Cooperative Research and Monitoring Protocol for Spawning Areas in the US South Atlantic

Version 2.0

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Abstract

This white paper describes the design and implementation of a Cooperative Research and Monitoring Protocol for US South Atlantic Spawning Areas (CRMP SASA). The protocol aims to support South Atlantic Fishery Management Council (SAFMC) efforts outlined in Amendment 36 to the Snapper Grouper Fishery Management Plan (SG FMP) to design and implement an adaptive process to establish, monitor and manage Spawning Special Management Zones (SSMZs) surrounding multi-species spawning areas in the region.

Unfortunately, spawning times and locations are still largely unclear for many species throughout the region. Further, there are limited resources available to collect the biological data used to assess the status of some of the stocks that spawn in these areas. This document proposes to fill these gaps through a cooperative program with fishermen, the CRMP SASA.

During the design phase (2014–2015) a draft version of this protocol was used to predict, verify and characterize two multi-species spawning areas in support of the design and designation of SSMZs. During a proposed pilot phase (2016–2020) of the CRMP SASA and if funding is available, fishermen and observers will characterize additional sites and contribute biological samples through the CRMP SASA for key managed species (e.g. speckled hind and warsaw grouper), times (October to May) and locations (shelf-edge spawning areas) that are presently under-represented in the data available for assessments. In the long term (2017–2047), SSMZs should help conserve spawning stocks and replenish stocks through larval export and adult emigration. This CRMP SASA provides methods to monitor and evaluate the SSMZs.

This white paper analyzes the feasibility and needs of the CRMP SASA and proposes a draft protocol and phased strategy for its implementation. A fully implemented CRMP for the South Atlantic region would include field data collection at multiple (>20) sites (not necessarily all SSMZs), a data management center to serve a community of various users and an education and outreach program. The CRMP SASA provides a test case for the proposed SAFMC Citizen Science Initiative in the US South Atlantic region that could be replicated in other fisheries.

Cover Photo: Captain Mark Marhefka, South Atlantic snapper-grouper fisherman, served as a valuable collaborator in developing the cooperative research protocol described in this document. The photo was taken during a cooperative research trip at Georgetown Hole off South Carolina during February 2014 aboard his F/V *Amy Marie.* The data collected during that trip helped document spawning for several species including scamp grouper *Mycteroperca phenax***.**

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Process of Development:

This is a document designed to stimulate development of a SAFMC-led fishery citizen science program. By design, the document will evolve over time based on review and critique from peers and colleagues, field-testing and protocol improvement. Five reviewers provided extensive comments and suggestions on Version 1.0 that have been incorporated in this Version 2.0. Comprehensive reviews of this Version 2.0 are being requested from many individuals considered as experts in the field and/or as instrumental in the design and implementation of the program described herein. Reviewers will include fishermen, scientists, managers and others.

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CRMP SASA builds on nearly 20 years of research on spawning areas in many parts of the world (Heyman et al. 2004; Colin et al. 2003). The initial design and testing phase in the US South Atlantic was completed largely during 2014 and 2015.

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1.0 Introduction

This white paper describes the design and implementation of the Cooperative Research and Monitoring Protocol for US South Atlantic Spawning Areas (CRMP SASA). The protocol aims to support South Atlantic Fishery Management Council (SAFMC) efforts outlined in Amendment 36 to the Snapper Grouper Fishery Management Plan (SG FMP). The proposed action for Amendment 36 is to: "Specify a process for identifying spawning sites/aggregations for snapper grouper species, including speckled hind and warsaw grouper, based on the characteristics of sites important for spawning (bottom topography, current systems, etc.)". In direct support of this initiative, and with funding provided in part from the SAFMC, this paper offers specifics on the design and implementation of an adaptive process to identify, monitor and manage Spawning Special Management Zones (SSMZs) focused on multi-species spawning areas in the region.

1.1 Background

The SAFMC manages most fisheries within federal waters from the Virginia/North Carolina border through the Atlantic side of the Florida Keys (Figure 1). The Snapper Grouper Management Complex includes 59 finfish species, including grouper, snapper, jacks, grunts and porgies (Table 1), supports significant commercial and recreational fisheries and is managed via the SG FMP (SAFMC 1983, and as amended).

In an effort to end and prevent overfishing and to rebuild overfished stocks under federal management, Congress enacted the requirement that Annual Catch Limits (ACLs) and Accountability Measures (AMs) be developed through regular stock assessments and implemented (Magnuson-Stevens Fishery Conservation and Management Act (MSA) as amended 2006). Stocks that were deemed overfished required rebuilding plans and stocks undergoing overfishing required ACLs and AMs by 2011. All other stocks required ACLs and AMs by 2012.

The South Atlantic Snapper Grouper Management Complex includes speckled hind (*Epinephelus drummondhayi*) and warsaw grouper (*E. nigritus*). Currently, these stocks are both designated as undergoing overfishing, with an unknown overfished status. Stock assessments and studies of varying degrees of resolution and robustness have indicated a declining trend for both stocks (e.g. Ziskin et al. 2011). Harvest of these species is currently prohibited in federal waters of the South Atlantic. In order to comply with the MSA, the SAFMC is considering additional methods to reduce fishing mortality and restore depleted populations of managed species.

Many species in the snapper-grouper complex are long lived and migrate to spawn in aggregations where they are highly vulnerable to exploitation at specific places and times of the year (Domeier and Colin 1997; Coleman et al. 1999, 2000). In addition, many of these species' ranges cross national and regional boundaries (Figure 2). The status of several of these species has been difficult to assess and some are considered data-poor species, for which stock assessments have not been completed or are unreliable (NRC 2014). Most species that aggregate to spawn have experienced significant declines because they are easy to catch when aggregating and therefore more vulnerable to exploitation (Russell et al. 2014). Many are listed by IUCN as threatened or endangered (Sadovy and Erisman 2012).

Marine reserves at multi-species spawning sites have aided recovery in many areas and for many species (e.g. Beets and Friedlander 1992; Murawski et al. 2000; Nemeth 2005; Burton et al. 2005; Grüss et al. 2014). For example, the number of mutton snapper in the protected spawning aggregations at Riley's Hump in the Dry Tortugas increased from less than 100 in 2002 to 4,000 in 2009. In addition, fishermen in southeastern Florida credit Riley's for the recent and large increase in mutton snapper recruitment. Therefore SSMZs are likely to support recovery and maintenance of the species and ecosystems that depend on them. Additionally, since the sites can be relatively small, their protection is often politically feasible (i.e. minimal reduction in fishing area) and the costs for patrolling and management are low compared to their value for conservation and fisheries (Erisman et al. 2015). Spawning areas, like those proposed for SSMZs, are visited by large numbers of spawning fish at predictable times, so they can serve as convenient places to monitor data-poor stocks (Heyman 2014).

1.2 Vision

The vision of the CRMP SASA is a network of fishermen, scientists and managers who cooperatively identify a universe of possible sites, predict the most likely sites for verification, then verify, characterize, monitor and manage multi-species spawning areas throughout the US South Atlantic. Regular monitoring and biological sampling at these sites will support better stock assessments and sustainable management of the snapper-grouper complex.

1.3 Goals of the CRMP SASA

If implemented and successful, the CRMP SASA will achieve the following goals in the first five years.

- Five – 20 potential multi-species spawning areas will be identified by fishermen and prioritized by the SAFMC for validation.
- A cooperative research and monitoring system will be in place to allow fishing vessels to collect biological samples from various proposed and existing SSMZs, which will generate data that can be used to verify and monitor spawning activity and contribute to stock assessments for data-poor species.
- The presence of program participants at proposed and existing SSMZ sites will deter illegal fishing.
- Stakeholders, particularly commercial and recreational fishermen, will have an increased understanding of fish reproductive ecology and management and thus be more able and willing to participate in further cooperative research and monitoring programs.

1.4 Rationale and Design Constraints in Developing the CRMP SASA

At present, there is no existing system to monitor snapper-grouper spawning areas in the South Atlantic. The CRMP SASA is designed to fill that gap by working with fishermen to identify, verify and monitor spawning areas.

Shelf edges are primary target fishing areas for snapper-grouper fishermen in the region. The best habitat for larger groupers occurs in relatively narrow bands of hard bottom along the shelf edge that have highly rugose and rocky bottoms and strong and unpredictable currents (Koenig et al. 2000; Wyanski et al. 2000; Sedberry et al. 2006; Schobernd and Sedberry 2009; Farmer and Karnauskas 2013; Farmer et al. in prep.). They are difficult to anchor on and fish, even in the relatively small (30–50 foot) commercial fishing vessels that are most common in this fishery. Abundant sharks in these areas further challenge fishermen's ability to actually land groupers and snappers in these regions. Nonetheless, snapper-grouper fishermen are on the water nearly every day of the year and concentrate fishing efforts on these shelf edge areas. These fishermen possess a vast knowledge of the resources in their fishing areas.

South Atlantic snapper and grouper stocks are assessed through the South East Data Assessment and Review (SEDAR) process. Much of the data for these assessments are collected through the South Carolina Department of Natural Resources Marine Resources Monitoring, Assessment & Prediction (SCDNR MARMAP) Project and the Southeast Fishery-Independent Survey (SEFIS) Program of the SouthEast Fisheries Science Center. The 30-year MARMAP dataset serves as a national example of a high-quality data stream supporting stock assessments.

Though the MARMAP dataset is relatively comprehensive, there exist spatial and temporal gaps that result from funding and gear limitations. Biological samples from snapper-grouper species in shelf-edge habitats are limited in the database for two main reasons. First, though initial sampling was done in this area with bottom longlines that could be deployed at the shelf edge, funding limitations have since prohibited the use of this technique. Chevron traps, the primary gear in use presently, are difficult to set in the steep shelf areas, especially from the 110-foot R/V *Palmetto* (MARMAP's primary research vessel). They can also be difficult to retrieve from rugose and rocky areas where they may get stuck or lost. Further, MARMAP concentrates field data collection during April to October, leaving a gap between November and April (Farmer et al. in prep.), during which time several members of the snapper-grouper complex are known to spawn (Figure 3; Farmer et al. in prep.).

Most techniques for Atlantic snapper-grouper spawning area monitoring have been developed for tropical waters (Russell et al. 2014) in which most species spawn in 60–150 feet water depth (Kobara et al. 2013). The South Atlantic region includes some tropical habitat (i.e. from the Florida Keys north to Jupiter, FL) and species (e.g. mutton snapper (*Lutjanus analis*) and black grouper (*Mycteroperca bonaci*)) (Figure 2). The majority of the region, from north of Jupiter, FL to Cape Hatteras, NC, is subtropical and temperate and harbors groupers and snappers that occur at the shelf edge in 180–400 feet of water (Lindeman et al. 2000; Sedberry et al. 2006). Observations using SCUBA are feasible in waters <120 feet but prohibitively expensive and difficult in >150 feet. To study spawning areas in most of the SAFMC area therefore required the development of new techniques. The CRMP was designed to collect data cooperatively yet unobtrusively from commercial vessels with sufficient rigor to be usable in stock assessments.

Design constraints described above and a cooperative citizen science approach (Mackinson and Nøttestad 1998) have guided the development and choice of techniques described in this protocol. These design assumptions are as follows:

- There is a need for biological samples of groupers and snappers from rocky shelf edges in 60–400 feet and deeper during all times of year.
- Commercial fishermen are regularly and effectively fishing in these areas and times.
- All data must be collected as cost-effectively as possible while still being consistent with SAFMC standards and approved for inclusion in stock assessments.
- Fishermen are often aware of spawning areas and times that scientists and managers are not aware of and sometimes are willing to share this information (Johannes 1978, 1998).
- Some commercial fishermen in the South Atlantic are interested in and willing to participate in cooperative research that will protect fish where they spawn.
- It is expensive to send research vessels out in the 'off season' and/or to get the coverage implemented.
- It is expensive to charter commercial vessels for strictly research purposes.

1.5 General Description of Monitoring Protocol

This section of the white paper offers a general description of the CRMP SASA methods proposed for prediction, verification and monitoring of spawning areas in support of Amendment 36 to the SG FMP (SAFMC 2015). Some of these methods are well established and already in use while other methods are new and/or under development. Still others appear promising based on their use in other regions, but are untried in the US South Atlantic. Further details of all methods are provided in Section 2.

The CRMP SASA is an iterative and adaptive process that will involve broad cooperation among fishermen, managers and scientists in the US South Atlantic region. The basic steps in the process include prediction, verification, monitoring and research. These steps are in turn supported by a data management system to ensure that relevant, high-quality data are produced, stored and available for inclusion in stock assessments and for monitoring SSMZs. Finally, the CRMP SASA is supported by an education and outreach program that is designed to train data collectors, fishermen and the general public on the steps in prediction, verification, monitoring and research of spawning areas.

1.5.1 Prediction

In many areas of the world, experienced fishermen have become aware of spawning areas based on their extensive time and experience at sea (Johannes 1978). For example, a well-respected, patriarch fishermen, Peter Gladding, became aware of a multi-species spawning site at Riley's Hump in the Dry Tortugas based on his experiences fishing there for over 30 years. He alerted authorities of this information and then helped scientists with National Marine Fisheries Service (NMFS) to verify and characterize it (Burton et al. 2005). Riley's Hump was subsequently protected within the Florida Keys National Marine Sanctuary (FKNMS).

Similarly, fishermen have identified multi-species spawning sites in Cuba (Claro and Lindeman 2003), Belize (Heyman and Kjerfve 2008; Kobara and Heyman 2010), the Cayman Islands (Whaylen et al. 2004; Kobara and Heyman 2008), the west Florida shelf (Koenig et al. 2000; Coleman et al. 2011), Brazil (Silvano et al. 2006) and many areas in the Pacific (Johannes 1978). In the US South Atlantic, several attempts have been made to summarize the existing information from fishermen about the timing and location of spawning areas (e.g. Lindemen et al. 2000; Sedberry et al. 2004, 2006).

More recently, and as part of the development of Amendment 36, several snapper-grouper spawning areas have been identified by knowledgeable fishermen as part of a formal process of expert working groups (SAFMC 2012; 2013). Unfortunately, the time/date/species and locations of spawning fish provided by fishermen can be somewhat generalized and are unverified (Neis et al. 1999; Colin et al. 2003; Pet et al. 2006). The CRMP SASA provides a system to capture and formalize anecdotal information from key informants (see Section 2.1) in such a way that it can be considered alongside data collected using more traditional means.

In addition to anecdotal information from fishermen, the timing of spawning (season and lunar phase) for various species can be inferred from other sources, including published papers and summaries of histology studies (e.g. Matheson et al. 1986; Wyanski et al. 2000; Harris et al. 2002; SEDAR 2013). Much of the existing data on spawning seasons from the MARMAP database has been used to evaluate seasonality (Farmer et al., in prep; Figure 3) and general areas of spawning for many of the larger members of the snapper-grouper complex.

In addition to anecdotal information and published studies, spawning site predictions can be made with the aid of bathymetric data and maps. As indicated above, spawning sites often occur at distinctive bathymetric features such as promontories and channels (Kobara et al. 2013). ArcGIS or other Geographic Information Systems, anecdotal information, published studies and bathymetry data can be used to make very specific predictions of spawning areas (Section 2.1). This type of layered dataset can be used to develop a suite of possible spawning sites and times that the SAFMC can then prioritize for verification efforts (Section 2.2).

1.5.2 Verification, Monitoring and Research

Verification: Fish spawning can be verified directly in one of two ways – by observing gamete release and 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; Pet et al. 2006). 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 observations of fish densities three to four times the normal average for a given site (Domeier and Colin 1997; Colin et al. 2003; Heyman et al. 2004). To verify such predicted sites, fishermen and observers working in the CRMP framework[1] will navigate to predicted sites to verify snapper-grouper

[1] Permits for this work are required by NMFS. Research conducted in support of this document was conducted under a letter of acknowledgment (LOA) to MARMAP from NMFS. Research

spawning using various techniques, including underwater video (Section 2.2), CPUE (Section 2.3) and collection of biological samples (Section 2.4). Verification of spawning will most often be documented with histology data (i.e. assessing the state of fishes' gonad condition from sampled tissue).

