Prediction and Verification of Snapper-Grouper Spawning Aggregation Sites on the Offshore Banks of the Northwestern Gulf of Mexico

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FINAL REPORT

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I. Abstract

This project provided the first attempt to predict and verify multi-species reef fish spawning aggregations in the northwestern Gulf of Mexico. We used three sources of information to identify spawning aggregations: (1) anecdotal information learned from interviews with fishermen, (2) fisheries dependent and independent data, and (3) geomorphological models that predict likely locations based on habitat features known to be associated with aggregations. To verify predicted sites, we worked collaboratively with commercial and charter captains to verify snapper-grouper spawning using various techniques, including underwater video, catch per unit effort (CPUE), and collection of biological samples (gonadal tissue for histology and otoliths for aging). For this study, we used a suite of tools for field verification of spawning aggregation sites based on cooperative monitoring methods developed during this project and formalized for the U.S. South Atlantic (Heyman, 2016). Fisher interviews revealed a set of possible spawning times and locations for several fish species in several locations in the Gulf of Mexico, most of which require additional sampling for verification. Verification techniques were utilized to characterize Cubera snapper, horse-eye and crevalle jack, and sheepshead aggregation sites. Additional effort is needed to identify, characterize, and monitor spawning aggregations in the Gulf of Mexico. These data in turn can be used to help monitor and manage stocks. Regional variations in species composition, fleet dynamics, scientific understanding, governance regimes and local capacity dictate the need for regionally-specific work plans. Nonetheless, monitoring spawning aggregation sites will likely contribute to more robust stock assessments for multiple species, and ultimately support the rebuilding and recovery of reef fish throughout their natural range. Information collected during this project will be disseminated via peer-reviewed publications and will be made available to relevant management bodies.

II. Executive Summary

Species within the reef fish complexes that spawn in transient but predictable aggregations can and should be monitored at their spawning sites, rather than when the fish are dispersed into their home ranges that may span hundreds of thousands of square miles. Though reef fish are fished extensively in the western Gulf of Mexico, no spawning sites have been documented in the Gulf outside of the west Florida Shelf, the Florida Keys, and the Dry Tortugas. The most likely place for them to occur, based on studies from the Wider Caribbean and the eastern Gulf, would be the banks on the northwestern Gulf of Mexico, which have both vertical and horizontal discontinuity in the correct depth zones, and are close to the continental shelf. This project was the first such study in the region and aimed to predict and verify multi-species spawning aggregations in the northwest Gulf of Mexico. This in turn will allow consolidation of existing methods and further development of robust fishery-dependent and independent data collection methods, designed to evaluate the status of all of the stocks that use multi-species spawning aggregation sites.

We used three sources of information to identify spawning aggregations: (1) anecdotal information learned from interviews with fishermen, (2) fisheries dependent and independent data, and (3) geomorphological models that predict likely locations based on habitat features known to be associated with aggregations.

1) Commercial and recreational fishermen that frequently fish in the Gulf of Mexico were queried in informal interviews about the time and location of spawning aggregations for various species. In order to collect and collate these data, we developed and used an anecdotal data information form and associated database (following Heyman, 2016).

2) At the onset of the project, we believed that the most likely sources of publically available data that might reveal information on the timing and location of spawning aggregations included NMFS landings data, SEAMAP larval data, and bathymetry data from a variety of sources. A relatively comprehensive search and analysis revealed that there was very little to be learned about spawning aggregation timing and location based on any of these sources.

3) Existing comprehensive bathymetric datasets for the Gulf of Mexico however, were found inadequate for predicting spawning aggregation sites in large part because their resolution is too coarse and/or inconsistent. There only exists a small portion of the Gulf of Mexico that is both shallower than 200 meters (m) and also has high-resolution multi-beam data available (shown as a dark line in Figure 1). Therefore, a small area on the shelf break (within this dark band), less than 200 m, was selected for bathymetric prediction of spawning areas. The area selected contained an area that was identified by an interviewed commercial fisherman as a Cubera snapper spawning aggregation site.

The most valuable techniques for the verification of spawning aggregations are fishery dependent surveys, underwater visual assessments, and mapping aggregation locations in relation to local bathymetry and habitat (Kobara et al., 2013). The complementary deployment of underwater passive acoustic recorders at select verified locations to monitor sound production associated with spawning aggregations can provide validation of fish abundance, site usage, and readiness to spawn (Rowell et al., 2012; Schärer et al., 2012a,b; Appeldoorn et al., in press; Rowell et al., in press). Data gathered using these relatively simple techniques can together

provide scientific verification of spawning aggregations, excellent data for improved stock assessments for various species, and a baseline for future monitoring.

To verify predicted sites, we worked collaboratively with commercial and charter captains to verify snapper-grouper spawning using various techniques, including underwater video, catch per unit effort (CPUE), and collection of biological samples (gonadal tissue for histology and otoliths for aging). For this study, we used a suite of tools for field verification of spawning aggregation sites based on cooperative monitoring methods developed during this project and formalized for the U.S. South Atlantic (Heyman, 2016).

Primary Findings:

- Fisher interviews revealed a set of possible spawning times and locations for several fish species in several locations in the Gulf of Mexico, most of which require additional sampling for verification.
- Available public and historical data sources (e.g. NOAA Fisheries, SEAMAP larval distribution and abundance data) were found inadequate to predict times and locations of spawning aggregations, but bathymetry data were compiled and proved useful for prediction in limited geographic areas.
- Drop video cameras, biological sampling, quantitative video analyses, fisher interviews, and geomorphological predictions were used to characterize a Cubera snapper *Lutjanus cyanopterus* spawning aggregation site in the Chain Lumps area of the western Gulf of Mexico.
- Drop video cameras and fisher interviews revealed indications of spawning aggregations of horse-eye *Caranx latus* and crevalle jacks *C. hippos*, at the West Flower Garden Banks. Fisher interviews revealed that scamp *Mycteroperca phenax* also spawn there though attempts to verify them in this project were unsuccessful.
- Drop cameras, biological sampling, fisher interviews, dockside sampling from charter vessels, temperature loggers, and passive acoustic hydrophone data were used to characterize a sheepshead, *Archosargus probatocephalus* spawning aggregation at the Galveston ship channel.

This project provided the first attempt to predict and verify spawning aggregations on the banks of the northwestern Gulf of Mexico. All four objectives were met with varying levels of success. Field verification of spawning aggregations in the waters of the Gulf of Mexico is an important but difficult task. Sites are generally small, remote, and transient in time, often occurring during periods of rough weather and requiring multi-day trips for evaluation. This project has illustrated the value of the described approach by documenting several spawning aggregations in both nearshore and offshore waters. Additionally, the project compiled and analyzed fishery-dependent and fishery-independent data, expert fishery knowledge, and geomorphological predictions of likely spawning aggregation sites that can be used in subsequent studies.

A great deal of additional effort is needed to identify, characterize, and monitor spawning aggregations in the Gulf of Mexico. These data in turn can be used to help monitor and manage stocks. Regional variations in species composition, fleet dynamics, scientific understanding, governance regimes and local capacity dictate the need for regionally-specific work plans. Nonetheless, monitoring spawning aggregation sites will likely contribute to more robust stock

assessments for multiple species, and ultimately support the rebuilding and recovery of reef fish throughout their natural range.

III. Purpose

Description of Problem:

The Reef Fish Complex

Many reef fish are top predators and comprise most of the highly desired and heavily exploited fishes in the U.S. South Atlantic, Gulf of Mexico and the Wider Caribbean, supporting commercial and recreational fishing, diving and tourism industries, and coastal culture. Many of these species share similar life-history characteristics that reduce their resilience to fishing pressure—they are long-lived, slow to reproductive maturity, and migrate to spawn in aggregations (Huntsman and Waters, 1987; Coleman et al., 1999; 2000). Because of their shared life history characteristics and habitats, the "reef fish complex" has traditionally been targeted within multi-species fisheries (Lindeman et al., 2000; Ault et al., 2005; Kadison et al., 2006; Patterson III et al., 2012). Yet management in U.S. federal waters, as governed by the Magnusson-Stevens Fishery Conservation and Management Act (MSFCMA), is applied mostly at the level of stocks.

Unfortunately, however, many reef fish stocks have experienced significant declines, some to critical levels (Sadovy De Mitcheson et al., 2008; Sadovy De Mitcheson and Erisman, 2012). Managers have responded with an assortment of species-specific regulations, adjusting catch limits, gear and permit limits and time/area closures, all of which reduce fishing access. Unfortunately, because of the multi-species nature of the reef fish complex, unintended bycatch and mortality of managed species occurs (regulatory discard) and/or other species are harvested below allowable levels to avoid overfished species (Lindeman et al., 2000; Ault et al., 2005; Kadison et al., 2006; Patterson III et al., 2012).

The management of reef fish complexes has been difficult throughout their geographic range, as basic life history statistics, catch and effort data, and landings information are difficult and expensive to obtain. With a few exceptions most reef fish stocks are considered, "data-poor fisheries" as defined by Honey et al. (2010).

The Value of Cooperative Science with Fishermen

Because of their continuous interaction with the environment and the resources, fishermen maintain a deep ecological understanding of the species they target. This information can complement scientific research and provide practical information that can be used in management (Pitcher et al., 1998; Johannes et al., 2000; Berkes, 2012). Interviews with fishermen may provide valuable local ecological knowledge (LEK), especially with regards to where and when large aggregations of spawning fish occur (Johannes, 1998; Sedberry et al., 2006; Johannes and Neis, 2007).

When fishermen participate in research, they become cognizant of the methods used to collect data and the way that the data are used to guide management decisions. They are more trusting of the data and more supportive of subsequent stock assessment results (Mackinson and Nøttestad, 1998; Neis et al., 1999; Heyman, 2011). This increases their support for additional cooperative research and data collection projects. Furthermore, their involvement in the research contributes to fishermen's sense of pride and worth, fosters their sense of responsibility for stewardship, and leads to a functional and adaptive management process (Mackinson and Nøttestad, 1998; Berkes, 2012; Heyman and Granados-Dieseldorff, 2012).

The Value of Monitoring Spawning Aggregation Sites

Salmon fisheries are perhaps the best monitored and best managed set of species in the world. This is due in large part to the fact that fishers and managers take advantage of their natural history whereby the salmon return to their natal rivers to spawn. Because of this, fisheries data collection is concentrated in space and time, allowing extremely efficient allocation of sampling, monitoring, enforcement, and management resources. Thus the accuracy of stock assessments can be increased and the critical life history stages are protected so as to promote maximum sustainable harvest.

Using the same logic, species within the reef fish complexes that spawn in transient but predictable aggregations can and should be monitored at their spawning sites, rather than when the fish are dispersed into their home ranges that may span hundreds of thousands of square miles. Since multi-species reef fish spawning aggregations have been identified in many areas of the Wider Caribbean (Kobara et al., 2013) and the eastern Gulf of Mexico (Coleman et al., 2011), the same was thought to be true for the banks of the northwest Gulf of Mexico (Heyman, 2008).

The Wider Caribbean region offers an extensive set of examples of scientists working with fishermen to map, characterize, and protect multi-species snapper-grouper spawning aggregations (e.g. Lindeman et al., 2000; Claro et al., 2001; Heyman and Kjerfve, 2008; Granados-Dieseldorff et al., 2013). These experiences and examples serve as a guide and template for continued work in the Caribbean, as well as expanded work that recognizes regional differences in the U.S. South Atlantic and Gulf of Mexico.

Studies in the Caribbean appear to indicate that transient, multi-species reef fish aggregations occur predictably at shelf edges, associated with vertical and horizontal curvature and these sites can be located through collaborative research using a combination of fisher knowledge, bathymetric maps and models, and other ancillary data. To document and verify these aggregations, a combination of underwater visual observations (e.g. Heyman et al., 2004; Kaddison et al., 2006; Heyman and Kjerfve, 2008); and passive acoustic monitoring (e.g. Rowell et al., 2011; 2012; in press; Schärer et al., in press) techniques may be employed.

Situation Analysis in the U.S. Gulf of Mexico

The eastern edge of the Gulf of Mexico is characterized by the steep west Florida escarpment. Working collaboratively with fishermen, researchers have documented multi-species spawning

aggregations of gag, scamp, and red snapper along the west Florida shelf edge, which served as impetus for the creation of the Madison Swanson Fishing Reserve, Steamboat Lumps, and the Edges Reserves on the west Florida shelf (Koenig et al., 2000; Coleman et al., 2011). The aggregation sites in the eastern Gulf are associated with ridges, ledges and pinnacles (vertical discontinuities) along the shelf edge.

Though reef fish are fished extensively in the western Gulf of Mexico, no spawning sites have been documented in the Gulf outside of the west Florida Shelf, the Florida Keys, and the Dry Tortugas. The most likely place for them to occur, based on studies from the Wider Caribbean and the eastern Gulf, would be the banks on the northwestern Gulf of Mexico, which have both vertical and horizontal discontinuity in the correct depth zones, and are close to the continental shelf.

The reefs and banks of the northwest Gulf of Mexico as described first in detail by Rezak et al. (1985) result from salt dome diapirs and are capped by coral reefs, creating excellent reef fish habitat. These areas are well known by fishermen who target gag, scamp, and many other reef fish species. The banks are likely to harbor aggregations of spawning reef fish and there exists some anecdotal evidence that aggregations of Marbled grouper *(Dermatolepis inermis)* and Cubera snapper have existed at Geyer Bank. The Flower Garden Banks National Marine Sanctuary presently includes three banks, East and West Flower Garden Banks and Stetson Bank, and has proposed to include several additional banks within the boundary (NOAA, 2010). Documenting spawning aggregations would add significant impetus for including areas within the boundary expansion. Yet no comprehensive study of the timing and location of the spawning aggregations for reef fish species had been undertaken for the banks of the northwestern Gulf of Mexico.

This project was the first such study in the region and aimed to predict and verify multi-species spawning aggregations in the northwest Gulf of Mexico. This in turn will allow consolidation of existing methods and further development of robust fishery-dependent and independent data collection methods, designed to evaluate the status of all of the stocks that use multi-species spawning aggregation sites. The long-term vision of this project was to provide managers of reef fish fisheries valuable data to allow more fishing opportunity while conserving stock-complex integrity.

Objectives:

1) Conduct key-informant interviews with commercial and recreational fishermen of the offshore banks of the northwestern Gulf of Mexico about the location and timing of spawning aggregations;
2) Compile, synthesize, and analyze available fisheries-dependent and independent data that indicate spawning activity for the region and by bank;
3) Use spatial statistics to combine predictive variables into a reduced universe of predicted spawning aggregation sites/times/species for field verification; and
4) Conduct field verification of selected spawning aggregation sites in collaboration with commercial and for-hire recreational fishermen.

IV. Approach

Statement of Work:

We used three sources of information to identify spawning aggregations: (1) anecdotal information learned from interviews with fishermen, (2) fisheries dependent and independent data, and (3) geomorphological models that predict likely locations based on habitat features known to be associated with aggregations.

Key informant interviews

Fishermen have discovered most reef fish spawning aggregations, prior to their "verification" by scientists (Johannes, 1998; Lindeman et al., 2000; Sedberry et al., 2006; Heyman, 2011). The LEK of fishermen is maintained in their memories, historical log books and photos, catch and sales records, charts and stored GPS coordinates, etc. This information can be organized, consolidated, and documented using in-depth key informant interviews. There are several key elements to the success of such interviews. First and foremost is to develop the trust and honest collaboration of fishermen, who are wary of sharing such data with fishing competitors or regulators. Another key element for success for these interviews is that the person(s) conducting the interviews must have a solid understanding of what is known about the species and family of fishes under scrutiny, including their life history characteristics, habitat preferences, and spawning seasonality and signs. Finally, the interviewer and fishermen must bring appropriate tools to facilitate information exchange. These include fish ID guides to help identify species (given differences in common names in some areas) and tools, maps, charts, and GPS coordinates that can be used to display geographic information (including appropriate units, coordinate systems, depth contours, and other navigational aids), in ways that fishermen are most familiar with, thus facilitating a two way dialogue and information exchange.

Commercial and recreational fishermen that frequently fish in the Gulf of Mexico were queried in informal interviews about the time and location of spawning aggregations for various species. In order to collect and collate these data, we developed and used an anecdotal data information form and associated database (following Heyman, 2016).

Analysis of existing fisheries dependent and independent data

There are a variety of published and grey literature reports, maps, and valuable data sets that can be mined for data and information concerning spawning aggregation times and locations. At the onset of the project, we believed that the most likely sources of publically available data that might reveal information on the timing and location of spawning aggregations included NMFS landings data, SEAMAP larval data, and bathymetry data from a variety of sources. A relatively comprehensive search and analysis revealed that there was very little to be learned about spawning aggregation timing and location based on any of these sources. Specific findings from these analyses are detailed below (Findings).

Geomorphological models

Based on previous studies, many multi-species spawning aggregation sites occur in areas with locally distinctive bathymetric signals that include a combination of steep shelf edges and either vertical (pinnacles) or horizontal discontinuities (promontories) (Kobara et al., 2013). Successful prediction of the location of various spawning aggregation sites for reef fishes in Belize, Mexico, the Cayman Islands, and the U.S. South Atlantic was accomplished by using these signals within a model to scan bathymetric data (Kobara and Heyman, 2008; 2010; Heyman et al., 2014; Farmer et al., personal communication). The goal of this portion of the study was to evaluate if this method could be adopted for use in the western Gulf of Mexico.

