SEDAR
Southeast Data, Assessment, and Review

SEDAR 47
Stock Assessment Report

Southeastern U.S. Goliath Grouper

June 2016

SEDAR
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

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Southeastern U.S. Goliath Grouper

SECTION I: Introduction

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EXECUTIVE SUMMARY

SEDAR 47 addressed the stock assessment of Goliath Grouper in the southeastern United States. The assessment was developed by the State of Florida, without SEDAR participation. SEDAR provided a mechanism for Peer Review, as it does for other Cooperators of the program. The Review Workshop took place May 17-19, 2016 in St. Petersburg, FL.

The Stock Assessment Report is organized into 5 sections. Section I – Introduction contains a brief description of the SEDAR Process and a list of SEDAR abbreviations. The Data/Assessment Report can be found in Section II. It documents the data recommendations and details the assessment model. Consolidated Research Recommendations from all stages of the process can be found in Section III for easy reference. Section IV documents the discussions and findings of the Review Workshop (RW). Finally, Section V– Addenda and Post-Review Workshop Documentation consists of any analyses conducted during or after the RW to address reviewer concerns or requests. It may also contain documentation of the final RW-recommended base model, should it differ from the model put forward in the Assessment Report for review.

The final Stock Assessment Report (SAR) for Southeastern U.S. Goliath Grouper was disseminated to the public in June 2016. The Council's Scientific and Statistical Committees (SSC) will review the SAR for these stocks. The SSCs are tasked with recommending whether the assessments represent Best Available Science, whether the results presented in the SARs are useful for providing management advice and developing fishing level recommendations for the Council. An SSC may request additional analyses be conducted or may use the information provided in the SAR as the basis for their Fishing Level Recommendations (e.g., Overfishing Limit and Acceptable Biological Catch). The Gulf of Mexico South Atlantic and Fishery Management Council's SSCs will review the assessment at their July and October 2016 meetings, followed by the Council receiving that information at their August and December 2016 meetings, respectively. Documentation on SSC recommendations are not part of the SEDAR process and are handled through each Council.

1 SEDAR PROCESS DESCRIPTION

SouthEast Data, Assessment, and Review (**SEDAR**) is a cooperative Fishery Management Council process initiated in 2002 to improve the quality and reliability of fishery stock assessments in the South Atlantic, Gulf of Mexico, and US Caribbean. SEDAR seeks improvements in the scientific quality of stock assessments and the relevance of information available to address fishery management issues. SEDAR emphasizes constituent and stakeholder participation in assessment development, transparency in the assessment process, and a rigorous and independent scientific review of completed stock assessments.

SEDAR is managed by the Caribbean, Gulf of Mexico, and South Atlantic Regional Fishery Management Councils in coordination with NOAA Fisheries and the Atlantic and Gulf States Marine Fisheries Commissions. Oversight is provided by a Steering Committee composed of NOAA Fisheries representatives: Southeast Fisheries Science Center Director and the Southeast Regional Administrator; Regional Council representatives: Executive Directors and Chairs of the South Atlantic, Gulf of Mexico, and Caribbean Fishery Management Councils; a representative from the Highly Migratory Species Division of NOAA Fisheries, and Interstate Commission representatives: Executive Directors of the Atlantic States and Gulf States Marine Fisheries Commissions.

SEDAR is normally organized around two workshops and a series of webinars. SEDAR 47 differed from this process, as SEDAR was only involved in organizing the Review Workshop during which independent experts review the input data, assessment methods, and assessment products. The completed assessment, including the reports of all stages and all supporting documentation, is then forwarded to the Council SSC for certification as 'appropriate for management' and development of specific management recommendations.

SEDAR workshops are public meetings organized by SEDAR staff and the lead Cooperator. Workshop participants are drawn from state and federal agencies, non-government organizations, Council members, Council advisors, and the fishing industry with a goal of including a broad range of disciplines and perspectives. All participants are expected to contribute to the process by preparing working papers, contributing, providing assessment analyses, and completing the workshop report.

2 SEDAR ABBREVIATIONS

ABC	Acceptable Biological Catch
ACCSP	Atlantic Coastal Cooperative Statistics Program
ADMB	AD Model Builder software program
ALS	Accumulated Landings System; SEFSC fisheries data collection program
AMRD	Alabama Marine Resources Division
ASMFC	Atlantic States Marine Fisheries Commission
B	stock biomass level
BAM	Beaufort Assessment Model
BMSY	value of B capable of producing MSY on a continuing basis
CFMC	Caribbean Fishery Management Council
CIE	Center for Independent Experts

CPUE	catch per unit of effort
EEZ	exclusive economic zone
F	fishing mortality (instantaneous)
FMSY	fishing mortality to produce MSY under equilibrium conditions
FOY	fishing mortality rate to produce Optimum Yield under equilibrium
FXX% SPR	fishing mortality rate that will result in retaining XX% of the maximum spawning production under equilibrium conditions
FMAX	fishing mortality that maximizes the average weight yield per fish recruited to the fishery
F0	a fishing mortality close to, but slightly less than, Fmax
FL FWCC	Florida Fish and Wildlife Conservation Commission
FWRI	(State of) Florida Fish and Wildlife Research Institute
GA DNR	Georgia Department of Natural Resources
GLM	general linear model
GMFMC	Gulf of Mexico Fishery Management Council
GSMFC	Gulf States Marine Fisheries Commission
GULF FIN	GSMFC Fisheries Information Network
HMS	Highly Migratory Species
LDWF	Louisiana Department of Wildlife and Fisheries
M	natural mortality (instantaneous)
MARMAP	Marine Resources Monitoring, Assessment, and Prediction
MDMR	Mississippi Department of Marine Resources
MFMT	maximum fishing mortality threshold, a value of F above which overfishing is deemed to be occurring
MRFSS	Marine Recreational Fisheries Statistics Survey
MRIP	Marine Recreational Information Program
MSST	minimum stock size threshold, a value of B below which the stock is deemed to be overfished
MSY	maximum sustainable yield
NC DMF	North Carolina Division of Marine Fisheries
NMFS	National Marine Fisheries Service