Monitoring: The techniques described above can be used to verify the presence of a spawning area in space and time. Additional sampling using the same protocols over time will form the basis for monitoring the status of spawning areas. Monitoring physical data (e.g. temperature and currents) at these sites will provide a solid baseline and allow the testing of hypotheses about possible influences on stocks such as spawning time or season. Fish counts from video (e.g. Max Count) or number of observed courtship behavior events (as a function of effort) can serve as an index of abundance at the spawning site. The proportion of fish spawning can be estimated both from video and from histology. Repeated measurements of these parameters over time constitute monitoring.

Research: There are numerous research questions that can be addressed once the CRMP SASA program has been implemented, particularly if monitoring is standardized and completed on a regular basis at various sites throughout the US South Atlantic region. Based on strong support for the idea that multi-species spawning aggregations occur predictably at shelf-edge reef promontories in the Caribbean (Kobara et al. 2013), the CRMP offers the ability to test the same hypothesis for the US South Atlantic. Additional research ideas can be found in Kobara et al. (2013), but examples include:

- Single-species research questions can be addressed to clarify spawning time, sex ratios, fecundity and courtship and spawning behavior.
- Conventional and acoustic tag and recapture studies centered at SSMZ sites can be used to address questions of adult migration and connectivity.
- Oceanographic studies at SSMZ sites can help explain larval transport.
- Regional issues of climate change such as long-term trends in water temperature, species range expansions and changes in the timing (season) of spawning by individual species can be addressed by monitoring at SSMZ sites.

1.5.3 Data Management and Distribution

The data management system developed for this program must address issues of quality control, standardization and redundancy. A suitable institution will require sufficient physical and human resources to maintain and house a secure yet accessible data repository. Details of the proposed data management and distribution system are provided in Section 3.

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permits for future studies described in the CRMP SASA program will need to be requested from NMFS.

1.5.4 Education and Outreach

The CRMP SASA will provide a monitoring and research platform but will also serve to educate stakeholders in the fishing industry, fish consumers and the broad general public. The immediate education/outreach component involves training observers and fishermen in the use of the techniques described herein. In the longer term, the program can work in partnership to generate and distribute relevant information to educate fishermen and fish consumers. Various techniques envisioned for this component are outlined in Section 4.

1.6 Expected Outcomes

This protocol will be immediately useful for verifying suspected spawning areas in the US South Atlantic. This information will be used in the proposed Amendment 36 to the SG FMP, which would protect spawning areas through their designation as SSMZs. Multi-species spawning areas in well-enforced SSMZs should contribute benefits to both fisheries management and biodiversity conservation (Erisman et al. 2015). This protocol can be used to monitor SSMZs and evaluate their effectiveness over time.

Methods herein can be used to document time series data on fish density, abundance, size frequency, sex ratios and spawning output by species within the SSMZs. Methods herein can also be used to collect gonad weights and samples for histology, which in turn can help define spawning times and locations more precisely. Stocks are concentrated in space and time at these sites so the protocol supports monitoring many species. Finally, the protocol fosters the collection of biological samples of fishes that are typically under-represented in fisheries independent sampling (i.e. 'data-poor' species) and thus help fill existing data gaps and support stock assessments.

The numbers and sizes of spawning fishes are expected to increase as seen in protected spawning areas elsewhere (Beets and Friedlander 1992; Burton et al. 2005; Heppell et al. 2012; Grüss et al. 2014). Assuming a constant rate of recruitment, increased spawning activity and volume should contribute to stock replenishment over the long term (Gaines et al. 2010). Calculating the percentage of the total stock represented at each individual spawning site and summing them could ultimately provide another index of regional stock abundance (Kobara et al. 2013; Heyman 2014). Changes in length frequency distribution collected from aggregation areas can be related to fishing mortality and provides a metric for stock condition that may be less visible with other metrics such as CPUE (Erisman et al. 2014). This protocol can be used to determine spawning season duration and spawning frequency which (along with batch fecundity) can help define age specific fecundity and thus refine estimates of population reproductive potential (e.g. SPR) used in stock assessments (Lowerre-Barbieri et al. 2011; Fitzhugh et al. 2012).

There will also be social benefits from implementing the CRMP SASA. Continued monitoring presence at SSMZ sites during the time of spawning will serve as a deterrent to illegal fishing (Heyman 2014). By increasing citizen (fishermen) involvement in research, conservation and monitoring, the program will educate key stakeholders (Bonney et al. 2009; Dickinson et al. 2012). The intention of the CRMP is to engage fishermen in the scientific process of SSMZ identification with the expectation that increased participation will yield increased confidence in, and support for, SSMZ management. Combining scientific observations with local fishermen's knowledge has proven valuable in supporting management of small-scale fisheries in other areas (Mackinson and Nøttestad 1998; Neis et al. 1999; Johannes 1998; Johannes et al. 2000; Grüss et al. 2014). Perhaps the most important outcome of the CRMP SASA is that it is providing a test case for the developing Citizen Science Program of the SAFMC and could be replicated in other fisheries.

2.0 Field Data Collection

2.1 Predicting and Selecting Sites for Verification

In most regions of the world, fishermen generally locate spawning aggregation sites, and in some cases alert managers and scientists to their existence (e.g. Johannes 1978, 1998; Neis et al. 1999; Koenig et al. 2000; Claro and Lindeman 2003; Kobara et al. 2013). In the US South Atlantic, for example, Peter Gladding, a well-respected commercial fisherman from the Florida Keys, offered anecdotal information about the spawning aggregations at Riley's Hump. The information led to their protection and rapid recovery within the protected area, which now serves to export larvae and adults to surrounding areas (Burton et al. 2005). Additional possible spawning sites for groupers and snappers in the US South Atlantic have been revealed through a series of fishermen surveys and interviews (Coleman et al. 1999; Lindeman et al. 2000; Meadows 2012). More recently, SAFMC-sponsored marine protected area (MPA) expert workgroup meetings and their reports synthesized results from fishermen and scientists working together to identify possible spawning locations, particularly for warsaw grouper and speckled hind (SAFMC 2012, 2013).

In order to predict SSMZ sites to support prioritization for verification following models developed for the Caribbean (Kobara et al. 2013), anecdotal accounts from fishermen are being synthesized along with fisheries dependent and independent data into predictive models of spawning area times and locations in the US South Atlantic (Farmer et al. in prep). The models use bathymetric data from various sources and rely heavily on fisheries independent data from MARMAP 1990-2013 and SEFIS 2010-2013. This process has identified several potential spawning areas in the federal waters adjacent to each state in the region. The process of site identification and selection is iterative, adaptive and ongoing. New sites are identified or brought forward by fishermen, and then prioritized for possible analysis and consideration as an SSMZ at a later date.

2.1.1 Anecdotal Information and Fishermen Interviews

As fishermen become more aware of spawning activity, in part via the education and outreach program described herein, they are likely to encounter and/or provide further information about spawning activity that they witness or are aware of from the past. Formal efforts to gather these data via surveys or interviews have been successful (e.g. Lindeman et al. 2000; Meadows 2012; SAFMC 2012, 2013). More often, however, fishermen often observe evidence of spawning activity and do not report it for various reasons. Fishermen might not recognize the signs. They may wish to keep the information and location secret. In many cases, if they do report it, the information is often relayed as a story and is rarely captured (Neis et al. 1999; Johannes and Neis 2007).

In order to capture, quantify, store, formalize and ultimately cite anecdotal information, CRMP offers the Anecdotal Observation Data Sheet (see Appendix 1). The data sheet allows the user to enter specific data on the species, time and location of observations, the spawning signs or evidence recorded and ancillary physical information on currents, tides or seawater temperatures. In addition, the sheet allows the user to attach photographs (either underwater or of gonads) to support their anecdotal information. Scientists and fishermen should work together to capture the information on the form in an iterative fashion. Fishermen might tell the story to the scientist for recording. The scientist can fill in the information as appropriate and ask the fishermen detailed follow-up questions that can be incorporated into a draft. Fishermen should review the draft to ensure accuracy and completeness.

Data collected using the Anecdotal Observation Data Sheet can support the process of site identification and verification but would not be sufficient for monitoring (see section 1.5 for differences). Additional indirect evidence of spawning activity can be gathered rapidly and efficiently using the Citizen Science Dock Sampling Data Sheet (Appendix 1; and see Section 2.4.1). For example, if a head boat comes in and mates clean their fish, the Dock Sampling Data Sheet could be used to document size frequency and gonad condition for the fish caught that day. If, for example, a large percentage of the female fish of one particular species contained hydrated gonads, it would serve as an indication that these fish came from a spawning area and time. By extension, regular dock sampling could be used to show lunar or seasonal spawning periodicity and this is a commonly used fisheries dependent technique (e.g. Harris et al. 2004, 2007). In this way, trained citizen scientists could use the Dock Sampling Data Sheet to document or monitor spawning seasons.

2.1.2 Site Mapping

Using ArcGIS or other Geographic Information System software, detailed base maps for proposed SSMZ sites can be developed using layers of readily available data. The most important data sets include:

- Nautical charts showing latitude and longitude as well as Loran C lines
- Bathymetry data
    - nautical charts
    - coastal relief models
    - multi-beam surveys
- Proposed or existing SSMZ boundaries
- Coastlines and terrestrial information showing ports and rivers
- Locations of spawning fish by species, as identified through SCDNR MARMAP, CRMP SASA or other sources.

Additional data that can be valuable include:

- Maps showing prevailing currents as derived from models or drifters
- Satellite-derived data showing
    - Sea surface temperature
    - Ocean color
    - Sea surface height
- ROV or AUV tracks
- Monitoring sites
- Other data as appropriate

When general maps of each site are developed, new data collected through this (or other programs) can be added to the maps. By using GIS, maps of various scale, orientation, vertical exaggeration, perspective and time period can be generated rapidly. Maps can also be rapidly updated as new data become available. During the Pilot Phase of CRMP, base maps for some proposed SSMZ sites were developed. For example, fishermen were well aware of spawning activity at Georgetown Hole and the coordinates that they offered were consistent with the clear promontory shape that was illuminated via multi-beam mapping of the same site (Harris et al. 2013; Figure 4). As further data are collected from the site, these can be added to illustrate, for example, the locations where spawning fish are documented (Figure 5).

2.1.3 Site Selection

At present, there is no formal process to prioritize or select proposed SSMZ sites for field data collection towards spawning area verification. The SAFMC should design a process of prioritizing sites for further verification and regular monitoring. Reiterating the scoping document for Amendment 36 (SAFMC 2015), the process of site identification and management is, by definition, adaptive. If new data become available through monitoring, there is a process to include that information in management. For example, if new data were to illustrate an important spawning area for speckled hind, just outside existing SSMZ boundaries, the boundaries of the SSMZ could be altered to incorporate the newly discovered spawning area. As another example, if a previously undiscovered large multi-species spawning area is identified and verified, a new SSMZ could be designated at the site. Similarly, there is a proposed sunset clause to Amendment 36 such that if no spawning is verified in 10 years within an SSMZ, it will be removed.

2.2 Underwater Video for Spawning Verification and Monitoring

Spawning activity can be documented using visual observations. Video of gamete release serves as direct evidence of spawning (Domeier and Colin 1997; Colin et al. 2003; Heyman et al. 2004). In shallow waters (i.e. < 100 feet) SCUBA can be used to document spawning using underwater visual observations and video surveys (Colin et al. 2003; Heyman et al. 2004).

Much of the spawning habitat for larger snapper-grouper complex fishes in the US South Atlantic region, however, occurs along the shelf edge, in water depths between 150 and 600 feet (Lindeman et al. 2000; Sedberry et al. 2006; Schobernd and Sedberry 2009; SAFMC 2012; 2013). As part of the development of this protocol, several video monitoring techniques (see Mallet and Pelletier (2014) for a review) were evaluated for their utility in documenting spawning areas. Two techniques have been selected. These techniques were selected based on their ability to collect high-quality data efficiently.

The CRMP SASA offers two methods to deploy GoPro underwater cameras from commercial fishing vessels to capture video in proposed or existing SSMZs. Both of these systems can be used to document courtship and spawning for verification purposes, and can be used to document species presence/absence, as well as catch per effort in either number of fish per time or density of fish per time.

2.2.1 Drop Camera Setup

The drop camera setup shown herein was designed on-the-go starting during February 2014 with Mark Marhefka. At that time, the GoPro camera was simply adhered to his "L-Bar" on his commercial "bandit rig" fishing gear (Box 1).

The author has since experimented with various attachment methods and setups, baited and non-baited deployments, various water depths and depths of deployment, times of day, various wave heights, various housings, various weights and floats, etc. After 18 months of experimentation, the equipment and deployment procedure was finalized and recommended as standard for CRMP SASA. See Appendix 2 for procedure details.

Box 1: GoPro camera on commercial gear

The drop camera setup is called the V-Go Swim (V-Go) based on its v-shape and that it is deployed directly on commercial fishing gear for fast deployment and retrieval. Instead of being moored, which requires subsequent retrieval, the V-Go is attached to a commercial bandit reel and equipped with a GoPro 3+ camera in a "dive housing" (Figure 6). The V-Go system serves to protect the camera (e.g. triggerfish bite them regularly) and also serves to help orient and stabilize the camera within the current. The V-Go Swim has the advantages of being small and compact (easily packed in carry-on luggage and stored/deployed on deck from a five gallon bucket). It has no moving parts or batteries. It has the disadvantage that it only sees in a single direction – behind the vessel or down current.

To date, videos collected using the V-Go Swim housing have been used for verification, i.e. to note species presence/absence and to document courtship behavior (Heyman 2015; LGL 2015; Figure 7). There are several ways that underwater video data can be used to measure fish abundance or density for monitoring purposes (Bacheler et al. 2013; Mallet and Pelletier 2014). The most commonly used metric, MaxN, i.e. the maximum number of fish in a single frame during the viewing interval, provides a conservative (minimum) measure of the number of fish that are on a given reef, with certainty. Though it often underestimates true abundance, MaxN is relatively simple and repeatable (Schobernd et al. 2014). MaxN is currently suggested as the most appropriate technique to monitor fish abundance using video at SSMZ sites. Further discussion and consultation with various underwater video quantification experts will be needed to select and standardize quantitative measures of density for long-term monitoring.

2.2.2 Submersible Rotating Video (SRV) System

To meet the needs of researchers on deeper reefs, Koenig and Stallings (2015) developed the Submersible Rotating Video (SRV) System for use with GoPro cameras (Box 2; Figure 8).

While the V-Go system mentioned above can be easily and rapidly deployed for verification purposes, the SRV system may be more appropriate for monitoring.

The SRV consists of a waterproof canister housing that encases a gear motor that is run by a rechargeable battery. The motor shaft extends through the top of the canister and attaches to a round platform that serves as the mounting point for a GoPro digital HD camera. The system rotates the camera slowly in order to capture an entire 360° rotation every 2 minutes. The SRV can be deployed and left in place on the bottom for up to an hour. The 2-minute rotation simulates the stationary visual point count method, the most commonly used method to count reef fish (Bohnsack and Bannerot 1986). But the common method was developed for and implemented by divers while the SRV system can be deployed in much deeper waters than divers can safely work, and it removes the potential impact of fish wariness to divers' presence (Koenig and Stallings 2015).

Box 2: Stationary Rotating Video (SRV) System

Videos are examined on a computer screen for enumeration. Fish counts are made on the first 10 revolutions (i.e. 10 replicate counts). Each of the rotations serves as a subsample or replicate count for repeated measures of the fish density at the site, offering greater statistical power.