For all of the previous studies, we had a consistent set of bathymetric data (field collected) from which to make geomorphologically based predictions. The first step towards this approach for the western Gulf, therefore, was to evaluate the existing sources of bathymetric data for consistency and resolution. Existing comprehensive bathymetric datasets for the Gulf of Mexico however, were found inadequate for predicting spawning aggregation sites in large part because their resolution is too coarse and/or inconsistent (Table 1).

There only exists a small portion of the Gulf of Mexico that is both shallower than 200 meters (m) and also has high-resolution multi-beam data available (shown as a dark line in Figure 1). Therefore, a small area on the shelf break (within this dark band), less than 200 m, was selected for bathymetric prediction of spawning areas. The area selected contained an area that was identified by an interviewed commercial fisherman as a Cubera snapper spawning aggregation site.

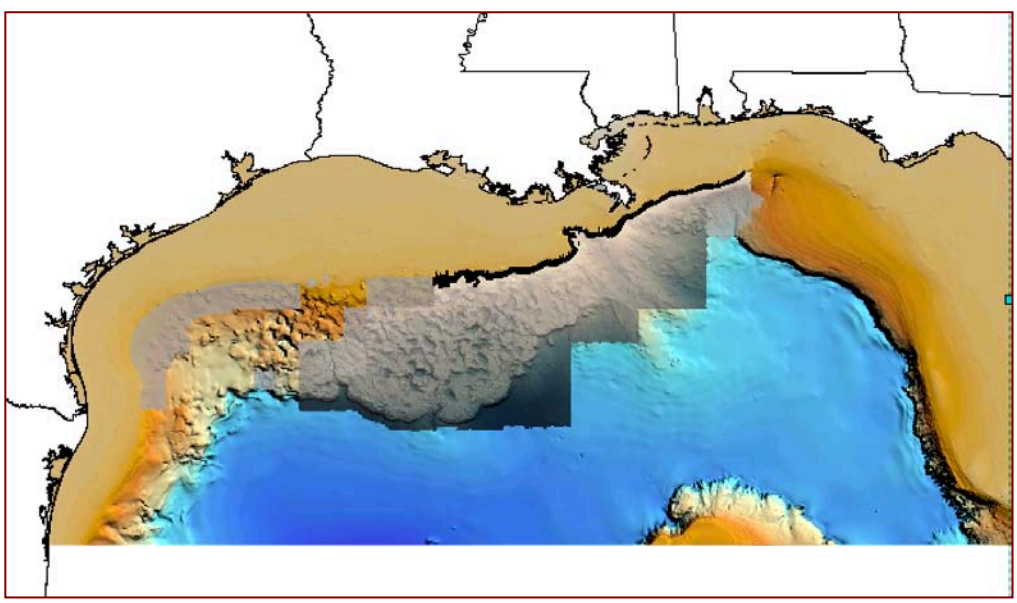


Figure 1. Available multi-beam data in the Gulf of Mexico. The dark line illustrates the areas shallower than 200 m within this dataset.

Since most currently available bathymetric datasets are not provided with appropriate resolution for our quantitative model, we instead chose to use high-resolution multi-beam bathymetric datasets collected for a bank on which we also had predictive information data from fisher interviews.

We downloaded freely available multi-beam bathymetric data (4-5 m horizontal resolution) from United States Geographical Survey (USGS) at: http://pubs.usgs.gov/of/2002/0411/data.html for an area near Rezak Bank (Figure 2). Those data were then used to predict spawning aggregation locations based on geomorphic features. We tested both the bathymetric position index (BPI) calculation (Wright et al., 2005) and the Benthic Terrain Model (BTM) toolbox of ArcGIS and chose the latter to proceed with predictions.

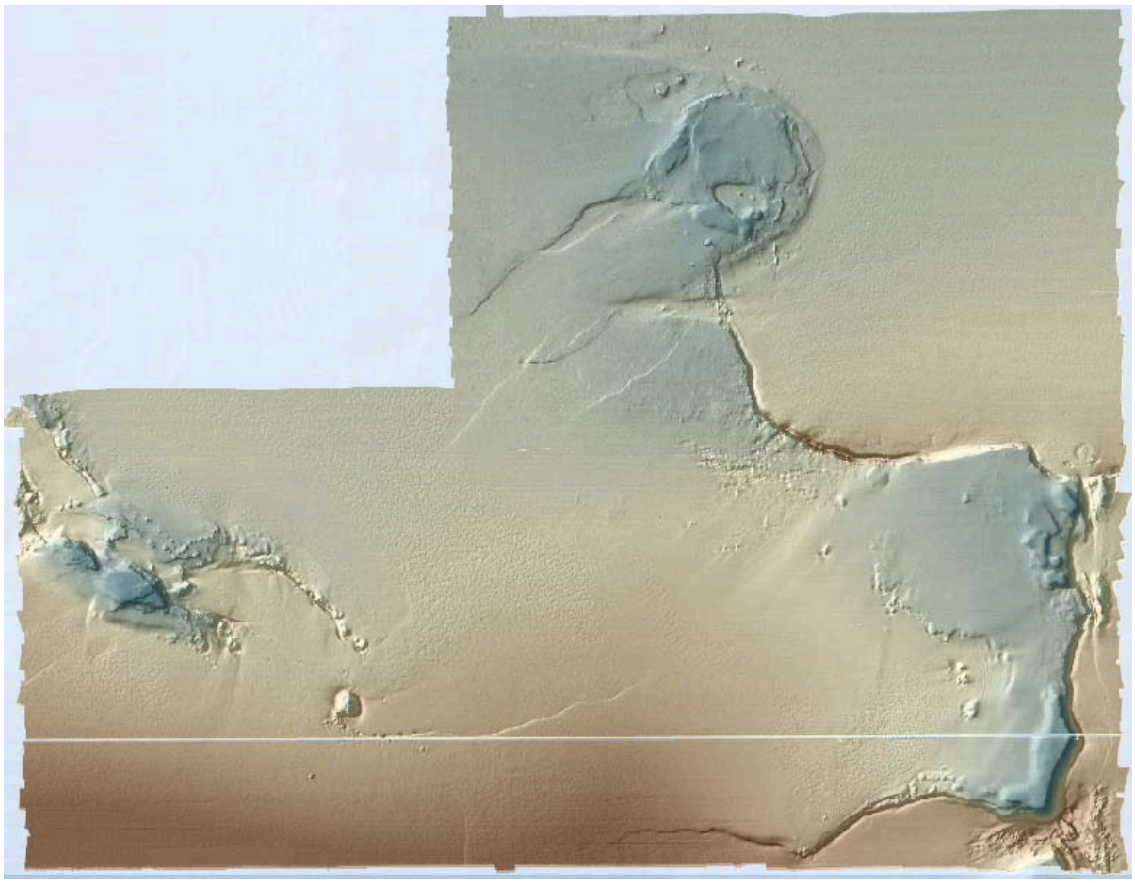
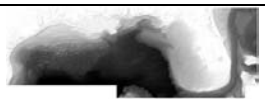
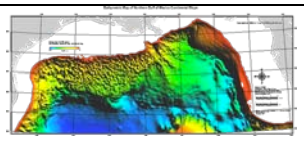
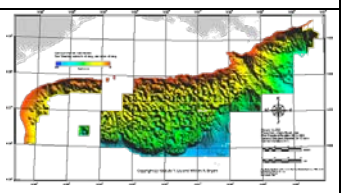
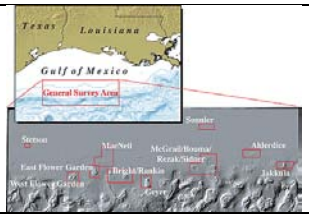


Figure 2. High resolution (4-5 m horizontal) multi-beam data in an area near Rezak Bank suspected to include a spawning aggregation of Cubera snapper. Note that the map does not contain graticules, scale, or depth data to obscure its location.

Table 1. Bathymetric data sources for the Gulf of Mexico

Data	Source	Link	Resolution	Area
Coastal Relief Model	NOAA NCEI	http://www.ngdc.noaa.gov/mgg/coastal/model.html	3-arc sec (~90 m)	
Merged multi-beam and seismic	Texas Sea Grant	CDROM or http://gcoos.tamu.edu/products/topography/MB-UTM.html	300 m	
Multi-beam grid in northwestern Gulf	Texas Sea Grant	CDROM or http://gcoos.tamu.edu/products/topography/MB-UTM.html	50 m	
Multi-beam soundings in northwestern Gulf	Texas Sea Grant	CDROM or http://gcoos.tamu.edu/products/topography/MB-Pts.html	various	
Banks in northwestern Gulf	USGS	http://pubs.usgs.gov/of/2002/0411/data.html	4-5 m	

The multi-beam bathymetric data shown above (Figure 2) were classified according to several spatial statistics using ArcGIS BTM toolbox. The slope at every point was classified as flat (0-5 degrees), moderate (5-12), steep (12-19), or very steep/drop-off (19-89). The shelf edge break was defined as the line at which the slope exceeds 20 degrees vertical. Sinuosity was calculated for each point along the shelf edge break and is a measure of the horizontal curvature of the shelf edge within a moving window of a selected radius (one km in this case). Areas with high sinuosity values are considered as reef promontories and likely spawning aggregation sites. Rugosity was calculated using the division of surface area over planar area. The output values represent ranges from one in flat areas to four in areas of high variation (Wright et al., 2005).

Field verification of spawning sites

The most valuable techniques for the verification of spawning aggregations are fishery dependent surveys, underwater visual assessments, and mapping aggregation locations in relation to local bathymetry and habitat (Kobara et al., 2013). The complementary deployment of underwater passive acoustic recorders at select verified locations to monitor sound production associated with spawning aggregations can provide validation of fish abundance, site usage, and readiness to spawn (Rowell et al., 2012; Schärer et al., 2012a,b; Appeldoorn et al., in press; Rowell et al., in press). Data gathered using these relatively simple techniques can together provide scientific verification of spawning aggregations, excellent data for improved stock assessments for various species, and a baseline for future monitoring.

Fish spawning can be verified directly in one of two ways – by observing gamete release or by documenting hydrated oocytes or post-ovulatory follicles in the gonads of female fishes at the site (Colin et al., 2003; Heyman et al., 2004). Indirect evidence of spawning areas includes elevated, site-specific catch per unit effort (CPUE) of gravid fishes of a single species, observation of courtship behaviors and coloration, and fish densities three to four times the normal average for a given site during non-spawning periods (Colin et al., 2003; Heyman et al., 2004; Domeier, 2012).

To verify predicted sites, we worked collaboratively with commercial and charter captains to verify snapper-grouper spawning using various techniques, including underwater video, catch per unit effort (CPUE), and collection of biological samples (gonadal tissue for histology and otoliths for aging). For this study, we used a suite of tools for field verification of spawning aggregation sites based on cooperative monitoring methods developed during this project and formalized for the U.S. South Atlantic (Heyman, 2016). A letter of authorization (LOA) research permit that allowed collection of biological samples was acquired from NOAA Fisheries in 2015 for the field work. The techniques outlined below are demonstrated with sheepshead as an exemplar and were utilized for the additional species reported in the “Findings” section of this report.

Fishery dependent survey / Underwater video / Biological sample processing

Biological sampling was conducted from commercial and charter fishing vessels, haphazardly during March and April 2015 at the Buccaneer oil and gas field and at the Galveston jetties along the ship channel (Figure 3). Based on the results from the first year’s sampling, indicating that

spawning was definitely occurring at the jetties, and in order to collect the maximum number of samples at the lowest possible costs during 2016, samples were primarily collected from cooperating recreational guides at dockside in the marina, after they caught them near the Galveston jetties. Intensive sampling occurred during February, March, and April 2016.

Figure 3. Study location showing both the Buccaneer oil and gas field and the jetties on either side of the Galveston ship channel.

All samples were collected using hook and line fishing, with the exception of four fish caught with a spear at the Buccaneer field, where it was difficult to catch sheepshead with hook and line, due to competition for the bait from red snapper. The location and time of capture for each fish were recorded using a Garmin 72H handheld GPS and each fish was tagged at the time of capture. Catch was recorded as the number of fish captured at each location and these data were recorded along with the total number of hooks in the water for the total amount of fishing time at each site in order to calculate CPUE in fish caught per hook hour (the number of hooks times the soak time).

At the dock, total length (TL) and fork length (FL) were measured to the nearest mm, and whole weight was measured to the nearest 0.1 kg. These data were recorded along with the tag number and sex. Otoliths were removed (Figure 4) and were placed in individually labeled sample envelopes for subsequent age analysis.

Gonads were removed from each fish, photographed and weighed to the nearest 0.1 g (Figure 5). Gonadosomatic indices were calculated as 100 times the ratio of gonad weight to whole fish weight to measure spawning season. A small sample of the gonad tissue was cut from the center of one of the ovaries or testes using sharp razor blade. Each sample was placed in an individually labeled tissue-processing cassette and preserved in 10% formalin for a minimum of 24 h to assure complete fixation. All samples were then transferred to 90% EtOH for shipping to the lab.

At the laboratory of Dr. Brad Erisman, University of Texas, all otoliths were secured with epoxy to individually labeled wooden blocks and a thin section was cut from the core of the otolith using a double-bladed isomet saw. These samples were polished as necessary and read for age using a compound-dissecting microscope equipped with a video screen. Two readers read all ages independently and a third reader read the few where discrepancies between readers occurred until a consensus on the age was reached.

All histology samples were processed at the Crowder Histological Laboratory and mounted thin sections were returned to LGL for reading. Each thin section was examined under a stereo dissecting microscope and the various development stages were recorded following the development schema of Erisman et al. 2007 (Table 2).

Figure 4. Otoliths are easily removed from sheepshead after a triangular section is removed from their head.

Figure 5. Sheepshead gonads were removed, photographed, and weighed to the nearest 0.1 g.

Table 2. Description of gonadal development stage descriptions following Erisman et al. (2007).

Gonadal development class	Macroscopic	Microscopic
Ovaries		
F1 (immature)	Gonad small and thin; clear, pink or cream in color: oocytes indiscernible; indistinguishable from M1 males	Thin gonad wall; tightly packed primary growth state oocytes (chromatin nucleolar, perinucleolar) and oogonia; no evidence of previous spawning
F2 (mature, inactive)	Gonad small but rounded; gray in color with thickened gonad wall; oocytes small or indiscernible; often indistinguishable from M1 males	Thick gonad wall; primary growth stage and cortical alveolar oocytes abundant; previous spawning indicated by the presence of distinct muscle bundles or vitellogenic oocytes in late stages of atresia
F3 (mature, active)	Gonad large; cream in color with transparent gonad wall; large vitellogenic oocytes visible and tightly packed throughout ovary	Thin gonad wall; large vitellogenic oocytes abundant; primary growth stage oocytes present in variable abundance; hydrated oocytes and post-ovulatory follicles absent; no large scale atresia
F4 (mature, ripe)	Gonad large with clear, hydrated oocytes; eggs released with application of light abdominal pressure	All oocyte developmental stages present with the exception of post-ovulatory follicles; hydrated oocytes few to abundant; atretic vitellogenic oocytes may be present
F5 (mature, ripe and post-spawn)	Gonad resembles F4 or F6 females	All oocytes developmental stages present, including both hydrated ooctyes and post-ovulatory follicles
F6 (post-spawn)	Gonad flaccid with visible capillaries; visible ooctyes less abundant than in F3 or F4 females; hydrated oocytes absent	Thick gonad wall; most oocyte developmental stages present with the exception of hydrated oocytes; post-ovulatory follicles and muscle bundles present; atretic vitellogenic oocytes present and often abundant; intralamellar debris and cytoplasmic strands present
Testes		
M1 (immature or inactive)	Gonad small and thin; indistinguishable from F1 and F2 females	Stroma present in variable amounts; early proliferation of spermatocytes evident; sperm sinuses and seminiferous lobules may be present; previtellogenic oocytes may be present and variable in abundance
M2 (mature, active)	Gonad larger and more rounded than M1 males; grayish in appearance; some milt may be visible	Most stages of sperm development present; spermatozoa abundant within seminiferous lobules and sperm sinuses
M3 (mature, ripe)	Gonad large and white copious amounts of visible milt; milt release possible with light abdominal pressure	Seminiferous lobules enlarged, coalesced and filled with mature spermatozoa; sperm sinuses large and full of mature spermatozoa; early stages of spermatogenesis rare or absent
M4 (post-spawn)	Gonad flaccid with visible blood; milt release may still occur with abdominal pressure	Thick gonad wall; seminiferous lobules are separated and smaller than in M3 males; lobules and sperm sinuses mostly empty and contain very little or no mature spermatozoa; stromal tissue and spermatogonia present

For video observations we used a V-Go video drop camera setup equipped with GoPro 3+ digital video cameras (Heyman, 2016). Water clarity near the jetties was generally less than three feet and precluded the systematic use of video drop cameras for density counts. Nonetheless, when occasional clarity allowed for some video to be shot at the jetties (Figure 11), and very clear video was shot at the Buccaneer oil and gas field (Figure 12), as well as the Cubera site (Figure 6) and the Flower Garden Banks (Figure 10). These videos were used to document and illustrate fish density, courtship coloration, and behaviors.

Figure 6. Cubera snapper descending in the water column as captured in a still frame extracted from drop camera video near Rezak Bank.

