Cooperative Research and Monitoring Protocols for Fish Spawning Aggregations in the Wider Gulf of Mexico

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Acknowledgements

The protocols presented herein have been developed over the last 20 years and are based on the varied experiences of the authors. The techniques have been tested and used by so many scientists, students and fishermen in so many places (Belize, Mexico, Indonesia, Venezuela, Honduras, the Cayman Islands, Puerto Rico, The US Virgin Islands, the Bahamas, the Turks and Caicos Islands, Florida, and the U.S. Gulf of Mexico and U.S. South Atlantic Regions) that listing them would undoubtedly result in regrettable omissions of important contributors. Instead, we offer grateful thanks to all of the fishermen, students, managers, scientists and others that have participated on research expeditions and contributed in diverse ways to this work. Thanks to Susan Dufault for help with editing and formatting. This document is a result of research funded by the National Oceanic and Atmospheric Administration's RESTORE Act Science Program under award NA15NOS4510230 to the University of Texas at Austin.

Purpose and Use of this Document

Spawning aggregations are vital nodes in the life history of many marine fish species occurring in a variety of habitats over large geographic areas and have been studied with various techniques. Although the importance of spawning aggregation sites has been recognized by fishermen and managers for decades, the utility of these sites for managing and monitoring fisheries resources has not been fully realized, due in large part to a lack of data from which to synthesize patterns and processes that are relevant for management. Aggregation sites occur in diverse habitats ranging from estuarine river mouths to deep rocky shelf edges. Aggregations are most often discovered and frequently visited by fishermen yet they are rarely effectively incorporated into research and monitoring programs. This document is intended to simplify and standardize cooperative field data collection at spawning aggregation sites for use in monitoring and application to management. Scientists and fishermen have successfully used these techniques in the U.S. South Atlantic, Belize, Honduras, Guatemala, and Mexico and they are appropriately packaged herein for use in the wider Gulf of Mexico.

The document is not intended as a comprehensive guide to the subject of spawning aggregation research or monitoring and does not contain information about data analysis and processing. This document provides a menu of protocols that can be used for cooperative research in the Gulf of Mexico by trained observers and fishermen and data sheets for standardized data collection.

Overview of Methods and their Use

This manual provides field methods to collect data for the prediction, verification, characterization and monitoring of spawning aggregations. The process is iterative, adaptive and ongoing. Field practitioners can use a variety of methods, depending on available resources and local conditions. Methods can be used alone or in combination for prediction, verification and characterization and can be used repeatedly over time for monitoring purposes. The methods and their intended uses are summarized in Table 1 and detailed below, with data sheets for each method provided in Appendix 1.

Prediction is needed to identify the time and location of sites if not known by researchers or fishers. Anecdotal accounts from fisher interviews (Protocol 1) are often a good starting point, along with the known spawning seasons for various species. Similarly, dockside sampling surveys (Protocol 2b) can be used to see if and when spawning fish are being landed in local markets. The general locations of spawning aggregations can be sketched (Protocol 3a) and sometimes predicted using satellite images, aerial photographs and bathymetric charts (Protocol 3b). Fishery managers and fish-marketing agents can provide export data and fishery landings and export data. Other information for prediction can be found in published scientific studies, reports, popular articles, and online.

Characterization involves developing maps and descriptions of various species spawning use in space and time. Site mapping is very valuable for site characterization (Protocol 3). Indirect

evidence of aggregations includes increased catch per effort during spawning time (Protocol 2a); increases in density of fish at the spawning site and courtship coloration and behavior (Protocols 4a,b,c). If fishing is occurring at the site, landings and catch per effort data can be collected in the field (Protocol 2a) and used for biological sampling (Protocol 2c). Additional underwater observations can be made with a variety of methods (Protocols 4a,b,c). The location of landings and underwater observations can be overlaid on bathymetric maps (Protocol 3b) to create accurate maps and clarify site characterizations.

Verification is provided only from direct evidence of spawning by observation or video of gamete release (Protocols 4a,b,c) or documentation of hydrated oocytes from females collected at the time and location of spawning (Protocol 2c).

Monitoring spawning aggregation sites must follow the needs of managers for information and can be done at regular intervals using various techniques, and according to the resources available. The underwater visual census technique using divers or remote camera systems (Protocol 4a) has been used most commonly in tropical waters for monitoring. Passive hydroacoustics (Protocol 5a) is promising for the near future, providing a kind of remote sensing. Other emerging techniques for research at aggregations include acoustic telemetry, whereby acoustic tags are implanted in fish that are caught and released from a spawning site and can be recorded with mobile or stationary receivers (Protocol 5b). This can provide an excellent indication of site fidelity and migration from spawning sites to home ranges. Similarly, advanced sonar technologies (Protocol 5c) can be used to monitor aggregations but these techniques are beyond the scope of this document that is centered on cooperative monitoring with fishermen.

Selecting Appropriate Monitoring Protocols

Every area is different so team leaders must select appropriate techniques for each situation, purpose and time. In order to help guide users to appropriate techniques, a summary of the various techniques is offered with their purpose, target users, and appropriate depths and water clarity (Table 1). Teams often use multiple techniques during each given field expedition. Summarizing each trip therefore can be made easier with the Sampling Trip Summary Report data sheet (Appendix 1).

Table 1: Protocols with their purpose, appropriate conditions, data sheets and target user. A key to the abbreviations is below the table.

Type of Method	Protocol #	Protocol Name	Purpose and expected outcome	Type of Use (P,V,C,M,R)	Depth (S,M,D)	Water clarity (L, M, H, VH)	Data Sheet	Target Users
Field Expedtion		Trip Summary	To provide a summary of the location, timing and equipment used on a CRMP trip.	V, M, C			Trip Summary Data Sheet	Trained data collector
Fisher interviews	1	Fisher interviews	To capture and quantify anecdotal information that can be used to predict the time and location of fish spawning aggregations.	P, V, C	S, M, D	L, M, H, VH	Anecdotal Observation Data Sheet	Trained data collector, fishermen
Fishery Dependent Methods	2a	Landings and catch per effort	To provide detailed site-specific landings and effort during CRMP sampling trips and to collect biological samples.	P, V, C, M	S, M, D	L, M, H, VH	Landings and Catch per Effort Data Sheet	Trained data collector, trained fishermen
	2b	Dockside sampling surveys	To document the size:frequency and gonad condition of fishes being processed at landing sites and thus illustrate spawning seasons.	P	S, M, D	L, M, H, VH	Citizen Science Dock Sampling Data Sheet	Trained fishermen
	2c	Biological sampling	To determine age, growth, and reproductive status from individual fish.	V, M, C	S, M, D	L, M, H, VH	Biological Sampling Data Sheet	Trained data collector, trained fishermen
Fishery Independent Methods	3a	Preliminary site mapping	To sketch the location of fish spawning aggregation sites in relation to known landmarks and bathymetry.	C	S, M, D	L, M, H, VH	Sketch map and Description	Fisherman or trained data collector
	3b	Adaptive bathymetric mapping	To create bathymetric maps with single beam sonar showing spawning areas by species.	V, C	S, M, D	M, H, VH	GIS Map	Trained data collectors, trained fishermen, and GIS operator
Underwater Visual Assessment	4a	Underwater visual census (UVC)	To verify and quantify the number and size composition of fishes in spawning aggregations; to document courtship and spawning behaviors.	V,C,M	S, M	H, VH	Underwater Visual Census	Trained data collector
	4b	Diver underwater video survey	To record courtship and spawning behavior and to verify abundance and size ranges collected via UVC.	V, C, M	S, M	M, H, VH	Video Camera Data Sheet	Trained data collector, fisherman, divers
	4c	Drop cameras	To record position and times and file names for drop camera videos.	V, C, M	M, D	M, H, VH	Video Camera Data Sheet	Trained data collector, fisherman, divers
Emerging Technologies	5a	Passive hydroacoustics	Quantitative assessment of species' timing and level of participation in spawning event; possible direct evidence of FSA	C, M, R	S, M	L, M, H, VH	To be developed	Trained researcher
	5b	Acoustic telemetry	To document spawning site utilization and site fidelity, residency time, migration routes and distances; possible indirect evidence of FSA	C, M, R	S, M	L, M, H, VH	To be developed	Trained researcher
	5c	Split-beam sonar mapping	To quantify fish density and biomass using sonar	C, M, R	M, D	M, H, VH	To be developed	Trained researcher

Key

Type of Use: **P**rediction, **V**erification, **C**haracterization, **M**onitoring, **R**esearch
Depth: **S**hallow (<10m), **M**edium (10 – 30m), **D**eep (>30m)
Water Clarity: **L**ow (<1m), **M**edium (1 – 5m), **H**igh (5-15m), **V**ery **H**igh (>15m)

Fisher Interviews

Protocol 1: Fisher Interviews

Purpose: To capture and quantify anecdotal information that can be used to predict the time and location of fish spawning aggregations.