The SRV is appealing for monitoring SSMZ sites for several reasons. First, it offers a 360° view of the site. This is particularly valuable given that many reef fish gather to spawn at shelf edges. Indeed, during field trials in 2015 at the shelf edge at Georgetown Hole, videos taken with the SRV showed big differences in habitat and fish abundance from one side of the rotation to the other (Figure 9). Second, several units can be deployed simultaneously over a larger area than can be sampled with a single camera. While this increases the amount of data for processing, it may offer a more complete picture of the fish activity and abundance over a larger fish spawning area. Third, these units could be installed and left in place for a week or more and programmed to collect data for short periods at pre-designated times. This would increase temporal coverage.

Monitoring spawning sites can be complex given the spatial and temporal variability between species and years. The process to characterize the dynamics and establish a quantitative baseline at SSMZ sites will likely be accomplished during the first two years of monitoring at each site (e.g. Heyman et al. 2005). SRV systems will likely prove valuable for characterization and monitoring.

2.3. Landings and Catch per Unit Effort

There are several methods that can be used to provide evidence of spawning that can be accomplished via fishing and biological sampling. Spawning areas may be implicated if the catch rate per effort of fully mature or running ripe females of a single species at a particular place and time increases greatly over average for that area and/or other areas and times (Colin et al. 2003;

Heyman et al. 2004). To evaluate this requires careful monitoring of catch per effort and visual analysis of gonad condition of the fishes captured.

For this component of the CRMP SASA, an observer aboard a commercial fishing vessel keeps careful track of fishing effort and landings at each fishing site using the Landings and Catch per Effort Data Sheet (Appendix 1). At each fishing site, the observer begins a new sheet and records the location with a handheld GPS, noting the waypoint number (and can later add the latitude and longitude to the sheet). The observer also notes the physical conditions of water and air temperature, wind and current speed and direction, time of day and water depth. The data sheet allows the observer to record the number of hooks and lines and to record the start and end time for each fisher (line) at the site. Then, for each line, the observer records the number of fish of each species caught and discarded. The tally can be done during fishing and should be re-checked when the boat moves off the site.

Most commercial snapper-grouper vessels in the US South Atlantic gut their fish at sea and then pack their fish in ice until they remove them at the dock after the trip. In order to gather valuable data for spawning from a commercial vessel without getting in the fishermen's way, the observer will mark (tag) the subset of fish of interest and these will remain un-gutted, but packed with the rest of the fish until the end of the trip. Fish can be tagged using spaghetti-type dart tags (e.g. from Floy) though labeled plastic wire ties have proven less expensive, easier to apply in the field and simpler to read (Figure 10). Biological sampling will take place on shore at the end of the trip. In this way, the fishermen can process most of their catch normally both at sea and at the dock, with the exception that some fish will be marked and removed for biological sampling. In addition, a larger team of scientists/observers can work together on land to do the biological sampling, making light and rapid work (Figure 11).

During data analysis, the catch per effort by species (number of fish per hook hour) can be calculated for each site/time and serve as a metric that can be compared to other recorded sites and times for monitoring SSMZs. When these data are displayed on a map using ArcGIS, the species caught by area can be illustrated in relation to depth, bathymetry and existing or proposed SSMZ boundaries. These types of maps can be very helpful in designing SSMZs. For example, the proposed SSMZ at Georgetown Hole could be designed to minimize interaction with speckled hind and warsaw grouper as recorded via the CRMP SASA during 2014 (LGL 2015; Figure 12).

2.4 Biological Sampling

Commercial vessels collecting data for the CRMP need to be in close touch with relevant authorities and scientific partners to ensure that their movements and activities are well coordinated, transparent and legal. The dates and times of data collection trips will be conducted by pre-arrangement only such that scientists and managers are aware of and agree that the proposed sampling is needed to fill existing data gaps. When vessels are returning from sampling trips, they should report their catch (in general terms) so that port samplers can be ready with appropriate equipment, data sheets and sample containers.

2.4.1 Length, Weight, Gonad Weight, Visual Condition

Biological sampling for the CRMP is consistent with standard fisheries sampling techniques that have been used for decades so only an overview of these techniques is presented here with some further detail in Appendix 2. Basic measurements of length (both fork length and total length), weight (un-gutted) and gonad weight are made using standard measuring boards and appropriate scales and recorded on the Biological Sampling Data Sheet (Appendix 1). The ratio of the weight of the gonads to the weight of the entire fish is called the gonosomatic index (GSI) (GSI = gonad weight/(whole fish weight – gonad weight) x 100) (Rhodes and Sadovy 2002). The higher the index, the closer the fishes are to spawning. Repeated measures of gonosomatic index throughout the year are used to indicate spawning season (e.g. for vermillion snapper) (Hood and Johnson 1999).

In addition to the standard measurements, CRMP includes the use of photographic evidence as part of biological sampling. These photographs serve as backup on species identification and to avoid any questioning of the legitimacy of the data collected by citizen scientists. Two photos are taken of each sampled fish. The photo numbers are recorded on the data sheet and the photos are stored in the CRMP database. One photo is of the fish caught along with their extracted gonads (e.g. Figure 13). This photo serves as a record of the fish for species identification, a record of the sex of the fish and a visual indication of the gonad condition and size. A second photo is used to record the gonad condition using a close-up (macro) photograph of the gonads with a small incision such that the eggs are more clearly visible (Figure 14B).

Visual inspection of gonads and the eggs contained inside can offer a trained citizen scientist a rapid indication of the spawning condition of the fishes being caught. In general terms, reproductive organs of fishes increase in size as a function of age/size and seasonally as a function of maturity and as they near spawning time (Figure 13). In reality, there are wide variations in the development patterns, timing and rates of reproduction and these vary among species and locations, and histological analysis is the only truly diagnostic way to evaluate gonad condition and spawning (Lowerre-Barbieri et al. 2011; Brown-Peterson et al. 2011). Nonetheless, there are visual observations that a trained citizen scientist can make that serve as strong evidence of spawning and can greatly assist in identifying the timing and location of spawning areas.

Many fishermen have observed, for example, that fish that are "ripe and running" may come onto the deck leaking eggs or milt. This is an indication of imminent spawning. Males can be ready to spawn and exhibit ripe and running gonads for several weeks prior to and even after spawning events. When females are found with hydrated gonads and/or eggs spilling from their gonopores, they will spawn within 12 hours or less. Ripe and running female fishes serve as direct evidence of spawning at that time and location. This visual observation can be confirmed using histology (see below). Visual observations of development stages can be somewhat complex and nuanced but are not beyond the capacity of fishermen trained as citizen scientists. A key component of the CRMP SASA implementation plan is to offer specific tools and training via development of a "Citizen Scientists Guide to Fish Reproduction and Development".

2.4.2 Gonad Sampling for Histology

Trained experts will largely be responsible for conducting sampling for histology at the dock, along with biological sampling, and the sample numbers will be noted on the Biological Sampling Data Sheet. Sample analysis is highly technical, time-consuming and requires an appropriate analytical laboratory (e.g. SCDNR MARMAP). Therefore, the CRMP SASA program is designed to collect histology samples, and then send these to an appropriate analytical laboratory for preparation and analysis, along with the ancillary data on the time, location, species, length, weight, gonad weight and physical conditions at the sampling location. For details on collection of gonads for histology, please see Appendix 2.

2.4.3 Otolith Collection for Aging

Otoliths, the inner ear bones of fish, are made of calcium carbonate. Fish deposit a new layer of growth daily and seasonally, and these can be used, like tree rings, to age the fish. As is the case with gonad histology, aging fish using the otolith requires an analytical laboratory to prepare the samples and highly trained technical people to read them. These skills may eventually become part of this program but for the present, CRMP SASA will only collect otolith specimens for analysis by experts at SCDNR MARMAP or some other appropriate and trusted laboratory.

Otolith removal will be an important component of the training for observers and citizen scientists in the CRMP SASA. The subject of otolith removal, preparation, reading, analysis and use in aging has been covered in detail in many other locations (e.g. Matheson et al. 1986; Wyanski et al. 2000; Harris et al. 2002, 2004, 2007; White and Palmer 2004; Burgos et al. 2007). A brief summary of this technique can be found in Appendix 2.

2.5 Other Methods

There has been rapid development of various new techniques that have only recently become available for monitoring and characterization of spawning areas, recently reviewed for Caribbean applications by Kobara et al. (2013). Several of these techniques may be highly appropriate for the CRMP SASA for use in monitoring SSMZs in the US South Atlantic region.

2.5.1 Conventional Tagging

Fish mark and recapture techniques have long been used to evaluate migration routes and distances and to illustrate connectivity between various locations (e.g. McGovern et al. 2005). While these techniques are not fully applicable to monitoring any one specific SSMZ location, it would be valuable to understand the linkages between SSMZ locations. Conventional tagging methods (i.e. external dart tags with an identification code) can be used to mark fish at the time and location of spawning. Tagged and recaptured individuals can be used to evaluate the connectivity (i.e. distances, travel times, site fidelity) between or among different spawning areas. McGovern et al. (2005) showed for example that nearly a quarter of the gag that were tagged in that study moved over 185 km, and most of those were tagged off South Carolina and recaptured in Georgia, Florida or the Gulf of Mexico. Questions of connectivity will become particularly interesting and valuable at the regional scale, described in section 6.0 of this white paper as the proposed Cooperative Research and Conservation Program for Western Central Atlantic Spawning Aggregations (CRCP WCASA).

2.5.2 Sonic Tagging and Active Acoustic Arrays

Sonic tags have been used extensively in recent years to document the movement of fish and other mobile marine animals. In short, these systems rely on a combination of sonic tags that move with the organisms and moored acoustic receivers. The tags emit a unique series of acoustic pings at specific intervals and frequencies that serve as a fingerprint for each tag. The sounds can be received and recorded (along with the time and date) by the receivers when the tags are within range (up to 900 m, depending on the size of the tag). Several studies have used these systems to illustrate spawning site fidelity and use of spawning sites (e.g. Mann et al. 2009; Coleman et al. 2011).

Once spawning areas are clearly defined in the US South Atlantic, acoustic receivers can be installed at the sites (probably three or four at each site to capture a larger area) for monitoring. At the same time, tags could be installed on species of interest to evaluate their use of the spawning area. The most common type of acoustic array for marine applications uses Vemco 69-kHz VR2W receivers (http://vemco.com/products/vr2w-69khz/), a compact, light-weight device that can easily be moored on the bottom and left to collect data for up to one year. There already exist cooperative telemetry networks in the US Atlantic (the ACT and FACT networks; http://www.theactnetwork.com) and Gulf of Mexico (iTAG; http://gcoos.tamu.edu/?p=8777), and the global Ocean Tracking Network (OTN; http://members.oceantrack.org/) that maintains a global repository for acoustic tracking data. An array in the US South Atlantic could be linked into these networks. In this way, fishes (and whale sharks or other organisms) tagged with Vemco tags that came within range of the receivers would be detected. This would illustrate connectivity of the spawning areas and further illustrate their value in terms of careful management and protection. Similarly, fishes tagged with Vemco tags in the US South Atlantic might be detected anywhere else that they travel outside of the US South Atlantic region, including the Gulf of Mexico, the Caribbean and waters off the northeastern US.

2.5.3 Passive Acoustic Monitoring

Spawning fish emit species-specific courtship and spawning sounds. Using underwater hydrophones (e.g. DSG-ST Ocean Acoustic Recorder from Loggerhead Instruments) recordings of these sounds have been used to document and monitor spawning aggregations (Mann et al. 2009). Studies with hydrophones and video simultaneously are needed to calibrate the sound recordings by species. When species calls are identified, species-specific sounds and intensities (calls per unit time) have been used to document the precise timing and peak intensity of spawning for various species (Schärer et al. 2012, 2014; Rowell et al. 2015).

The disadvantage of these systems is that the spawning location needs to be identified accurately prior to their installation since their range is relatively short (~ 500 m). The advantage of these underwater hydrophones is that they serve as remote sensing devices, monitoring the 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 SSMZ sites, once spawning areas are located and verified using techniques described above.

2.5.4 Split-beam Sonar Mapping

Acoustic technologies are increasingly being used to quantify marine biomass (see review by Taylor 2006). Different than traditional, single-beam sonar used in fish finders, split-beam sonar systems (e.g. Simrad EK 60) direct two perpendicular sonar beams into the water. Split beam systems thus allow mapping fish densities much more accurately in space and time. These systems can be operated from a relatively small boat (e.g. commercial snapper grouper vessels). The vessel uses the system to create a map of the area of interest by driving the vessel back and forth over the area of interest while recording split-beam sonar data. The data are stored and can be analyzed subsequently to illustrate the locations, densities and volumes of fish schools in relation to the bottom. These systems have been used to quantify fish biomass at spawning sites in various areas (e.g. Taylor et al. 2006). Split-beam, active hydroacoustic technologies will likely prove valuable for verification and monitoring of SSMZs.

2.6 Statistical Methods and Utility of the Data

Initial data collected using the protocol described herein will serve to verify spawning areas, species and times. As additional data are collected and analyzed within the proper statistical framework, the same techniques described herein for verification can generate indices of abundance at spawning areas during and between spawning times. Ancillary data on the physical, spatial and temporal environment (e.g. lunar day, season, seawater temperature, depth, etc.) will be collected concomitantly with biological data (fish length and age frequency, abundance, gonosomatic index, sex ratio, geomorphology, peak spawning time) at SSMZ sites throughout the South Atlantic region. As more data are collected over time and space, the data will allow for more in-depth analysis of the explanatory relationships between environmental factors and spawning time and location. An increased sample size in general will tighten confidence intervals around spawning times and locations, and support monitoring that will be able to detect quantitative changes in spawning populations within and among SSMZs.

3.0 Data Management and Distribution

All existing data collected using the CRMP SASA are stored in a database built on a Microsoft Excel platform. Various sets of data are connected with linking variables such that queries can be used to extract sets of data for any combination of species, sites or dates. The database has been used to generate a verification report for the Georgetown Hole area (LGL 2015).

At present, all data are collected on waterproof data sheets, with waterproof pens. For data security, hard copy originals are stored together and copies (in .pdf form) are stored as three identical digital copies in different locations. When the protocols and datasheets described herein (Appendix 1) are finalized via a process of vetting and peer review, the data collection sheets will be transformed into digital apps such that data can be entered directly onto tablets or smart devices and then transferred via the Internet to the database.

Once the protocol is finalized, the existing database will be upgraded to an SQL or Oracle type database system with a map-based front end. Some data products will be available publicly and updated automatically, others will be available to users via queries. The specific form and function of the data management system will be developed adaptively to match the needs of the data producers and consumers, though an initial evaluation of the requirements is presented below.

The current data management system's design was based, in part, on concepts developed for other citizen science projects (e.g. Twidale and Marty 2000; Marty and Twidale 2000). These researchers recognized that the process of scholarly research is dedicated to data quality and as such, can be very slow. By contrast, fisheries managers generally need information within much shorter time frames. To address this, Twidale and Marty created innovative, collaborative activities and approaches to data quality and data management, which CRMP will employ.

In order to check data quality and to engage users, CRMP SASA will allow users to report errors that they find in the data that they helped produce when it is displayed online (e.g. beta release of data). For example, Anecdotal Evidence Sheets will be posted and users will be permitted to comment on and/or point out errors or additions. Regular reports of errors identified and remedied will also be made available online, offering credit to those that make changes and thus providing further incentive for users to carefully check data. This in turn will lead to an overall increase in data quality (Twidale and Marty 2000). All of the changes and corrections will be stored as part of the database, such that the evolution of the data can be tracked.