NOAA	National Oceanographic and Atmospheric Administration
OY	optimum yield
SAFMC	South Atlantic Fishery Management Council
SAS	Statistical Analysis Software, SAS Corporation
SC DNR	South Carolina Department of Natural Resources
SEAMAP	Southeast Area Monitoring and Assessment Program
SEDAR	Southeast Data, Assessment and Review
SEFIS	Southeast Fishery-Independent Survey
SEFSC	Fisheries Southeast Fisheries Science Center, National Marine Fisheries Service
SERO	Fisheries Southeast Regional Office, National Marine Fisheries Service
SPR	spawning potential ratio, stock biomass relative to an unfished state of the stock
SSB	Spawning Stock Biomass
SS	Stock Synthesis
SSC	Science and Statistics Committee
TIP	Trip Incident Program; biological data collection program of the SEFSC and Southeast States.
TPWD	Texas Parks and Wildlife Department
Z	total mortality, the sum of M and F

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Southeast Data, Assessment, and Review

SEDAR 47

Southeastern U.S. Goliath Grouper Species

SECTION II: Data and Assessment Report

29 April 2016

Updated*: 24 May 2016

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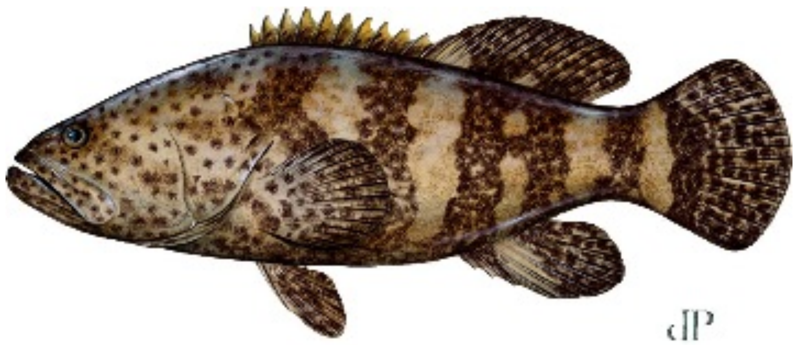
*** Minor grammatical/typo corrections, page number updates, and the addition of an appendix were included in the update of the report originally submitted to the Review Panel**

SEDAR 47 Stock Assessment Report for

Goliath Grouper of the South Atlantic and Gulf of Mexico, 2016



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FWC Report IHR2016-001, May23, 2016

Executive Summary

- This stock assessment of Goliath Grouper of the Southeastern U.S. uses modified indices of abundance through 2014 and some observed data on the ages of offshore fish.
- Commercial landings were re-estimated from the reported historical landings data. Recreational landings and releases were re-estimated from the reported values by NMFS. A release mortality rate for recreational releases was assumed. Size and age structure of catches (landings and releases) are poorly known, and the magnitudes of historical commercial and recreational landings are uncertain.
- Episodic mortality events such as red tide and cold-kills were noted through the collections of dead specimens and corresponded to specific periods of decline in the abundance indices. Indices of abundance developed from estuarine sources of data trended upward until 2007, and declined afterwards. Some upward trends in abundance look evident beginning in 2011, but are still low overall. These declines in the indices occurred after red tide on the West Florida shelf in 2005 and cold-kills in 2008 and 2010 in the Everglades National Park and other estuaries. Juvenile Goliaths (0-6 years old) are resident in mangrove areas of the Everglades/Ten Thousand Islands, and are adversely affected (like Common Snook) by cold-weather events.
- A revised estimate of natural mortality based on maximum age of Goliaths was based on a recently published article (Then et al. 2015).
- Two age-structured assessment models were employed for SEDAR 47. Both models require knowledge of the species' life history parameters such as growth rates, age at maturity, age-specific natural mortality rates, fecundity rates, length and weight at age, indices of abundance which are proportional to actual abundance and the ages appropriate for each index and parameters for fishing mortality during defined time periods for which they solve.
- The catch-free model (Porch et al. 2006) estimated natural mortality, growth rate, reproductive rate, and vulnerability of Goliaths associated with the indices of abundance based on priors developed from research studies to solve for management reference points. This model (also used in SEDAR 6 and 23) produces relative measures of stock status because it attempts to reconstruct population abundance over time using only life history parameters and indices of abundance and does not use historical landings to estimate the scale of removals.
- The stochastic stock reduction analysis (SSRA; Martell et al. 2008) uses fixed values for natural mortality, growth rates, reproductive rates and vulnerabilities to solve for management reference points. The SSRA reconstructs population abundance and age structure consistent with the historical levels of removals (landings), life history parameters, and indices of abundance.
- Uncertainty in the estimates produced by both models was explored with Markov Chain Monte Carlo (MCMC) simulations. Both models indicated a declining trend in relative stock abundance after 2012 possibly as a response to cold-weather events that occurred in 2008 and 2010 in South Florida. Both models also indicated that the spawning stock biomass (SSB) likely exceeded the management reference target ($SSB_{50\%SPR}$) in the more recent years.
- Both models suggest that Goliaths are no longer in the overfished condition.

Contents

I. Introduction

1. SEDAR Process Description

Since 2002, SEDAR (Southeast Data, Assessment, and Review) is a cooperative Fishery Management Council process to improve the quality and reliability of fishery stock assessments in Southeastern U.S. (South Atlantic and Gulf of Mexico) and the U.S. Caribbean. The SEDAR process is organized around three workshops (Data, Assessment, and Review), seeks to engage all stakeholders in the development and transparency of the information assembled for the assessment as well as for the transparency of the assessment methods and results, and to provide a rigorous independent scientific review of the assessment.