Preparation: Be prepared for the interview by developing an understanding of the likely times, locations and species that the fisher is likely to be aware of. Bring visual aides that can facilitate the conversation. Be respectful of the fisher at all times. The interview process can be an important part of developing a partnership for future cooperative monitoring work.

Field Equipment Checklist

- ❒ Anecdotal Observation Data Sheets
- ❒ Nautical chart, satellite images and other maps showing bathymetry
- ❒ Field guide to local fish species
- ❒ Table of spawning times by species, season and lunar period
- ❒ Photos of gonad development stages
- ❒ Photos or videos of fish spawning behaviors
- ❒ Digital camera

Procedure:

- Identify fishermen amenable to being interviewed.
- Explain the reason for your inquiries.
- Listen closely and take notes.
- Use field guides as necessary to confirm species identity, gonad state, spawning coloration or spawning behaviors.
- Complete the Anecdotal Observation Data Sheet as appropriate: species, time and location of observations; spawning indicators observed; other evidence recorded; and ancillary physical information on currents, tides or seawater temperatures.
- Request photographs, videos to support the anecdotal information.
- Take photographs of any evidence provided.
- Ask detailed follow-up questions.
- Review the completed data sheet with the fisherman to ensure accuracy and completeness.

Post-trip Processing:

- Enter all the information collected into spreadsheet or database.
- Archive original data sheets.
- Backup hard copy and digital data to external hard drives.

Fishery Dependent Methods

Protocol 2a: Landings and Catch per Effort

Purpose: To provide a measurement of catch per unit of fishing effort in situations when an observer can accompany fishermen while they are fishing. This can provide data on catch rates as well as site/time specific samples for biological sampling.

Preparation: This method requires that an observer or data collector be present while fishing is occurring. Optimally, this method should be combined with biological sampling, whereby a team can meet the fishing vessel at the dock for biological sampling of selected and tagged fish.

Field Equipment Checklist

- ❒ Sampling Trip Summary Report, Catch per Effort Data Sheet, several copies of each, printed on waterproof paper
- ❒ Waterproof pencils, pens or markers
- ❒ Plastic clipboards
- ❒ Laminated print copies of protocols
- ❒ Digital camera, battery charger, spare fully charged battery, spare memory card, USB cable, lens cleaning cloth and lens cleaner
- ❒ Handheld GPS, battery charger, spare fully charged battery, USB cable
- ❒ Labeled fish tags, or zip ties
- ❒ Field guide

Procedure:

- Complete a new Catch per Effort Data Sheet for each fishing site
- Record the location with a handheld GPS, noting the waypoint number (can later add the latitude and longitude to the sheet).
- Record the physical conditions of water and air temperature, wind and current speed and direction, and water depth.
- Record the type of gear, number of hooks and lines and the start and end time for each fishing site.
- Record the number of fish of each species caught and discarded, as well as an estimate of the total weight of both discarded and retained fish by species.
- Mark or tag (using a spaghetti-type dart tag, e.g. Floy tag, or labeled plastic wire tie) the subset of fish of interest for biological sampling.
- Marked fish will remain un-gutted until biological sampling can be done on shore.

Post-Trip Data Processing:

- Enter all data into appropriate spreadsheet or database; archive originals and create backups.
- Complete a Sampling Trip Summary Report.

Protocol 2b: Dockside Sampling

Purpose: To document the size distribution and visual observations of gonad condition of fishes being processed at landing sites or markets. Regular dockside sampling can illustrate spawning seasons and times for many species.

Preparation: Pre-arrange dockside sampling efforts with fishermen or market operators. Dockside sampling is labor intensive and best accomplished with at least 2 data collectors. Be as unobtrusive as possible and try not to interrupt the workflow.

Field Equipment Checklist

- ❒ Citizen Science Dock Sampling Data Sheet, several copies, printed on waterproof paper
- ❒ Waterproof pencils, pens or markers
- ❒ Plastic clipboard
- ❒ Sharp knife and serrated blade knife
- ❒ Scalpel, replacement blades
- ❒ Digital scale
- ❒ Fish measuring board
- ❒ Digital camera, battery charger, spare fully charged battery, spare memory card, lens cleaning cloth and lens cleaner

Procedure:

- Meet fishers at pre-arranged time and location.
- Complete all columns of the Dock Sampling Data Sheet
- Record measurements of length (TL and FL) and weight of each fish captured.
- Record visual observations of gonad condition.
- Take occasional photos of gonads as backup documentation of visual assessments.

Post-Trip Data Processing:

- Enter all data into appropriate spreadsheet or database; archive originals and create backups.

Protocol 2c: Biological Sampling

Purpose: To determine age, growth and reproductive status from biological samples. This method is most valuable when the sample time and location are known and documented, i.e. via the Catch per Effort Data Sheet.

Preparation:

Camera settings for photographing gonads

- Set the camera's internal time and date for the sampling location
- Clean memory card and ensure batteries are fully charged
- Set camera on macro mode and maximum resolution
- Clean lens with moist lens paper or soft cloth

Sample collection preparation

- Pre-label histology cassettes for histology samples.
- Pre-label coin envelope pairs.
- Prepare sample jar with 10% buffered formalin.

Equipment Checklist

- ❒ Biological Sampling Data Sheet, several copies, printed on waterproof paper
- ❒ Waterproof pencils, pens or markers
- ❒ Plastic clipboard
- ❒ Sharp knife and serrated blade knife
- ❒ Scalpel, replacement blades
- ❒ Chisels of various sizes
- ❒ Forceps of various sizes
- ❒ Digital scales for both whole fish and for gonads
- ❒ Fish measuring board
- ❒ Digital camera, battery charger, spare fully charged battery, spare memory card, lens cleaning cloth and lens cleaner
- ❒ Pre-labeled histology cassettes
- ❒ Pre-labeled coin envelopes for otoliths
- ❒ Sample jar containing 10% buffered formalin

Procedures:

Prior to dissection

- Record the tag number, waypoint or capture location, and species of each fish.
- Measure and record fish total length (TL) and fork length (FL).
- Measure and record the total weight of each fish, noting if gutted or whole.

Gonad sampling for histology

- Open the gut cavity with a shallow cut from the pelvic fins to the anus.
- Open cavity to expose internal organs and remove gonads.
- Weigh the gonads to the nearest gram
- Visually assess sex and the development stage

- Make an incision in the gonad about two thirds of the way from the distal end
- Remove a small piece of tissue and place into a pre-labeled cassette; the sample should be no thicker than 3 mm and no larger than a US dime; do not stuff the cassette with tissue; small pieces are better than large ones for sample preparation
- Close the cassette and deposit it into a sample jar containing 10% buffered formalin

Gonad photography

- Take photographs in good natural light
- Photograph the entire gonads along with the entire fish for fish ID and sex verification
- Record the number of the photo on the Biological Sampling Data Sheet
- Take a close-up (macro) photo of the gonad
- Ensure the photos are in sharp focus; record the number of the best macro photograph on the Biological Sampling Data Sheet

Sagittal otolith sampling

- There are many ways to remove otoliths. Choose a method depending on the species and the fate of the fish (i.e. to be marketed as filet or whole). The method below is good for snapper species that will be marketed whole.
- Cut, bend and fold the operculum to open wide access to the gills.
- Cut away the gill arches at their anterior attachment point.
- Use a chisel to scrape away tissue and reveal the otolith capsule.
- Open the capsule with a chisel to provide access to the sagittal otoliths.
- Remove the otoliths with a long forceps.
- Wipe the otolith clean of tissue, rinse with fresh water, and pat dry.
- Place otoliths in pre-labeled envelopes.

