregon State University – BI450 *Marine Biology and Ecology* (5 years) and BI351 *Marine Ecology* (4 years); Guest Lecture: BI 351 *Marine Ecology* (Summer Session 2015)

Management outcomes - I. Management application or adoption of:

i. New fundamental or applied knowledge

A unique aspect of this project was the establishment of a SAB (see Appendix A for a list of members), a collaboration of federal, state, and non-governmental stakeholders, to help guide outputs and ensure their utility for managers. This group enabled us to meet our goals to not only provide a better understanding of the underlying processes that regulate PR and whether PR helps sustain the coral reefs in the FLKeys and DT, but also provide information to help determine if PR would benefit from further protection. The SAB was invited to the annual PI meetings, as well as had their own separate SAB meeting that followed the PI meetings. In addition to the annual SAB meetings, we held a one-day meeting on February 27, 2018 for the SAB and other interested stakeholders to hear about the project's results and discuss how they might be useful in addressing resource management issues.

To ensure the flow of information throughout the life of the project, data from our four ROV cruises were recorded in six reports (Reed et al. 2012a, 2012b, 2014c, 2015, 2016, 2017a). The reports detailed information on ROV dives conducted at PR and DT by individual block following the SEADESC format (Partyka et al. 2007), which was designed to facilitate management decisions by providing a consistent level of information for each dive site. Reed et al. (2017b) provided a detailed characterization of the benthic and fish assemblages summarizing/analyzing data from all four ROV cruises (2012–2015) covering both PR and DT. All of these reports were given to the SAB and findings were discussed at our annual PI and SAB meetings. These reports will not only be useful in the present, but also for comparing future research to better understand the long-term health and status of PR and the MCEs of DT.

In September 2014, Peter Ortner on behalf of the project, submitted proposals for extending the PR HAPC (to the Coral Working Group of the Gulf of Mexico Fishery Management Council) and the TER boundaries (to the FKNMS) based on our first three field seasons (2012–2014). The PR HAPC recommendations were based on the new coral area found in the Central Basin to the west of the current HAPC boundary, and the information on the South Drop Off and West Ridge. The TER recommendations were to include a fringing reef outside the western boundary of the North TER (note: we also submitted video of this reef) and Miller's Ledge to the west of the South TER boundary. John Reed also gave an oral presentation to the Coral Working Group of the Gulf of Mexico Fishery Management Council on our PR boundary expansion recommendations.

In June 2018, the Gulf of Mexico Fishery Management Council voted to expand the PR HAPC to include the new coral area in the Central Basin discovered by us in 2014 and the West Ridge and South Drop Off. The expanded area extends fishing restrictions (no bottom trawl, buoy gear, pot or trap, and bottom anchoring by fishing vessels year round) to the east and south of the 2005 HAPC boundaries. There was a concession made in the newly expanded area that allows bottom longlines to continue fishing this area (they are prohibited within the original HAPC boundaries). This expansion was a direct result of information from our project.

The history of this expansion began back in 2013 with the Council hosting a workshop to discuss how corals may be affected by fisheries. Our project participated in and presented at this workshop. From this workshop, a book was released titled *Interrelationships between coral reefs and fisheries* (Bortone 2014). One of the recommendations from the workshop was to reevaluate coral areas in the Gulf of Mexico that might warrant special protections. In 2014, the Council convened a working group to discuss which areas in the Gulf warrant specific coral protection. John Reed presented to this group the findings from the PR cruises to date and Peter Ortner issued a proposal to the Council to expand the PR HAPC based on our findings. In August 2016, a meeting was held at the direction of the Council to prioritize the areas for further protection. In May 2017, the Council released draft Amendment 9 to the Fishery Management Plan for the Coral and Coral Reefs of the Gulf of Mexico, U.S. waters (http://gulfcouncil.org/wp-content/uploads/N-4-Coral-9-draft-options-May-2017.pdf), which included an expansion of the PR HAPC as one of the alternatives. In June 2018, the Council voted to expand the PR HAPC.

The FKNMS, through its Advisory Council, has been conducting a review of sanctuary regulations. As part of this review, the Sanctuary Advisory Council has identified PR as one of the areas that should be considered for potential inclusion within the FKNMS. We have been working directly with the FKNMS and their Advisory Council to provide requested information, including high-resolution images and map shape files of our proposed boundaries for PR and DT. We have also met one-on-one with the FKNMS staff to address questions they had about the PR habitat and its significance. Our Bioeconomics Group has worked directly with the Sanctuary's socioeconomist (Bob Leeworthy) to help assess the socioeconomic impacts of adding FKNMS regulations to PR, including the potential impact to commercial fisheries. The Management Review process is still underway and the outcome of whether PR is included as part of the sanctuary is still off into the future. If it were included in the FKNMS, PR would be protected from non-fishing related activities such as anchoring, discharges and dumping, cable laying or oil, gas, and mineral extraction.

ii. New or improved skills

N/A

iii. Information from publications, workshops, presentations, outreach products

Throughout the project period, we received direct requests to present to different management advisory groups. These included:

(1) FKNMS Advisory Council
- 11 Dec 2012 – Robert Cowen and Peter Ortner gave an overview of the PR project.
- 18 Aug 2015 – Shirley Pomponi provided a 101-presentation on PR and its associated organisms.
- 19 Feb 2019 (planned) – Kimberly Puglise, our NCCOS Program Manager, will discuss the project's findings on connectivity, how PR adds to the potential resilience of FLKeys reefs, and the benthic habitats present at PR.