1.1 Management Overview

An overview of the fishery management plans, fishery management council boundaries, and state management regulations were presented in SEDAR 23. Briefly, the State of Florida implemented a 12"TL size limit on 7/1/1977 for state waters. The South Atlantic Fishery Management Council (SAFMC) set a 12" TL size limit for federal waters it manages on 8/31/1983. The Gulf of Mexico Fishery Management Council (GMFMC) set a 50" TL size limit on 2/21/1990. The Florida Marine Fisheries Commission (now combined into the Florida Fish and Wildlife Conservation Commission), reacting to concerns raised by fishermen about the decline of this species, persuaded the State of Florida to prohibit the retention of Goliath Grouper in state waters on 2/1/1990. The GMFMC on 8/30/1990 and the SAFMC on 10/30/1990 prohibited retention from federal waters of the Exclusive Economic Zone. This prohibition on retention has been continuously in effect since 1990.

There have been several management reference points set for Goliath Grouper by the two Councils. Currently, the management proxies for the SAFMC for maximum sustainable yield (MSY) and optimum yield (OY) are 40% static spawning potential ratios (SPR) and 50% SPR, respectively. The proposed (GMFMC MSST Management Options Paper, October 2015) management proxies for the GMFMC for (MSY) and (OY) are 50% SPR (static). The state of Florida does not set management goals for Goliath Grouper, and usually defers to the FMCs in co-managing fisheries in Florida waters.

1.2 Assessment History and Review

Commercial and recreational landings, releases, size and age structure, and other parameters useful for typical stock assessment models were deemed unreliable or poorly known (GMFMC 1990, SAFMC 1990). An initial attempt at assembling information for assessing Goliath Grouper began with SEDAR 3 (2004), and after the data workshop the decision was made to proceed to a formal assessment. The catch-free model (Porch et al. 2006) was developed for SEDAR 6 (2006), with the assessment concluded that the species had undergone overfishing and was overfished in the past, but with the prohibition on retention there was a significant reduction in fishing mortality and that, depending upon assumptions regarding the reduction in fishing mortality, the spawning stock biomass (SSB) appeared to be on a trajectory to recovery to the management proxies for OY ($F_{50\%SPR}$ and $SSB_{F\ at\ 50\%SPR}$) sometime during the 2005-2015 time period.

SEDAR 23 (2010) re-examined the status of Goliath Grouper using the catch-free model using indices of abundance through 2009 and varying the priors on the percent reduction in F after the moratorium as well as values used for natural mortality, and found that under some scenarios the SSB had recovered sufficiently to the OY proxies sometime during 2008-2015 unless the longevity (maximum age) of this species was much older than known. An update assessment for the Florida FWC (O'Hop et al. 2015) was produced last year, which used slightly different recreational catch indices and updated REEF and Everglades Angler Survey indices, did not alter that perception of recovery. However, the impact of the cold kills of 2008 and 2010 became more evident in the indices and the assessment results.

II. Data Review and Update

1. Introduction

Although there has been recent research on the life history of Goliath Grouper in the Gulf of Mexico and the South Atlantic focused on characterizing habitat preference, sizes, ages, movements (conventional and acoustic tags), sounds (particularly from aggregations), feeding ecology, nursery habitat, mercury levels, etc., information for addressing assessment needs (particularly age structure of the offshore portion of the population) is not yet available but may be available from a Cooperative Research Project (CRP) scheduled for completion later in the year. Twenty-five researchers, students, and fishery managers attended the FWC Goliath Grouper Workshop on March 14-16, 2016. Recent and current projects focused on Goliath Grouper were discussed, and research recommendations for SEDAR 47 were developed. However, no SEDAR 47 Data Workshop was held. The information discussed in this section is focused on updates of data and indices from various sources as noted.

1.1 Terms of Reference

Because no SEDAR 47 Data Workshop was held, there are no Terms of Reference.

2. Life History

2.1. Stock Definition and Description

Goliath Grouper (*Epinephelus itajara*) have typically been placed in the family Serranidae, subfamily Epinephelinae (e.g., http://www.calacademy.org/scientists/projects/catalog-of-fishes). Recently the members of this genus were placed into the family Epinephelidae (Page et al. 2013).

2.2. Population Genetics

Goliath Grouper [*Epinephelus itajara* (Lichtenstein 1822)] are distributed throughout the tropics, subtropics, and warm temperate waters of the Atlantic Ocean, Gulf of Mexico, Caribbean Sea, and southward to southeastern Brazil. There are genetic differences between Goliath Grouper in U.S. waters and those in the Belize and South America (Craig et al. 2009) and populations in those areas would be treated as different stocks. The genetic affinities of Goliaths elsewhere in the Caribbean are currently unstudied.

Tissue samples of Goliath Grouper captured for tagging purposes, and from dead specimens from around the state, have been collected over the years and is being used for a number of purposes. Recently, genetics data from specimens from around Florida from the Tampa Bay area, Florida Keys, and southeast Florida were examined and the data suggested that there was no stock differentiation between those areas. However, there was evidence from an analysis of kinship that specimens from southeast Florida and the Florida Keys appear more closely related than specimens from the Gulf of

Mexico (M. Tringali, S. Seyoum, and A. B. Collins, FWC, St. Petersburg, FL, personal communication). For the purposes of this assessment and as in SEDAR 23 (2010), the Goliath Grouper in Southeastern U.S. waters are treated as a single stock.

2.3. Tagging

Tagging studies have been part of several Cooperative Research Program studies, and the focus of the analyses to date has been on movements of individuals to and from sites. Most of these movements showed high site fidelity and that some individuals traveled long distances to sites which have been identified as important spawning (Collins 2014, Koenig and Coleman 2013). Analyses of the tagging data are not yet complete.

2.4. Larval Transport/Connectivity

No new research for this topic, with the exception that Tzadik et al. (2015) have found unique isotopic signatures in the fin rays of juvenile Goliaths that are correlated with the habitat where they settle and should serve as unique signatures to distinguish the nursery habitats of individual fish.