Post-trip Sample and Data Processing:

- Enter all data into an appropriate spreadsheet; archive original data sheets; create digital backup copies and store to an external hard drive.
- Download all photographs and archive them as appropriate in your database.
- Transfer the jar containing gonad cassettes in formalin, along with ancillary data, to an appropriate analytical lab for histological analysis.
- Alternately, cassettes can be transferred to a sample bottle containing 70% ethyl alcohol after 48 hours in formalin for mailing to a lab.
- Transfer otolith to an appropriate analytical lab for aging, along with ancillary data.

Fishery Independent Methods

Protocol 3a: Preliminary Site Mapping

Purpose: To create iterative sketch maps of the location of fish spawning aggregation sites in relation to known landmarks, bathymetry, and benthic habitat characteristics.

Preparation: Prepare sketches of the aggregation area based on best available data and information and update or re-draw the sketch as additional details become available. Additionally, create base maps of the area around the spawning aggregation site using Geographic Information System (GIS) software (e.g. ESRI's ArcMap) and including nautical charts, available bathymetry data, and satellite imagery. Maps must be geographically referenced, and include accurate scales and depths. The GIS map can inform the sketch map and vice versa. Each map should be appended with a site description that provides geographic context and detailed descriptions of the benthic biological cover and physical attributes of the site as observed using SCUBA.

Field Equipment Checklist

- ❒ Boat and engine with fuel
- ❒ Handheld GPS, battery charger, spare fully charged battery, USB cable
- ❒ VHF radio, flares, life vests, anchor and long rope
- ❒ Full SCUBA gear for 2 divers: tanks, mask, fins, snorkel, BC, regulator, weights and belts, watch, depth and pressure gauges and dive compass
- ❒ Dive computers are highly recommended for every diver
- ❒ Dive safety equipment, including dive flag, sausages, whistles, and flashlight or strobe
- ❒ DAN Oxygen Kit
- ❒ First Aid Kit
- ❒ Underwater compass
- ❒ Underwater slates and pencils, pens or markers
- ❒ Sketch maps and GIS maps with GPS coordinates and graticules, laminated if possible
- ❒ Underwater measuring tape or marked rope (50-100 m)
- ❒ Small floats

Procedure for underwater mapping with divers and a boat:

- Divers swim the perimeter of the aggregation, either towing a floating buoy with a GPS, or followed closely by a boat with a GPS.
- Divers mark the aggregation with either a weighted line on the bottom or with temporary anchors on the bottom with small floating buoys.
- Divers release floats to the surface from major points along the aggregation boundary.
- GPS coordinates for each of these positions are taken from the boat.

Post-Trip Data Processing:

- Update sketch maps and GIS maps to show the location of the aggregation and to calculate area.

Protocol 3b: Adaptive Bathymetric Survey (ABS)

Purpose: To create bathymetric maps of aggregation sites using single beam sonar.

Preparation: Plan field surveys using sketch and GIS maps. Surveys should be designed to capture a high density of points in areas of rapidly changing slope and low density elsewhere. Survey grids can be constructed and uploaded into the integrated GPS/Depth sounder or handheld GPS for navigational aid. Additional survey data can be gathered for areas that require increased detail. Prior training or experience with field mapping is required.

Field Equipment Checklist

- ❒ Boat and engine with fuel
- ❒ 12 volt car battery
- ❒ Safety gear including VHF radio, flares, life vests, first aid kit, anchor and long rope
- ❒ Lowrance Map Sounder[1] with internal GPS and recording capability (e.g. HDS 7)
- ❒ Standard Duel Frequency Transducer or Airmar TM 260 transducer[2]
- ❒ Removable SD card with at least 16GB storage capacity
- ❒ Handheld GPS, battery charger, spare fully charged battery, USB cable
- ❒ Sketch maps with survey plan

Procedure:

- Install the Lowrance GPS map sounder on the vessel. These units have an internal GPS and a transducer that can be mounted temporarily, on nearly any vessel.
- Record (log) points (latitude, longitude, and bottom depth) along a grid of track lines that completely covers of the aggregation and its immediate surroundings travelling at speeds of between 3 and 20 knots.
- Track lines should be between 20 and 100 m apart, with higher density in areas where the slope changes rapidly in the aggregation area
- Use the 200 kHz setting whenever possible. Use the 50 kHz setting when the depths are beyond 500 m or when 200 kHz continues to lose contact with the bottom.

Post-trip Processing for ABS:

- Save the data to a removable SD card and then download to a computer for processing.
- Data should be transformed to .csv file format, parsed, and loaded into a spreadsheet.

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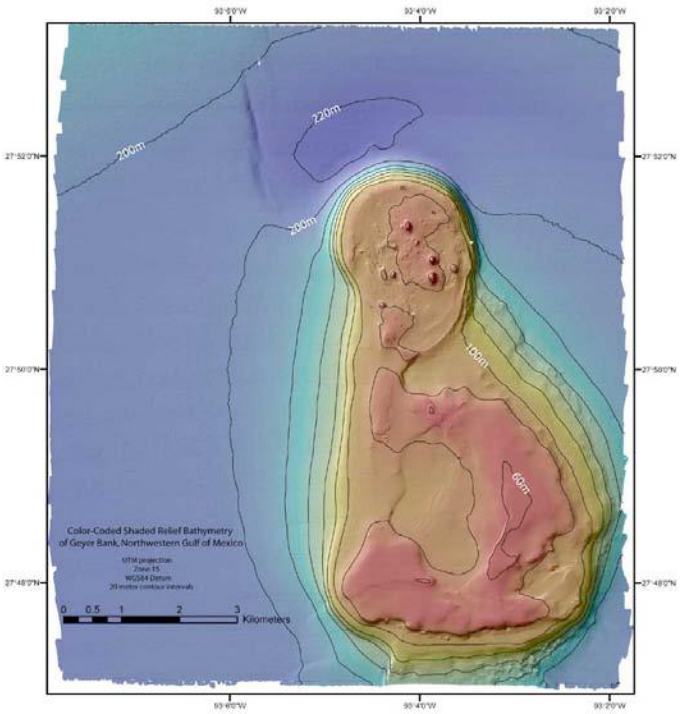
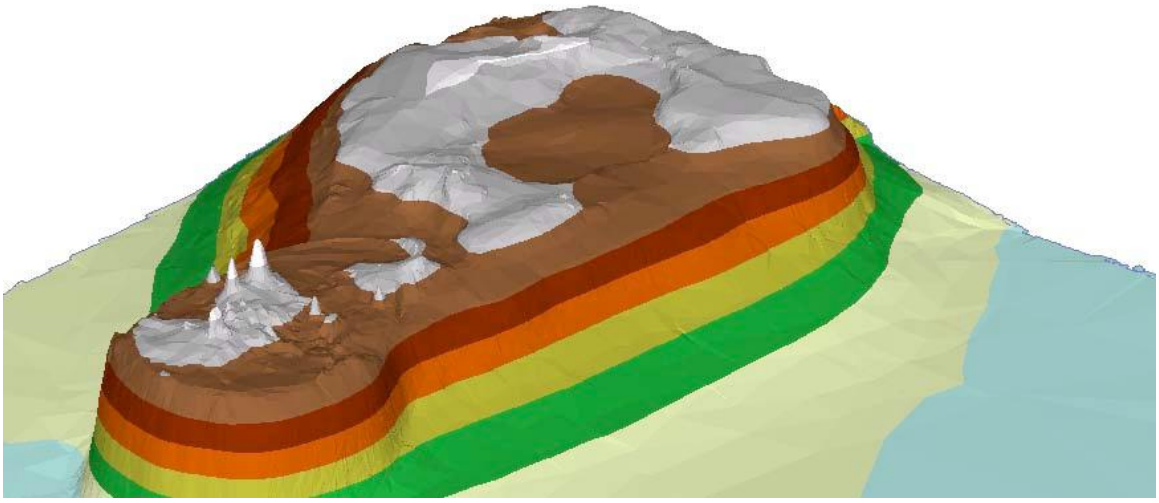
[1] While other brands can be used it is important that the data will be collected in a format that can be transferable to standard UTM coordinates. Lowrance has made these conversions readily available while many other brands' (e.g. Garmin) data are not easily de-coded.