Sound production monitoring

Sound production in groupers has been well documented and attributed to reproductive behavior at spawning aggregations for a number of species (Mann et al., 2010; Schärer et al., 2012a; 2012b), including red grouper (Nelson et al., 2011), black grouper (Schärer et al., in press), and goliath grouper, *Epinephelus itajara* (Mann et al., 2009). The sounds can be used to locate new spawning aggregations (Rowell et al., 2011) and determine species abundance, habitat use, and spawning periodicity (Rowell et al., 2012; Appeldoorn et al., in press; Rowell et al., in press).

In an attempt to record courtship sounds attributable to spawning fish species, we installed a digital hydrophone within the sheepshead spawning aggregation from 20 February – 21 April 2016. A DSG-ST digital recorder (Loggerhead Instruments, USA) was deployed near the end of the north jetty at Galveston channel, approximately 12 feet below the water surface and about 150 feet from the end of the jetty. An ONSET Tidbit temperature logger was installed with the hydrophone. The DSG-ST recorded at an interval of 2 minutes every 15 minutes, yielding 5808 acoustic recordings. Mr. Timothy Rowell analyzed the acoustic record.

Project Management:

Principal Investigator:

Ms. Judy L. Jamison	Executive Director

Foundation Staff:

Mr. Frank C. Helies	Program Director
Ms. Gwen Hughes	Program Manager
Ms. Charlotte Irsch	Grants/Contracts Specialist

Overall project quality control and assurance was assumed by the Gulf & South Atlantic Fisheries Foundation, Inc. through its office in Tampa, Florida. Foundation staff were responsible for all administrative and programmatic activities, with oversight by the Foundation's Board of Trustees.

While the Foundation took the lead in project management, this project required the cooperation and active participation of many individuals, particularly staff with LGL Ecological Research Associates, Inc. The essential personnel that were integral in ensuring the successful completion of this project include:

LGL Ecological Research Associates, Inc.
- Dr. Benny Gallaway, President
- Dr. William Heyman, Senior Marine Scientist
- Dr. Scott Raborn, Biostatistician
- Mr. Kyle McCain, Fisheries Technician
- Ms. Susan Dufault, Marine Scientist

Dr. Shin Kobara
Mr. Timothy Rowell
Dr. Brad Erisman and students, University of Texas

Commercial/Charter Fisher Participants
- Capt. Buddy Guindon
- Capt. Scott Hickman
- Capt. Wayne Werner
- Capt. Shane Cantrell
- Capt. Jason Rittenhouse

Dr. Michael Burton, NOAA Fisheries Partner

V. Findings

Results:

Key-informant interviews

Commercial and recreational fishermen that frequently fish in the Gulf of Mexico were queried in informal interviews about the time and location of spawning aggregations for various species. Because much of these data are confidential, we only report a summary of the metadata and offer a few examples of the kinds of information that were collected. In total, we conducted over 20 interviews, which led to 10 credible reports of spawning aggregations in the western Gulf of Mexico. Many of these reports include multi-species observations and several have guided verification work conducted in this project. Three of these reports led to three of our most important field verification programs conducted in this study: 1) a Cubera snapper aggregation in the western Gulf of Mexico, 2) an aggregation of scamp at the Flower Garden Banks, and 3) an aggregation of sheepshead at the Galveston jetties.

Compile and analyze available data

At the onset of the project, we believed that the most likely sources of publically available data that might reveal information on the timing and location of spawning aggregations included NMFS landings data, SEAMAP larval data, and bathymetry data from a variety of sources. A relatively comprehensive search and analysis revealed that there was very little to be learned about spawning aggregation timing and location based on any of these sources.

NMFS landings data are generally lumped by trip, month, or year and are reported with only very coarse geographic information. Dockside sampling for these data generally includes length and weight measurements and otolith collection for age determination, but does not generally include collection of gonad tissue for histology, nor specific geographic information on landings. There may be more information that can be gleaned from proprietary data collected using vessel monitoring systems (VMS) and correlating to trip landings (N. Farmer, personal communication) but that was beyond the scope and access that we had available to us for this project.

Dr. Scott Raborn evaluated the utility of SEAMAP larval data for locating the time and location of spawning aggregations. Unfortunately, he found that the data were too coarse, spatially and temporally to be useful. Though this time series of larval fish data is the most comprehensive available for this region, the taxonomic resolution of specimens and the spatio-temporal resolution of samples are limited. Species level identification is lacking for some larval fish in this region (Carassou et al., 2012) and inconsistent across the SEAMAP time series (Muhling et al., 2012). The SEAMAP sampling grid is coarse with minimal replication at each station. Stations are typically ≈50 km apart, and sampling is centered on May (termed the "spring plankton survey" in the SEAMAP documentation) and September-October (the "fall plankton survey"). Moreover, sampling occurs to a maximum vertical depth of 200 m where bottom depths allow, or to within 1-5 m of the bottom over shallower depths. Thus, specimens from oblique tows over the slope occur somewhere between the surface and 200 m of vertical depth, with no stratification into discrete depth bins. Furthermore, no information exists for vertical depths deeper than 200 m. Thus, while some broad scale patterns in larval fish assemblages are

detectable with SEAMAP data (e.g., Briggs and Ressler, 2001; Muhling et al., 2012), horizontal, vertical, and seasonal gradients remain less defined over the continental slope compared to the shelf edge shoreward.

Existing published literature about spawning aggregations in the Gulf of Mexico is restricted to those sites described for the eastern Gulf on the west Florida Shelf (e.g. Koenig et al., 2000; Coleman et al., 2011) and the southern Gulf in the waters of Mexico (e.g. Brulé, et al., 1999; 2003; Tuz-Sulub et al., 2006). Several studies offer indications of spawning season for species that are believed to spawn in the western Gulf, but none of those have spatial information or details about spawning aggregations. Indeed, there is a total lack of information on spawning aggregations of reef-associated fishes in the western Gulf of Mexico, which served in part as impetus for this study.

The only published account of a spawning aggregation in the region is for an aggregation of sheepshead *Archosargus probatocephelus* around petroleum platforms in the Buccaneer oil and gas field (Gallaway and Martin, 1980). Those aggregations have not been revisited prior to this project.

Using spatial statistics to predict spawning aggregation sites

Existing comprehensive bathymetric datasets for the Gulf of Mexico were found inadequate for predicting spawning aggregation sites in large part because their resolution is too coarse and/or inconsistent. Using a small portion of multi-beam data, we calculated slope, rugosity, and sinuosity along the shelf break and within appropriate depth ranges to predict potential spawning locations. High likelihood areas are illustrated with yellow circles in Figure 7 and appear as shelf edge reef promontories, consistent with areas throughout the Caribbean (Kobara et al., 2013) and the U.S. South Atlantic (Farmer, personal communication). One of these sites was verified as a Cubera snapper spawning aggregation site using field verification during this study (see below).

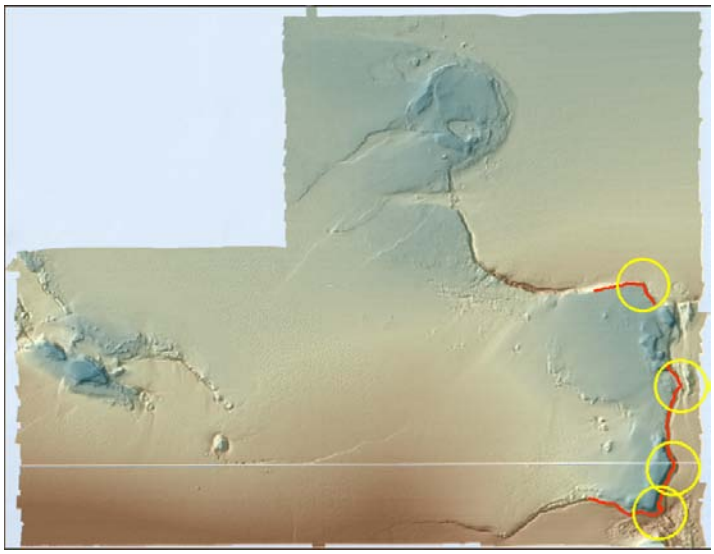


Figure 7. Predicted spawning aggregation sites occur at reef promontories along the shelf edge of a submerged bank in the western Gulf of Mexico.

Field verification of spawning sites

Three different spawning aggregation sites were investigated using our field verification procedures. Each is discussed below.

Field verification of a Cubera snapper spawning aggregation

Drop cameras, biological sampling, quantitative video analyses, fisher interviews, and geomorphological predictions were used to characterize a Cubera snapper *Lutjanus cyanopterus* spawning aggregation site in the Chain Lumps area of the western Gulf of Mexico.

Quantitative digital video analysis was performed for over 20 drop camera deployments in the area believed to be a spawning area by a commercial fishermen and near to the areas predicted using geomorphologic cues. Max Count (the largest number of fish of a given species in a single frame) was recorded by location for Cubera snapper and these data were superimposed on a map showing their location (Figure 8). Two Cubera snapper were captured at the same location where the two highest Max Count videos were recorded (n=15 and n=22), just at the shelf edge (Figure 8) at the sharpest and most extreme reef promontory predicted by geomorphological analysis (Figure 8). These data serve as direct evidence and verification of a spawning aggregation of Cubera snapper (Figure 9). We also observed other species that may be spawning in the area, most notably black jack *Caranx lugubris*. These were seen in large numbers and we observed ripe ovaries in many of them.

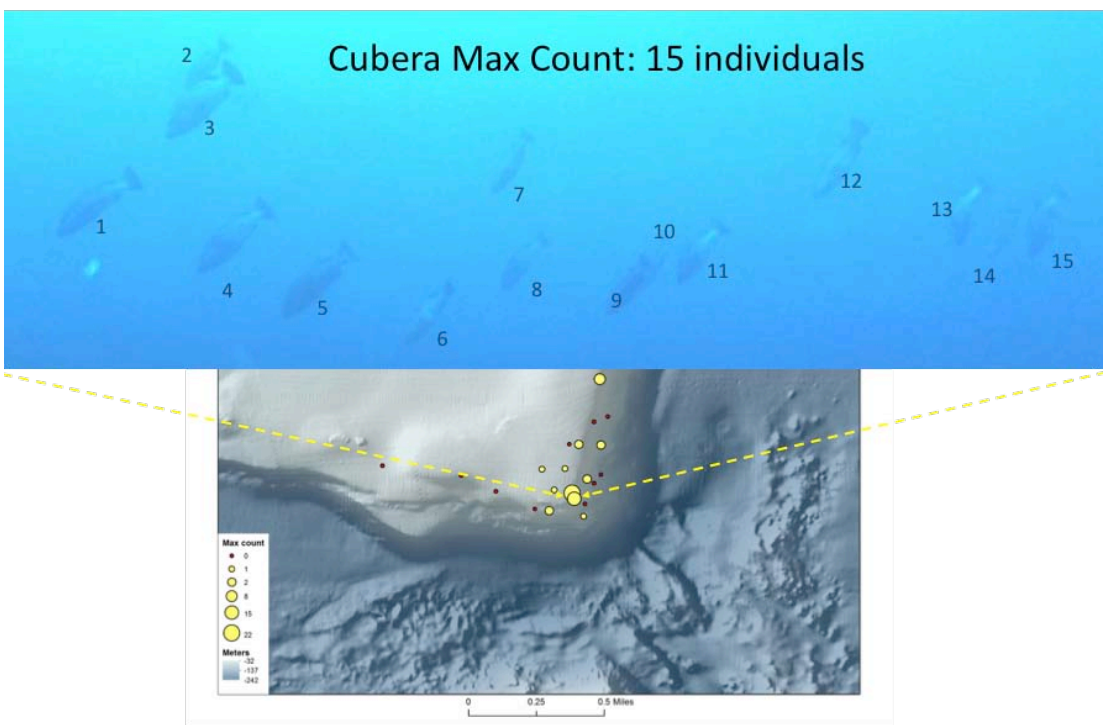


Figure 8. The Max Count of Cubera snapper at this location was extracted from the still frame above and plotted on the map below.

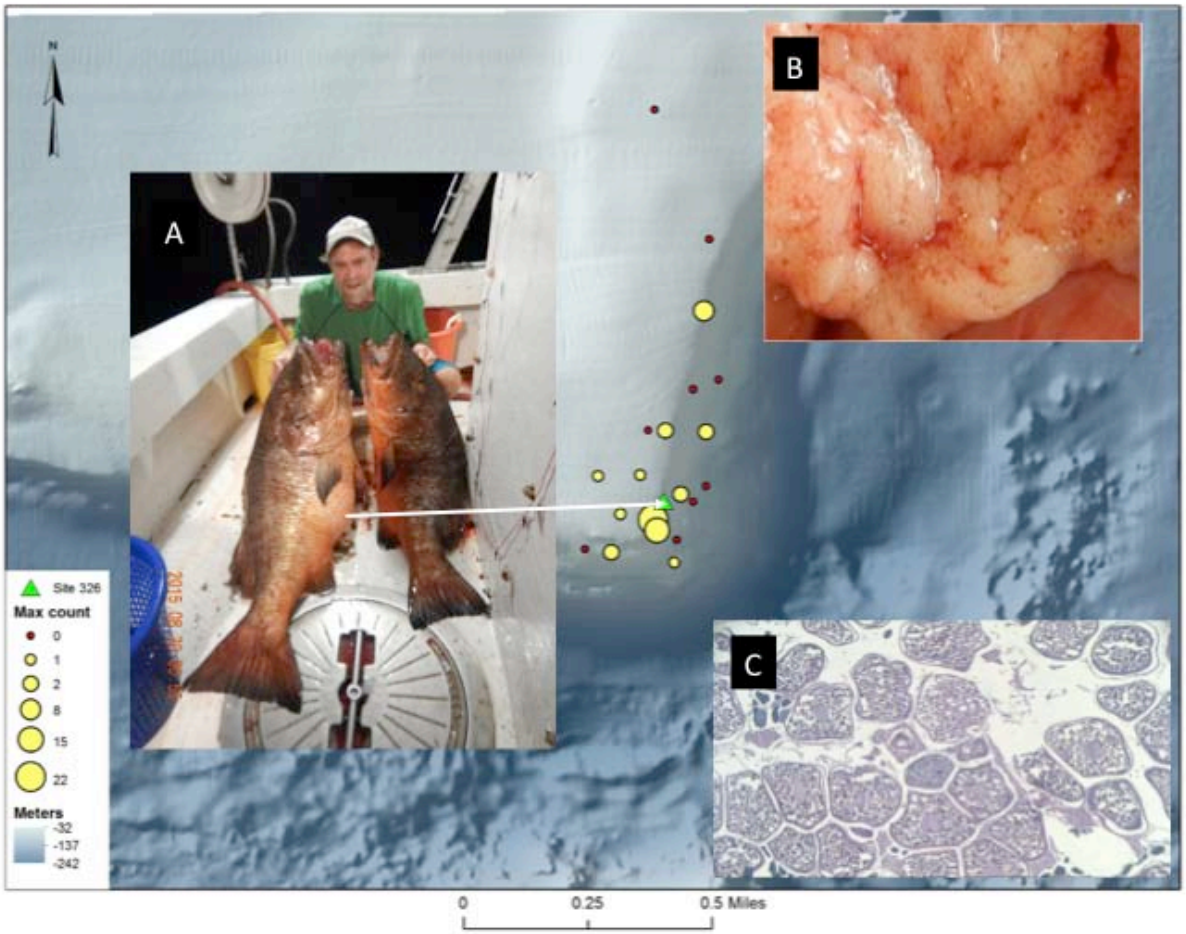


Figure 9. Two Cubera snapper were caught at the site marked with a green triangle. A) The fish on the right was a male that weighed 61 pounds, was 1174 mm TL and was 30 years of age, and was spawning at the time of capture. The fish on the left was a female that weighed 95 pounds, was 1346 mm TL and was 39 years of age. B) The female contained 4.6 pounds of ovaries packed with fully formed embryos. C) A histological sample of this fish shows that the fish was in the initial stages of hydration and spawning was imminent.

Field verification of jack spawning aggregations at the West Flower Garden Bank

Drop video cameras and fisher interviews revealed indications of spawning aggregations of horse-eye jack *Caranx latus* (cover photograph) and crevalle jack *Caranx hippos* (Figure 10) at the West Flower Garden Banks. Fisher interviews revealed that scamp also spawn there, though attempts to verify this during this project were not successful.