2.5. Distribution and stock structure in Florida

In Florida, young Goliaths recruit to estuarine mangrove areas of tidal rivers blending in with mangrove leaf litter in their early years, stay in this habitat for 5-6 years, and disperse offshore to high profile hard-bottom habitats and artificial reefs and wrecks (Koenig et al. 2007). The Everglades in southwest Florida is thought to have the largest amount of habitat left in Florida suitable for juvenile Goliath recruitment and survival. Several areas that have documented seasonal aggregations of Goliaths are either suspected or confirmed as spawning sites (Mann et al. 2009, Koenig and Coleman 2013, Ellis et al. 2013).

2.6. Mortality

Natural Mortality

One of the unknowns when modeling populations is the rate of natural mortality (M) that a population experiences. For the purpose of assessing the status of fish stocks, natural mortality is the usual long-term mortality rate due to predation, disease, old age, or other natural losses to populations. Basically, all mortality that is not associated with fishing. Methods of estimating natural mortality may employ catch curves, growth parameters, water temperature, or demographic methods. If a population is thought to be unfished or lightly fished, estimating total mortality (Z) from, say, catch curves may be useful in deriving an estimate of natural mortality. Hoenig (1983) originally devised a method based on sampling populations that were thought to be lightly exploited, and developed a relationship between the maximum age observed from the sampling and Z derived from catch curves. This method has been adopted by many researchers and is quite commonly used in SEDAR and other assessments as a more objective way of estimating an **upper bound** on the rate of natural mortality. Episodic losses from virulent epizootics, cold kills, red tide, etc. can modify short-term or long-term natural mortality rates and have proven challenging with many existing assessment methods.

Recently, Then et al. (2015) re-examined the data used by Hoenig and added more information on other species to derive a new relationship (they termed it "$\text{Hoenig}_{\text{nls}}$" for the nonlinear least squares approach used for fitting the curve) for estimating natural mortality. The new curve estimates an upper bound for M quite a bit higher than Hoenig's original method (see Fig. 10), and avoids the calculation biases in estimation inherent with original method. The Hoenig_{nls} estimate for Goliath, using a maximum age of 37 years (the oldest specimen known) gives an estimate of 0.18 (Fig. 2.6.1, label "GoliathG-nls"). The older relationship used in SEDAR 23 using the same maximum age estimated an upper bound for M at 0.12 [Fig. 2.6.1, label "GoliathG(S23)"]. This is a very large change in natural mortality rate and has implications for modeling age from length as well as affecting model estimation of SPR (spawning potential ratio) reference points and spawning biomass ratios.

The upper bound on the natural mortality estimate (M) resulting from whichever of Hoenig's equations is used is an average and constant (e^{-M}) over all ages in the population. From the study of populations, relatively higher mortality typically occurs in the earlier life history stages of animals than in later stages of life. As fish grow in size, they eventually become less vulnerable to predators and the rate of loss to predation slows. Lorenzen (1996, 2005) examined this relationship and proposed methods to calculate age-specific natural mortality rates (M) for a population. It is typical in recent years for SEDAR assessments to use age-specific M, and the catch-free model was adapted to use age-specific M in SEDAR 23.

Release Mortality

There is only indirect evidence from research studies on release mortality in Goliaths. Koenig et al. (2007) and Brusher and Schull (2009), working in tidal mangrove areas in the Everglades, captured live Goliath juveniles using blue crab traps and hook and line gear. In both studies, there were numerous recaptures and release mortality was thought to be low, perhaps 5% or less. Collins (2014) and Koenig and Coleman (2013), working in offshore areas, captured live Goliath adults and sub-adults using hook and line gear. Both research studies experienced little if any immediate release mortality even when there was evidence of barotrauma, indicating that if the fish are released properly (vented if necessary) and re-pressurized to the depth of capture, there is a reasonable expectation of survival for the individual.

2.7. Age and Growth

Available Size and Age Data

Bullock et al. (1992) provided the earliest research data on size and age of Goliaths, and those specimens were chiefly fish from commercial and recreational harvests. There are other potential sources of data available on sizes of Goliaths in various habitats and numbers caught by fishers or observed by divers. Koenig et al. (2007), and Koenig and Coleman (2009, 2013) conducted studies of juvenile Goliaths in estuarine habitats and adults in offshore habitats. Brusher and Schull (2009) researched sizes and recapture rates of Goliaths in the Everglades National Park using several methods. Collins and Barbieri (2010) and Collins (2014) studied Goliath Grouper at several offshore sites on the West Florida shelf and (Koenig and Coleman 2013, Ellis et al. 2013) off of southeast Florida, and provided information on sizes of Goliaths in those habitats as well as documenting habitat usage, telemetry on movements of individual fish, and information on barotrauma and effect on recapture rates. Phelan (2009, 2010) provides monthly information on numbers of Goliaths and estimates of their sizes observed by divers at several wrecks and artificial reefs off of Florida's East Coast. However, the exact methods used for length estimation (which appears slightly too high) is a little unclear in Phelan's reports and no quality assurance information on the length measurement process is presented. Additionally, a few fish (possibly 22) from the Koenig and Coleman (2013) CRP study of Goliaths at spawning sites on the southeast coast have been aged using fin rays in 2012, and these aged specimens give a first glimpse, albeit preliminary, at the age composition of offshore fish. Approximately 800 specimens from this and other studies may eventually be aged if the methods for aging fin rays proves reliable for older fish (20+ years). The results of the aging portion of the Koenig and Coleman (2013) study are anticipated late in 2016.

Maximum Age

The oldest Goliath Grouper known was 37 years old at the time of capture and was a specimen in the Bullock et al. (1992) study. Because Goliath Grouper have been fished for many decades (Fig. 3.1.1) and probably heavily fished (which was the reason for the prohibitions on retention of Goliaths in 1990 imposed by the Florida Marine Fisheries Commission and the two federal fishery management councils), and because data on the ages for older specimens (328 specimens were 7 years or older) of this species comes mostly from collections from 1984-1989 (Bullock et al., 1992), the observed maximum age (37 years) may be an underestimate for the longevity of this species before they were heavily fished. Some other species of grouper have been shown to live to older ages in U.S. waters (e.g., Snowy, Yellowmouth, Yellowedge; Fig. 2.6.2). It is possible that Goliath Grouper may have a greater maximum age than is presently known, and if so, a lower M may be more appropriate.