[2] We recommend an Airmar TM 260 transducer. It can be mounted permanently or placed in the shallow bilge area in the stern of most any single-hulled skiff. It is far more powerful and more accurate than the transducer that comes with standard map sounders. It has an array of seven dedicated 50 kHz elements that produce a beam with a 19° cone angle and a single, large diameter 200 kHz element that produces a beam with a 6° cone angle and that can penetrate to about 1,000 m.

- Filter the data to remove invalid points.
- Remove points with depths shallower than the minimum or deeper than the maximum depth recorded during the survey.
- Upload the data into ArcGIS and use Inverse Distance Weighted (IDW) interpolation to produce a digital elevation model (i.e. a bathymetric map) and overlay the map over existing data in the GIS.
- Collect additional bathymetric data as needed to fill gaps and to increase accuracy. New data can be incorporated with the existing data and re-interpolated to create a new bathymetric surface.





Underwater Visual Assessments

Protocol 4a: Diver Underwater Visual Census

Purposes: To quantify the number and size composition of selected aggregating fishes (by species) in spawning aggregations less than 40m depth; to verify the timing and location of the aggregation; to document any courtship and spawning behaviors; and to assess changing patterns of site usage for monitoring purposes.

Preparation: GIS maps and sketch maps showing the location of the aggregation site should be reviewed carefully prior to any underwater visual census. For subsequent site monitoring trips, details acquired during verification and previous monitoring trips should be reviewed and plotted on updated sketches and maps. Prior training in underwater visual census is required for all data collectors.

Each site team should design a census plan to ensure that the entire area is surveyed systematically, and without double counting or missing fish. On a straight section along a reef dropoff, a set of divers swimming parallel to the wall edge, each counting and examining a swath (belt transect) may work well. When an aggregation is nestled in a spur and groove system, divers can be deployed to survey different spurs simultaneously. If divers are working as teams to count the fish, the boundaries or widths of the area to be covered by each diver should be established before the dive to prevent double counts. It is often best to quantify aggregations in the late afternoon. If possible, another dive should be made 30-60 minutes before sunset to observe courtship and spawning behaviors as they are most common at this time. The timing and number of dives is ultimately left to the discretion of the team leader and boat captain.

Small floats or colored rocks can be anchored and left on the bottom to indicate aggregation boundaries and the start and stop points of previous and future dives. For groupers, this technique works well, since many species maintain fidelity to bottom areas during aggregation periods. For snappers and jacks, which tend to roam in their aggregations, several dives will be needed to verify the most common area of the aggregation and to enumerate the fishes within.

Members of the dive team should prepare underwater slates before the dive. Each team member should be assigned specific tasks for each dive, for example:

- Estimate size ranges (cm) and numbers for a single species or all species
- Take physical measurements, such as depth (m), temperature, current direction and speed
- Take still photos, videos, and observe courtship and coloration changes

Field Equipment Checklist

❒ Boat and engine (or preferably two) with fuel
❒ Depth sounder, GPS, VHF radio, flares, life vests, anchor and long rope
❒ Full SCUBA gear for 4 divers: tanks, mask, fins, snorkel, BC, regulator, weights and belts, watch, depth and pressure gauges and dive compass
❒ Dive computers are highly recommended for every diver
❒ Dive safety equipment, including dive flag, sausages, whistles, and flashlight or strobe

- ❒ DAN Oxygen Kit
- ❒ First Aid Kit
- ❒ GoPro camera, battery charger, spare fully charged battery, spare memory card, USB cable, lens cleaning cloth and lens cleaner
- ❒ Handheld GPS, battery charger, spare fully charged battery, USB cable
- ❒ Underwater slates and pencils, pens or markers
- ❒ Laminated copies of protocol
- ❒ Sketch maps and GIS maps with GPS coordinates and graticules, laminated if possible
- ❒ Underwater measuring tape or marked rope (50-100 m)
- ❒ Floats

Procedure:

Ensure Dive Safety

- Each team should have a pre-arranged emergency evacuation plan that includes the location and available modes of transport to the nearest recompression chamber.
- All teams should be equipped with an oxygen kit.
- In the event of accident, oxygen treatment should begin immediately.
- All members should carry dive insurance. Divers Alert Network (DAN) is very popular.
- At least one member of each team should be trained in First Aid and cardio-pulmonary resuscitation (CPR).
- The dive team leader should review the safety protocol with the dive team prior to each dive, and ensure that all team members understand their roles and the procedures.

Record environmental conditions at the site

- Measure and record air temperature, wind speed and direction. The Kestral 2500 Weather Meter is an excellent unit for this purpose.
- Record weather conditions.
- Measure and record surface water temperature and underwater temperature at the depth of the aggregations. Temperature can be monitored continuously using an *in-situ* temperature logger such as the HOBO TidbiT® V2 or other recording thermistor.
- Estimate or measure the speed and direction of surface currents. Experienced fishermen can accurately estimate current speed and direction.
- To measure surface currents, place a current drogue in the water at the spawning site and let it drift for 5 minutes to overcome inertia.
- Record the initial location using the average function on the GPS.
- At regular intervals of about 30 minutes, record the location of the drogue and the time.
- Use the GPS distance and bearing functions to plot current speed and direction.

Underwater Visual Census

- Conduct UVC dives at the spawning site to estimate the numbers and sizes of all aggregating fish. Record the start and stop time and location of each dive.
- One diver should collect video data (see following section).
- Record courtship and spawning behaviors observed.

Data Processing for Underwater Visual Census:

- As soon as the dive is complete, divers should work together to compile data collected during the dive. Use video footage to help quantify the visual estimates.
- Transfer all the measurements and diagrams from underwater slates to paper datasheets.
- Enter the data from the datasheets into a spreadsheet and create backups.

Protocol 4b: Underwater Video Survey

Purpose: To record time-stamped observations of the succession of events up to and including spawning, i.e. color changes, interactions between individuals, and courtship and spawning behaviors. To help calibrate UVC abundance estimates and size ranges by species.

Preparation:

- Select an appropriate camera system and housing (e.g. GoPro).
- Verify that the internal time and date are accurate for the sampling location.
- Ensure that the mini-SD card (16 GB or greater) is clean.
- Check that the battery has been recently and fully charged.
- Set camera to video mode
- Set resolution and frame rate to 1080i and 60 fps, respectively (or higher if available).
- Clean the camera lens and housing port with lens cleaner and cloth.

Field Equipment Checklist:

❒ Underwater video camera, battery charger, spare fully charged battery, spare memory card, USB cable, lens cleaning cloth and lens cleaner

Procedure:

- In association with a UVC dive team, film aspects of the spawning aggregation.
- While filming, hold the camera as still as possible. Make only slow, steady movements of the camera focus.

Post-trip Processing:

- As soon as the dive is complete, all divers should work together as a team to record all of the information from the dive on the UVC data sheet.
- Use the video to support UVC observations and notes.
- Any unusual events or observations should be discussed and recorded in detail
- Download videos from the camera, organize and archive videos and backup copies.
- Video naming convention: YYYY_MM_DD_Last name of boat captain_filename e.g. 2016_06_03_Rios_0004
- Clean and dry the camera and erase the memory card in preparation for the next dive.

Protocol 4c: Drop Camera Deployment

Purpose: To quantify the number and size composition of all fish (by species) in an aggregation, without the use of SCUBA; verify the timing and location of the aggregation; document any courtship and spawning behaviors; and accurately describe, monitor and map the biological and physical characteristics of the spawning site. Repeated measures over time can be used to assess seasonal or annual patterns of site usage for verification and monitoring purposes.

Two options are provided to deploy underwater video cameras from a vessel: the V-Go Swim setup and the Submersible Rotating Video (SRV) system. The V-Go Swim can be easily and rapidly deployed for site verification purposes. The SRV system offers a 360° vantage and replicate counts as it rotates every 2 minutes. While more expensive, the SRV may be more appropriate for monitoring.

Preparation:

- Select the appropriate housing for deployment (SRV or V-Go Swim).
- Prepare the GoPro video camera following instructions for Protocol 4b (above).
- Use safety tethers (e.g. plastic zip ties) around the camera connection to the housing.
- Attach a temperature logger (e.g. TidbiT®v2, UTBI-001) to the housing with a zip tie.