3.1 Evaluating Stakeholders and their Needs

The CRMP SASA is designed to support several communities of stakeholders. Stakeholders and their relationship to the CRMP can be divided between *data producers* and *data consumers* though several can be considered as both. Broadly, commercial (and for-hire recreational) fishermen in the US South Atlantic are considered the key stakeholder groups given that they have the most to gain or lose in fisheries management. Other important stakeholders and *data consumers* include decision-makers with SAFMC, fisheries enforcement officers, scientists, seafood consumers, chefs, students and the general public. Following design theory from other programs, it is assumed that citizen scientists' interest and willingness to participate is galvanized when they see their data actually used for decision-making (Bonney et al. 2009; Dickenson et al. 2012). Similarly, data consumers have specific interests and needs so CRMP data products will be tailored for specific audiences. CRMP will also include educational products that explain how and why data are collected and their relevance to fisheries management (see section 4 on Education and Outreach).

3.2 Evaluating Monitoring System Needs: Data Collection, Entry, Management, Storage and Output

There are several issues associated with the development of any long-term monitoring and data management system. Some of the most important characteristics include:

- System must have standardized data collection and entry methods
- Data collectors must be trained and certified
- System must meet present needs
- System must be adaptable to meet future potential needs
- Data entry must be relatively simple and user friendly
- Data output must be relatively simple and user friendly

In order to address these concerns, CRMP has been developed cooperatively with relevant stakeholders, scientists and managers (see Acknowledgments). As it progresses, the protocols will be upgraded with assistance from key experts in fishing, management and scientific communities and formally vetted through a public and open peer-review process. The final system will entail a protocol and certification course for observers, to ensure that the data that they collect are accurate and consistent across all sites.

When data are returned to the central data management system, they will undergo rigorous checking before and after being entered into the database. In order to check translation errors and to perform an occasional data audit, a 5% random spot check will be conducted each year, whereby original data submissions will be compared to the database entries to evaluate possible data entry errors.

3.3 Quality Assurance/Quality Control

When data are entered in the database, quality assurance/quality control (QA/QC) systems will be implemented using a three-tier review system. The first tier will include data checking for duplicates and flagging unrealistic or wild outlier data points. All duplicate entries will be removed. The second tier will consist of statistical testing based on the statistical limits of binned data using means and standard deviations. Outliers, defined as 2.3 standard deviations away from the mean, will be identified and flagged. This process would help to identify possible errors, but also possibly interesting and valuable data. For example, if a value for catch per effort was extraordinarily high at a given time/location – it may be an indication of a spawning area. Tertiary QA/QC will occur during the synthesis and analysis phase. Again, data points that emerge and appear unrealistic will be flagged and removed from the analysis. Using this three-tiered system of flagging will alert users of suspect data that they can examine directly to determine their utility as part of specific analyses. Again, collaborative systems of data checking will also be explored and employed following successful citizen science projects (Dickinson et al. 2012).

3.4 Evaluating Criteria for Institutional Homes for CRMP SASA

There is currently no existing program, system or group that is filling the institutional gap of regional spawning area prediction, verification, monitoring and research, envisioned as the CRMP SASA. The needed institutional home should foster broad collaboration and be responsible for collecting, storing, managing and serving data on spawning aggregations within the US South Atlantic. Key elements evaluated for appropriate CRMP SASA institutional housing are:

- Long-term commitment
- Willingness and interest
- Institutional capacity
- Scientific credibility
- Trust of all stakeholders, including fishing industry and managers

There are several possible institutional homes for the CRMP for the South Atlantic region, including:

- Federal agencies
- Regional fisheries management councils
- State agencies
- Universities
- Private research or consulting companies
- Non-governmental organizations

Though all institutions to be considered for evaluation must be trustworthy and credible, some amount of distrust between stakeholder groups has hindered cooperative research in the region. This program must not be seen as too tightly tied to any single institution because the trust, confidence and support of all stakeholders are of paramount importance.

There are logical efficiencies, economies of scale and regional conservation and management benefits that can be gained by building and operating a single Cooperative Monitoring and Conservation Program for Western Central Atlantic Spawning Aggregations (CMCP WCASA) (section 6.0). Though there are regional differences and various suites of techniques will be required, the core data will be similar across platforms. The analysis herein provides a basis for broad discussion about the most appropriate institutional home for the CRMP SASA database.

4.0 Education and Outreach

To maximize its effectiveness and reach, the CRMP SASA will include a small, targeted education and outreach program. The first goal of this component will be to ensure that data collectors – both fishermen and observers – are properly trained for data and sample collection and management. This training will include on-the-water training for approximately five fishermen and five observers. Similarly, as the number of underwater videos produced in this program will increase rapidly, there will be a need to train additional video observers to quantify fish numbers and densities by species and to identify and describe courtship and spawning behaviors.

As funding becomes available a "Citizen Scientists Guide to Fish Reproduction and Development" (Figure 15) will be developed for release in the US South Atlantic Region. The final product is envisioned as a two-sided laminated pamphlet that shows snapper-grouper gonad development stages and how they can be recognized visually and through histology. This will allow a wider group of stakeholders, both on the water and in the fish houses, to recognize when they encounter spawning fishes and potentially contribute to data collection.

For the longer term and depending on available funding, the education and outreach program would produce several products largely targeting fishermen and seafood consumers. These products will include:

- A web-based map and data server with a menu of standard data products tailored to various user groups
- An online virtual classroom for monitoring training, education and outreach
- A series of mini-documentary films from users in the network
- A fisher-ambassador program supporting fishermen participation in management
- Fisher exchanges

More details about these products and programs will be outlined in subsequent drafts of this white paper.

5.0 Implementation Plan and Program Needs

There is a direct and immediate need to collect data for verification of proposed SSMZ sites in order to support the design and monitoring of SSMZs proposed in Amendment 36 to the SG FMP (SAFMC 2015). The protocol described herein has been used to predict and verify a spawning aggregation at Georgetown Hole (LGL 2015), though it continues to evolve with additional testing and development. The envisioned CRMP SASA implementation phases are as follows:

Design Phase 2014–2015

The development of this first formal draft of the CRMP SASA builds on nearly 20 years of research on spawning areas in many parts of the world, and the initial design and testing phase was completed largely during 2014 and 2015.

Pilot Phase 2016–2020

The pilot phase of the CRMP SASA would entail prediction and field data collection for verification at multiple sites using a standardized monitoring protocol and adequate equipment, with funding for monitoring and data analysis. Sustained effort over this time will ensure that robust partnerships, monitoring efforts, outreach materials and data management systems are put into place.

Initial steps to implementation are:

1. Finalize this protocol.
2. Develop training materials and implement courses for fishermen and new observers.
3. Design, build and implement a full-scale data management system (with adequate staffing and support) with input from experts and users that will be able to grow with the program and support management needs. The system will include a web-based map and data server with a menu of standard data products tailored to various user groups. For example, users could request monitoring data for specific sites (e.g. number/density by species over time). The system will require adequate hardware and software and management, and will be supported via an annual user conference.
4. In close consultation with the SAFMC, select and prioritize areas and times for field data collection. Collect new data at high-priority times and locations. Define a process by which additional potential SSMZ sites that are identified or revealed during the pilot phase can be added to the priority list and data collection process and program.
5. Purchase and maintain materials and supplies for data collection. Primary materials and supplies for data collection in this program are listed within each section of the monitoring protocol but primarily consist of GoPro cameras with dive housings and deployment gear, Hobo Tidbit temperature loggers, materials for biological sampling and preparation, data sheets and GPSs.
6. Develop educational and outreach materials. Define strategies to disseminate the information.

Long-term Monitoring Phase 2017-2047

Monitoring of SSMZ sites should continue indefinitely in order to support stock assessments and, ultimately, as a new and robust data stream that can be used to evaluate population status. Repeated counts of the number of individuals and their size/age frequency at various SSMZ sites might provide an independent evaluation of the stock. Using the CRMP protocol, biological samples could be taken both within and outside established SSMZs as a means to support targeted research or stock assessment needs. In addition, SSMZ sites could be used as long-term monitoring stations for passive and active acoustic receivers to monitor the movement of individual fishes and overall spawning activity and for physical measurements of temperature and, ultimately, currents and other physical water quality aspects.

Ideally, the CRMP in the US South Atlantic would serve as a seed for a wider, regional program, the CRCP WCASA (Heyman 2014; Section 6.0).

6.0 Regional Approach: Cooperative Research and Conservation Program for Western Central Atlantic Spawning Aggregations (CRCP WCASA)

The CRMP SASA described within this white paper is designed to serve the US South Atlantic region. The approach of monitoring and conservation of multi-species spawning aggregations has significance throughout the western central Atlantic region (Heyman 2014; Figure 16). Indeed, many of the species that aggregate to spawn in the US South Atlantic also inhabit waters of the Caribbean and the Gulf of Mexico.

In some areas in the Western Central Atlantic (Figure 16) great strides have been made in identifying and characterizing spawning areas, particularly in the Caribbean. Extensive site-based characterization work over the past 20 years (Aguilar-Perera and Aguilar-Dávila 1996; Claro and Lindeman 2003; Whaylen et al. 2004; Nemeth 2005; Heyman and Kjerfve 2008; Kobara and Heyman 2010; Schärer et al. 2012) and regional data sharing have fostered regional synthesis about the timing and location of multi-species spawning aggregation sites (Kobara et al. 2013). By contrast, there exists almost no information about the timing and location of spawning areas in the US waters of the Gulf of Mexico. Further monitoring of known sites, along with prediction, verification and monitoring of new sites and regionally coordinated monitoring and management efforts are needed to track the status of the spawning sites and the populations that they represent (Heyman 2014).

In conclusion, the CRMP SASA described herein could form the first major citizen science program in the US that involves fishermen in data collection for management purposes. If successful and implemented, it could serve as a model and seed for the implementation of similar regional programs that together could be linked at the scale of the Western Central Atlantic. The program could ultimately help to monitor and restore healthy snapper-grouper populations throughout the region.

7.0 Literature Cited

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

Beets J, Friedlander A (1992) Stock analysis and management strategies for red hind, Epinephelus guttatus, in the U.S. Virgin Islands. Proceedings of the Gulf and Caribbean Fisheries Institute 42:66-79

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

Burgos JM, Sedberry GR, Wyanski DM, Harris PJ (2007) Life history of red grouper (*Epinephelus morio*) off the coasts of North Carolina and South Carolina. Bulletin of Marine Science 80:45–65

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

Cuellar N, Sedberry GR, Machowski DJ, Collins MR (1996) Species composition, distribution and trends in abundance of snappers of the southeastern USA, based on fishery independent sampling. In: Arreguin-Sanchez F, Munro JL, Balgos MC, Pauly D (eds) Biology, fisheries and culture of tropical groupers and snappers. ICLARM Conference Proceedings 48, pp 59–73

Daniel EA (2003) Sexual maturity, spawning dynamics, and fecundity of red porgy, *Pagrus pagrus*, off the southeastern United States. M.S. Thesis, College of Charleston, 79 p

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. Prediction and verification of the timing and location of reef fish spawning activity in the Atlantic Ocean off the southeastern United States, in preparation

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 MS, Sautter LR, Johnson KL, Luciano KE, Sedberry GR, Wright EE Siuda ANS (2013) Continental shelf landscapes of the southeastern United States since the last interglacial. Geomorphology, available online at http://dx.doi.org/10.1016/j.geomorph.2013.02.014

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

Heppell S, Semmens BX, Archer SK, Pattengill-Semmens CV, Bush PG, McCoy CM, Heppell SS, Johnson BC (2012) Documenting recovery of a spawning aggregation through size frequency analysis from underwater laser calipers measurements. Biological Conservation 155:119–127

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

Kelly A (2014) Age, growth, and reproduction of gray triggerfish *Balistes capriscus* off the southeastern U.S. Atlantic coast. M.S. Thesis, College of Charleston, 54 p

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

Marty PF, Twidale MB (2000). Unexpected help with your web-based collections: encouraging data quality feedback from your online visitors. In D. Bearman & J. Trant (Eds.), *Museums and the Web 2000*. Pittsburgh: Archives & Museum Informatics. Available online at http://www.archimuse.com/mw2000/papers/marty/marty.html

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) (1983) Fishery Management Plan, Regulatory Impact Review and Final Environmental Impact Statement for the Snapper Grouper Fishery of the South Atlantic Region. South Atlantic Fishery Management Council, Charleston,

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

SEDAR (2011) SEDAR 25 - South Atlantic black sea bass stock assessment report. SEDAR, North Charleston, 146 p, available online at http://www.sefsc.noaa.gov/sedar/Sedar_Workshops.jsp?WorkshopNum=25

SEDAR (2013) SEDAR 36 – South Atlantic snowy grouper stock assessment report. SEDAR, North Charleston, 146 p, available online at http://www.sefsc.noaa.gov/sedar/Sedar_Workshops.jsp?WorkshopNum=36

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.

Twidale MP, Marty PF (2000) An Investigation of Data Quality and Collaboration. http://people.lis.illinois.edu/~twidale/pubs/dq.html

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

Tables and Figures

Table 1: Species managed in the snapper-grouper complex of the US South Atlantic. Species marked in bold are known to reproduce via seasonal migration to specific spawning areas (Sedberry et al. 2006; Coleman et al. 2011; Kobara et al. 2013). Ecosystem Component Species (*) do not have specific management measures in place (list of species from SAFMC website (Accessed 22 July 2015)). South Atlantic common names provided by Rusty Hudson.

Common Name	Species Name	Common Name in South Atlantic
Sea basses and Groupers (Serranidae)		
Gag	***Mycteroperca microlepis***	**Gray grouper; males: Blackbelly or charcoal**
Red grouper	***Epinephelus morio***	
Scamp	***Mycteroperca phenax***	**Lacey tail**
Black grouper	***Mycteroperca bonaci***	**Carbarita**
Rock hind	*Epinephelus adcensionis*	
Red hind	***Epinephelus guttatus***	**Strawberry grouper**
Graysby	*Cephalopholis cruentata*	
Yellowfin grouper	***Mycteroperca venenosa***	
Coney	*Cephalopholis fulva*	
Yellowmouth grouper	*Mycteroperca interstitialis*	
Goliath grouper	***Epinephelus itajara***	**Jewfish**
Nassau grouper	***Epinephelus striatus***	
Snowy grouper	*Epinephelus niveatus*	Chocolate grouper
Yellowedge grouper	*Epinephelus flavolimbatus*	
Warsaw grouper	*Epinephelus nigritus*	
Speckled hind	*Epinephelus drummondhayi*	Kitty Mitchell
Misty grouper	*Epinephelus mystacinus*	
Black sea bass	*Centropristis striata*	Greenhead (large males)
Bank sea bass *	*Centropristis ocyurus*	
Rock sea bass *	*Centropristis philadelphica*	
Wreckfish (Polyprionidae)		
Wreckfish	*Polyprion americanus*	Helmethead

Common Name	Species Name	Common Name in South Atlantic
Snappers (Lutjanidae)		
Queen snapper	*Etelis oculatus*	
Yellowtail snapper	***Ocyurus chrysurus***	
Gray snapper	***Lutjanus griseus***	**Mangrove or Mango**
Mutton snapper	***Lutjanus analis***	**Dean Mutton**
Lane snapper	***Lutjanus synagris***	
Cubera snapper	***Lutjanus cyanopterus***	
Dog snapper	***Lutjanus jocu***	
Schoolmaster *	*Lutjanus apodus*	
Mahogany snapper	*Lutjanus mahogoni*	
Vermilion snapper	*Rhomboplites aurorubens*	Beeliner, Redeyes
Red snapper	*Lutjanus campechanus*	Chicken, Pony, Sow and Mule (based on size)
Silk snapper	*Lutjanus vivanus*	Yelloweye
Blackfin snapper	*Lutjanus buccanella*	
Black snapper	*Apsilus dentatus*	
Porgies (Sparidae)		
Red porgy	*Pagrus pagrus*	Pinky, pink snapper, pink porgy
Knobbed porgy	*Calamus nodosus*	
Jolthead porgy	***Calamus bajonado***	
Scup	*Stenotomus chrysops*	
Whitebone porgy	*Calamus leucosteus*	
Saucereye porgy	***Calamus calamus***	
Longspine porgy *	*Stenotomus caprinus*	
Grunts (Haemulidae)		
White grunt	*Haemulon plumieri*	
Margate	***Haemulon album***	
Tomtate	*Haemulon aurolineatum*	Red mouth grunt
Sailor’s choice	*Haemulon parra*	
Cottonwick *	*Haemulon melanurum*	
Jacks (Carangidae)		