Growth and weight-at-length

Bullock et al. (1992) proposed a growth curve from specimens collected during the course of their study. Subsequent collections of juvenile and adult Goliaths added considerably to the amount of size and age data available, and the new growth curve used in SEDAR 23 was obtained (Fig. 2.6.3). As most of the new data were from specimens collected during Brusher and Schull's (2009) study on juveniles in the Everglades or were from specimens collected after cold-kills, red tides, bridge demolitions, or confiscations, few of the specimens were large or old and no new information has been learned about the maximum age of this species.

There are few other groupers that compare with the size of Goliath Grouper. The current record kept by the International Game Fish Association is for a specimen caught on May 20, 1961 off of Fernandina Beach and weighed 680 pounds. The largest Goliath Grouper from historical accounts in newspapers in the Florida Keys was 8' with an estimated weight in excess of 600 pounds that was caught on January 2, 1935 at the Curry Fish Dock in Key West, and another fish weighing 620 pounds was caught on November 21, 1936 from the Boca Chica Bridge. The largest specimen in a research study (Bullock et al. 1992) contained a specimen that was nearly 7' long and weighed 434 pounds (gutted weight), and the oldest Goliath Grouper from that study was 37 years old. Weight at length of Goliaths is in Fig. 2.6.4.

2.8. Reproduction

Reproductive characteristics

Bullock et al. (1992), using histological methods on samples of gonads, found no conclusive evidence of protogynous hermaphrodism as found in some other species in this genus. Recently, Koenig and Coleman (2013) presented findings using a novel biopsy technique to collect small samples of gonadal tissue rather than sacrificing live specimens that may support a finding of protogyny in Goliaths, but their findings have not yet undergone peer review. If their findings are supported, Goliaths may have a reproductive strategy termed “diandric protogyny” similar to that described recently in *Epinephelus andersoni* in South African waters (Fennessy and Sadovy 2002). In this type of reproductive life history, there are two types of males. Some males are born that way, and others may transition from females in response to some behavioral cue which is not known. Koenig and Coleman (2013) believe that this transition in Goliath females to males may occur toward the end of the spawning season in November.

Spawning Season

Spawning has been observed (and confirmed with collections of eggs) by Koenig et al. (2007) and Koenig and Coleman (2013) to occur around new moon periods in August and September, and there are indications (characteristic sound production, chorusing; Mann et al. 2009) that spawning activities may begin as early as July.

Age/Size at Maturity

Bullock et al. (1992) provided estimates of maturity for Goliaths using histological methods to assess the state of gonads of male and female specimens. Males were first mature at sizes between 110-115 cm TL at 4-6 years of age, and all males less than 110 cm TL or less than 4 years old were immature. Females were first mature between 120-135 cm at ages 6-7, and all females less than 120cm or less than 6 years of age were immature. On the basis of these maturity estimates and the size measurements or diver observations, it is assumed that most Goliaths caught in the Everglades National Park would be juveniles, and most Goliaths (but not all) observed offshore would be adults.

Fecundity

Fecundity is not well-documented. Bullock and Smith (1991) had worked up two female gonads and estimated batch fecundity to be 38,922,168 ± 1,518,283 and 56,599,306 ± 1,866,130 oocytes.

Sex Ratio

Neither Bullock et al. (1992) nor Koenig and Coleman (2013) found sex ratio at size to differ significantly from 1:1.

Distribution and Characterization of Spawning Aggregations

As mentioned above (Spawning Season), aggregations have been observed to form at specific sites in July to October. Sound production by multiple individuals (chorusing) is more evident on moonless nights and is much reduced for several days around the full moon (Mann et al. 2009; Ellis et al. 2013). From acoustic telemetry, individuals in the aggregations, which may number in the dozens to over a hundred fish, may visit several sites in an area during the spawning season (Koenig and Coleman 2013). Several fish (84.2% of tagged fish) returned to the same spawning site where they were originally tagged after one year, and 77.8% of them returned after two years.

2.9. Habitat and Movements

Goliath Groupers utilize mangrove habitats in estuaries as young-of-year and juveniles, and move generally offshore to high-relief habitats (e.g., coral reefs, wrecks, artificial reefs, etc.) as they get older [e.g., Brusher and Schull (2009), Koenig et al. (2007), Koenig and Coleman (2009), Collins and Barbieri (2010), Collins (2014)]. These movements from estuarine habitats (Fig. 3.3.7) to offshore areas (Fig. 3.3.8) coincide with increasing size and age (Fig. 3.3.9). There may be some association of these offshore movements with maturity, but from what is known of Goliaths in estuarine habitats they are moving out of the estuaries at smaller sizes and younger ages than the known sizes and ages at maturity (see above heading Age/Size at Maturity). And, there are occasional smaller (and presumably younger) specimens found offshore, but the majority of individuals in the offshore areas are larger, older, and mature.

Juvenile Goliaths in mangrove habitats of the Ten Thousand Islands (Everglades National Park) exhibit some movements related to tidal patterns but have relatively small home ranges indicating high site fidelity. Juveniles show a preference for highly structured red mangrove habitats that have been partially eroded and undercut or where overhangs are significant, or where there is sufficient structure (submerged trees, limestone solution holes) adjacent to red mangrove habitat (Frias-Torres 2006). Juveniles in mangrove-lined rivers had a home range averaging 586 meters, but those around mangrove islands had home ranges which averaged 170 meters (Koenig et al. 2007). Individual Goliaths which settle onto offshore high-relief habitats are often seen repeatedly (tags re-sighted or from movements monitored by acoustical tagging) at the same site over much of the year (Koenig and Coleman 2009, Collins 2014). Eighty-two percent of recaptured adult Goliaths (about 170 fish) had moved less than 1 km from the site where they were originally tagged (Koenig and Coleman 2009).