Field Equipment Checklist:

- ❒ Video Log data sheet, several copies, printed on waterproof paper
- ❒ Waterproof pencils, pens or markers
- ❒ Plastic clipboards
- ❒ GoPro camera, battery charger, spare fully charged battery, spare memory card, USB cable, lens cleaning cloth and lens cleaner
- ❒ V-Go or SRV housing
- ❒ Temperature loggers, base station, and USB cable
- ❒ Handheld GPS, battery charger, spare fully charged battery, USB cable
- ❒ Nautical chart with locations of aggregation sites identified
- ❒ Floats, 12 lbs buoyancy
- ❒ Weights, 20-25 lbs, with retrieval line attached

Procedure:

V-Go or SRV Camera Deployment

- Attach 20-25 lbs. anchor weight, ~1 foot below the camera housing.
- Attach an 8” floating buoy (~12 lb. lift) to the top of the housing.
- Connect a retrieve line to the anchor weight.
- Attach the camera housing to an appropriate deployment line.

- Take a GPS point immediately before camera deployment.
- Start camera and note time and GPS position on the data sheet.
- Lower the unit carefully over the side of the vessel and drop steadily to the bottom.
- Let the unit collect data on the bottom for 10 minutes and then slowly retrieve.
- While the unit is on the bottom, try to keep just enough slack in the retrieve line so that it does not pull up on the anchor weight.
- Turn the camera off as soon as it is back on deck and record end time.
- Record the duration of deployment (surface to surface), depth, camera type and video file name

Post-trip Processing:

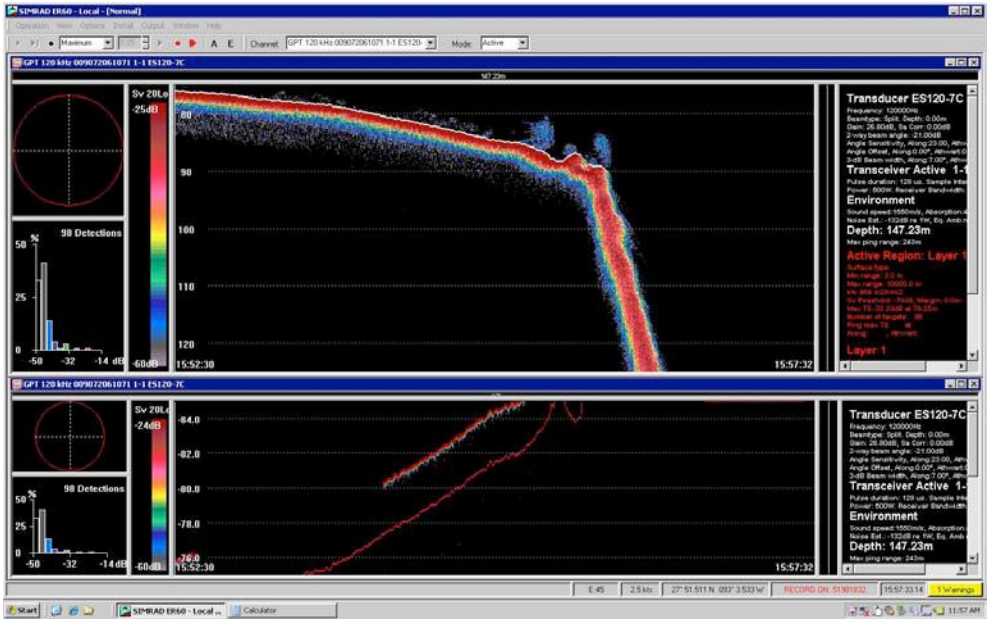
- Download videos and name them with the naming convention in Protocol 4b.
- Organize and archive videos and save backup copies to external hard drives.
- When complete, erase the memory card and clean the camera in preparation for the next monitoring trip.
- Download data from the temperature logger, transfer it to the spreadsheet or database and create a backup copy of the offloaded data.
- Examine the videos on a computer screen for enumeration. Record the MaxN, that is, the maximum number of fish in a single frame during the viewing interval for each species of interest, as a relative index of abundance. Make note of any courtship or spawning behaviors.

Emerging Technologies

5a: Passive Acoustic Monitoring
Spawning fishes emit species-specific courtship and spawning sounds. Using underwater hydrophones (e.g. DSG-ST Ocean Acoustic Recorder) recordings of these sounds have been used to document and monitor the precise timing and peak intensity of spawning for various species. The advantage of these underwater hydrophones is that they serve as remote sensing devices, monitoring spawning areas constantly throughout the year and requiring only a bi-annual data download and battery change. Passive acoustic receivers could form a key component of long-term monitoring at spawning aggregation sites.

5b: Acoustic Telemetry
These systems rely on a combination of sonic tags that are implanted in the fish that are detected by moored acoustic receivers. The most commonly used arrays use Vemco VR2 receivers (http://vemco.com/products/vr2w-69khz/). Each tag emits unique acoustic pings at specific intervals that serve as a fingerprint for each tag. The VR2 receivers record each ping (along with time and date) when the tags are within range. These techniques have been used to illustrate spawning site fidelity and use of spawning sites in various areas. In addition, these arrays can become part of the Ocean Tracking Network (OTN; http://members.oceantrack.org/) in order to share data on fish movement.

5c: Split-beam Sonar Mapping
Split-beam sonar systems (e.g. Simrad EK 60) allow accurate mapping of fish densities in space and time and have been used to quantify fish biomass at spawning sites in various areas. Data from these acoustic surveys can be processed to illustrate fish densities and biomass in relation to bottom features (see fish school shown at shelf edge, below). Repeated surveys could be valuable for monitoring spawning sites in the future. The methods and equipment are beyond the scope of this document.



Appendix 1: Data sheets

This appendix contains a data dictionary and the data sheets necessary for trained citizen scientists (including fishermen and observers) to collect and enter data into a standardized database.

List of Data Sheets and Their Purpose

Data Sheet Name	Target Users	General Purpose
Summary Trip Report	Trained data collector, trained fishermen	To provide a summary of the location, timing and equipment and personnel on a CRMP research/fishing trip
Catch per Effort Data Sheet	Trained data collector, trained fishermen	To provide detailed landings and effort for single sites during a CRMP research/fishing trip
Drop Camera Data Sheet	Trained data collector, trained fishermen	To record position and times and file names for drop camera videos collected on a CRMP trip
Biological Sampling Data Sheet	Trained data collector	To provide biological information for individual fish collected at all sites during a CRMP research/fishing trip
Anecdotal Observation Data Sheet	Trained data collector, fisherman, divers	To report spawning aggregation data gathered from fishermen or fishers during times/places unrelated to CRMP sampling
Citizen Science Dock Sampling Data Sheet	Trained data collector, trained fishermen	To provide biological information for individual fish caught during fishing trips unrelated to the CRMP
Underwater Visual Census	Trained data collector, trained divers, trained fishermen	To provide quantitative visual estimates of species size distribution and abundance and signs of courtship or spawning behavior
Video Log Data Sheet	Trained data collector, trained fishermen	To keep track of meta data for drop camera videos

Data Dictionary

Variable	Description
Date Collected	Date fish caught (enter as DD/MM/YY). Use value from and the Catch per Effort Data Sheet to report date collected on Biological Sampling Data Sheet.
Fish Gutted or Whole	Note if fish was gutted or whole (entry should be G or W) when measured at dock after trip.
Fish Weight	Record weight of whole fish (kg) measured at dock after trip.
Fish and Gonad Photo # and Camera	Take photo of whole fish with gonad removed and displayed on the fish's side. Record the photograph number and on which camera it was taken.
Gonad Collected	Note if gonad was collected for histology (entry should be Y or N).
Gonad Macro Photo # and Camera	Take macro photo of gonad and record the photograph number and on which camera it was taken.
Gonad State: Visual	Note development state of gonad as assessed visually. Options are immature (I), early development (ED), late development (LD), ripe and running (RR), spent (S) or resting (R).
Gonad Weight	Record weight of the gonad in grams. Note unit if not measured in grams.
Length: Fork	Record fork length of the fish and units (measured at dock after trip). Fork length (cm) is measured from the tip of the jaw or snout with closed mouth to the center of the fork in the tail.
Length: Total	Record total length of the fish and units (measured at dock after trip). Total length (cm) is measured from the most forward point of the head, with the mouth closed, to the farthest tip of the tail with the tail compressed or squeezed, while the fish is lying on its side.
Otolith Collected	Note if the otoliths were collected (entry should be Y or N). Otoliths should washed with water, dried and placed into appropriately labeled envelopes.
Sex	Note sex of the fish (entry should be M or F).
Species	Enter species of fish as common name (e.g. sheepshead) or Latin name (e.g. *Archosargus probatocephalus*) or by SCDNR MARMAP species code (if known).
Tag ID	Number on tag from fish tagged on board, for large fish only. Use value from Catch per Effort Data Sheet to report Tag ID on Biological Sampling Data Sheet.
Waypoint #	Waypoint number of location where fish was caught as recorded on handheld or vessel GPS. Use value from Landings and Catch per Effort Data Sheet to report waypoint number on Biological Sampling Data Sheet.