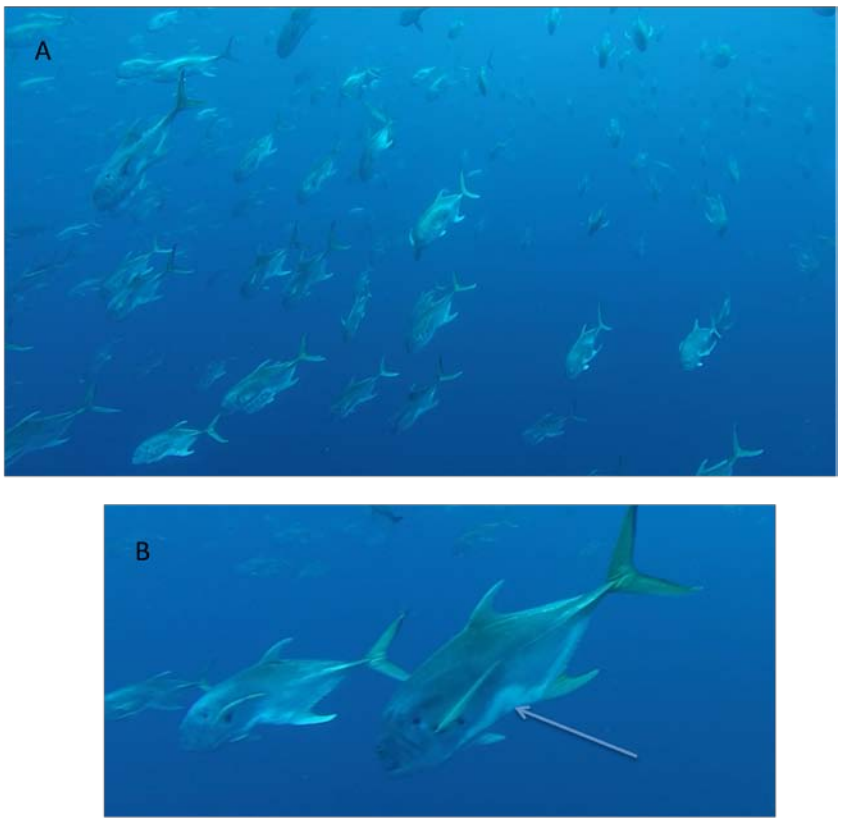


Figure 10. A) Crevalle jack aggregations at Flower Garden Banks, B) showing courtship coloration on their abdomen.

Field verification of sheepshead spawning aggregations at the Galveston jetties

Drop cameras, biological sampling, fisher interviews, dockside sampling of recreational vessels, temperature loggers, and passive acoustic hydrophone data were used to characterize a sheepshead *Archosargus probatocephalus* spawning aggregation at the Galveston ship channel (see Figure 3 above).

Sheepshead (n=312) were collected from spawning aggregations at the Galveston jetties between 20 February and 8 April 2016 and were sampled at the dock from a total of 28 chartered trips. Catch per unit effort was consistently recorded at between 0.9 and 2.4 fish/hook*hour. Total numbers of fish captured per trip ranged between two and 60 with a mean of 14.4 ± 12.5. During the peak of the season, there were as many as 24 vessels fishing the jetties which would capture a mean of ~345 fish/trip (690 fish/day). At maximum capture rates recorded herein, 24 vessels catching 60 fish/day could produce as many as 1,440 fish/trip or 2,880 sheepshead per day. Since anglers could only keep five fish/day, however, some of these would be discarded live and likely survive.

Figure 11. Sheepshead aggregation (still shot extracted from GoPro video) recorded on 2 April 2015 near the seaward end of the jetty on the south edge of the Galveston ship channel in 6 feet of water depth. In spite of relatively poor visibility (< 10 feet), there are six sheepshead visible in this frame.

Figure 12. Aggregation of sheepshead (n $\geq$ 15) photographed at the Buccaneer artificial reef site on 7 April 2015 using GoPro drop camera setup. There are at least 15 sheepshead visible.

In total, 312 sheepshead were sampled during the 2016 fishing season. Total length (mm) for all male (n=128) and female (n=120) sheepshead captured and aged during this study is plotted as a function of age (years) (Figure 13). **Note: Figures 13-21 are provided at the end of this section.** Females ranged from 2-23 years of age and males ranged from 2-20. Most fish were concentrated between ages 2-10.

Gonosomatic index (GSI) for female sheepshead ranged between 1.2 and 16.8% (i.e. between one and 17% of total body weight). GSI varied among individuals but did not show a seasonal trend. This observation is consistent with continuous batch spawning throughout the spawning season (Figure 14).

Figure 15A shows a gonad sample from a female sheepshead in the F4 stage with many hydrated oocytes. This indicates that spawning was imminent for this fish at the south jetty at the time of collection. Figure 15B shows histology from a female sheepshead in the F5 stage that contains hydrated oocytes indicating imminent spawning, and post ovulatory follicles indicating that spawning had already occurred. There are oocytes in various stages of development in both slides consistent with continuous, daily batch spawning behavior.

Male sheepshead (n=152) collected during each week of the spawning season from the Galveston jetties reflect continuous spawning throughout the sampling period (Figure 16A). By contrast, female sheepshead began to spawn during the week of March 6, and spawned continuously through the rest of the sample period (Figure 16B).

The measured mean daily seawater temperature shows a clear and typical spring rising trend through the sheepshead spawning season (Figure 17).

The DSG-ST digital recorder successfully recorded ambient sound from 20 February 2016 to 21 April 2016. Five unique fish sounds were observed in the recordings but differed greatly in the number of occurrences and persistence throughout the dataset. Calls attributed to black drum (*Pogonias cromis*; Figure 18) were the most prominent of the five sounds identified and were registered throughout the sampling period. Calls of black drum occurred throughout each day but increased during the evening hours when chorusing by large numbers of individuals was observed (Figure 19). The dominant frequencies of black drum calls and chorusing were between 70 and 300 Hz. Sound pressure levels within the 73–301 Hz band fluctuated across the entire study period (Figure 20) with higher levels of sound production in the months of February and March in comparison to April. Diel patterns in black drum calling and chorusing was seen with maximum sound production levels measured each evening at ~18:00 CST (Figure 21).

The DSG-ST also recorded sounds produced by sand seatrout (*Cynoscion arenarius*). The dominant frequencies of sand seatrout calls and chorusing were between 325 and 450 Hz. While calls of sand seatrout were recorded in the month of February, sound pressure levels within the 325–448 Hz band were highest in amplitude during the months of March and April. Similar to black drum, sand seatrout calling rates and chorusing levels exhibited diel patterns with maximum sound production observed later in the evening ~20:00 – 21:00.

The DSG-ST also recorded the presence of silver perch (*Bairdiella chrysoura*) sound production from February through April. The dominant frequencies of silver perch sound production were between 1000 and 1700 Hz. Sound pressure levels within the 999 – 1696 Hz band were highest in the months of March and April. Maximum levels of silver perch sound production were observed during the hours of ~20:00-21:00 CST.

The sources of two remaining unique sounds could not be identified to an individual species. Observations of these sounds were rare and random throughout the sampling period; thus, time series of sound pressure levels attributable to each sound could not be generated. The dominant frequencies of the first unidentified sound were centered on 650 Hz and it likely was produced by a sciaenid due to the characteristics of the call. The last sound from an unidentifiable source was centered on a frequency of 100 Hz. Due to the rarity of these calls it is unlikely that either was produced by sheepshead, which were aggregated at the site throughout the majority of the sampling period.

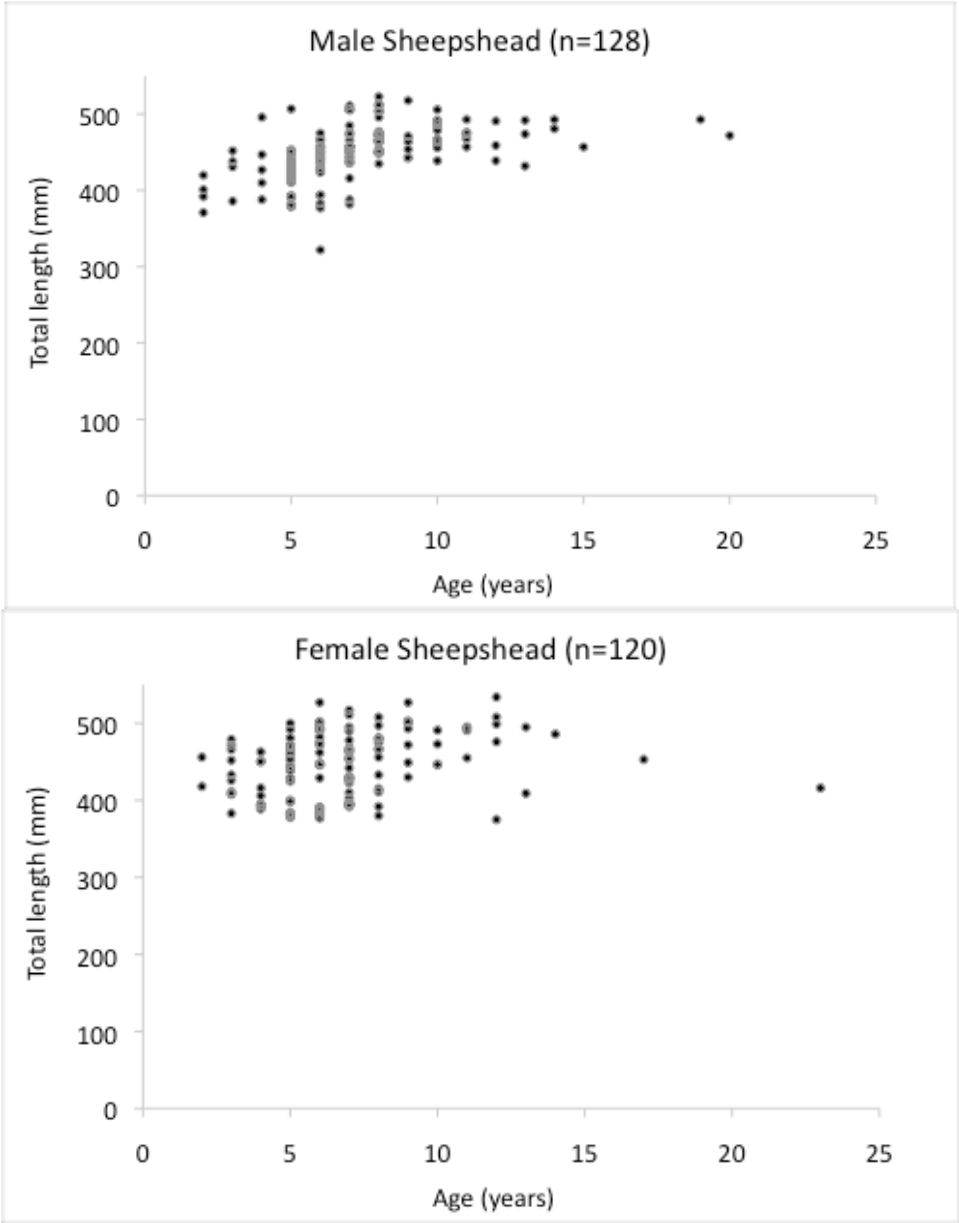


Figure 13. Total length (mm) for all male (n=128) and female (n=120) sheepshead captured and aged during this study are plotted as a function of age (years). Females ranged from 2-23 years of age and males ranged from 2-20. Most fish were concentrated at ages 2-10.

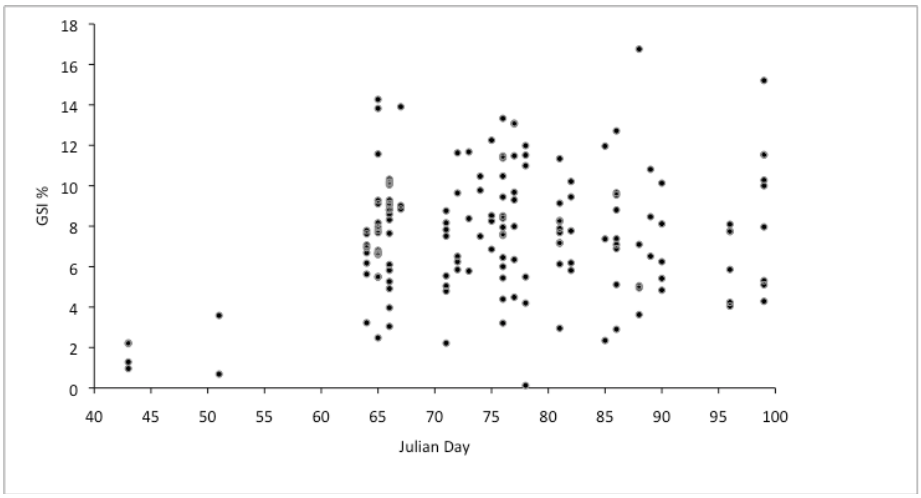


Figure 14. Gonosomatic index (GSI) for female sheepshead ranged between 1.2 and 16.8% (i.e. gonad weight accounted 1-17% of total body weight). GSI varied among individuals but did not show a seasonal trend.

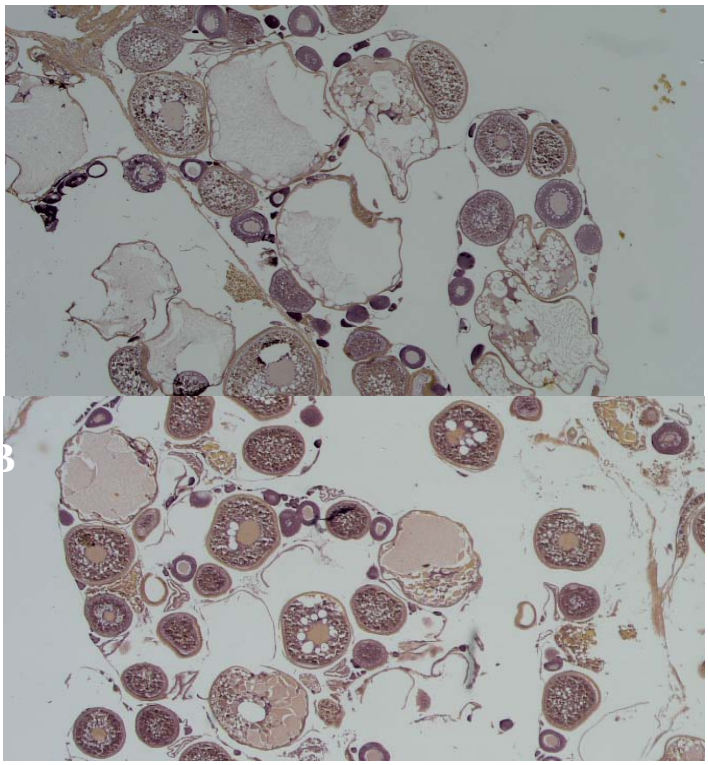


Figure 15. A) Histology sample from a female sheepshead in F4 stage showing hydrated oocytes and indicative that spawning was imminent for this fish at the south jetty at the time of collection. B) Histology sample from a female sheepshead in F5 stage contains hydrated oocytes indicating imminent spawning, and post-ovulatory follicles indicating that spawning has already occurred. There are oocytes in various stages of development in both slides consistent with continuous batch spawning behavior.

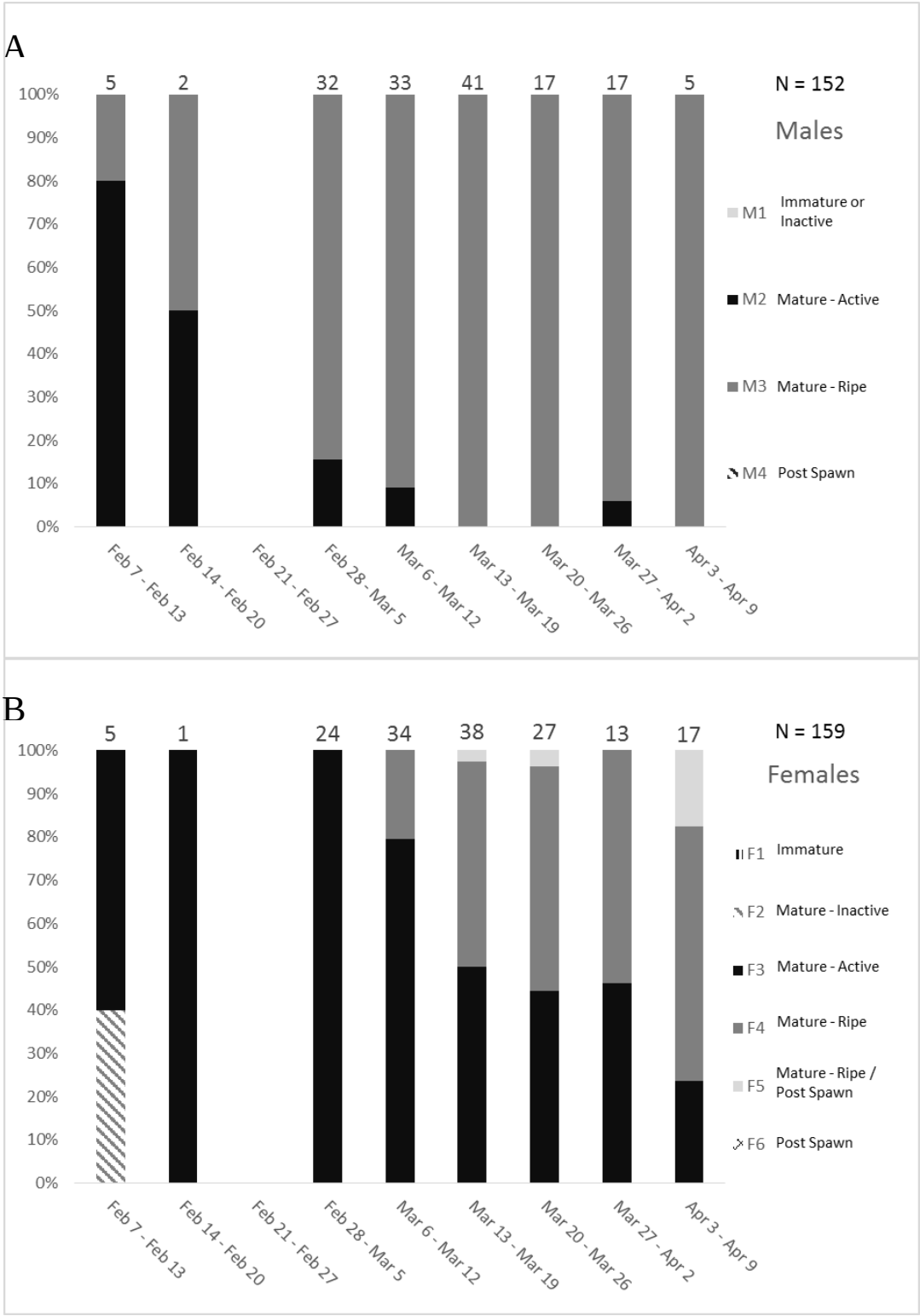


Figure 16. A) Percentages of each gonadal maturity phase for male sheepshead (n=152) collected during each week of the spawning season from the Galveston jetties. B) Percentages of each gonadal maturity phase for female sheepshead (n=159).