(2) Gulf of Mexico Fishery Management Council
- 21 May 2013 – Robert Cowen presented the project at the Council's Workshop on Interrelationship between coral reefs and fisheries; Esther Goldstein and Su Sponaugle presented a poster on the spatial variation in the early life history traits of the bicolor damselfish.
- 4–5 Dec 2014 – John Reed presented a proposal for expanding the PR HAPC to the Council's Coral Working Group. The information presented was based on the from PR cruises, including CIOERT cruises of 2010 and 2011 (FloSEE I

and II), and the project's cruises of 2012–2014, and included the discovery of the coral rich Central Basin and the West Ridge.

(3) South Atlantic Fishery Management Council

- 9 June 2014 – Peter Ortner gave an overview of the PR project goals and objectives and expected results and uses.

We also received a request from Doug Gregory, Executive Director of the Gulf of Mexico Fishery Management Council, to provide an electronic copy and list of all project publications to date. We also provided this list to the FKNMS and continue to update it on an annual basis as new publications become available. Several of our key publications are still in prep, so we will continue providing these documents after award closure.

iv. New or improved methods or technology

We have expanded the Physical Oceanographic model to high resolution. This increase in resolution of the model over the PR area will be valuable tool for managers and scientists interested in connectivity pathways throughout the Gulf of Mexico and Florida Straits region (and beyond).

v. New or advanced tools.

The Bioeconomics group is working directly with the FKNMS and Bob Leeworthy to analyze spatial alternatives and assess the socioeconomic impacts of adding sanctuary regulations to PR using a similar method to what was done for the FLKeys. This information will be used as part of the Draft Environmental Impact Statement (DEIS) being prepared for the proposed boundary expansion. The DEIS evaluates the environmental consequences of the various alternatives under the National Environmental Policy Act.

Management outcomes - II. Societal condition improved due to management action resulting from output (examples: improved water quality, lower frequency of harmful algal blooms, reduced hypoxic zone area, and improved sustainability of fisheries).

The Gulf of Mexico Fishery Management Council voted to expand the PR HAPC in June 2018. It is our hope that this expansion will help protect the new coral area discovered during our project and improve the sustainability of fisheries, especially red grouper for which PR is a prime habitat.

VII. Evaluation

Describe the extent to which the project goals and objectives were attained. Provide explanation for modification of goals and objectives.

Although funding problems early on in the project led to delays in the overall project schedule (and ultimately required the project to be extended by 1.5 no-cost extension years), overall most of the objectives of this project were met. The main exceptions are as follows:

- The ISIIS transects and MOCNESS net tows were truncated due to an over-programmed sampling plan for the RV *Walton Smith*. The lead technician onboard (Mr. Cedric Guigand) was responsible for all activities that occurred throughout the day and night (except ROV operations – though he also helped with the launch and recovery as well), and it became clear that the nighttime activities of ISIIS towing and MOCNESS tows was too much to accomplish safely and adequately.

- Several of the project hypotheses/tasks have not yet been completed as they were cut from the project as a result of funding cuts by NCCOS to address their budget shortfalls in 2012–2014. The hypothesis were:

    - *Assimilate and Synthesize Regional Ecosystem Databases*
    - *Link abundance and size structure to spatially-explicit reproductive output of selected reef fish species in PR MCE to the SCEs*
    - *To preliminarily quantify two key reef processes: benthic primary productivity and settlement/recruitment potential of corals.*

- Several species of fish and corals that were originally targeted in the proposal were not abundant enough for sampling – or were only present in FLKeys or PR locations. We therefore made substitutions as follows: i) bluehead wrasse not present at PR, replaced with Lionfish; ii) No *Mycteroperca bonaci or M. phenax groupers* were obtained from PR, so these species were dropped from our analyses; iii) *Porites* was not present on PR, we planned to replace this with *Agaricia*, while retaining *Porites* for analyses related to genetic structure from deep (20–40 m) to shallow (< 10 m) depths in the FLKeys – Note – the agariciids have proven to be challenging due to many morphs and species diversity; iv) *Halimeda* – as with the agariciids was found to be a diverse genus which precluded our attempts to collect enough for PR and Florida Keys comparisons.

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Appendix A. Stakeholder Advisory Board

*Purpose of Board***.** A unique aspect of this project is an integration of Federal, state, and non-governmental stakeholders into the project to help guide its outputs to ensure their utility for resource managers. The Board meets regularly with project leadership and provides guidance as to the project outputs (e.g., maps of species distribution and species connectivity pathways, user friendly databases, and graphic illustrations) that would be of most use for management of these ecosystems.