Sampling Trip Summary Report

Cooperative Research and Monitoring Protocol

Project Name _____

Vessel Owner/Captain Name _____

Vessel Name _____

Trip Area _____

Trip Objective _____

Port of Departure (city/state/nation)_____

Trip Start Date (MM/DD/YYYY) _____

Trip End Date (MM/DD/YYYY) _____

Participants on board _____

Payment agreement _____

Fishing gears Bandit reel long line handline rod/reel trap spear

Research techniques SCUBA Video drop camera Video rotator rig temperature logger

Passive acoustic hydrophone Active acoustic hydrophone

Single beam mapping multi-beam mapping split-beam mapping

Biological sampling ID tagging Acoustic tagging

Other_____

Comments

Data Collector Name _____

Data Collector Signature _____

Catch and Effort Data Sheet

Captain:	Vessel:	Area/Site:	Page: of
Data collector:	Wind Speed:	Wind Dir (N):	Date:
Lattitude:	Airtemp:	Current Dir:	Wpt/Site #:
Longitude:	SST:	Current Speed:	Start Time (24):
Total # Anglers:	Total # Hooks:	Depth:	End Time (24):

Catch Data

Species	# Kept	# Discarded	Total weight kept (kg)	Total weight of discards (kg)

Tagged Fish					Tagged Fish				
Tag #	Species	Length (TL)	Weight (kg)	kept y/n	Tag #	Species	Length (TL)	Weight (kg)	kept y/n

Unique ID:_____

Biological Sampling Data Sheet
Cooperative Research and Monitoring Protocol

Project Name_____ Vessel Name_____ Data Collector Name_____ Page _____ of ____

Tag ID	Latitude (Dec deg)	Longitude (Dec deg)	Species	Date Collected (DD/MM/YY)	Sex (M/F)	Length: Fork (cm)	Length: Total (cm)	Fish Gutted or Whole (G/W)	Fish Weight (kg)	Otolith Collected (L, R, or Both)	Gonad State, Visual (I, ED, LD, RR, S, R)	Gonad Collected (Y/N)	Gonad Weight (g)	Gonad Macro Photo # and Camera	Fish and Gonad Photo # and Camera

Anectodotal Observation Data Sheet

Cooperative Research and Monitoring Protocol

Observer Contact Information	**Aggregation Location information**
Name:	Aggregation Date:
Phone #:	Area/Site:
Email:	**Lattitude:**
Address:	**Longitude:**
	Diving or Fishing:

Spawning Indicators

Gonad State Based on Visual Observation

Male ED LD RR SPENT IMMATURE

Female ED LD RR SPENT IMMATURE

Plese provide photos of the gonads as verification

ED - Early Development

LD - Late Development

RR - Ripe and Running

Under Water Observations

Courtship Behavior:

Color Changes:

High Density (3X):

Please provide video or photo documentation

Species	# observed	Time/date	Comments - What did you see or experience?

Additional Notes

Data recorder contact Information

Name:

Phone #:

Email:

Date form completed:

Unique ID:_____

Citizen Science Dock Sampling Data Sheet
Cooperative Research and Monitoring Protocol

Data Collection Location_____ Data Collector Name_____ Page _____ of _____

Date Collected (DD/MM/YY)	Boat Captain or Vessel Name	General Location Fish Caught	Species	Sex (M/F)	Length: Fork (cm)	Length: Total (cm)	Fish Weight (kg)	Gonad State: Visual (I, ED, LD, RR, S, R)

Underwater Visual Census Data Sheet

Cooperative Research and Monitoring Protocol

Survey Date:	**Time In:**	**Time Out:**
Team Leader:	**Team Members:**	
Location[3]:	**GPS coordinates[4]:**	
Surface Conditions		
Air Temperature		
Water Temperature		
Surface Current Speed and Direction[5]		
Sea State		
Wind Speed and Direction[6]		
Number of fishing boats nearby		
Underwater Conditions		
Depth		
Temperature		
Visibility		
Estimated Survey Area		
Estimate of Current at Spawning Depth		

Species	**<10**	**10-20**	**21-30**	**31-40**	**41-50**	**51-60**	**61-70**	**71-80**	**81-90**	**91-100**	**101-110**	**111-120**	**121-130**	**Total**	**Spawning Behaviors[7]**

[3] Write a detailed site description including sketches of the spawning bank, on the back of this sheet or additional sheets. In addition, please write any anecdotal information gathered on the spot, and note any further or abnormal observations.

[4] For all sites, GPS coordinates should be taken in UTM with datum, WGS 84.

[5] Sea current direction is the direction in which the current is moving, e.g. current is moving, e.g. current is moving to the south at .5 knots so write, "south current, 0.5 knots". Please also note if current speed is estimated or calculated with a current drogue.

[6] Wind direction is the direction from which the wind is coming, e.g. wind is from the northeast at 5 – 10 knots then write, "Northeast wind, 5 – 10 knots".

[7] Note the number of fish of each species within each size ranges (cm). Please note any of the observed spawning behaviors using the following letters: a) grouping, b) fighting, c) color changes, d) bite wounds, e) gravid, f) courtship, g) spawning.

Date entered in SPAGS Database: _____

User Name: _____

Survey ID: _____

Video Log Data Sheet

Cooperative Research and Monitoring Protocol

Captain: Vessel: Area/Site: Page: of

Data collector: Date:

GPS #	Latitude (DD.DDDD)	Longitude (DD.DDDD)	Time Start	Time End	Depth (m)	Camera Type	Deployment (diver, V-GO, SRV)	File name on camera

Unique ID:_____

Appendix 2: Supporting Literature

Aguilar-Perera A, Aguilar-Dávila W (1996) A spawning aggregation of Nassau grouper *Epinephelus striatus* (Pisces: Serranidae) in the Mexican Caribbean. Environmental Biology of Fishes 45:351−361

Bacheler NM, Schobernd CM, Schobernd ZH, Mitchell WA, Berrane DJ, Kellison GT, Reichert MJM (2013) Comparison of trap and underwater video gears for indexing reef fish presence and abundance in the southeast United States. Fisheries Research 143:81–88

Bohnsack JA, Bannerot SP (1986) A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA Technical Report NMFS 41. US Department of Commerce. 15 p

Bonney R, Cooper CB, Dickinson J, Kelling S, Phillips T, Rosenberg KV, Shirk J. (2009). Citizen Science: A developing tool for expanding science knowledge and scientific literacy. BioScience 59:977–984.