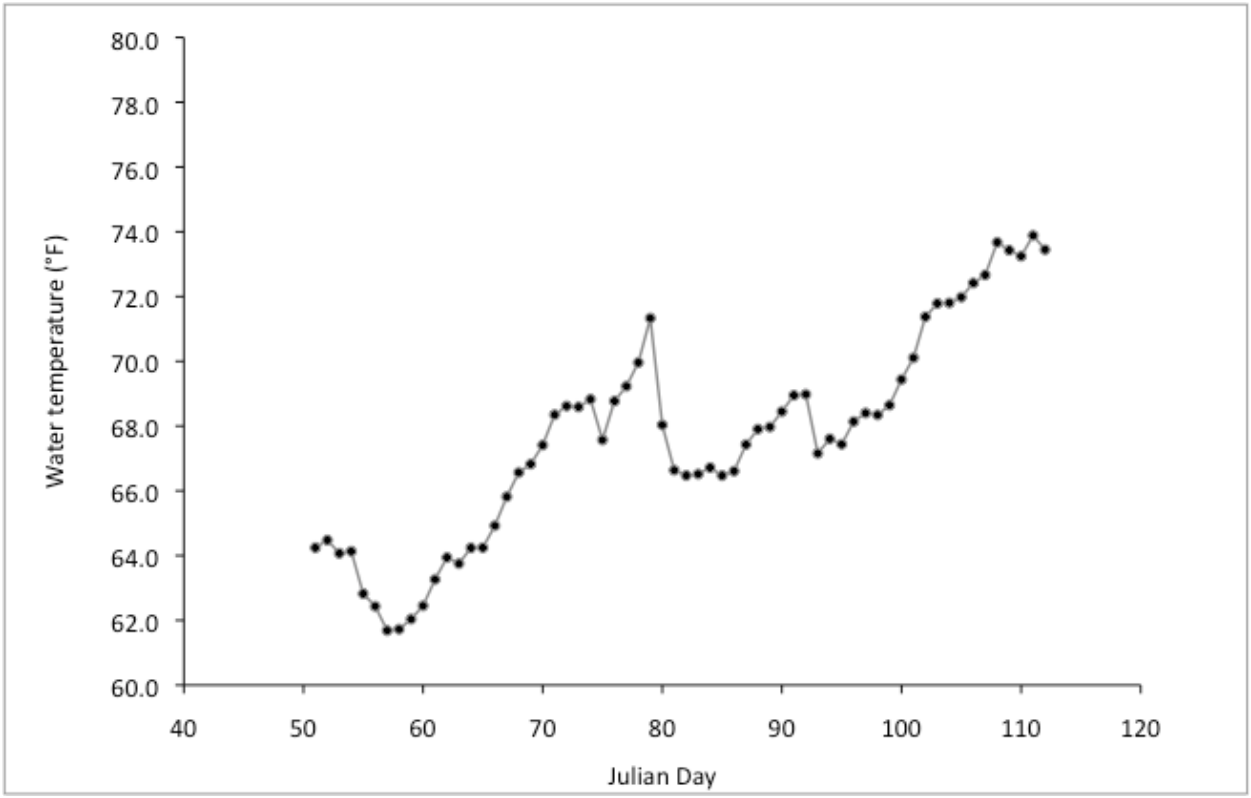


Figure 17. Mean daily seawater temperature (°F) measured with a Hobo Tidbit temperature logger deployed 12 feet below mean sea level at the north jetty in Galveston, Texas is plotted for each day of collection between Julian Days 51 (2 February 2016) and Day 112 (16 April 2016). The temperature shows a clear and typical spring rising trend through the sheepshead spawning season.

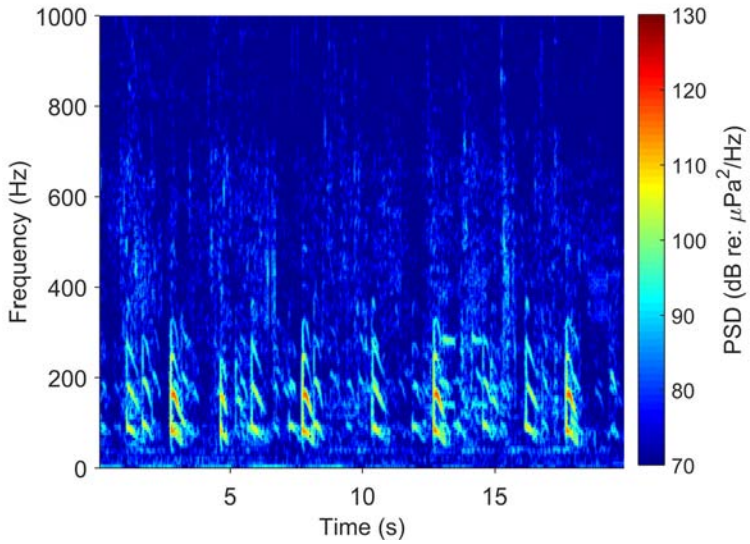


Figure 18. Spectrogram of a series of individual black drum (*Pogonias cromis*) calls during a period of time without chorusing.

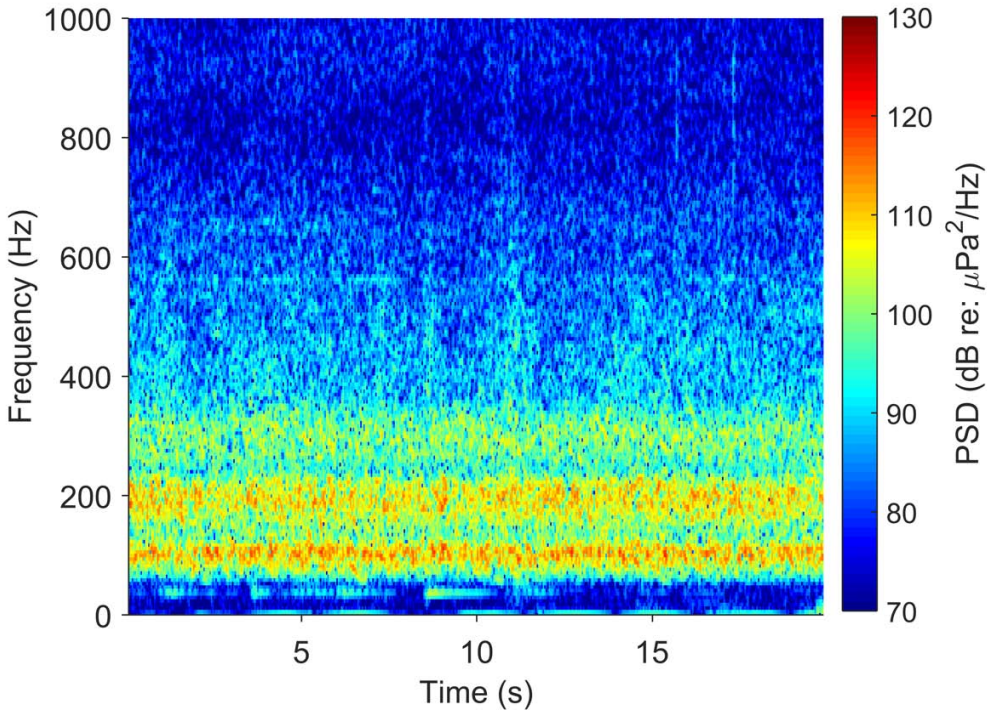


Figure 19. Spectrogram of a black drum (*Pogonias cromis*) chorusing during the evening hours. Chorusing is made up of an unknown total of individual calls.

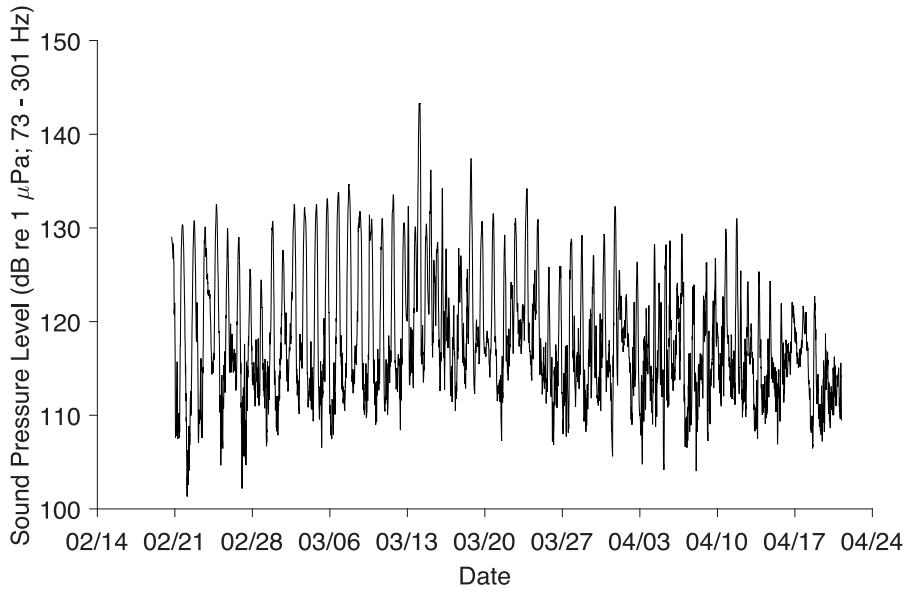


Figure 20. Time series of sound pressure levels in the 73-301 Hz band, indicative of changes in black drum (*Pogonias cromis*) calls and chorusing.

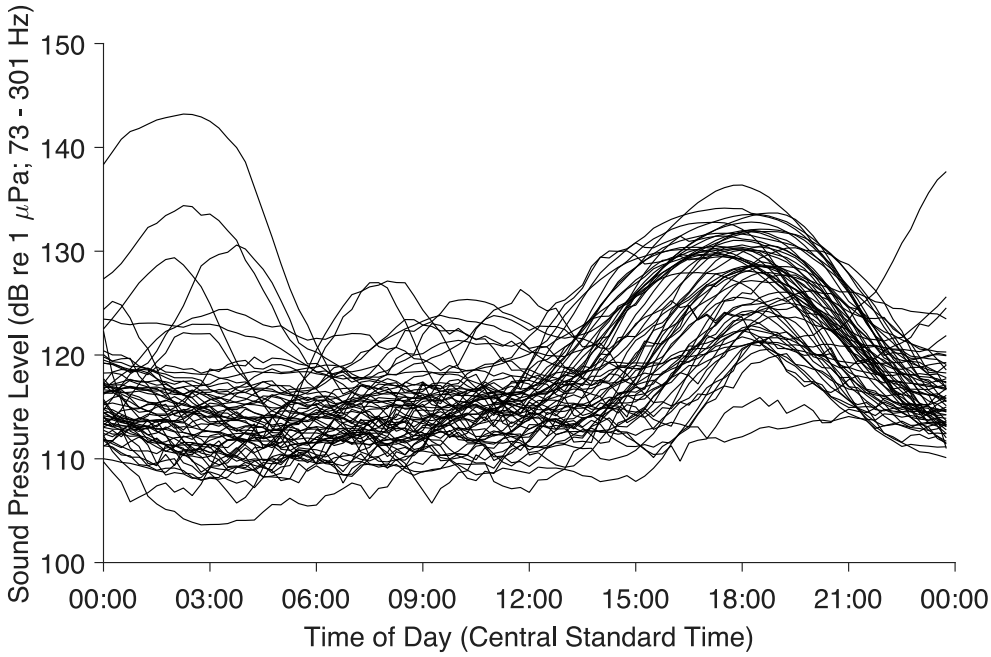


Figure 21. Daily time series of sound pressure levels in the 73-301 Hz band overlaid to depict diel patterns in black drum (*Pogonias cromis*) calls and chorusing. Sound levels reached a maximum ~18:00 Central Standard Time; deviations from this pattern resulted from nearby vessel operation.

Problems Encountered:

We initially believed our study would focus almost entirely on the snapper-grouper complex species associated with outer shelf edge banks. And, indeed, such studies were conducted at the Flower Garden Banks and other shelf edge banks to the east. However, our approach to using fishery-dependent surveys where fishermen were contracted to fish at the time and location of predicted spawning sites proved problematic. Charter fishermen had fast and efficient vessels, but typically needed to leave and return to the dock on a daily basis. In contrast, commercial vessels spent protracted time at sea (2 weeks or more), but would spend a large fraction of their time at sites other than aggregation sites. Nevertheless, we were able to verify predicted spawning aggregation sites using industry vessels, although not to the extent we originally envisioned. Thus, Objective 4 "conduct field verification of selected spawning aggregations…." was met, but only to the extent originally envisioned for the sheepshead. To be entirely successful for shelf edge sites, a different logistics plan than used in this study would be necessary. A dedicated, contracted commercial or charter vessel can target sampling an individual site at a much higher and more-frequent temporal scale than used in the study, though at a higher cost.

Additional Work Needed:

Additional efforts are needed to further characterize the multi-species spawning aggregations that have been identified and verified during this study. These include the scamp and jack

aggregation at West Flower Garden Banks, the sheepshead and black drum aggregations at the Galveston jetties, and the Cubera snapper aggregations. The methods described herein, repeated with greater frequency and at different times can be used to further characterize spawning aggregations. Passive acoustic receivers (e.g. DSG-ST used in this study) would be particularly valuable in documenting the scamp aggregations at the West Flower Garden Bank. Finally, additional efforts are needed to verify the time and location of several spawning sites that have been described by fishermen in interviews but have not been visited. It will be important that new data being generated be used to support stock assessments.

VI. Evaluation

Achievement of Goals and Objectives:

This project provided the first attempt to predict and verify spawning aggregations on the banks of the northwestern Gulf of Mexico. All four objectives were met with varying levels of success. Field verification of spawning aggregations in the waters of the Gulf of Mexico is an important but difficult task. Sites are generally small, remote, and transient in time, often occurring during periods of rough weather and requiring multi-day trips for evaluation. This project has illustrated the value of the described approach by documenting several spawning aggregations in both nearshore and offshore waters. Additionally, the project compiled and analyzed fishery-dependent and fishery-independent data, expert fishery knowledge, and geomorphological predictions of likely spawning aggregation sites that can be used in subsequent studies.

An unexpected finding was that the only documented spawning aggregation of any reef fish in federal waters in the northwestern Gulf of Mexico was for the sheepshead *Archosargus probatocephalus* (Gallaway and Martin, 1980). However, these aggregations had not been studied since their discovery in the late 1970's. As described herein, we documented sheepshead aggregations still occur. Consistent with the design of the sampling program in the proposal, the sheepshead investigations provided a valuable way to test methods in that they could be conducted in a half day, near to shore. Because of their proximity to shore, more spawning aggregation verification data were collected than would have been possible to collect at shelf edge sites where spawning aggregations were not known with certainty on either a temporal or spatial basis.

A great deal of additional effort is needed to identify, characterize, and monitor spawning aggregations in the Gulf of Mexico. These data in turn can be used to help monitor and manage stocks. Regional variations in species composition, fleet dynamics, scientific understanding, governance regimes and local capacity dictate the need for regionally-specific work plans. Nonetheless, monitoring spawning aggregation sites will likely contribute to more robust stock assessments for multiple species, and ultimately support the rebuilding and recovery of reef fish throughout their natural range.

Dissemination of Results:

Dr. Will Heyman offered an oral presentation based on preliminary results that were funded under this project. The talk was entitled, *Cooperative Research and Monitoring Program for the Western Central Atlantic*. It was presented as the culminating talk within a NOAA sponsored

workshop on data-limited stock assessments, held on November 11, 2015 in Panama City, Panama, as part of the 68th Annual Gulf and Caribbean Fisheries Meeting. The presentation was very well received (Appendix A).

Summary reports of the project's findings were also published as part of the "Foundation Project Update" section of the "Gulf and South Atlantic News", a publication of the Gulf & South Atlantic Fisheries Foundation, Inc. This newsletter is distributed to over 700 organizations and individuals throughout the region. An electronic version of this newsletter (PDF) is also included in the regular updates to the Foundation's website (www.gulfsouthfoundation.org).

Copies of this project's Final Report will be published and distributed to various federal and state fishery agencies, university extension/Sea Grant offices, and Industry associations. In addition, PDF copies of the Final Report will be made available for download from the Foundation's website.

Additionally, the research team plans to disseminate project results through a peer-reviewed publication for sheepshead and the discovery of a Cubera snapper spawning aggregation site as well as provide presentations to relevant management bodies such as the Gulf of Mexico Fisheries Management Council if requested.