Member	**Affiliation**
Mr. Gregory Boland	Bureau of Ocean Energy Management, Environmental Sciences Division
Mr. Doug Gregory, Executive Director	Gulf of Mexico Fishery Management Council
Dr. James Byrne, Marine Science Program Manager	The Nature Conservancy
Mr. Billy Causey, Southeast Regional Director	NOAA National Ocean Service, Office of National Marine Sanctuaries
Dr. Roy E. Crabtree, Regional Administrator	NOAA National Marine Fisheries Service, Southeast Regional Office
Dr. Alyssa Dausman, Science Coordination Team Lead	Gulf Coast Ecosystem Restoration Task Force
Ms. Beth Dieveney, Deputy Superintendent	NOAA Florida Keys National Marine Sanctuary
Dr. Shannon Cass-Calay, Gulf and Caribbean Fisheries Branch Chief	NOAA National Marine Fisheries Service, Southeast Fisheries Science Center, Sustainable Fisheries Division
Dr. Tracy Ziegler, Fishery and Marine Biologist	National Park Service, Dry Tortugas National Park
Dr. Alan Leonardi, Director	NOAA Office of Oceanic and Atmospheric Research, Ocean Exploration and Research
Mr. Gil McRae, Director	Florida Fish and Wildlife Research Institute
Mr. Roger Pugliese, Senior Fish Biologist	South Atlantic Fishery Management Council
Ms. Cathy Tortorici	NOAA National Marine Fisheries Service, Southeast Regional Office

Appendix B. SAB Final Meeting Agenda.

AGENDA

Pulley Ridge Ecosystem Connectivity Briefing
January 24, 2018
CIMAS Conference Room
Third Floor CIMAS Building

0900-0930	Coffee and pastries
0930-0945	Welcome (Peter Ortner)
0945-1020	Project Overview (Bob Cowen)

Pulley Ridge – Site Overview

1020-1050	Benthic Community/Habitat (Dennis Hanisak)

Population Connectivity

1050-1120	Physical Oceanography (Villy Kourfalou)

Lunch and Tour

1120-1200	Tour of SUSTAIN facility (OPTIONAL)
1200-1245	Lunch

Population Connectivity (continued)

1245-1315	Population Dynamics (Su Sponaugle)
1315-1345	Population Genetics (Andrew Baker)

Bio-economics

1345-1415	Bioeconomics (David Die)
1415 -1430	Wrap up (Peter Ortner)

Pulley Ridge SAB Meeting - February 28, 2018					
Attendee	**Affiliation**	**Email**	**Attend**	**In Person**	**Web**
Beth Dieveney	NOAA/FKNMS	beth.dieveney@noaa.gov	Y	Y	
Bill Kiene	NOAA/ONMS	william.kiene@noaa.gov	Y		Y
Scott Daggett		Dagwood7142@gmail.com	Y		
Morgan Kilgour	GMFMC	morgan.kilgour@gulfcouncil.org	Y	Y	
Claire Roberts	GMFMC	Claire.roberts@gulfcouncil.org	Y	Y	
Karen Bohnsack	FL CRCP	Karen.bohnsack@dep.state.fl.us	Y		Y
Eric Brazer	Gulf of Mexico Reef Fish Shareholders'	eric@shareholdersalliance.org	Y	Y	
Janessy Frometa	NOAA/Restore	Janessy.frometa@noaa.gov	Y	Y	
Frank Parker	NOAA/Restore	frank.parker@noaa.gov	Y		Y
Chris Bergh	Sanctuary Advisory Council (SAC) Conservation and	cbergh@tnc.org	Y	Y	
Ben Daughtry	SAC Commercial Fishing - Marine Life	ben@aquariumencounters.net	Y		Y
Dennis Hanisak	Florida Atlantic	dhanisak@fau.edu	Y		Y
Peter Hood	SERO	Peter.Hood@noaa.gov	Y		Y
Mandy Karnauskas	SEFSC	mandy.karnauskas@noaa.gov	Y	Y	
Stephanie Farrington	HBOI-FAU	sfarrington@hboi.fau.edu	Y		Y
Chiara Pacini	UM Graduate Student (Die)		Y	Y	
Alexandra Norelly	UM Graduate Student (Die)		Y	Y	
Project Team					
Robert Cowen	OSU	Robert.cowen@oregonstate.edu	Y	Y	
Peter Ortner	UM/RSMAS	portner@rsmas.miami.edu	Y	Y	
Su Sponaugle	OSU	Su.Sponaugle@oregonstate.edu	Y	Y	
Villy Kourafalou	UM/RSMAS	vkourafalou@rsmas.miami.edu	Y	Y	
Andrew Baker	UM/RSMAS	abaker@rsmas.miami.edu	Y	Y	
Shirley Pomponi	HBOI-FAU	spomponi@hboi.fau.edu	Y	Y	
David Die	UM/RSMAS	ddie@rsmas.miami.edu	Y	Y	
Project Manager					
Kimberly Puglise	NOAA/NCCOS	kimberly.puglise@noaa.gov	Y	Y	