Brown-Peterson NJ, Wyanski DM, Saborido-Rey F, Macewicz BJ, Lowerre-Barbieri SK (2011) A standardized terminology for describing reproductive development in fishes. Marine and Coastal Fisheries 3:52–70

Burton ML, Brennan KJ, Muñoz RC, Parker RO Jr (2005) Preliminary evidence of increased spawning aggregations of mutton snapper (*Lutjanus analis*) at Riley's Hump two years after establishment of the Tortugas South Ecological Reserve. Fishery Bulletin 103:404–410

Claro R, Lindeman KC (2003) Spawning aggregation sites of snapper and grouper species (Lutjanidae and Serranidae) on the insular shelf of Cuba. Gulf and Caribbean Research 14:91–106

Coleman FC, Koenig CC, Eklund AM, Grimes C (1999) Management and conservation of temperate reef fishes in the grouper-snapper complex of the southeastern United States. In: Musick JA (ed) Life in the slow lane: ecology and conservation of long-lived marine animals. American Fisheries Society Symposium 23, Bethesda. pp 233–242

Coleman FC, Koenig CC, Huntsman GR, Musick JA, Eklund AM, McGovern JC, Chapman RW, Sedberry GR, Grimes CB (2000) Long-lived reef fishes: the grouper-snapper complex. Fisheries 25:14–20

Coleman FC, Scanlon KM, Koenig CC (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 PL, Sadovy YJ, Domeier ML (2003) Manual for the study and conservation of reef fish spawning aggregations. Society for the Conservation of Reef Fish Aggregations (SCRFA) Special Publication No. 1 (version 1.0), 98 + iii p, available online at http://www.scrfa.org

Dickinson, JL, Shirk JL, Bonter DN, Bonney R, Crain RL, Martin J, Phillips T, Purcell, K (2012) The current state of citizen science as a tool for ecological research and public engagement. Frontiers in Ecology and the Environment 10:291–297

Domeier ML, Colin PL (1997) Tropical reef fish spawning aggregations: defined and reviewed. Bulletin of Marine Science 60:698–726

Erickson DL, Harris MJ, Grossman GD (1985) Ovarian cycling of tilefish (*Lopholatilus chamaeleonticeps*, Goode and Bean) from the South Atlantic Bight, U.S.A. Journal of Fish Biology 27:131–146

Erisman BE, Apel AM, MacCall AD, Román MJ, Fujita R (2014). The influence of gear selectivity and spawning behavior on a data-poor assessment of a spawning aggregation fishery. Fisheries Research 159,75–87. doi:10.1016/j.fishres.2014.05.013

Erisman B, Heyman W, Kobara S, Ezer T, Pittman S, Aburto-Oropeza O, Nemeth R (2015) Location, location, aggregation: where small, well-placed management actions can yield big wins for fisheries and conservation. Fish and Fisheries, DOI: 10.1111/faf.12132.

Farmer NA, Heyman WD, Karnauskas M, Kobara S, Smart T, Ballenger J, Reichert M, Wyanski D, Tishler MS, Lindeman KC, Sedberry GR. 2017. Prediction and verification of the timing and location of reef fish spawning activity in the Atlantic Ocean off the southeastern United States. 12(3):e0172968

Farmer NA, Karnauskas M (2013) Spatial distribution and conservation of speckled hind and warsaw grouper in the Atlantic Ocean off the Southeastern U.S. PLoS ONE 8(11):e78682. doi:10.1371/journal.pone.0078682

Fitzhugh GR, Shertzer KW, Kellison GT, Wyanski DM (2012) Review of size- and age-dependence in batch spawning: implications for stock assessment of fish species exhibiting indeterminate fecundity. Fisheries Bulletin 110:413–425

Gaines SD, White C, Carr MH, Palumbi SR (2010) Designing marine reserve networks for both conservation and fisheries management. Proceedings of the National Academy of Sciences 107:18286–18293

Gilmore RG, Jones RS (1992) Color variation and associated behavior in the epinepheline groupers, *Mycteroperca microlepis* (Goode and Bean), and *M. phenax* (Jordan and Swain). Bulletin of Marine Science 51:83–103

Grüss A, Robinson J, Heppell SS, Heppell SA, Semmens BX (2014) Conservation and fisheries effects of spawning aggregation marine protected areas: what we know, where we should go and what we need to get there. ICES Journal of Marine Science, doi:10.1093/icesjms/fsu038

Harris PJ, Wyanski DM, Mikell PTP (2004) Age, growth, and reproductive biology of blueline tilefish along the southeastern coast of the United States, 1982–1999. Transactions of the American Fisheries Society 133:1190–1204

Harris PJ, Wyanski DM, White DB, Mikell PP, Eyo PB (2007) Age, growth, and reproduction of greater amberjack off the southeastern U.S. Atlantic coast. Transactions of the American Fisheries Society 136:1534–1545

Harris PJ, Wyanski DM, White DB, Moore JL (2002) Age, growth, and reproduction of scamp, *Mycteroperca phenax*, in the southwestern North Atlantic, 1979-1997. Bulletin of Marine Science 70(1):113–132

Harris PJ, Wyanski DM, White DB, Moore JL (2002) Age, growth and reproduction of scamp. Bulletin of Marine Science 70:113–132

Heyman WD (2016) Cooperative Research and Monitoring Program for Fish Spawning Areas in the US South Atlantic (CRMP SASA). Version 2.0, 14 February 2016. LGL Ecological Research Associates, Inc., Bryan TX.

Heyman WD (2014) Let them come to you: Reinventing management of the snapper-grouper complex in the Western Atlantic: A Contribution to the data poor fisheries management symposium. Proceedings of the Gulf and Caribbean Fisheries Institute 66:104-109

Heyman WD (2015) Final Report: Prediction and verification of multi-species snapper grouper spawning areas in the U.S. South Atlantic. Submitted to the South Atlantic Fishery Management Council (SAFMC) for contract SA-(14)-36. 20 May 2015. LGL Ecological Research Associates, Inc. 34 p

Heyman WD, Kjerfve B (2008) Characterization of transient multi-species reef fish spawning aggregations at Gladden Spit, Belize. Bulletin of Marine Science 83:531–551

Heyman W, Azueta J, Lara O, Majil I, Neal D, Luckhurst B, Paz M, Morrison I, Rhodes KL, Kjerve B, Wade B, Requena N (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 WD, Kjerfve B, Rhodes KL, Graham RT, Garbutt L (2005) Cubera snapper, *Lutjanus cyanopterus*, spawning aggregations on the Belize Barrier Reef over a six year period. Journal of Fish Biology 67(1):83–101

Hood PB, Johnson AK (1999) Age, growth, mortality, and reproduction of vermilion snapper, *Rhomboplites aurorubens*, from the eastern Gulf of Mexico. Fishery Bulletin 97(4):828–841

Johannes RE (1978) Reproductive strategies of coastal marine fishes in the tropics. Environmental Biology of Fishes 3:65–84

Johannes RE (1998) The case for data-less marine resource management: examples from tropical nearshore finfisheries. Trends in Ecology and Evolution 13:243–246

Johannes RE, Freeman MMR, Hamilton RJ (2000) Ignore fishers' knowledge and miss the boat. Fish and Fisheries 1:257–271

Johannes RE, Neis B (2007) The value of an anecdote. In: Haggan N, Neis B, Baird I (eds) Fishers' knowledge in fisheries science and management. UNESCO Publishing, Paris, pp 41–58

Kobara S, Heyman WD (2008) Geomorphometric patterns of Nassau grouper (*Epinephelus striatus*) spawning aggregation sites in the Cayman Islands. Marine Geodesy 31(4):231–245

Kobara S, Heyman WD (2010) Sea bottom geomorphology of multi-species spawning aggregation sites in Belize. Marine Ecology Progress Series 405:243–254

Kobara S, Heyman WD, Pittman SJ Nemeth RS (2013) Biogeography of transient reef fish spawning aggregations in the Caribbean: a synthesis for future research and management. Oceanography and Marine Biology: An Annual Review 51:281–326

Koenig CC, Stallings CD (2015) A new compact rotating video system for rapid survey of reef fish populations Bulletin of Marine Science 90(3): DOI: http://dx.doi.org/10.5343/bms.2015.1010

Koenig CC, Coleman FC, Grimes CB, Fitzhugh GR, Scanlon KM, Gledhill CT, Grance M (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

LGL Ecological Research Associates (LGL) (2015) Cooperative prediction and verification of multi-species spawning aggregations at Georgetown Hole: summary of results from 2014. Report Submitted to South Atlantic Fisheries Management Council, 9 June 2015. LGL Ecological Research Associates, Inc., Bryan

Lindeman KC, Pugliese R, Waugh GT, Ault JS (2000) Developmental patterns within a multispecies reef fishery: management applications for essential fish habitats and protected areas. Bulletin of Marine Science 66:929–956