VII. Literature Cited

Appeldoorn, R., M. Schärer-Umpierre, T. Rowell, and M. Nemeth. *In press*. Measuring relative density of spawning red hind (*Epinephelus guttatus*) from sound production: consistency within and among sites. *Proceeding of the Gulf and Caribbean Fisheries Institute*.

Ault, J.S., J.A. Bohnsack, S.G. Smith, and J.G. Luo. 2005. Towards sustainable multispecies fisheries in Florida, USA, coral reef ecosystem. *Bulletin of Marine Science* 76, 595-622.

Berkes, F. 2012. Implementing ecosystem-based management: evolution or revolution? *Fish and Fisheries* 13, 465-476.

Briggs, D.C. and P.H. Ressler. 2001. Distribution, and abundance of phytoplankton, zooplankton, ichthyoplankton, and micronekton in the deepwater Gulf of Mexico. Gulf of Mexico Sci. 1:7-29.

Brulé, T., C. Déniel, T. Colás-Marrufo, and M. Sánchez-Crespo. 1999. Red Grouper Reproduction in the Southern Gulf of Mexico, Transactions of the American Fisheries Society, 128:3, 385-402

Brulé, T., X. Renan, T. Colas-Marrufo, Y. Hauyon, and A.N. Tuz-Sulub. 2003. Reproduction in the protogynous black grouper (*Mycteroperca bonaci* (Poey)) from the southern Gulf of Mexico. Fish. Bull. 101:463–475.

Carassou, L., F. Hernandez, S. Powers, and W. Graham. 2012. Cross-shore, seasonal and depth-related structure of ichthyoplankton assemblages in coastal Alabama. Transactions of the American Fisheries Society 141: 1137−1150.

Claro, R., J.A. Baisre, K.C. Lindeman, and J.P. García-Arteaga. 2001. Cuban fisheries: historical trends and current status. Pages 194-219 *in* Claro R., Lindeman K.C., Parenti L.R. (Eds.), *Ecology of the Marine Fishes of Cuba*. Smithsonian Institution Press, Washington, D.C.

Coleman, F.C., C.C. Koenig, A.M. Eklund, and C. Grimes. 1999. Management and conservation of temperate reef fishes in the grouper-snapper complex of the southeastern United States. Pages 233-242 *In* J.A. Musick, ed. *Life in the slow lane: ecology and conservation of long-lived marine animals*. American Fisheries Society Symposium 23, Bethesda.

Coleman, F.C., C.C. Koenig, G.R. Huntsman, J.A. Musick, A.M. Eklund, J.C. McGovern, R.W. Chapman, G.R. Sedberry, and C.B. Grimes. 2000. Long-lived reef fishes: the grouper-snapper complex. *Fisheries* 25, 14-20.

Coleman, F.C., K.M. Scanlon, K.M., and C.C. Koenig. 2011. Groupers on the edge: Shelf edge spawning habitat in and around marine reserves of the northeastern Gulf of Mexico. *The Professional Geographer* 63, 456–474.

Colin, P.L., Y.J. Sadovy, and M.L. Domeier. 2003. Manual for the Study and Conservation of Reef Fish Spawning Aggregations. Society for the Conservation of Reef Fish Aggregations Special Publication No. 1 (Version 1.0), pp. 1-98+iii.

Domeier, M.L. 2012. Revisiting spawning aggregations:definitions and challenges. In: Reef Fish Spawning Aggregations: Biology, Research and Management. (eds Y. Sadovy de Mitcheson and P.L. Colin). Springer, New York, pp. 1–21.

Erisman, B.E., M.L. Buckhorn, and P.A. Hastings. 2007. Spawning patterns in the leopard grouper, *Mycteroperca rosacea*, in comparison with other aggregating groupers. Marine Biology, 151(5), 1849–1861. http://doi.org/10.1007/s00227-007-0623-2.

Gallaway, B.J. and L.R. Martin. 1980. Effects of gas and oil field structures and effluents on pelagic and reef fishes, demersal fishes and macrocrustaceans. Volume 3. *In*: Jackson, W.B. and E.P. Wilkens (editors) Environmental assessment of Buccaneer gas and oil field in the northwestern Gulf of Mexico, 1978-1979. NOAA Technical Memorandum NMFS-SEFC-37, 49 p.

Granados-Dieseldorff, P., W.D. Heyman, and J. Azueta. 2013. History and co-management of the artisanal mutton snapper (*Lutjanus analis*) spawning aggregation fishery at Gladden Spit, Belize, 1950-2011. *Fisheries Research* 147, 213-221.

Heyman, W.D. 2011. Elements for building a participatory, ecosystem-based marine reserve network. *The Professional Geographer* 63, 475-488.

Heyman, W.D. 2016. Cooperative Research and Monitoring Program for Fish Spawning Areas in the US South Atlantic (CRMP SASA). Draft 2.0, 14 February 2016. LGL Ecological Research Associates, Inc., Bryan TX. DOI: 10.13140/RG.2.1.4110.5682

Heyman, W.D. and B. Kjerfve. 2008. Characterization of transient multi-species reef fish spawning aggregations at Gladden Spit, Belize. *Bulletin of Marine Science* 83, 531-551.

Heyman, W.D. and P. Granados-Dieseldorff. 2012. The voice of the fishermen of the Gulf of Honduras: improving regional fisheries management through fisher participation. *Fisheries Research* 125-126, 129-148.

Heyman W.D., J. Azueta, O. Lara, I. Majil, D. Neal, B. Luckhurst, M. Paz, I. Morrison, K.L. Rhodes, B. Kjerve, B. Wade, and N. Requena. 2004. Spawning Aggregation Monitoring Protocol for the Meso-American Reef and the Wider Caribbean. Version 2.0. Meso-American Barrier Reef Systems Project, Belize City, Belize.

Heyman, W.D., M. Olivares, S. Fulton, L. Bourillón, J. Caamal, C. Ribot and S. Kobara. 2014. Prediction and verification of reef fish spawning aggregation sites in Quintana Roo Mexico pp. 73 – 81. In McConney, Medeiros and Pena (eds.) 2014. *Enhancing Stewardship in Small-Scale Fisheries: Practices and Perspectives.* CERMES Technical Report No. 73. 162pp. http://www.cavehill.uwi.edu/cermes/news/technical-reports.aspx

Honey, K., J.H. Moxley, and R.M. Fujita. 2010. From rags to fishes: data-poor methods for fishery managers. *Managing Data-Poor Fisheries: Case Studies, Models & Solutions* 1, 159-184.

Huntsman, G.R. and J.R. Waters. 1987. Development of management plans for reef fishes – Gulf of Mexico and U.S. South Atlantic. Pages 553-560 *in* J.J. Polovina and S. Ralston (Eds). *Tropical Snappers and Groupers: Biology and Fisheries Management*. Westview Press, Boulder.

Johannes, R.E. 1998. The case for data-less marine resource management: examples from tropical nearshore fin fisheries. *Trends in Ecology and Evolution* 13, 243-246.

Johannes, R.E., M.M.R. Freeman, and R.J. Hamilton. 2000. Ignore fishers' knowledge and miss the boat. *Fish and Fisheries* 1, 257-271.

Johannes, R.E. and B. Neis. 2007. The value of an anecdote, Pages 41-58 in: Haggan N., Neis B., Baird I. (Eds.), Fishers' knowledge in fisheries science and management. UNESCO Publishing, Paris.

Kadison, E., R.S. Nemeth, S. Herzlieb, and J. Blondeau. 2006. Temporal and spatial dynamics of *Lutjanus cyanopterus* and *L. jocu* (Pisces: Lutjanidae) spawning aggregations on a multi-species spawning site in the USVI. *Revista Biologia Tropical* 54(3), 69-78.

Kobara, S., and W.D. Heyman. 2008. Geomorphometric patterns of Nassau grouper (*Epinephelus striatus*) spawning aggregation sites in the Cayman Islands. *Marine Geodesy* 31, 231-245.

Kobara, S. and W.D. Heyman. 2010. Sea bottom geomorphology of multi-species spawning aggregation sites in Belize. *Marine Ecology Progress Series* 405, 243-254.

Kobara, S., W.D. Heyman, S.J. Pittman, and R.S. Nemeth. 2013. The biogeography of transient reef fish spawning aggregations in the Caribbean: a synthesis for future research and management. Pages 281-326 *in* R.N. Hughes, D. Hughes, and I.P. Smith, Eds. *Oceanography and Marine Biology: An Annual Review* 51, 281-326.

Koenig, C.C., F.C. Coleman, C.B. Grimes, G.R. Fitzhugh, C.T. Gledhill, K.M. Scanlon, and JM.A. Grace. 2000. Protection of fish spawning habitat for the conservation of warm temperate reef fish fisheries of shelf-edge reefs of Florida. Bulletin of Marine Science 66, 593-616.

Lindeman, K.C., R. Pugliese, G.T. Waugh, and J.S. Ault. 2000. Developmental patterns within a multispecies reef fishery: management applications for essential fish habitats and protected areas. *Bulletin of Marine Science* 66, 929-956.

Mackinson, S., and L. Nøttestad. 1998. Combining local and scientific knowledge. *Reviews in Fish Biology and Fisheries* 8, 481-490.

Mann, D.A., J.V. Locascio, F.C. Coleman, and C.C. Koenig. 2009. Goliath grouper *Epinephelus itajara* sound production and movement patterns on aggregation sites. *Endangered Species Research* 7, 229-236.

Mann, D., J. Locascio, M. Schärer, M. Nemeth, and R. Appeldoorn. 2010. Sound production by red hind *Epinephelus guttatus* in spatially segregated spawning aggregations. *Aquatic Biology* 10, 149-154.

Muhling, B.A., J.T. Lamkin, W.J. Richards. 2012. Decadal-scale responses of larval fish assemblages to multiple ecosystem processes in the northern Gulf of Mexico. Marine Ecology Progress Series 450:37–53.

Neis, B., D.C. Schneider, L. Felt, R.L. Haedrich, J. Fischer, and J.A. Hutchings. 1999. Fisheries assessment: what can be learned from interviewing resource users? *Canadian Journal of Fisheries and Aquatic Sciences* 56, 1949-1963.

Nelson, M.D., C.C. Koenig, F.C. Coleman, and D.A. Mann. 2011. Sound production of red grouper *Epinephelus morio* on the West Florida Shelf. *Aquatic Biology* 12, 97-108.

National Oceanic and Atmospheric Administration (NOAA). Office of National Marine Sanctuaries. 2010. Flower Garden Banks National Marine Sanctuary Draft Management Plan. NOAA, U.S. Department of Commerce. Silver Spring, MD.

Patterson III, W.F., C.E. Porch, J.H. Tarnecki, and A.J. Strelcheck. 2012. Effect of circle hook size on reef fish catch rates, species composition, and selectivity in the northern Gulf of Mexico recreational fishery. *Bulletin of Marine Science* 88, 647-665.

Pitcher, T.J., P.J.B. Hart, and D. Pauly. 1998. *Reinventing fisheries management*. Kluwer Academic Publishers, Dordrecht ; Boston.

Rezak, R., T.J. Bright, and D.W. McGrail. 1985. *Reefs and Banks of the Northwestern Gulf of Mexico: Their Geological, Biological, and Physical Dynamics*. John Wiley and Sons, New York, 259 pp.

Rowell, T.J., R.S. Appeldoorn, J.A. Rivera, D.A. Mann, T. Kellison, M. Nemeth, and M. Schärer-Umpierre. 2011. Use of passive acoustics to map grouper spawning aggregations, with emphasis on red hind, *Epinephelus guttatus*, off western Puerto Rico. *Proceeding of the Gulf and Caribbean Fisheries Institute* 63, 139-142.

Rowell, T.J., R.S. Appeldoorn, and M.T. Schärer-Umpierre. *In press*. Passive acoustics record grouper spawning activity at multi-species aggregations. *Proceeding of the Gulf and Caribbean Fisheries Institute*.

Rowell, T.J., M.T. Schärer, R.S. Appeldoorn, M.I. Nemeth, J.A. Rivera, and D.A. Mann. 2012. Sound production as an indicator of red hind, *Epinephelus guttatus*, density at a spawning aggregation. *Marine Ecology Progress Series* 462, 241-250.

Sadovy De Mitcheson, Y., A. Cornish, M. Domeier, P.L. Colin, M. Russell, and K.C. Lindeman. 2008. A global baseline for spawning aggregations of reef fishes. *Conservation Biology* 22, 1233-1244.

Sadovy De Mitcheson, Y., and B. Erisman. 2012. Fishery and biological implications of fishing spawning aggregations, and the social and economic importance of aggregating fishes. Pages 225-284 *In* Y. Sadovy de Mitcheson and P.L. Colin (eds.), Reef Fish Spawning Aggregations: Biology, Research and Management. Springer, Dordrecht.

Schärer, M.T., M.I. Nemeth, D. Mann, J. Locascio, R.S. Appeldoorn, and T.J. Rowell. 2012a. Sound production and reproductive behavior of yellowfin grouper, *Mycteroperca venenosa* (Serranidae) at a spawning aggregation. *Copeia* 1, 136-145.

Schärer, M.T., T.J. Rowell, M.I. Nemeth, and R.S. Appeldoorn. 2012b. Sound production and associated reproductive behavior of Nassau grouper, *Epinephelus striatus* (Pisces: Epinephelidae) at spawning aggregations. *Endangered Species Research* 19, 29-38.

Schärer, M.T., M.I. Nemeth, T.J. Rowell, and R.S. Appeldoorn. *In press*. Sounds associated with the reproductive behavior of the black grouper (*Mycteroperca bonaci*). *Marine Biology*.

Sedberry, G.R., O. Pashuk, D.M. Wyanski, J.A. Stephen, and P. Weinbach. 2006. Spawning locations for Atlantic reef fishes off the southeastern U. S. *Proceedings of the 57th Annual Gulf and Caribbean Fisheries Institute* 57, 463-514.

Tuz-Sulub, A., T. Brulé, K. Cervera-Cervera, and J.C. Espinoza-Mendez. 2006. Evidence for sexual dichromatisms in spawning aggregations of yellowfin grouper *Mycteroperca venenosa* and tiger grouper *Mycteroperca tigris* from the southern Gulf of Mexico. Journal of Fish Biology 69, 1744–1755. doi:10.1111/j.1095-8649.2006.01241.x

Wright, D.J. and W.D. Heyman. 2008. Marine and coastal GIS for geomorphology, habitat mapping and marine reserves. *Marine Geodesy* 31(4), 1-8.

Wright, D.J., E.R. Lundblad, E.M. Larkin, R.W. Rinehart, J. Murphy, L. Cary-Kothera, and K. Draganov. 2005. ArcGIS Benthic Terrain Modeler. Corvallis, Oregon, Oregon State University, Davey Jones Locker Seafloor Mapping/Marine GIS Laboratory and NOAA Coastal Services Center. Accessible online at: http://www.csc.noaa.gov/digitalcoast/tools/btm.