There were some interesting diurnal patterns of movements of Goliaths. Most of the day was spent nearly on the bottom at a site, and individual fish rose off the bottom at reefs and wrecks at night (Collins 2014). Spawning is believed to occur from July to October, and acoustic monitoring of Goliaths is consistent with this assertion (Koenig and Coleman 2009). It is known that Goliaths will aggregate at some wrecks sites, chiefly in deeper waters (30-50 m) for spawning (Koenig and Coleman 2009). Some Goliaths in these aggregations have traveled long distances (over 200 km) to reach those sites (Koenig and Coleman 2009, Collins 2014). Koenig and Coleman (2009) found that sound production by Goliaths was lower during full moons than at other times of the lunar cycle, and that it may be possible to identify Goliath Grouper spawning aggregations and spawning activities by using acoustic monitoring (Mann et al. 2009).

2.10. Other topics

The issue of bioaccumulation of mercury in Goliaths has been discussed by Tremain and Adams (2012) and Evers et al. (2009) and should be of concern in management considerations. Additional research on mercury levels in Goliaths is being conducted by Chris Malinowski at Florida State University. Muscle tissue concentrations of mercury in Goliaths over one meter in length from Florida waters (Tremain and Adams 2012) would likely exceed current FDA recommendations for consumption.

3. Catches, harvests, and releases

3.1 Commercial Landings

There has been fishing on Goliath Groupers documented throughout its range from historical accounts dating back to colonial times (e.g., Gould and Atz 1996). In 1883, Jordan (1884) noted catches of Goliath Grouper and other large reef fishes over several weeks in the Florida Keys made by larger vessels which were taken in live wells to Havana rather than being sold in the Florida Keys. Evermann and Bean (1897), investigating fish and fishing in Florida's Indian River Lagoon and adjacent marine waters, noted that four juvenile Goliaths (1 5/8" to 3") were caught in the Indian River; however, Goliaths were not noted as being part of the commercial landings (Wilcox 1897). Brice's (1897) account of fishing in the "principal fishing centers (Indian River, Lake Worth, Biscayne Bay, Key West, Tampa, Tarpon Springs, Apalachicola, Carrabelle, Pensacola, and others" of Florida from 1895 to 1896 noted that Goliaths caught and sold commercially were usually 100-250 pounds and up to 400-500 pounds, but he added that those above 250 pounds "do not sell well". Brice also noted that Key West dealers in 1895 purchased 10,000 pounds of Goliath Grouper from local fishermen. Schroeder (1924) updated the description of Key West fisheries, and noted the building of its first large-scale ice-making and cold-storage plant that was used to store excess catches of fish. In 1919, there were severe losses to the fishing industry when the one small ice-making plant in the city became disabled. The local fleet consisted of small boats equipped with sails, gasoline engines, or both which seldom ventured far from shore and fished at the numerous nearby reefs, and there were a few locally owned larger (30'-75') vessels and a number of larger vessels from the east and west coasts of Florida which came to Key West to fish during the winter. Cuban vessels fishing near Key West would sell to Key West seafood dealers. Vessels that targeted larger reef fish needed live wells since ice was only used for mullet, king mackerel, and Spanish mackerel. Schroeder (1924) reported that a portion of the catch was sold locally in Key West, but a much greater portion was sold in Cuba and to other U.S. cities. Fish were brought in alive, and were packed in ice for shipping to Cuba or elsewhere. Regarding Goliaths, Schroeder (1924) noted that the larger ones preferred moderately deep water with rocky or coral bottom, and small ones (1-10 pounds) were frequently taken in shallow water close to shore. During six weeks of July and August of 1918, 74 Goliaths ranging in weight from 35 to 350 pounds (averaging 125 pounds) were taken from Knight's Key. [Knight's Key is near Marathon, and was the site of a long, deep water dock built in 1906 to support the building of the Seven Mile bridge for Henry Flagler's Key West Extension of the Florida East Coast Rail System (http://www.keyshistory.org/KKD-Knights-Key-Dock.html). The dock had burned to the waterline probably in 1912, leaving only pilings. These structures provided habitat that probably attracted large Goliath Grouper back then, as the pilings of the Boca Grande phosphate pier near the mouth of Boca Grande Pass do today.]

There was no systematic recording of landings from commercial fisheries until the 1880s when the U.S. Congress tasked the Bureau of Commercial Fisheries with researching commercial wildlife (fish, shellfish, whales, seals, turtles, etc.) harvesting activities and developing an accounting of fisheries in the United States. The surveys did not regularly include the states of the southeastern U.S. and Gulf of Mexico until 1897. The first annual estimates of the commercial harvest of Goliath Grouper (at that time, identified as "jewfish" but known by fishermen of that time as "spotted jewfish", "gigantic jewfish", "guasa", "merou", "Jacob Evertzen", and a variety of other common names which undoubtedly was very confusing to both fishermen and scientists) were made in 1918 for the Gulf of Mexico and the South Atlantic of the United States. During this period, research on the identification of species and knowledge of their distribution became available that brought more clarity on where and how much of many species of fish and shellfish were harvested commercially.

The reported commercial landings of Goliath Grouper in Florida has varied through time, showing some periods with relatively high landings and other years when landings were more moderate, and the period after the prohibition on harvest beginning in 1990 (Fig. 3.1.1). Prior to 1973, there were appreciable commercial landings reported in Alabama and Texas, and occasional landings reported in other states of the southeastern U.S. (SEDAR 2010). Some of the Alabama and Texas landings may have come from fishing in the Campeche Banks off Mexico. Still, the majority of commercial landings in the southeastern U.S. were reported in Florida.