Common Name	Species Name	Common Name in South Atlantic
Greater amberjack	***Seriola dumerili***	**AJ**
Almaco jack	*Seriola rivoliana*	
Banded rudderfish	*Seriola zonanta*	Amberine
Bar jack	***Caranx ruber***	
Lesser amberjack	*Seriola fasciata*	
Tilefishes (Malacanthidae)		
Golden Tilefish	*Lopholatilus chamaeleonticeps*	
Blueline tilefish	*Caulolatilus microps*	Gray tile
Sand tilefish	*Malacanthus plumier*	
Triggerfishes (Balistidae)		
Gray triggerfish	*Balistes capriscus*	
Ocean triggerfish *	***Canthidermis sufflamen***	
Wrasses (Labridae)		
Hogfish	***Lachnolaimus maximus***	
Spadefishes (Eppiphidae)		
Atlantic spadefish	***Chaetodipterus faber***	

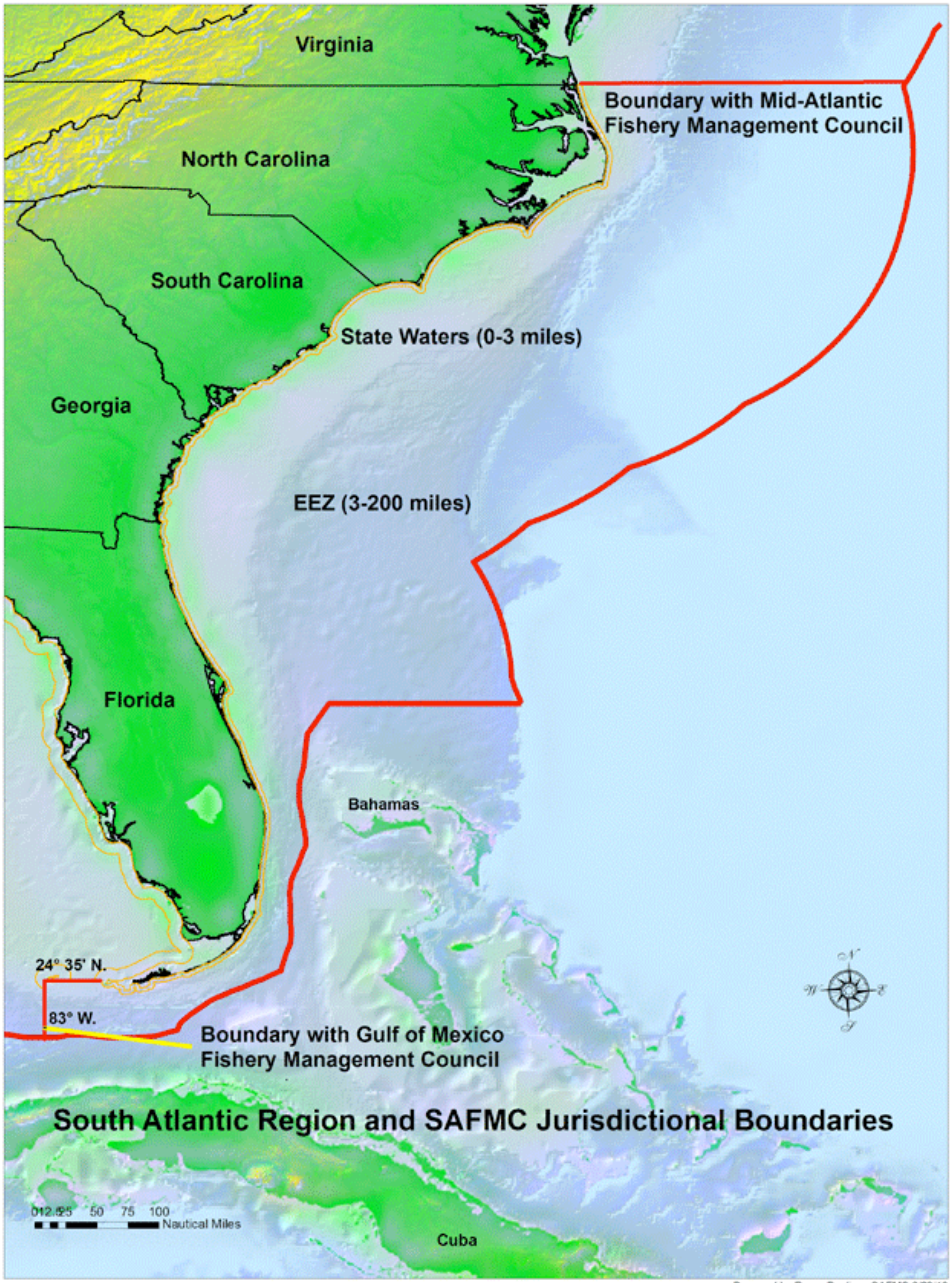


Figure 1: The US South Atlantic Region, under jurisdiction of the South Atlantic Fishery Management Council (http://safmc.net/sites/default/files/EEZoffSAStatesJune2010Web2.gif).

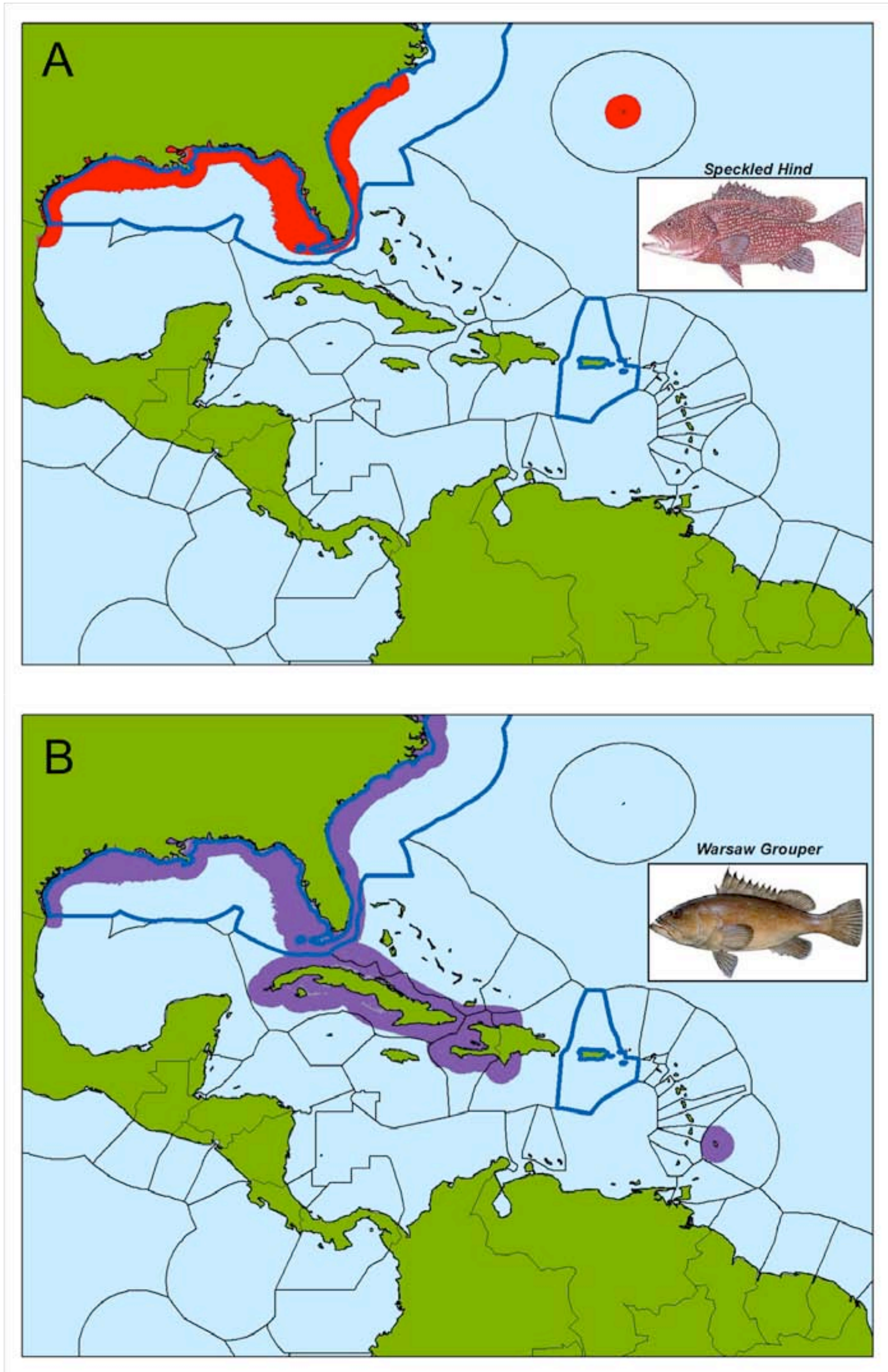


Figure 2: Species of the snapper-grouper complex have geographic ranges (data from IUCN Red List of Threatened Species, http://www.iucnredlist.org/details/7854/0) that range well beyond the US South Atlantic. A) Speckled hind *Epinephelus drummondhayi*, B) Warsaw grouper *Epinephelus nigritus*, C) Black grouper *Mycteroperca bonaci*, D) *Mycteroperca venenosa*.

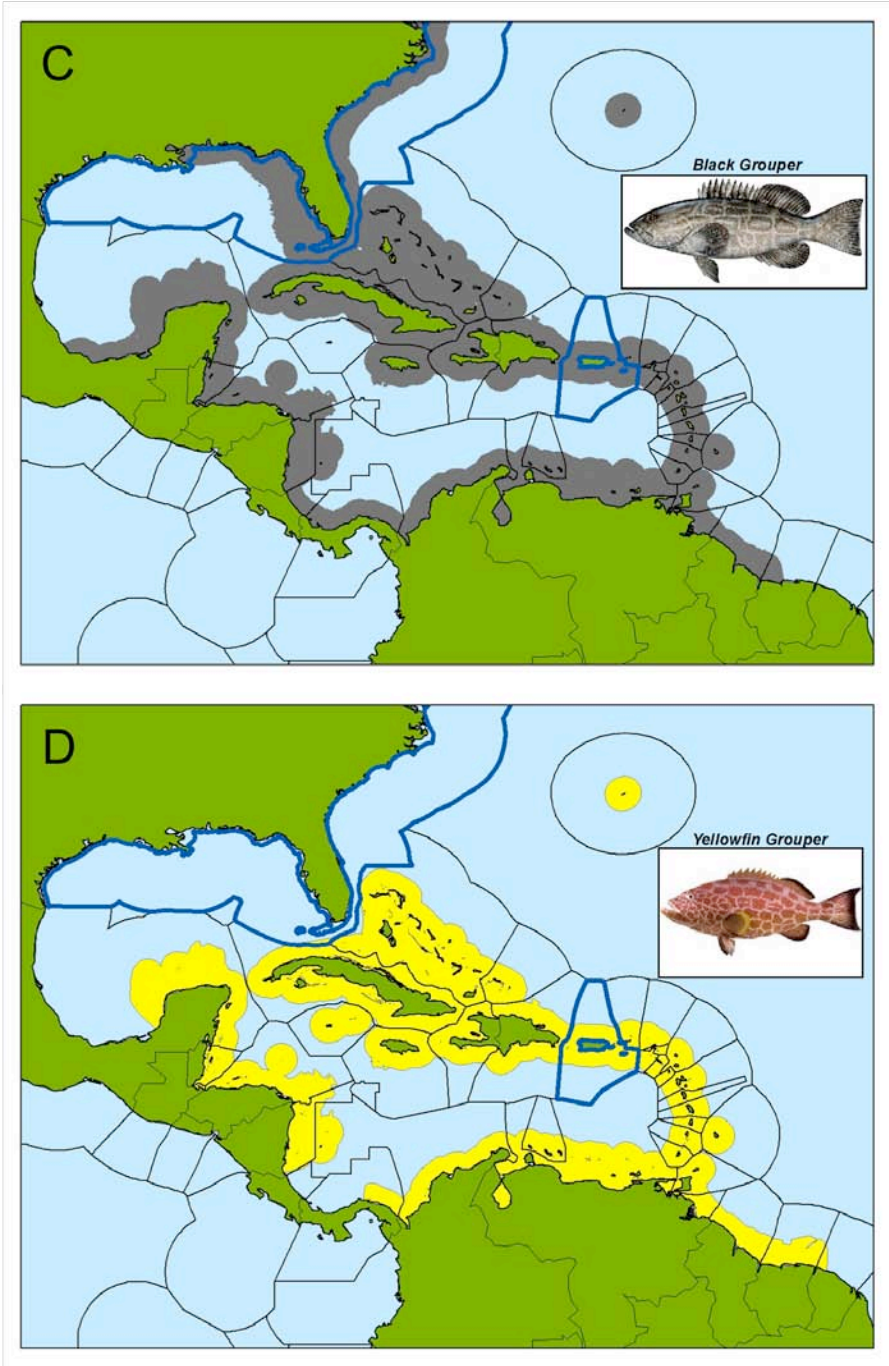


Figure 2 (cont'd): Species of the snapper-grouper complex have geographic ranges (data from IUCN Red List of Threatened Species, http://www.iucnredlist.org/details/7854/0) that range well beyond the US South Atlantic. A) Speckled hind *Epinephelus drummondhayi*, B) Warsaw grouper *Epinephelus nigritus*, C) Black grouper *Mycteroperca bonaci*, D) *Mycteroperca venenosa*.

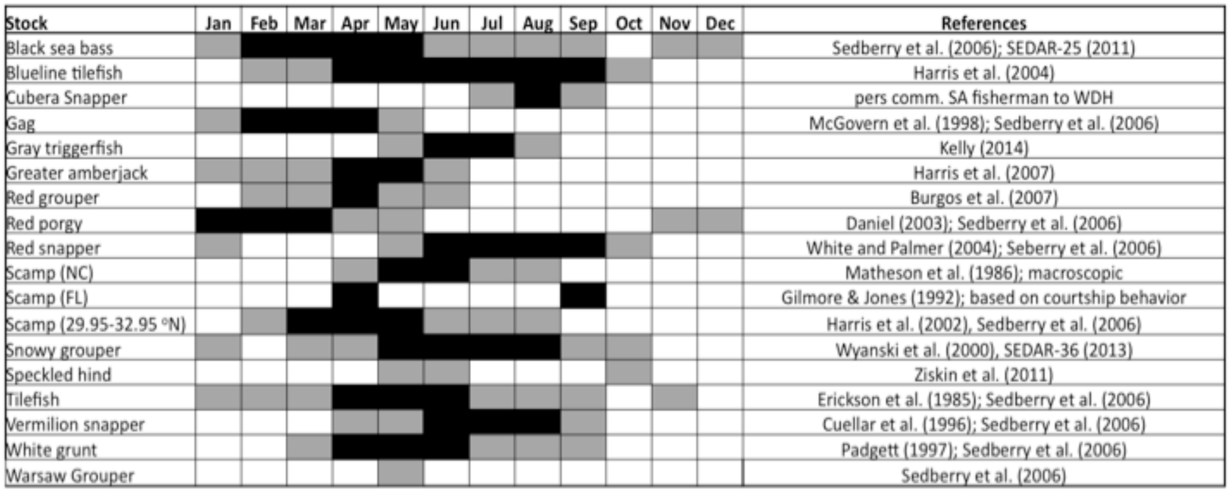


Figure 3: Peak spawning times for South Atlantic snapper-grouper species (Farmer et al. in prep).