Appendix A:

Cooperative Research and Conservation Program
Western Central Atlantic Spawning Aggregations
(CRCP WCASA)

William D. Heyman
LGL Ecological Research Associates, Inc.
12 November 2015

Cooperative Research and Conservation Program Western Central Atlantic Spawning Aggregations (CRCP WCASA)

William D. Heyman
LGL Ecological Research Associates, Inc.
12 November 2015

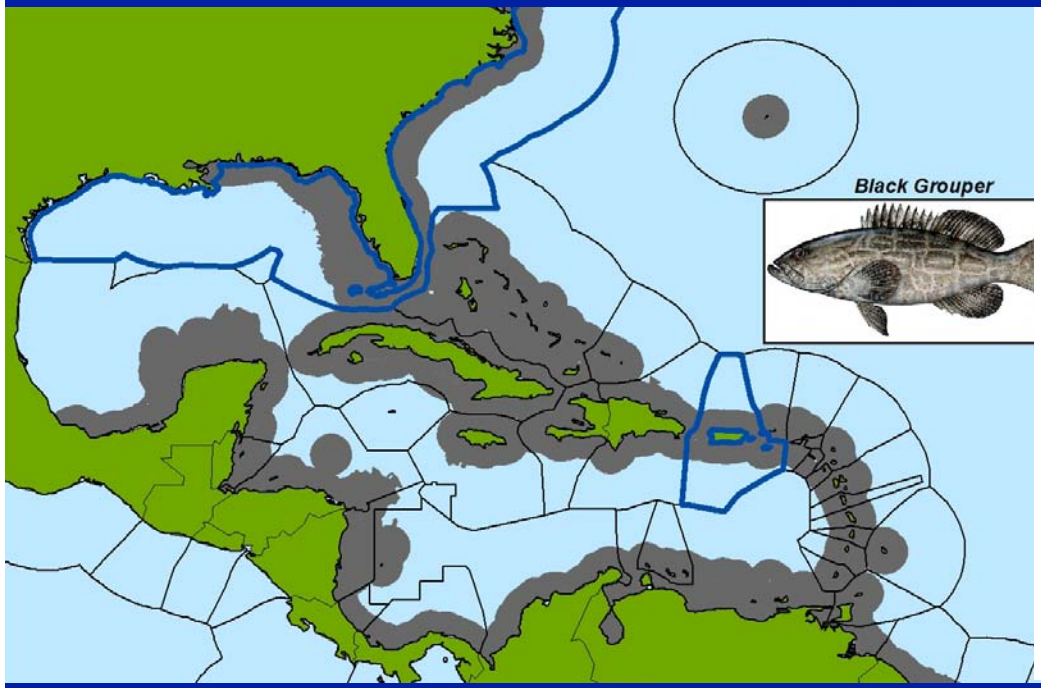
Thanks:

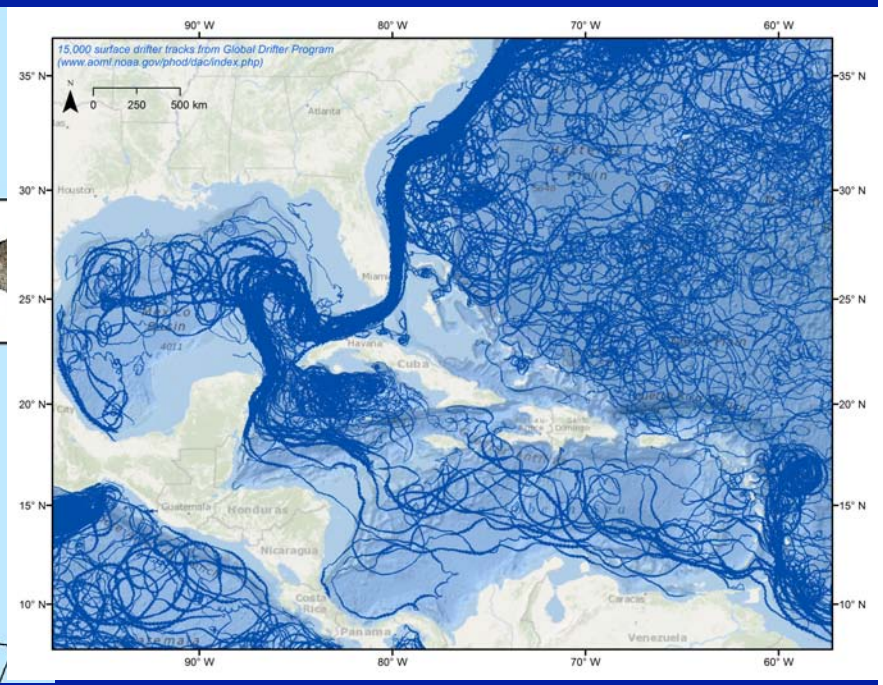
- South Atlantic Fishery Management Council
- LGL Ecological Research Associates
- Belize National Spawning Aggregations Working Group
- Gulf and Caribbean Fisheries Institute
- Comunidad y Biodiversidad (COBI)
- Summit and Oak Foundations
- Gulf and South Atlantic Fisheries Foundation
- NOAA Saltonstall-Kennedy Program
- Pew Charitable Trusts
- NOAA RESTORE Act Science Program

- Many, many fishermen

Species transcend political boundaries

Connectivity





Large predatory fish that spawn in aggregations are delicious

and vulnerable

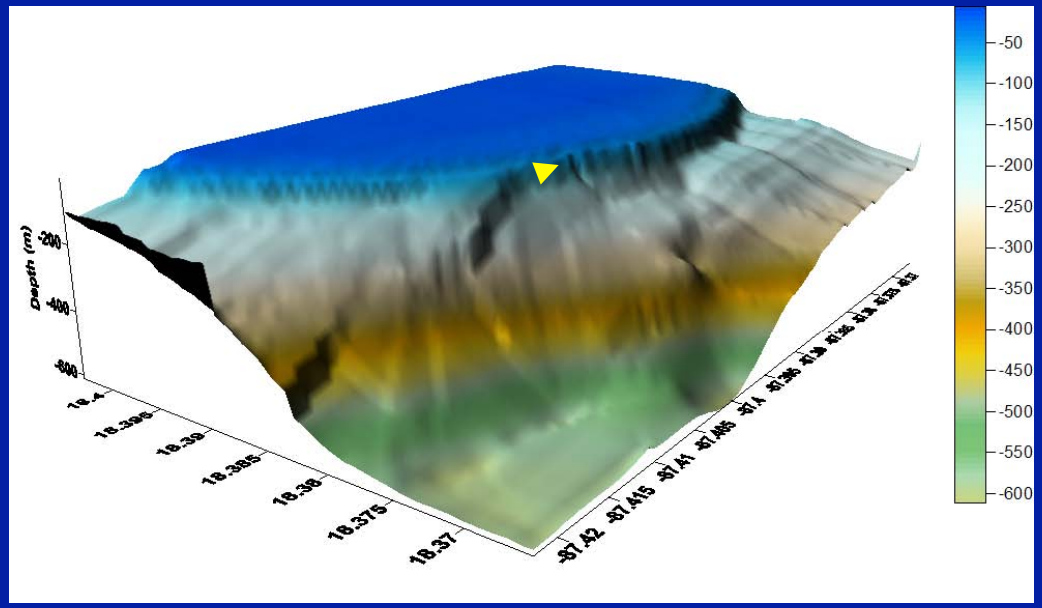
FISH and FISHERIES

Fishing groupers towards extinction: a global assessment of threats and extinction risks in a billion dollar fishery

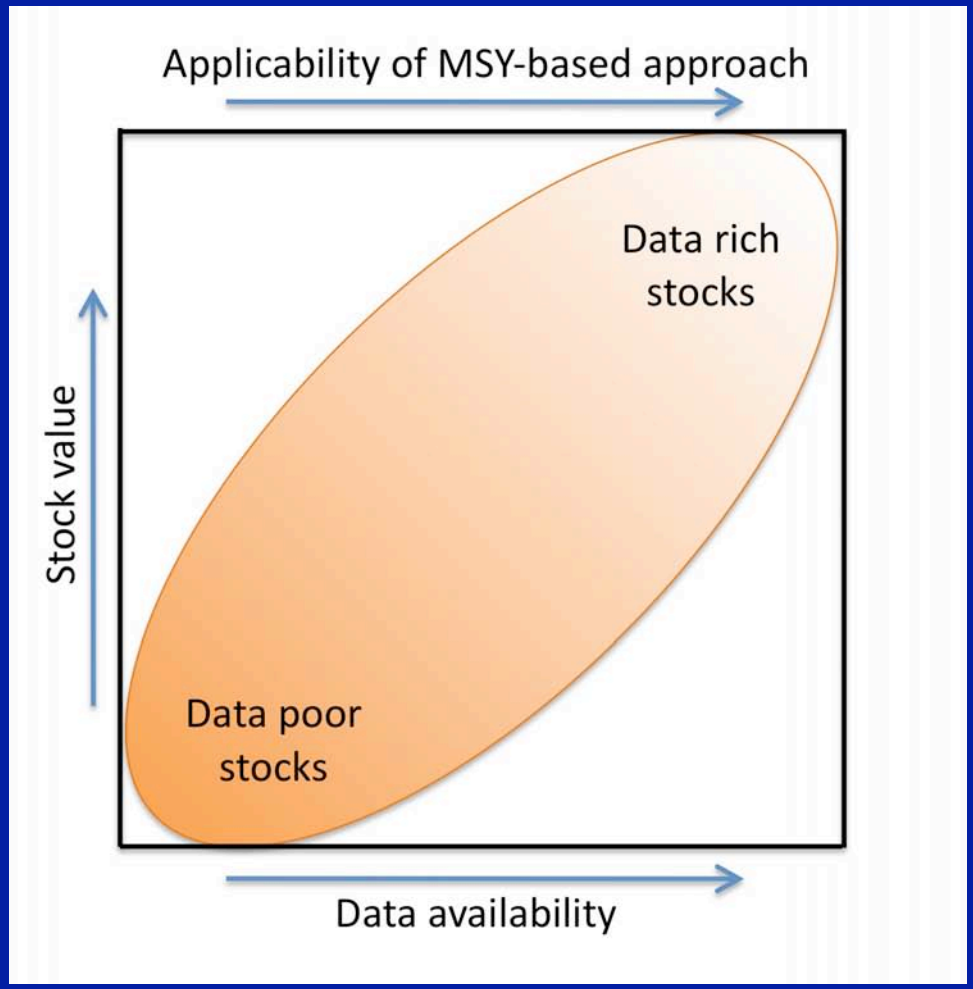
2012

Yvonne Sadovy de Mitcheson[1], Matthew T Craig[2], Athila A Bertoncini[3], Kent E Carpenter[4], William W L Cheung[5,6], John H Choat[7], Andrew S Cornish[8], Sean T Fennessy[9], Beatrice P Ferreira[10], Philip C Heemstra[11], Min Liu[12], Robert F Myers[13], David A Pollard[14], Kevin L Rhodes[15], Luiz A Rocha[16], Barry C Russell[17], Melita A Samoilys[18] & Jonnell Sanciangco[4]*

form multi-species spawning aggregations that occur predictably at reef promontories



Application of MSY-based control rules is unrealistic and alternate paradigms should be considered for data-poor stocks



National Research Council. 2014. Evaluating the Effectiveness of Fish Stock Rebuilding Plans in the United States

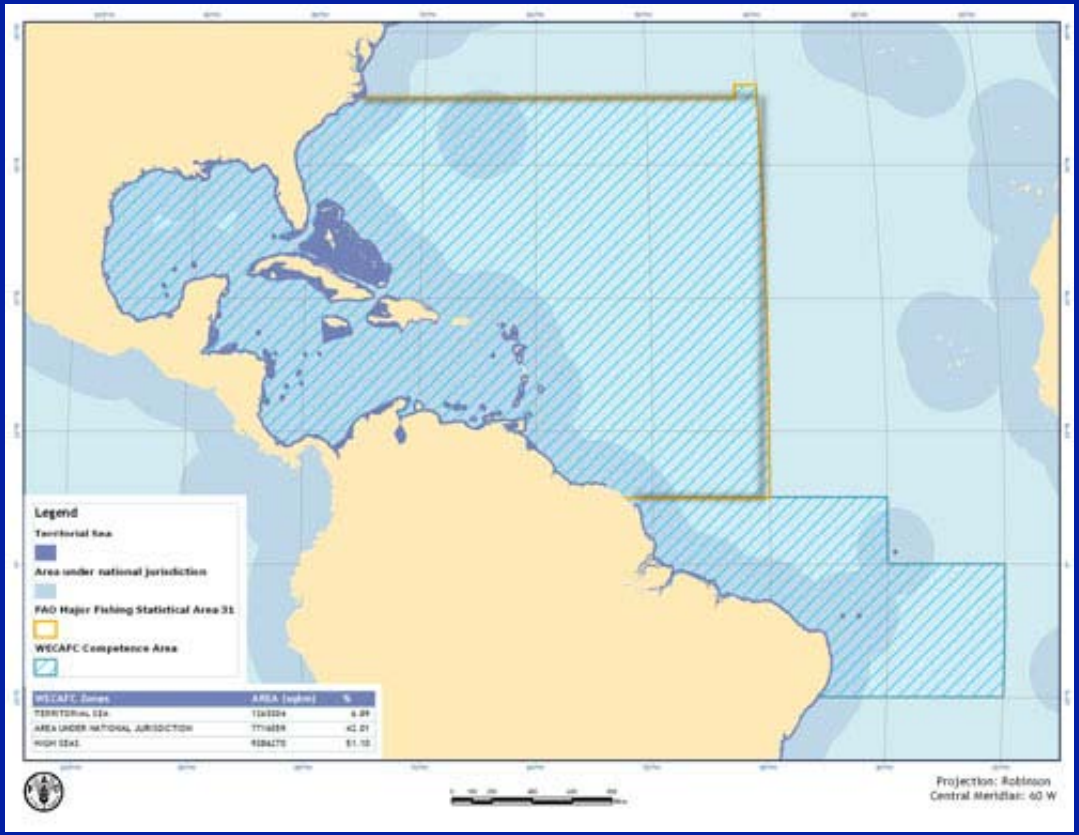
Spawning aggregation studies

- many existing projects
- little coordination or standardization
- limited funding
- FAO Western Central Atlantic Fisheries Commission (WCAFC) recommendations, 2014

Fishermen know when and where fish spawn

Ideal Citizen Scientists

Cooperative Monitoring and Conservation Program for Western Central Atlantic Spawning Aggregations (CMCP WCASA)



Vision

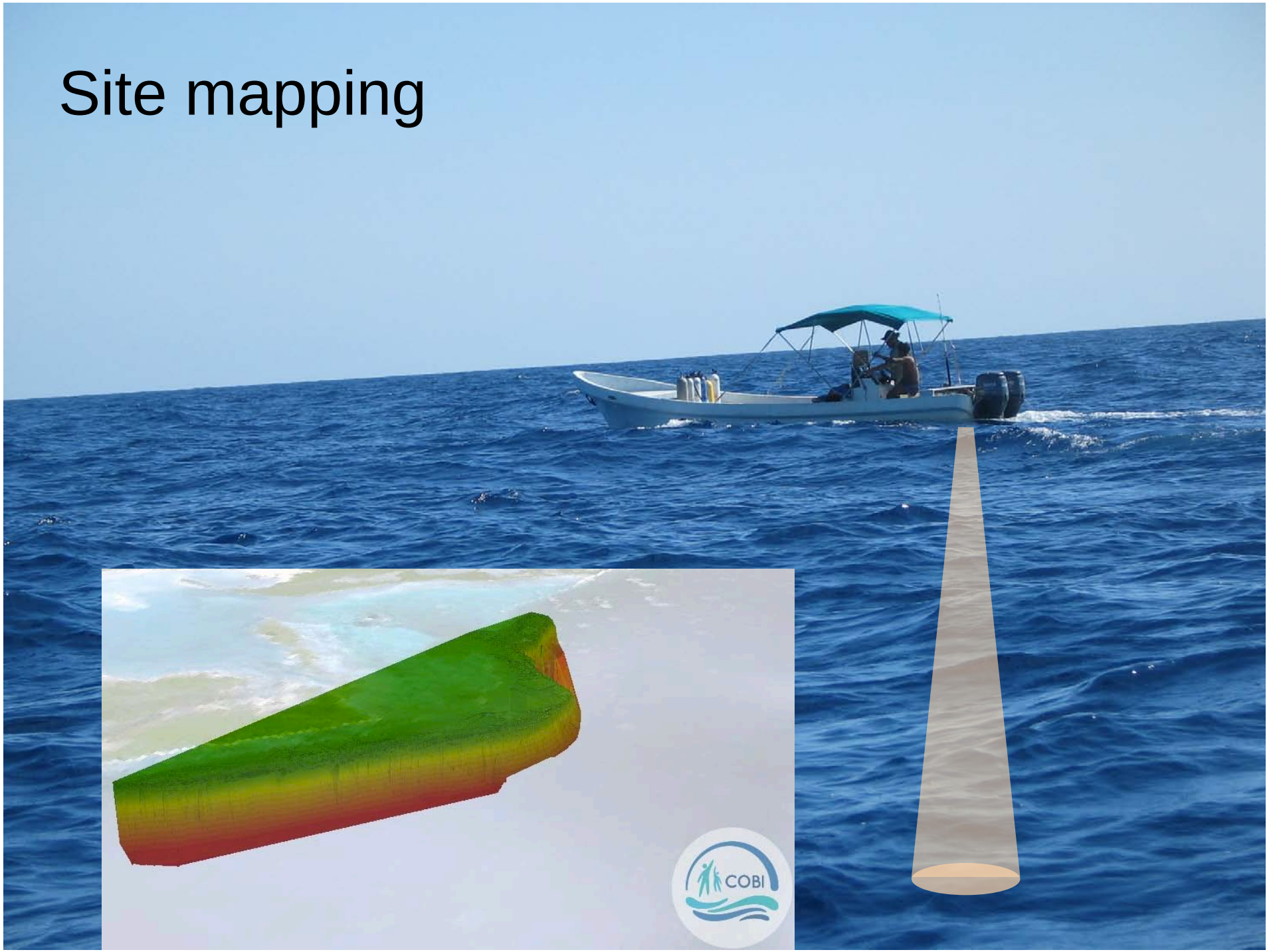
Cooperative Monitoring and Conservation Program for Western Central Atlantic Spawning Aggregations (CMCP WCASA)

A network of fishermen, scientists, and managers who cooperatively monitor and protect multi-species spawning aggregations and thus support sustainable management of the snapper grouper complex in the Western Central Atlantic.