There are two periods in the reported Florida commercial landings series that may need some adjustment. The first period is during World War II when commercial landings were particularly high and declining to lower levels to 1950. When domestic spending was lowered and the U.S. Bureau of Commercial Fisheries was not conducting regular surveys (Fig. 3.1.1, in blue), the State of Florida instituted its own surveys for most years of this period. Those Florida landings data existing (Fig. 3.1.1, in red) for 1938 to 1950 were available to fill in gaps in landings. The second period in need of adjustment concerned commercial landings reported in Lee County which increased dramatically through the 1970s and early 1980s, then decreasing thereafter. Numerous visits to a dealer's premises in Lee County in the early 1980s by biologists sampling Goliath Grouper for a study of its life history (Bullock et al. 1993) never saw expected levels of specimens consistent with the level of reported landings of this species at this dealer. With the implementation of the Florida commercial trip ticket system in 1984, additional data was available to inspect commercial landings reported by Florida dealers. Reported landings of Goliaths at this dealer declined (-93%) precipitously after May of 1984 compared with previous months and years. This unusual increase and decrease in reported landings in Lee County led to speculation that this dealer was over-reporting landings. The initial adjustments for the January, 1978 to May, 1984 period were made by developing a ratio of reported Goliath Grouper by the dealer with the suspected inflated landings compared with this dealer's reports from May, 1984 to December of 1986. This ratio ("adjustment factor", ~7%) was used to adjust this dealer's reported landings of Goliaths in the 1978 to 1984 period, and resulting in a downward adjustment to commercial landings for those years (Fig. 3.1.1, in red). For 1978-1984, this one dealer's unadjusted reports represented an average of 98.5% of the Goliath landings for Lee County for 1978-1984, and unadjusted Lee County averaged 78.9% of the total Goliath landings of West Florida (Florida Keys to Escambia County). In 1985-1986 after the suspected over-reporting had ended, the reported Lee County commercial landings of Goliaths represented less (~55%) of the West Florida landings.

By inspection of Lee County commercial landings of Goliaths, it appears that landings in this county began to increase in proportion to the rest of the West Coast of Florida in 1965. It is possible that the suspected inflation of landings from this dealer began earlier than 1978, but this cannot be examined directly since dealer-level landings were not available for previous years as only county-level landings are available. Unfortunately, because this dealer was in business in Lee County for over four decades and dealer-level landings were available only back to 1978, the adjustments to Lee County landings for 1965 to 1977 were even less certain. The ratio (~98.5%) of the dealer's reported landings in the 1978-1984 period was applied the reported landings of Lee County to estimate the contribution of this dealer's landings to Lee County for the 1965-1977 period. The "adjustment factor" (~7%) for the suspected over-reporting of this dealer was applied to the dealer's estimated portion of Lee County's landings, resulting in a downward adjustment for landings in this county (and for West Florida and regional totals) for 1965-1977. The results of this proposed adjustment are shown in red (Fig. 3.1.1). Average annual landings for Florida over 1973-1989 were 174,000 pounds before the adjustment, and 92,000 pounds after adjustment.

The commercial landings for 1950-1991 were needed as an inputs to the SSRA model, and these values (in pounds) are shown in Table 3.1.1. The suggested adjustments to Goliath commercial landings for 1964 to May, 1984 are highlighted in yellow.

3.2 Commercial releases/discards, discard mortality, and size/age structure

There is little information available from the NMFS Coastal Fisheries Logbook Program (CFLP), Reef Fish Observer Program (RFOP), or Shark Bottom Longline Observer Program (SBLOP) on the quantity, sizes, and disposition of released Goliath Grouper (K. McCarthy, NMFS Southeast Fishery Science Center, Miami, FL, personal communication). The CFLP is a mandatory logbook program which collects trip and set-level information on releases/discards from a 25% sample of commercial vessels annually. The RFOP and SBLOP are programs employing at-sea observers aboard commercial fishing vessels using particular fishing gears. In areas where Goliaths are likely to be encountered, commercial vessels using vertical line gear reported Goliath Grouper catches on less than 2% of their trips annually, but long line vessels reported catches of Goliaths usually on a higher percentage (1-14%) of trips (table 3.2.1). Also, the number of Goliaths reported caught tend to be higher on long line trips. Long line trips are generally longer in duration than the trips employing vertical line gears. Observers also noted catches of Goliaths from both of these gears (table 3.2.2).

There is no estimate of the magnitude of discards of Goliaths, discard mortality rates from any of the commercial fishing gears, or size/age composition of the catches.

3.3 Recreational catches, harvests, releases, and size/age structure

McClenachan (2009a, b) used historical photographs and newspaper accounts from 1923-1977 to document trophy fish landings and declines in Goliath Grouper catches on Key West charter boat trips from the 1956 to 1985, and she estimated that the average number of individual Goliaths displayed per trip declined 86% over that time period and that the maximum individual fish size caught and the proportion of large grouper caught from land versus offshore had decreased prior to 1950.

Recreational landings are more uncertain. There was no comprehensive field survey of recreational fishing until 1979 when the National Marine Fisheries Service implemented its Marine Recreational Fishery Statistics Survey (MRFSS). Prior to this survey, there was a mail survey conducted approximately every 5 years beginning in 1965 with methods devised by the U.S. Census Bureau (Deuel and Clark 1968, Duell 1973). However, the recall period was long, respondents were only asked about landed fish, and there is no way to scale the results of these mail surveys with the MRFSS or its successor, the Marine Recreational Information Program (MRIP). Basically, discounting the mail survey results, there are recreational estimates of Goliath Grouper landings and releases for the 1981-2015 using the field surveys of the MRFSS and MRIP. Texas opted out of the MRFSS coverage after 1986 and conducts its own seasonal survey of recreational fishing but has not encountered anglers who have caught and kept Goliaths. The angler survey that Texas conducts does not record information on released fish.

Though harvest was allowed until 1990, relatively few anglers were interviewed that had caught (kept or released) Goliaths on either coast of Florida (Fig. 3.3.1). Most catches are by anglers on private boats in estuarine and nearshore areas, but there is also a significant number of fish caught by shore anglers in estuarine habitats and by anglers on charter boats. Catches of this species increased beginning in 2000 and peaked in 2007, declining generally thereafter.