"Georgetown Hole (also called Devil's Hole): The cuspate bottom topography of Georgetown Hole contains steep and rugged bottom preferred by SH and WG, as well as known occurrences of these species in fishery independent sampling (including spawning locations of SH). . . and both include populations of many snapper grouper species. . . The Georgetown Hole is an important bottom- and pelagic-fishing area and a shelf-edge habitat where SH were caught. . .

NE corner: 32.70°N / -78.64°W (32°42'0"N / 78°38'24"W)
NW corner: 32.70°N / -78.48°W (32°42'0"N / 78°28'48"W)
SE corner: 32.54°N / -78.64°W (32°32'24"N / 78°38'24"W)
SW corner: 32.54°N / -78.48°W (32°32'24"N / 78°28'48"W)"

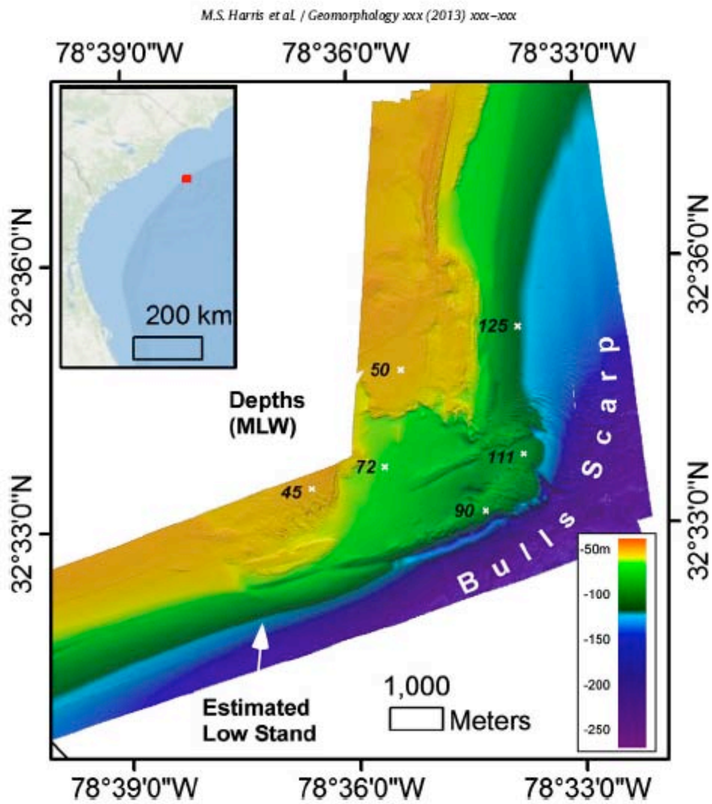


Figure 4: Predicted spawning aggregation site at Georgetown Hole. Prior to the availability of the high-resolution bathymetric data shown herein (Harris et al. 2013), fishermen were aware of the general location and described the area as a multi-species spawning area with high encounter rates of Warsaw grouper (WG) and speckled hind (SH) (location data and excerpts from SAFMC 2012).

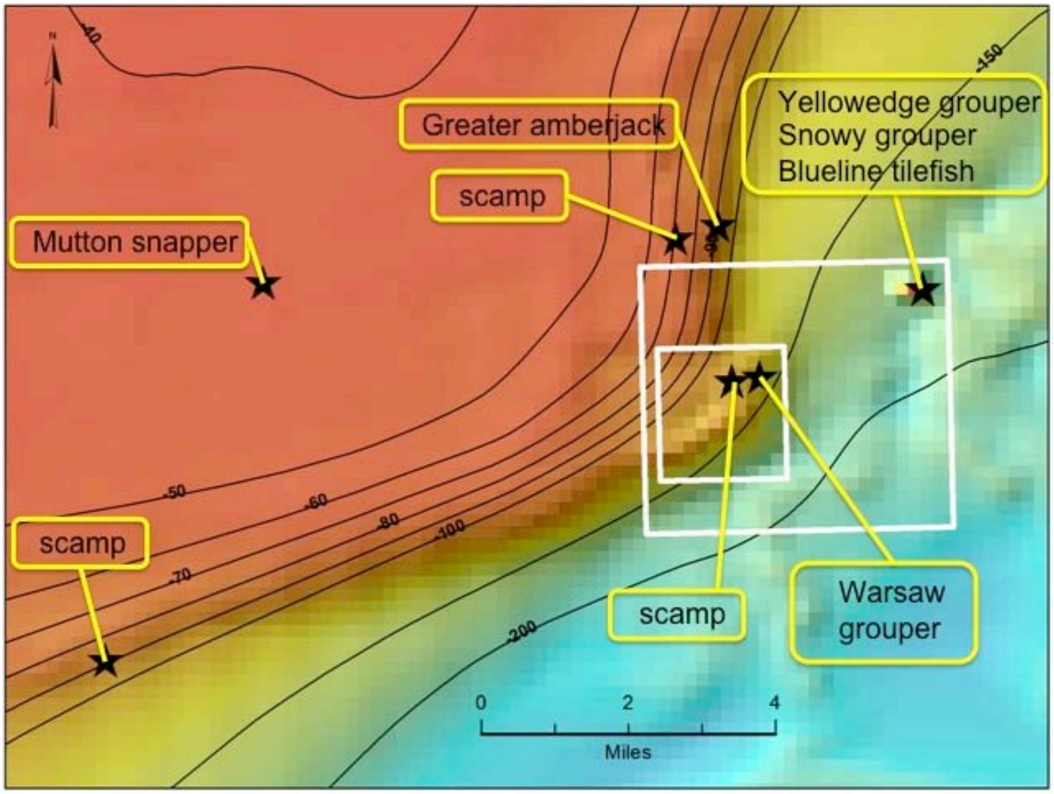


Figure 5: Spawning locations (black stars) for six snapper-grouper complex species in the area of Georgetown Hole as documented using the CRMP protocol during 2014. Biological samples were collected aboard the commercial fishing vessel F/V *Amy Marie*; histology analysis of female gonads used to document spawning was completed at SCDNR MARMAP. Contours are depth (m) based on multi-beam bathymetry data. White squares are proposed SMZ boundaries containing 3.0 and 15.1 square miles, respectively. (Map produced by K. McCain and included in LGL 2015.)

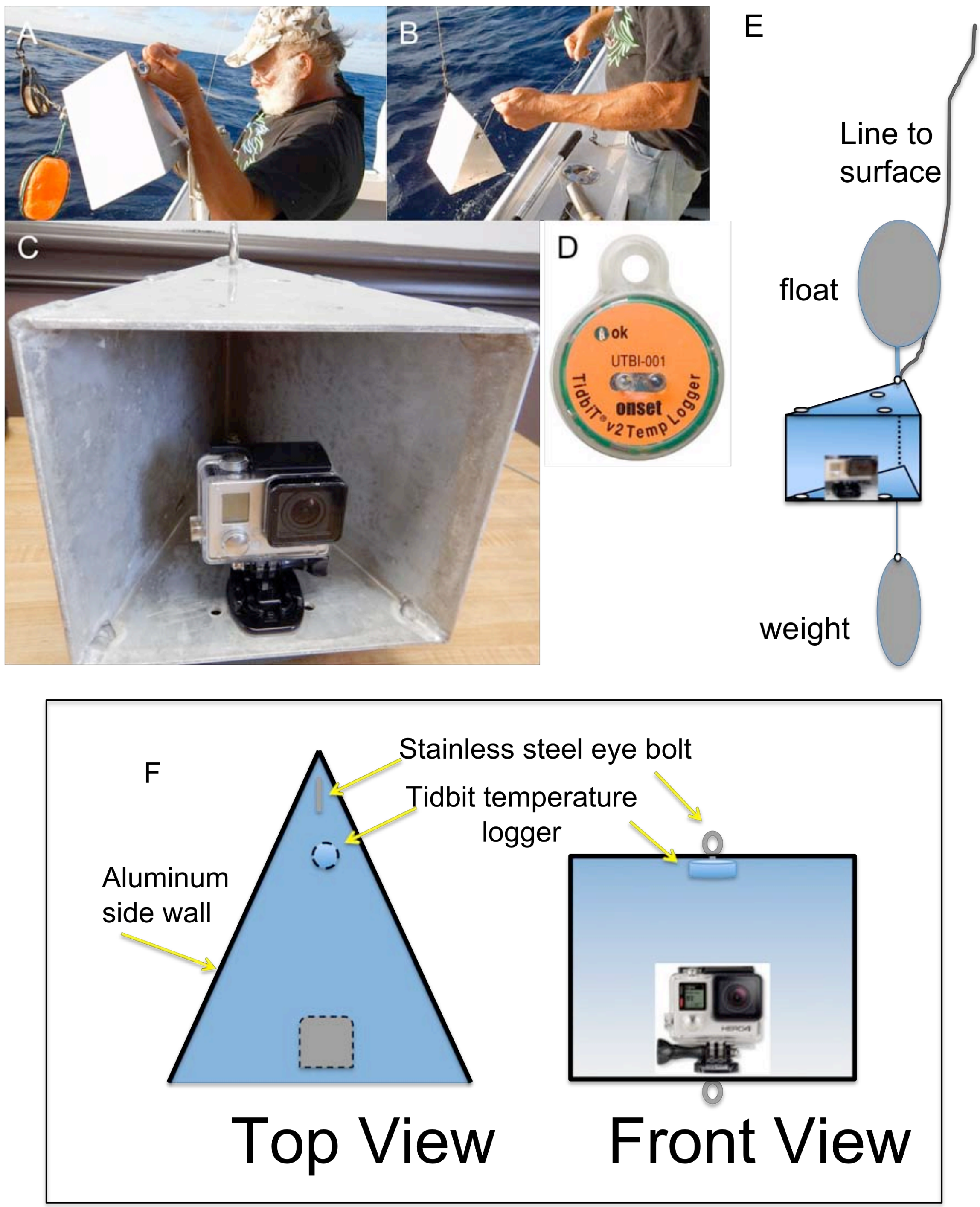


Figure 6: V-Go Swim video monitoring system was developed for use in the CRMP SASA. A, B) The system is small and portable making it quickly and easily deployed from a commercial snapper grouper vessel using electric or hydraulic bandit reels. C) A GoPro camera is attached within the small aluminum housing, along with a D) Tidbit V2 temperature logger. E) The housing is dropped to the bottom and held vertically by a buoy above and a weight below. F) Diagrams of top and front views.

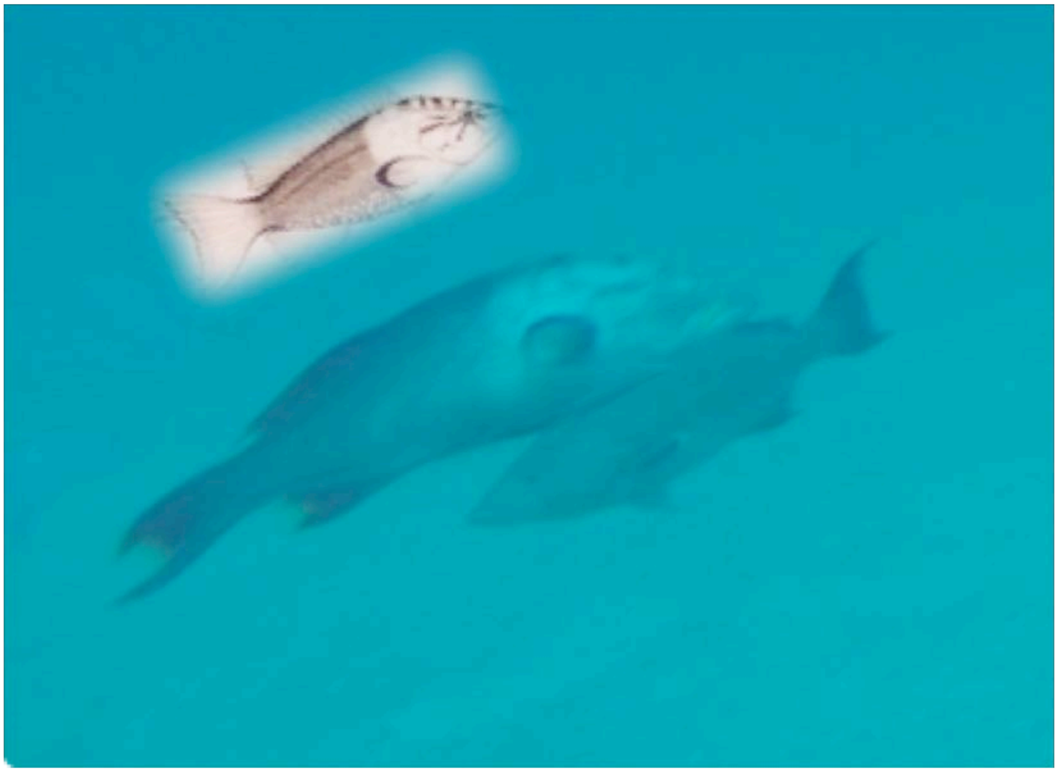


Figure 7: Courtship coloration (grey-head coloration phase shown with the inset diagram from Gilmore and Jones 1992) and behavior of scamp grouper (*Mycteroperca phenax*) recorded in the Georgetown Hole area with a GoPro 3+ camera in deployed on commercial bandit fishing gear from the F/V *Amy Marie* at 10:40 AM local time on 25 April 2014 in 42 m water depth. This occurred during the known spawning season for this species and serves as indirect (non-conclusive) evidence of spawning activity in the area.

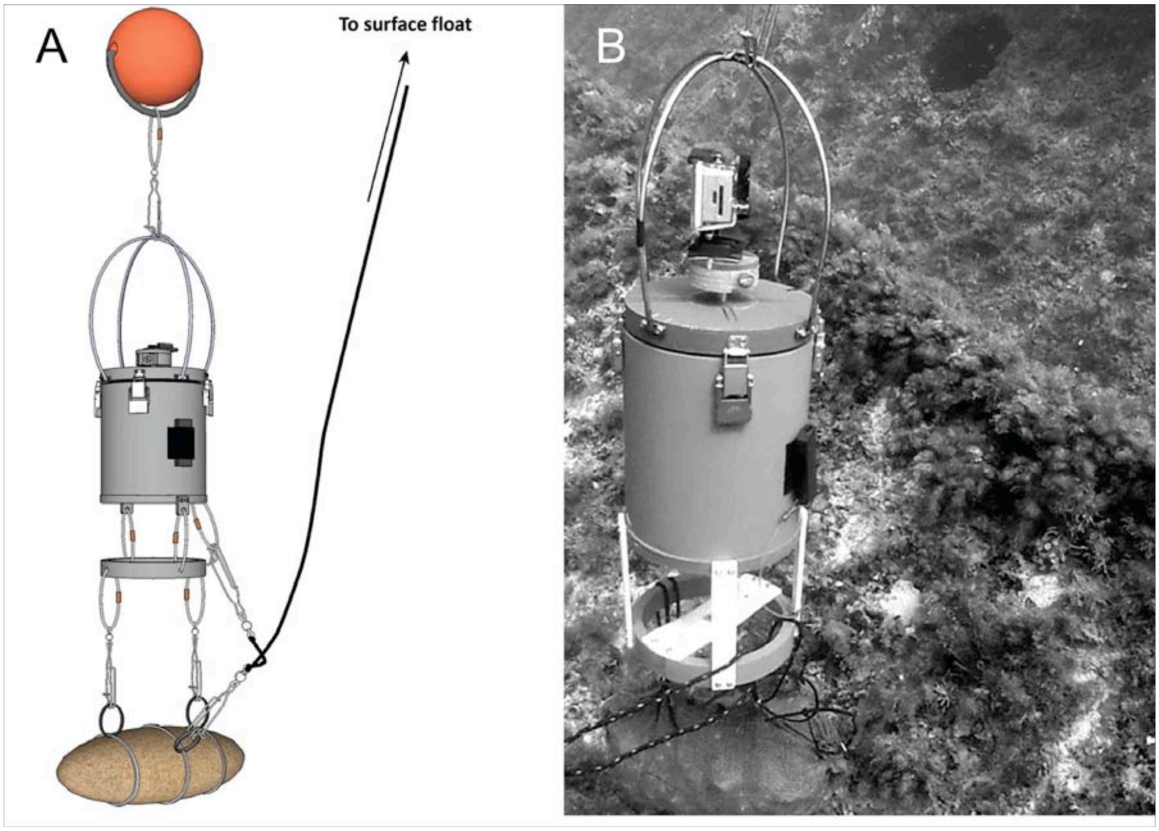


Figure 8: Submersible Rotating Video (SRV) System showing A) diagram of the unit including attachment points for buoy and weights, B) in action. This unit was developed to survey reef fishes. Design and images herein are from Koenig and Stallings (2015).