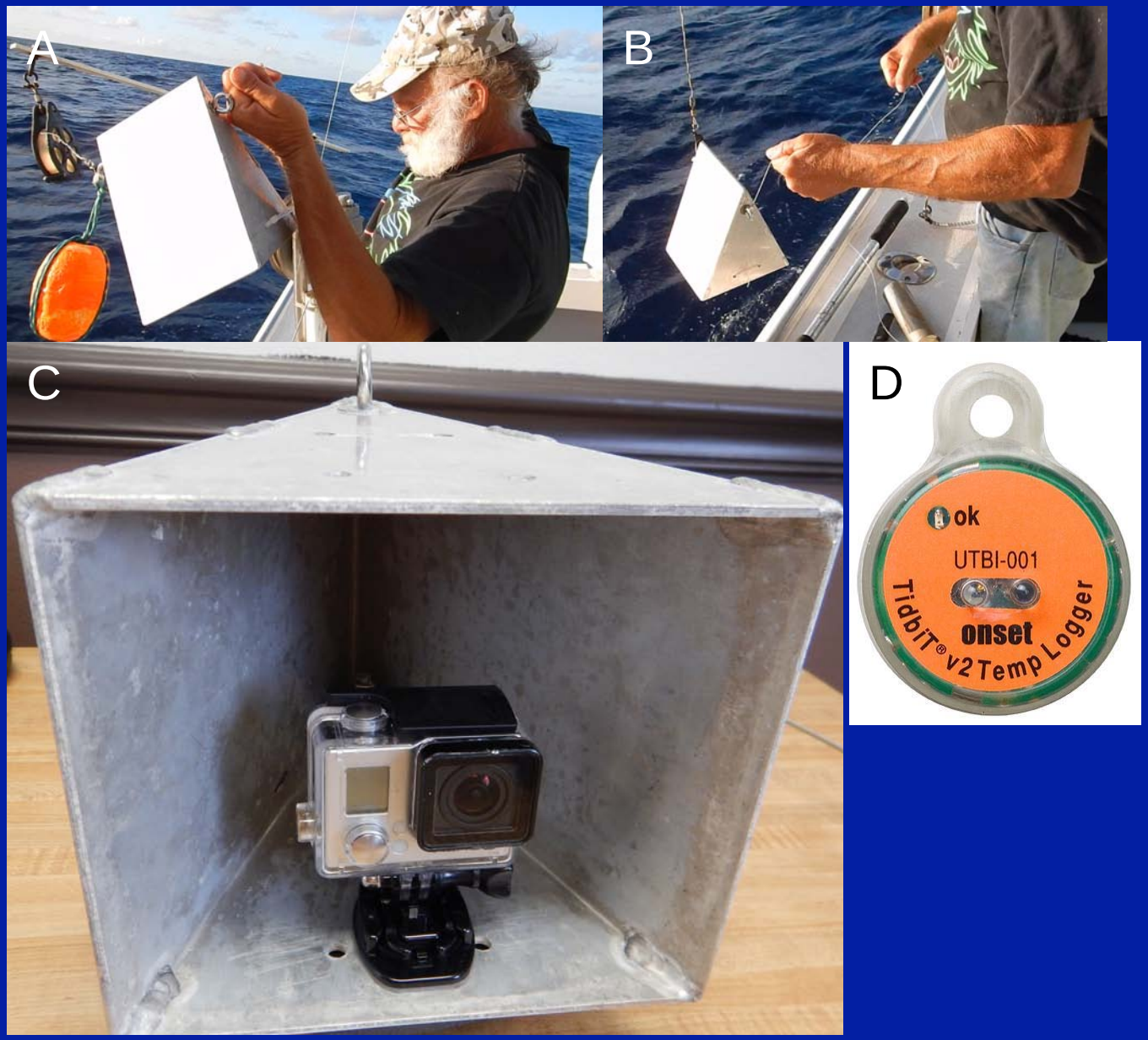
Standardized Methods

- Fisher interviews
- Site mapping
- Underwater video (drop cameras)
- Underwater visual assessments (SCUBA)
- Landings and catch per effort
- Biological sampling
- Histology
- Passive Acoustic monitoring

Site mapping

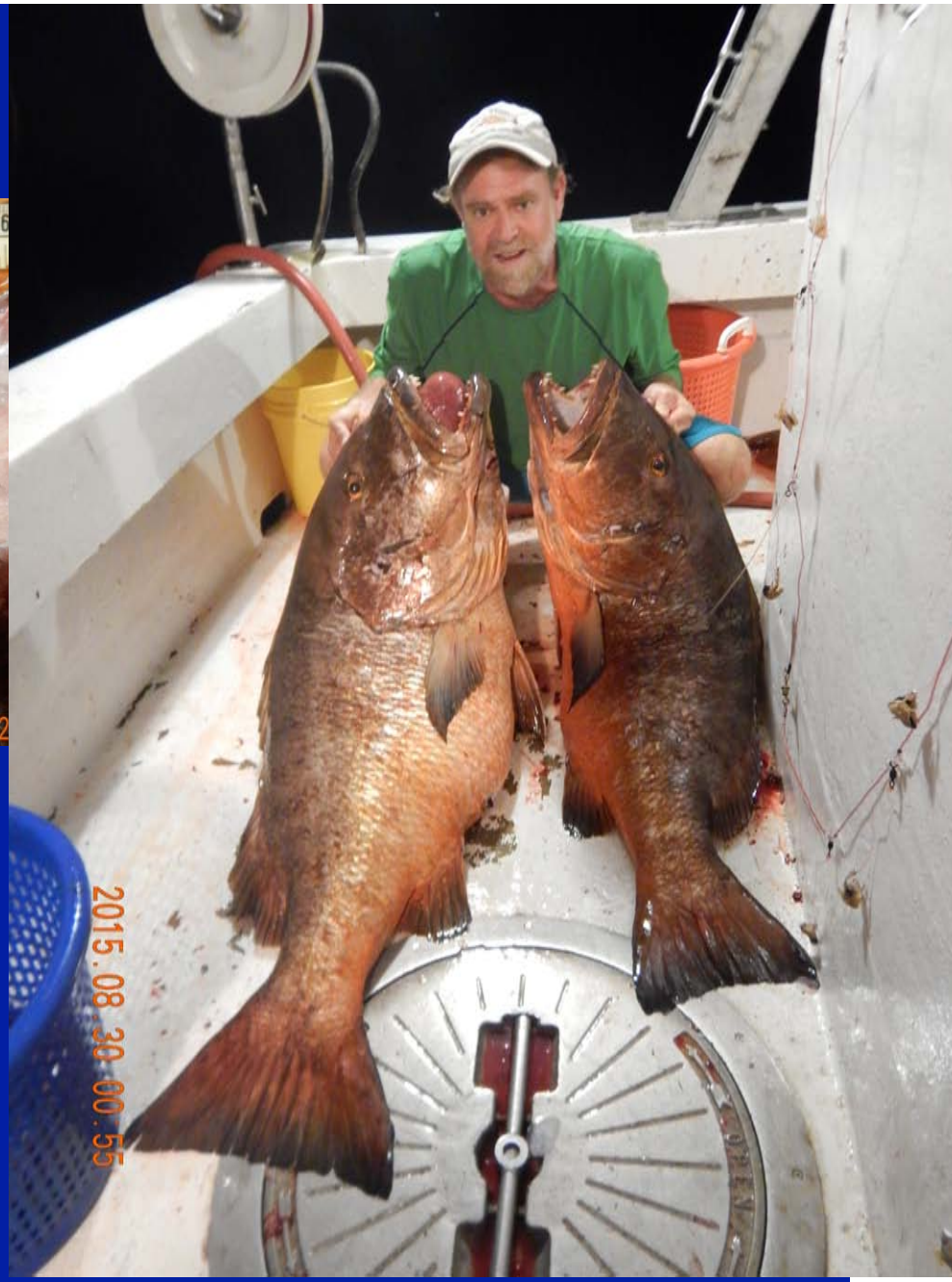


Drop Cameras



Landings and catch per effort

Biological Sampling



Length, weight, age, gonad weight, genetics,

Histology

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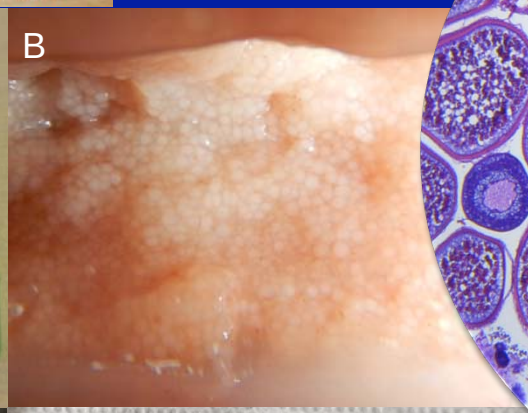
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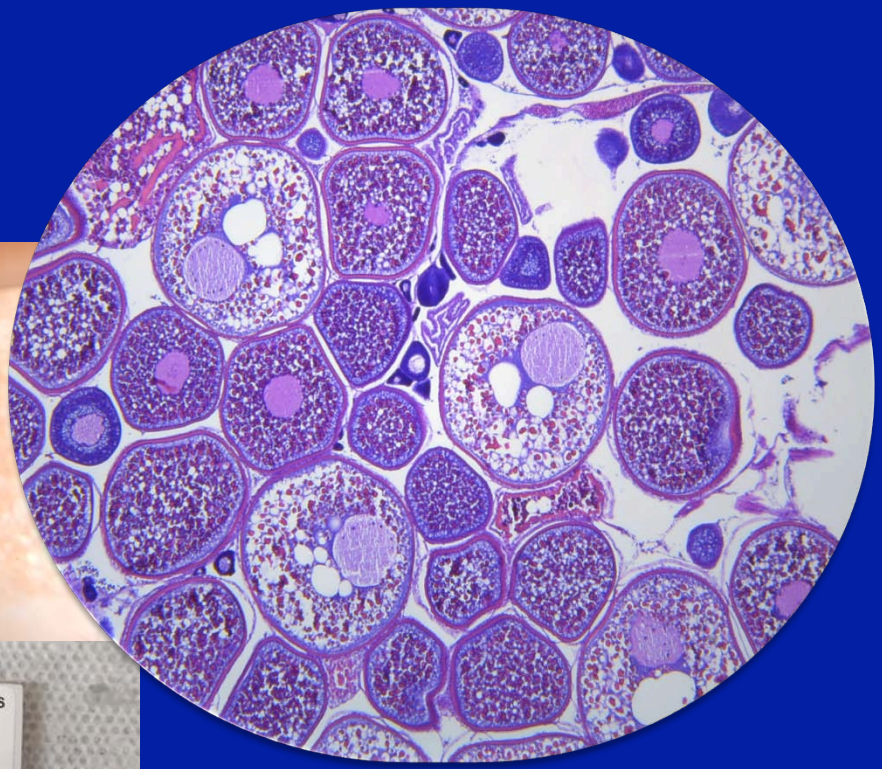

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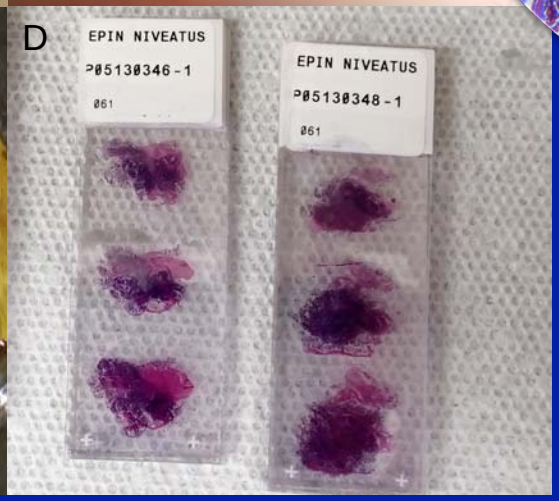
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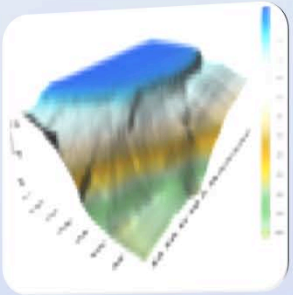
Database Structure

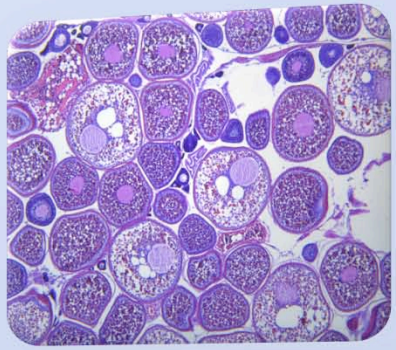
Fisher Interviews



Site map and sampling locations

Landings and catch per effort

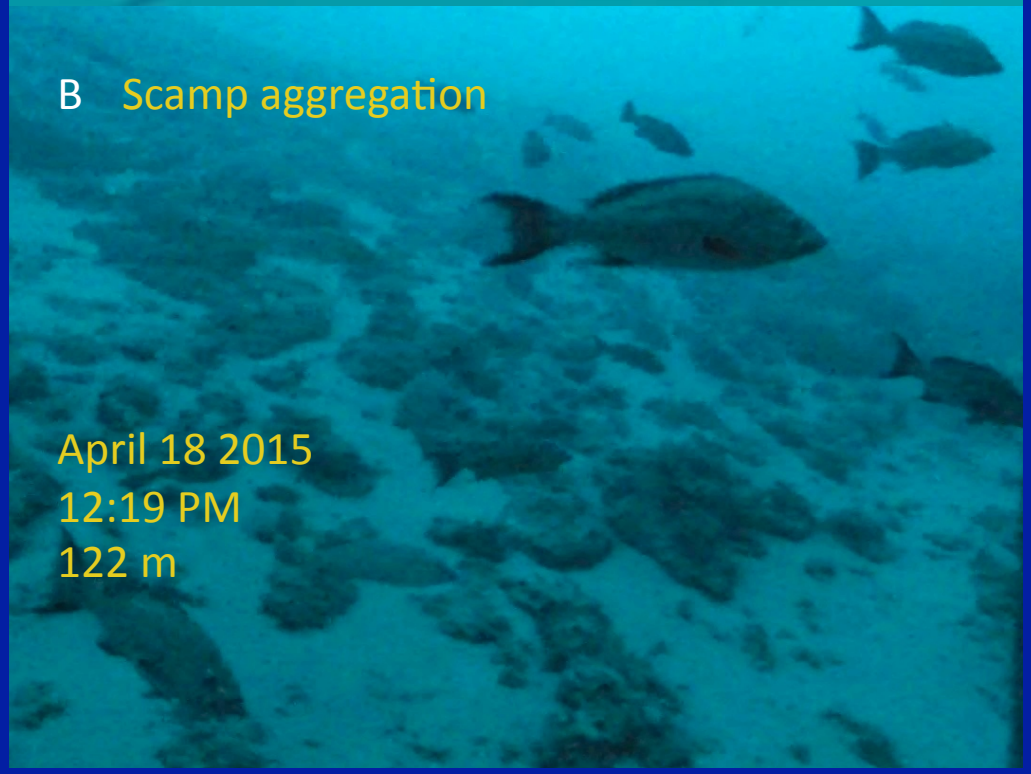
Video and visual counts



Histology data

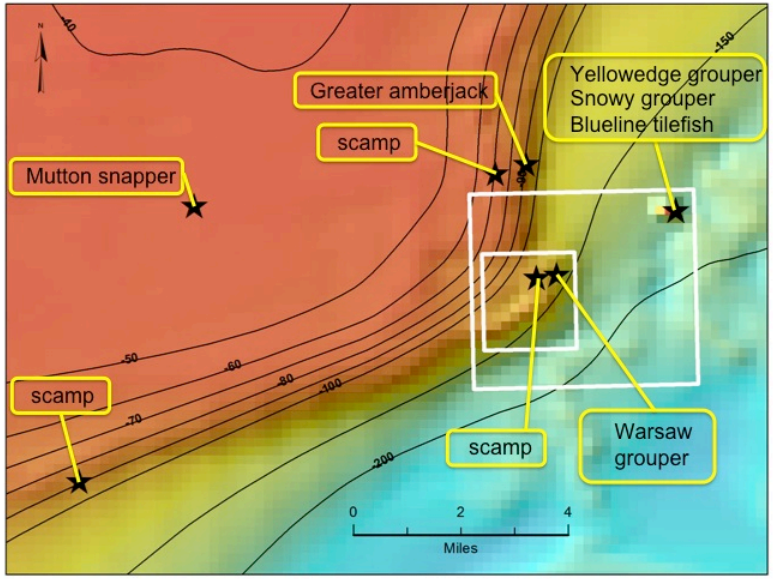
Data visualization and sharing

Spawning sites as coastal ocean observing stations



Georgetown Hole

Captain: Mark Marhefka
Vessel: F/V Amy Marie



System benefits

- Protect multi-species spawning aggregations
- Citizen involvement in data collection
- More and better data to manage data poor stocks
- Wider understanding and compliance
- Connectivity and exchange
- Eventual new data stream for stock assessments
- Assessments at the scale of species ranges
- Monitor range extensions from climate change

Status and Support for Approach

- Belize Spawning Aggregations Working Group
- COBI in Mexico
- South Atlantic Fisheries Management Council
- Guatemala
- Many fishermen

- NEXT STEPS
- Gulf of Mexico Fisheries Management Council
- Additional Caribbean partners

POLICYFORUM

28 March 2014 SCIENCE

CITIZEN SCIENCE

Next Steps for Citizen Science

Rick Bonney,[1]† Jennifer L. Shirk,[1] Tina B. Phillips,[1] Andrea Wiggins,[2,1] Heidi L. Ballard,[3] Abraham J. Miller-Rushing,[4]* Julia K. Parrish[5]

Strategic investments and coordination are needed for citizen science to reach its full potential.

CFMC/WECAFC/OSPESCA/CRFM[1] Working Group on Spawning Aggregations

Miami, USA, 29 -31 October 2013.

RECOMMEND . . . regional plan for the management and conservation of fish species that aggregate to spawn

RECOMMEND . . .member countries assess the timing, location and status, of all known transient multi-species spawning aggregations. . prioritize for monitoring, conservation and management

SOLICIT the support for, and the direct and immediate implementation by the countries in the Wider Caribbean. .

Vision: Cooperative Monitoring and Conservation Program for Western Central Atlantic Spawning Aggregations (CMCP WCASA)

To catalyze development of a network of fishermen, scientists, and managers who cooperatively monitor and protect multi-species spawning aggregations throughout the Western Central Atlantic, thus supporting regional recovery and resilience of the snapper grouper complex.