Lowerre-Barbieri SK, Ganias K, Saborido-Rey F, Murua H, Hunter JR (2011) Reproductive timing in marine fishes: variability, temporal scales, and methods. Marine and Coastal Fisheries 3:71–91

Mackinson S, Nøttestad L (1998) Combining local and scientific knowledge. Reviews in Fish Biology and Fisheries 8:481–490

Mallet D, Pelletier D (2014) Underwater video techniques for observing coastal marine biodiversity: a review of sixty years of publications (1952–2012). Fisheries Research 154:44–62 http://dx.doi.org/10.1016/j.fishres.2014.01.019

Mann DA, Locascio JV, Coleman FC, Koenig CC (2009) Goliath grouper *Epinephelus itajara* sound production and movement patterns on aggregation sites. Endangered Species Research 7:229–236

Matheson RH III, Huntsman GR, Manooch CS III (1986) Age, growth, mortality, food and reproduction of the scamp, *Mycteroperca phenax*, collected off North Carolina and South Carolina. Bulletin of Marine Science 38:300–312

McGovern JC, Wyanski DM, Pashuk O, Manooch CS III, Sedberry GR (1998) Changes in the sex ratio of Gag, *Mycteroperca microlepis*, from the Atlantic coast of the southeastern United States during 1976–1995. Fishery Bulletin U.S. 96:797–807

McGovern JC, Sedberry GR, Meister HS, Westendorff TM, Wyanski DM, Harris PJ (2005) A tag and recapture study of gag *Mycteroperca microlepis*, off southeastern U.S. Bulletin of Marine Science 76(1):47–59.

Meadows MST (2012) Spawning indicators of snappers (Lutjanidae) on the east coast of Florida determined from commercial and recreational fisher surveys. M, S. Thesis, University of Florida, Melbourne, 105 p

Murawski SA, Brown R, Lai HL, Rago PJ, Henderson L (2000) Large-scale closed areas as a fishery-management tool in temperate marine systems: the Georges Bank experience. Bulletin of Marine Science 66:775–798

Neis B, Schneider DC, Felt L, Haedrich RL, Fischer J, Hutchings JA (1999) Fisheries assessment: what can be learned from interviewing resource users? Canadian Journal of Fisheries and Aquatic Sciences 56:1949–1963

Nemeth RS (2005) Population characteristics of a recovering US Virgin Islands red hind spawning aggregation following protection. Marine Ecology Progress Series 286:81–97

National Research Council (NRC) (2014) Evaluating the effectiveness of fish stock rebuilding plans in the United States. National Academies Press, Washington, 143 p

Padgett SM (1997) Age, growth and reproductive biology of the white grunt, *Haemulon plumieri*, along the southeast Atlantic coast of the United States. M.S. Thesis, College of Charleston, 61 p

Pet JS, Mous PJ, Rhodes K, Green A (2006) Introduction to monitoring of spawning aggregations of three grouper species from the Indo-Pacific. A manual for field practitioners. Version 2.0 (January 2006). Publication from The Nature Conservancy Coral Triangle Center, Sanur, Bali, Indonesia. 98 p.

Rhodes KL, Sadovy Y (2002) Temporal and spatial trends in spawning aggregations of camouflage grouper *Epinephelus polyphekadion,* in Pohnepei, Micronesia. Environmental Biology of Fishes 63:27–39

Rowell TJ, Nemeth RS, Scharer MT, Appledoorn RS (2015) Fish sound production and acoustic telemetry reveal behaviors and spatial patterns associated with spawning aggregations of two Caribbean groupers. Marine Ecology Progress Series 518:239–254

Russell MW, Sadovy de Mitcheson Y, Erisman BE, Hamilton RJ, Luckhurst BE, Nemeth RS (2014) Status report – world's fish aggregations 2014. Science and Conservation of Fish Aggregations, California USA. International Coral Reef Initiative

Sadovy de Mitcheson Y, Erisman BE (2012) The social and economic importance of aggregating species and the biological implications of fishing on spawning aggregations In: Sadovy de Mitcheson Y, Colin PL (eds) Reef fish spawning aggregations: biology, research and management, Springer, New York, pp 225–284

SAFMC (South Atlantic Fishery Management Council) (2012) MPA Expert Workgroup Meeting Overview, May 16-17, 2012, Mighty Eighth Air Force Museum, Pooler, GA Version: 6-1-2012. South Atlantic Fishery Management Council, North Charleston, available online at http://www.safmc.net/LinkClick.aspx?fileticket=5Cl1M4ndCp8%3d&tabid=404

SAFMC (South Atlantic Fishery Management Council) (2013) MPA Expert Workgroup Meeting II Overview, February 4-6, 2013, Crowne Plaza, North Charleston, SC, Draft: 2-26-13. South Atlantic Fishery Management Council, North Charleston, available online at http://www.safmc.net/LinkClick.aspx?fileticket=0Oo5AINDZqM%3d&tabid=766

SAFMC (South Atlantic Fishery Management Council) (2015) Snapper Grouper Amendment 36 (Special Management Zones) Decision Document. South Atlantic Fishery Management Council, North Charleston, available online at: http://safmc.net/resource-library/snapper-grouper-amendment-36).

Schärer MT, Nemeth ML, Rowell TJ, Appeldoorn RS (2014) Sounds associated with the reproductive behavior of the black grouper (*Mycteroperca bonaci*). Marine Biology 161:141–147

Schärer MT, Rowell TJ, Nemeth MI, Appeldoorn RS (2012) Sound production associated with reproductive behavior of Nassau grouper *Epinephelus striatus* at spawning aggregations. Endangered Species Research 19:29–38

Schobernd ZH, Bacheler NM, Conn PB, Trenkel V (2014) Examining the utility of alternative video monitoring metrics for indexing reef fish abundance. Canadian Journal of Fisheries and Aquatic Sciences 71:464–471

Schobernd CM, Sedberry GR (2009) Shelf-edge and upper-slope reef fish assemblages in the South Atlantic Bight: habitat characteristics, spatial variation, and reproductive behavior. Bulletin of Marine Science 84:67–92

Sedberry GR, Cooksey CL, Crowe SF, Hyland J, Jutte PC, Ralph CM, Sautter LR (2004) Final report: characterization of deep reef habitat off the southeastern U.S., with particular emphasis on discovery, exploration and description of reef fish spawning sites. SCDNR Marine Resources Research Institute, Charleston 76 p

Sedberry GR, Pashuk O, Wyanski DM, Stephen JA, Weinbach P (2006) Spawning locations for Atlantic reef fishes off the southeastern U.S. Proceedings of the Gulf and Caribbean Fisheries Institute 57:463–514

Silvano, RAM, Maccord, PFL, Lima RV, Begossi, A. (2006) When does this fish spawn? Fishermen's local knowledge of migration and reproduction of Brazilian coastal fishes. Environmental Biology of Fishes 76:371-386. http://dx.doi.org/10.1007/s10641-006-9043-2

Taylor JC (2006). Emerging technologies for reef fisheries research and management. NOAA Professional Paper NMFS 5, 116 p

Taylor JC, Eggleston DB, Rand PS (2006) Nassau grouper (*Epinephelus striatus*) spawning aggregations: hydroacoustic surveys and geostatistical analysis. In Emerging technologies for reef fisheries research and management (JC Taylor, ed), p. 18–25. NOAA Prof. Paper NMFS 5

Whaylen L, Pattengill-Semmens CV, Semmens BX, Bush PG, Boardman MR (2004) Observations of a Nassau grouper, *Epinephelus striatus*, spawning aggregation site in Little Cayman, Cayman Islands, including multi-species spawning information. Environmental Biology of Fishes 70:305–313

White DB, Palmer SM (2004) Age, growth, and reproduction of the red snapper, *Lutjanus campechanus*, from the Atlantic waters of the southeastern U.S. Bulletin of Marine Science 75:335–360

Wyanski DM, White DB, Barans CA (2000) Growth, population age structure, and aspects of the reproductive biology of snowy grouper, *Epinephelus niveatus*, off North Carolina and South Carolina. Fishery Bulletin 90(1):198-218

Ziskin GL, Harris PJ, Wyanski DM, Reichert MJM (2011) Indications of continued overexploitation of speckled hind along the Atlantic coast of the southeastern United States. Transactions of the American Fisheries Society 140:384–439