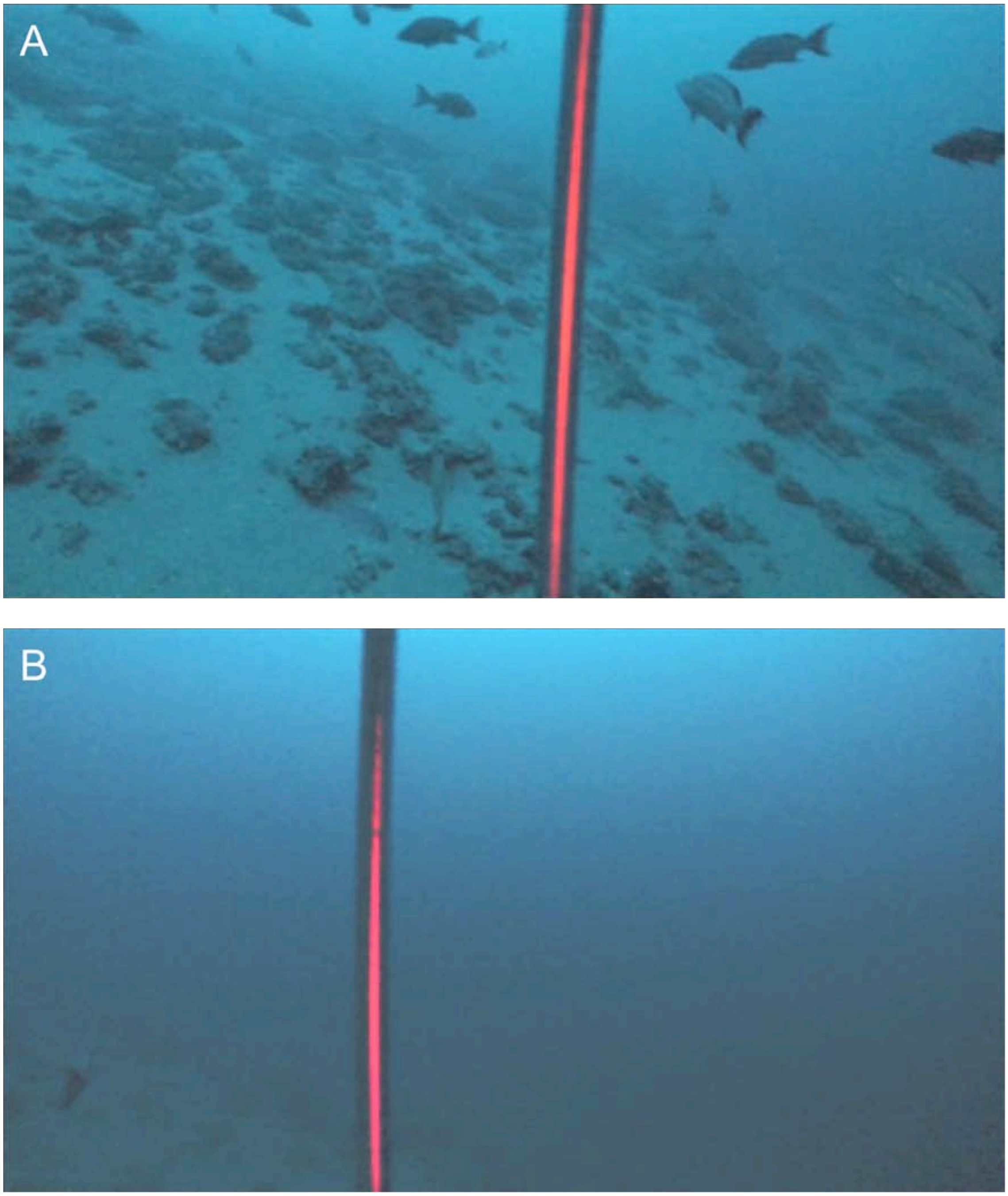


Figure 9: A) A dense grouping of scamp grouper (*Mycteroperca phenax*) associated with highly rugose and steeply sloping shelf edge at Georgetown Hole, recorded with a Submersible Rotating Video (SRV) system (Koenig and Stallings 2015). B) Taken only seconds later than (A), when the camera has rotated to point away from the shelf edge, the water appears deeper and the fish density is much lower. These still photos extracted from video illustrate the value of the SRV in providing a 360° view of the area being surveyed. There are clear differences in benthic habitat at the shelf edge and fish fauna between A) shallow and B) shelf edge camera views. A single camera facing only one direction may have mischaracterized (overestimated or underestimated) fish density at the site.

Figure 10: Top) A red grouper (*Epinephelus morio*) tagged with a plastic wire tie through the mouth during a sampling trip. Bottom) The same fish was photographed on 15 June 2015 with the reproductive organs removed and displayed on the side of the fish. The tag number (33) is clearly visible. The photo is entered into the CRMP database as backup to the recorded visual observation that this fish is male with relatively small, early development stage testes – i.e. not a spawner and not in spawning season.

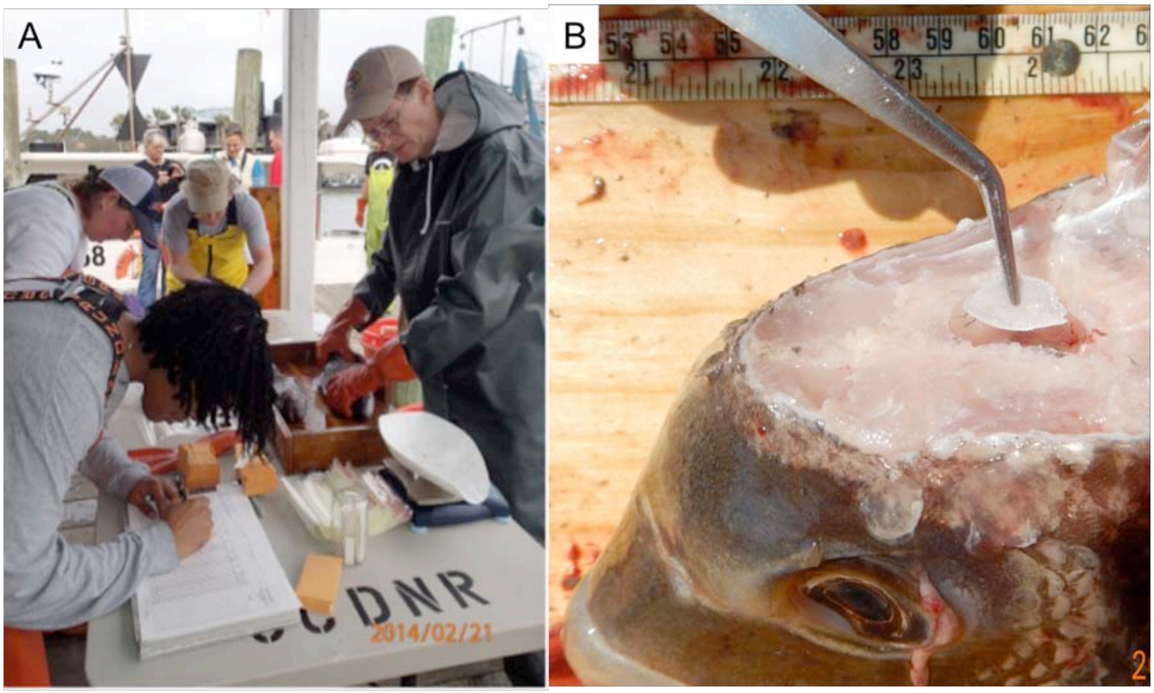


Figure 11: A) Team of scientists from SCDNR MARMAP working up samples from a commercial vessel collected using the incipient CRMP SASA protocol described herein. B) Otoliths being removed from the head of a sheepshead (*Archosargus probatocephalus*) for aging the fish.

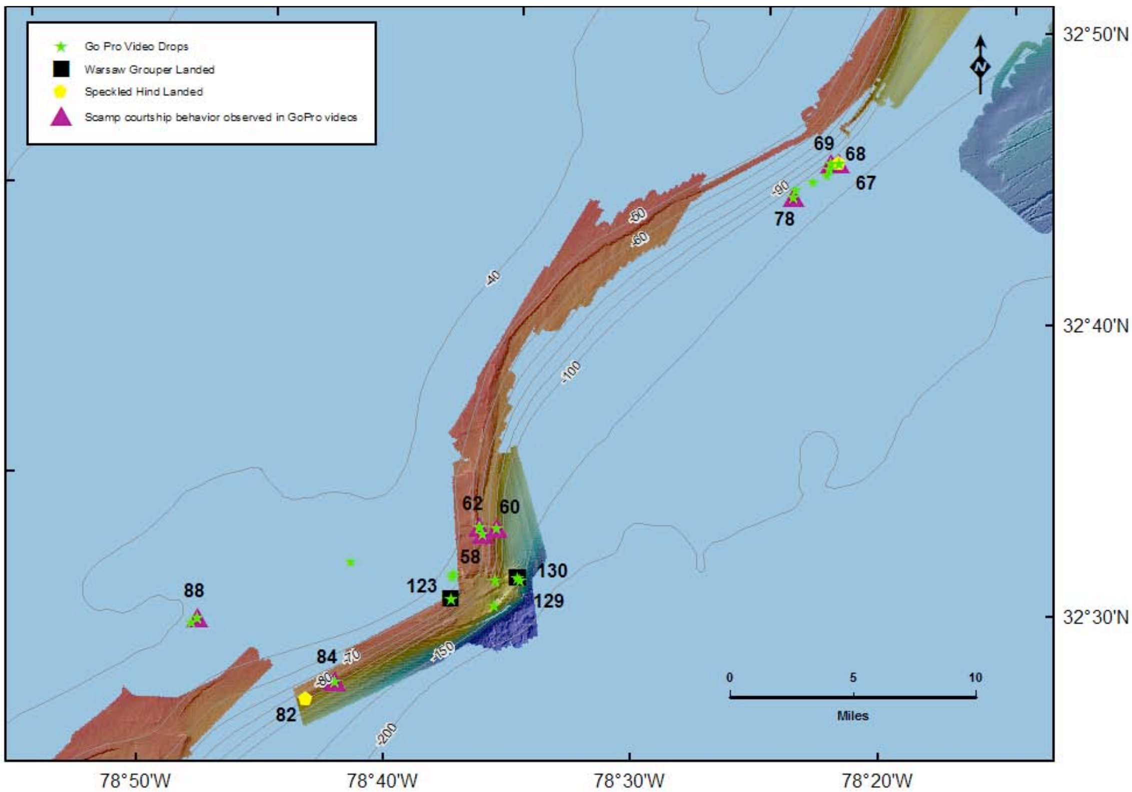


Figure 12: Map of Georgetown Hole illustrating the locations where speckled hind (*Epinephelus drummondhayi*; yellow pentagons) and Warsaw grouper (*Epinephelus nigritus*; black squares) were caught and recorded using this CRCP SASA protocol (from Heyman 2015). The locations where scamp grouper (*Mycteroperca phenax*) courtship behavior was documented are shown with magenta triangles, with reference to all camera drop locations during the 2014 (green stars). This type of data can be useful in designing and monitoring SMZs.

Figure 13: A) A female Almaco Jack (*Seriola rivoliana*) caught near the 881 Wreck along the shelf edge off North Carolina on 10 June 2015 in 31.3 fathoms of water. The gonads are removed and displayed on the side of the fish following section 2.4 and the photograph is stored in the CRMP database. The fish weight, 10.5 kg, and gonad weight, 0.46 kg, were recorded and used to calculate the gonosomatic index, 46 (GSI = gonad weight/(whole weight – gonad weight) x 100). The high GSI indicates that the sample was taken prior to but near the peak of spawning season. B) A female gag grouper (*Mycteroperca microlepis*) caught 11 June 2015 in the same area as the Almaco above. The resting state gonads and low GSI (1) are as expected given the sampling date in June, well after the end of the spawning season for gag grouper (Figure 2).

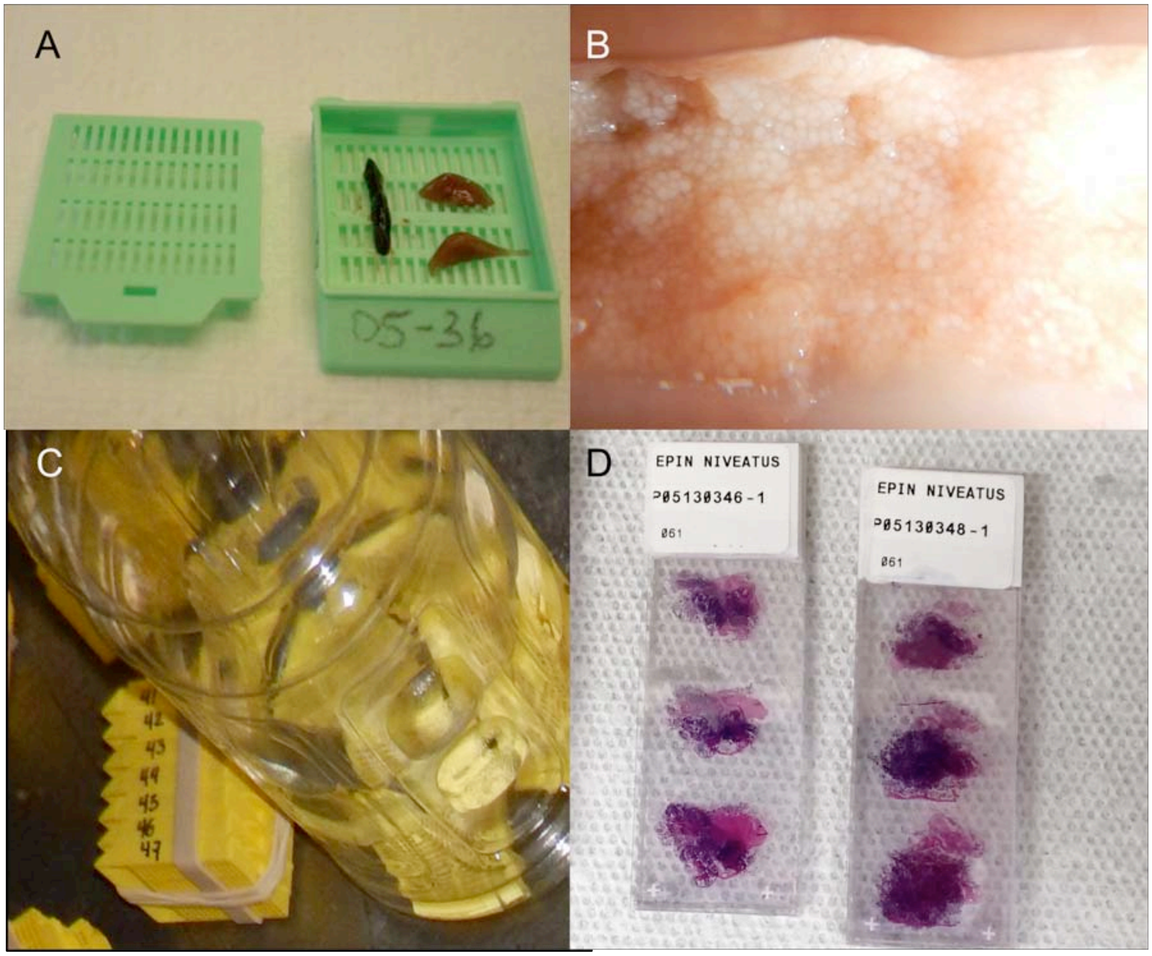
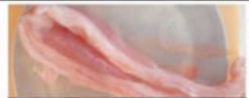


Figure 14: Gonad sampling for histology – A) Small sections (< 3 mm thick; less than the size of a US dime) are gently cut from B) the gonad and placed into an appropriately labeled histology cassette. C) Cassettes containing gonad tissues are transferred to 10% buffered formalin for fixing. D) Fixed samples are transported to an analytical laboratory for preparation. The end product is a thin, stained section of the fixed and prepared gonad tissue, affixed to a microscope slide, ready for analysis.

Code	Reproductive Development Stage	Macroscopic Description	Macroscopic Photo	Microscopic Description
I	Immature (never spawned)	Small ovaries, often clear, blood vessels indistinct.		Only oogonia and PG oocytes present. No artesia or muscle bundles. Thin ovarian wall and little space between
ED	Early development (ovaries beginning to develop, but not ready to spawn)	Enlarging ovaries, blood vessels becoming more distinct.		PG, CA, Vtg1, and Vtg2 oocytes present. No evidence of POFs or Vtg3 oocytes. Some atresia can be present.
LD	Late development (spawning capable: fish are developmentally and physiologically able to spawn during this spawning season)	Large ovaries, blood vessels prominent. Individual oocytes visible macroscopically.		Vtg3 oocytes present or POFs present in batch spawners. Atresia of vitellogenic and/or hydrated oocytes may be present. Early stages of OM can be present
RR	Running ripe, hydrated, actively spawning	Oocytes are hydrated, prominent and visible, sometimes leaking from the gonopore. This phase is rapid (24 hours maximum)		Oocytes undergoing late GVM, GVBD, hydration, or ovulation.
S	Spent, post Spawn (recent spawning)	Flaccid ovaries, blood vessels prominent. This phase is rapid (a few days maximum).		Atresia (any stage) and POFs are present. Some CA and/or vitellogenic (Vtg1, Vtg2) oocytes present.
R	Regenerating,resting, sexually mature but reproductivley inactive	Small ovaries with blood vessels reduced but present. Ovarian wall is thicker than those of immature fish		Only oogonia and PG oocytes present. Muscle bundles, enlarged blood vessels, thick ovarian wall; POFs may be present.

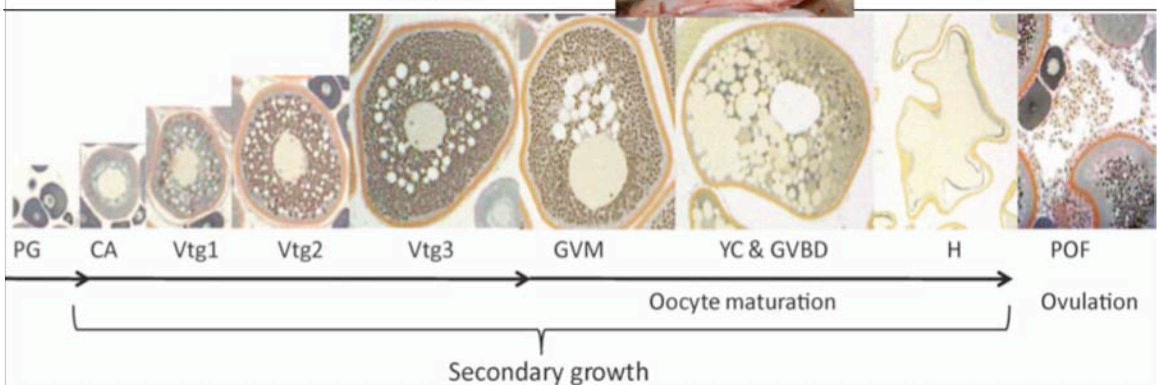


Figure 15: Female reproductive development stages can generally be identified based on macroscopic observations but definitively via microscopic observations via histology. The timing and details of each phase vary among reproductive strategies (e.g. batch vs. spawning) and species and are also temperature dependent. The phases and stages herein are drawn heavily from Brown-Peterson et al. (2011) but altered to be most useful for macroscopic observations that can be made by citizen scientists. Codes are to be assigned based on macroscopic observations and entered in the Biological Sampling Data Sheet at the time of collection. The actual phase will be determined unequivocally by histology at a later time. The bottom panel (from Lowerre-Barbieri et al. 2011) illustrates the phases of oocyte development described in the table and include: CA = cortical alveolar; GVBD = germinal vesicle breakdown; GVM = germinal vesicle migration; OM = oocyte maturation; PG = primary growth; POF = postovulatory follicle; Vtg1 = primary vitellogenic; Vtg2 = secondary vitellogenic; Vtg3 = tertiary vitellogenic.

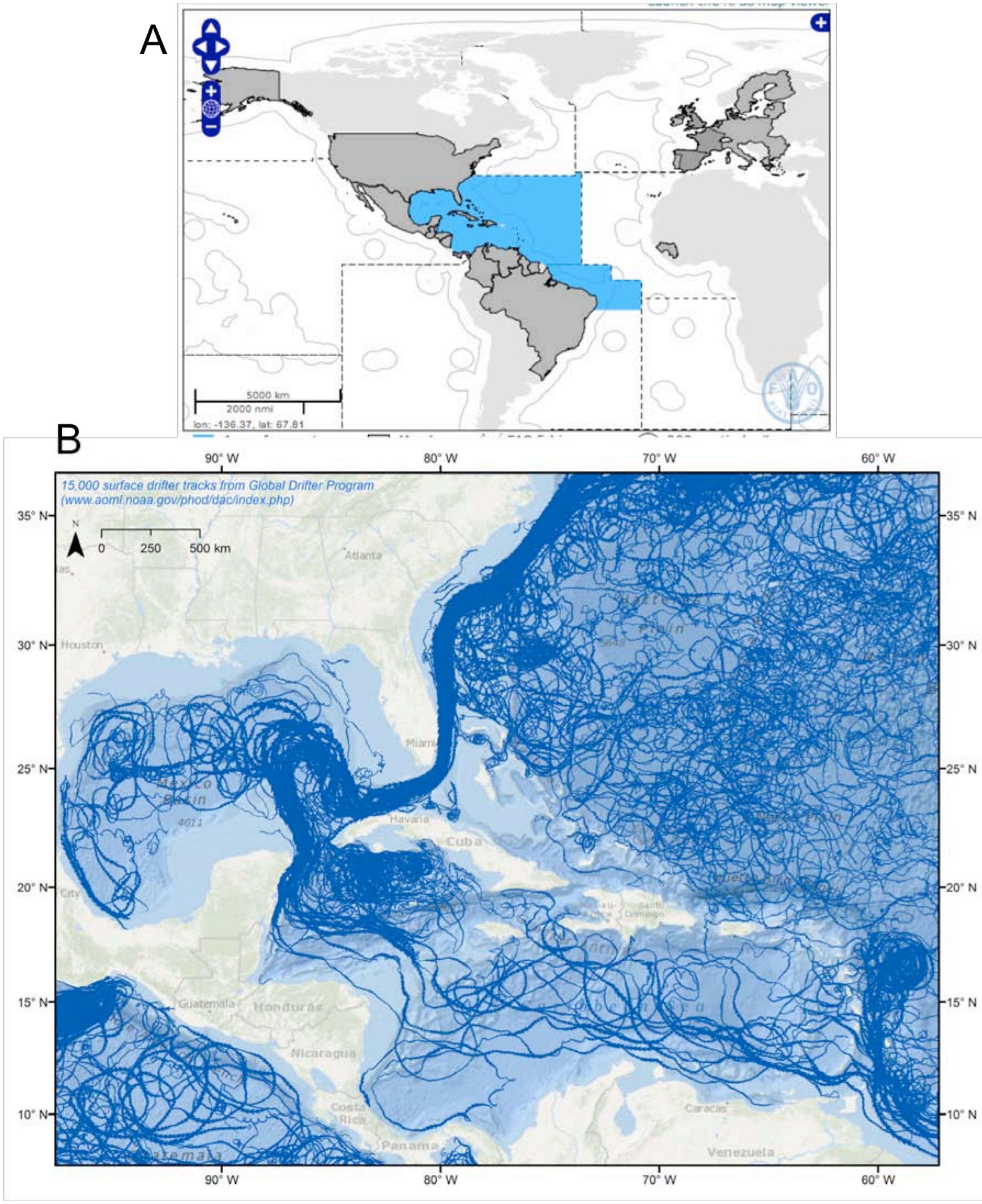


Figure 16: A) The Western Central Atlantic – the data collection zone of the Fisheries and Agriculture Program of the United Nations (FAO) includes the US South Atlantic, US Gulf of Mexico and the US Caribbean as well as 36 other nations and territories of the wider Caribbean and northern South America. B) The waters of the Western Central Atlantic are intimately linked by ocean currents as illustrated by drifter buoy tracks and shared marine and fisheries resources.

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 submit data to the CRMP SASA database.

List of Data Sheets and Their Purpose

Data Sheet Name	Target User	Purpose
Summary Trip Report	Trained data collector	To provide a summary of the location, timing and equipment and personnel involved for a single CRMP SASA sponsored research/fishing trip
Landings and Catch per Effort Data Sheet	Trained data collector	To provide details of the catch landed at a single site during a single CRMP SASA sponsored research/fishing trip
Biological Sampling Data Sheet	Trained data collector	To provide biological information for individual fish caught at all sites during a single CRMP SASA sponsored research/fishing trip
Anecdotal Observation Data Sheet	Trained data collector, Fisherman, divers	To report details of any anecdotal sighting of a spawning aggregation during a fishing or diving trip unrelated to the CRMP SASA
Citizen Science Dock Sampling Data Sheet	Trained data collector	To provide biological information for individual fish caught during a fishing trip unrelated to the CRMP SASA

Data Dictionary

Variable	Description
Date Collected	Date fish caught (enter as DD/MM/YY). Use value from Landings and 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 (and units) 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 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 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 L, R, or Both). 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 Landings and 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.

Summary Trip Report

Cooperative Research and Monitoring Program for South Atlantic Spawning Areas (CRMP SASA)

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 ____

Landings and Catch per Effort Data Sheet

Cooperative Research and Monitoring Program for South Atlantic Spawning Areas (CRMP SASA)

Page: of

Project: Collector: Area/Site: Captain: Date:

Waypoint #: Water temp: Wind Dir: Current Dir:

Latitude: Air temp: Wind Speed: Current Speed:

Longitude: Water depth (m):

Poles: # Hooks: Start Time:

Bandits: # Hooks: End Time:

Catch Data

Crew Member:

Species	# Caught	# Kept	# Discard	Notes

Crew Member:

Species	# Caught	# Kept	# Discard	Notes

Crew Member:

Species	# Caught	# Kept	# Discard	Notes

Crew Member:

Species	# Caught	# Kept	# Discard	Notes

Tagged Fish

Tag ID	Species	Notes

GoPro Footage

Camera	File #	Start time	End time	Notes

Biological Sampling Data Sheet

Cooperative Research and Monitoring Program for South Atlantic Spawning Areas (CRMP SASA)

Project Name_______________ Vessel Name________________ Data Collector Name______________ Page _____ of _____

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

Anectodotal Observation Data Sheet

Cooperative Research and Monitoring Program For South Atlantic Spawning Areas (CRMP SASA)

Form Date:

Contact Information

Name:

Phone #:

Email:

Address:

Location information

Aggregation Date:

Area/Site:

Latitude:

Longitude:

Diving or Fishing:

Spawning Indicators

Gonad State Based on Visual Observation

Male	ED	LD	RR	SPENT	IMMATURE
Female	ED	LD	RR	SPENT	IMMATURE

Please provide photos of the gonads as verification

ED - Early Development

LD - Late Development

RR - Ripe and Running

Underwater Observations

Courtship Behavior:

Color Changes:

High Density (3X):

Please provide video or photo documentation

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

Additional Notes

Citizen Science Dock Sampling Data Sheet

Cooperative Research and Monitoring Program for South Atlantic Spawning Areas (CRMP SASA)

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	Length: Total	Fish Weight	Gonad State: Visual (I, ED, LD, RR, S, R)

Appendix 2: Additional details for field data collection methods

This appendix expands on Section 2.0 of the Cooperative Research and Monitoring Protocol for Spawning Areas in the US South Atlantic (CRMP SASA) by providing detailed methodology for field data collection and analysis. Most techniques employed in this protocol are well accepted and standard (e.g. otolith removal and aging, biological measurements, histological analysis). Since many resources are available on these techniques, they are not elaborated on here. By contrast, a few of the methods described in this protocol are relatively new, for example video monitoring using drop cameras, so a few additional details are provided here.

Underwater video data collection using drop cameras

GoPro camera settings

- 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 with Pro-Tune turned off
- Set resolution and frame rate to 1080i and 60 fps, respectively
- Clean the camera and housing lens with lens paper and appropriate cleaner

V-Go housing setup

- Clean the flat camera mount and aluminum housing with alcohol
- Attach the flat camera mount to the aluminum housing and clamp for 12 hours
- Mount the camera such that the “feet” point out of the housing (i.e. towards the operator)
- Use safety tethers (e.g. plastic zip ties) around the camera connection to the base
- Attach a temperature logger (e.g. TidbiTv2, UTBI-001) to the housing with a zip tie

Drop camera deployment for either V-Go or SRV

- Attach 20-25 lbs of 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 (a bandit reel)
- Just prior to deployment take a GPS point
- 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

Data recording:

- Record each deployment sequentially on the Landings and Catch per Effort Data Sheet
- Record the time of deployment and retrieval (surface to surface)
- Record the video number shown on the camera (this will not be the same as the filename)
- Record the video file name (e.g. GoPro0008) on the Landings and Catch Per Effort Data Sheet; do this as soon as possible after recording
- Record location, temperature, depth, landings, weather conditions, time, species caught and any other data from the site

Camera settings for photographing gonads

- Follow directions above and set time and date on the camera
- Set camera on macro mode
- Set camera for maximum resolution (highest file size, maximum number of pixels)
- Clean lens with moist lens paper or soft cloth
- Take photos in natural light

Gonad photography

- Photograph the gonads along with the entire fish for fish ID and sex verification
- Record the number of the photo on the data sheet
- Take a close-up (macro) photo of the gonad (Figure 13; see section 2.4.1)
- Ensure the photos are in sharp focus; if needed, take several photos to ensure focus; record the number of the best macro photograph on the datasheet
- All photos will be later downloaded and stored in the CRMP database

Gonad sampling

- Using a sharp knife, remove the gonads entirely from the fish
- Weigh the gonads to the nearest gram
- Visually assess sex and the development stage
- Cut the gonad gently about 2/3 of the way from the distal end
- Remove a small piece of tissue and place into a pre-labeled cassette (Figures 13 and 14); the sample should be no thicker than 3 mm and no larger than a US dime; do not stuff the cassettes 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
- When all samples have been taken, the jar can be transferred, as is, to an analytical lab along with the ancillary data
- Alternately, after the cassettes have been in formalin for 10 days, they can be removed to another sample bottle containing 70% isopropyl alcohol
- Appropriate labeling and chain of custody for these samples is critical to ensure that samples are appropriately linked to their ancillary data