Total catch rates from the MRFSS/MRIP data were analyzed previously (O'Hop et al. 2015) using a two-stage general linear model to estimate annual trends in catch rates. Trip data comprised of total catches by shore anglers and combined catches of all anglers on boat trips were analyzed with a binomial sub-model for annual trends in the proportion of trips which caught Goliaths by coast and by area fished (estuarine or offshore). The catch rates of trips which caught Goliaths were analyzed with a lognormal sub-model to estimate trends in the number of Goliaths caught. Potential factors in the models were year, mode of fishing, area fished (estuarine, nearshore, offshore), hours fished (median hours per trip), number of anglers, and avidity (median days fished in the last two months for anglers interviewed). In contrast, SEDAR 23 used a single MRFSS/MRIP catch rate index based upon the proportion positives from the private/rental boat fishing mode using year, coast, and water body as classification levels.

On both coasts, catch rates in the estuaries peaked in 2006-2007 and declined first in 2008 and then more dramatically in 2010 (Fig. 3.3.2. a,b). In January of both 2008 and 2010, there were periods of sub-freezing weather over the course of several days, leading to cold kills of marine fish. A plausible interpretation of these data is that cold weather severely affected juvenile Goliath Grouper subsequently leading to lowered catch rates in Florida estuaries. Documentation (Fig. 3.3.3) of cold kills of Goliath Grouper and other marine fish in the Everglades National Park was provided by Peter Frezza (National Audobon Society; personal communication) for 2008 and by Everglades National Park for 2010 (Hallac et al. 2010). Cold kills were also observed in Charlotte Harbor in 2008, and in Tampa Bay and Indian River Lagoon in 2010. There were no extensive collections of cold-kill Goliaths made. Most of the Goliaths that were collected from Charlotte Harbor event were 1 to 3 years old. Those from Tampa Bay were mostly ages 4-6, but there were also single specimens of age 7, 8, 11, and 16 years. Catch rates in the offshore areas of Florida's East Coast (Fig. 3.3.2. c) peaked in 2007-2008 and declined thereafter to a low in 2012 but has since recovered somewhat. This trend in catch rates might be associated with the cold kills of 2008 and 2010 in that recruitment from the estuarine areas might have been lower in subsequent years. Catch rates in the offshore areas of Florida's West Coast (Fig. 3.3.2. d) peaked in 2005 and showed marked declines in 2006-2008 which coincided with an extensive red tide over much of the West Florida shelf during much of 2005. The impact of the cold kills of 2008 and 2010 were not as evident, though that may be the reason behind the lag in recovery of catch rates because recruitment from the estuarine areas affected by the cold kills was probably lower than usual.

Another source of recreational fishing data is the Everglades National Park (ENP) Angler Survey, conducted at boat ramps and other areas of the park beginning in 1974. This survey intercepts anglers at access points and solicits information on duration of the fishing trip, number of anglers fishing, species and numbers kept or released, areas fished, and other details. These data were also analyzed with two-stage general linear models to estimate annual trends in catch rates. Trip data comprised of total catches by shore anglers and combined catches of all anglers on boat trips were analyzed with a binomial sub-model for annual trends in the proportion of trips which caught Goliaths. The catch rates of trips which caught Goliaths were analyzed with a lognormal sub-model to estimate trends in the number of Goliaths caught. Potential factors in the models were year, area fished (sub-area of the Ten

Thousand Islands), hours fished, number of anglers, and skill level. The methods were based on a previous analysis by Cass-Calay (2010) for SEDAR 23.

As with catch rates observed in estuarine habitats from the MRFSS/MRIP survey, catch rates in the ENP peaked in 2007, declining in 2008 and then dramatically so in 2010 (fig. 3.3.4.). There has been a modest increase in catch rates of Goliaths in the ENP after 2010. As mentioned previously, these declines in catch rates occurred after the cold-kill events in January 2008 and 2010, showing that the effect of these events on juvenile Goliaths had long-lasting effects and that catch rates are still lower indicating that recruitment back to the impacted habitats has been relatively slow.

Standardized catch rates of Goliath Grouper in estuarine habitats from the ENP and from anglers fishing in estuarine areas intercepted by the MRFSS/MRIP survey were remarkably consistent in trend (Fig. 3.3.5) where the data overlapped. There is also a general concordance of the offshore MRFSS/MRIP and REEF diver observation index (Fig. 3.3.6) for southeast Florida and the Florida Keys. The observed distribution of Goliath juveniles and adults suggest that it would be advantageous for the assessment model to use combined MRFSS/MRIP indices by area (estuarine or offshore) potentially using coast (if significant) to scale differences in the estimated the MRFSS/MRIP catch rates.

As mentioned in section 2.6 (*Release Mortality*), there is no estimate of release mortality from recreational fishing, but from research studies Goliaths caught using recreational angling methods appear to survive the encounter with the fishing gear if handled properly. Researchers have suggested using a 5% release mortality rate until more definitive estimates are available.

There are few observations of the sizes or weights of recreationally caught fish, and age compositions are also unknown. There are sizes of landed fish (chiefly juveniles and sub-adults) from the ENP Angler Survey, mostly from 1975-1977 (table 3.3.2), but no sizes of any releases which is typical of most angler surveys. Knowing the size of a fish, however, often tells you very little about their age (Fig. 2.6.3) since there may be many ages present in the population at a given length. Age-length keys, especially when developed with ample sample sizes and across the years of interest, would be preferable. Stochastic ageing methods which use the growth curve, the variability of size at length, and decremented by natural mortality could also be used. However, this type of method tends to smear the age proportions across many ages for a given size in the upper, flatter portion of the growth curve.

There were also sizes and ages of fish collected from two research studies from the ENP (Koenig et al. 2007, Table 3.3.3; and Brusher and Schull 2009, Table 3.3.4) which were from habitats fished by anglers visiting the ENP. The combined specimens from these research studies which employed hook and line gear resulted in an age composition for catches and was used as a proxy for the ages of fish vulnerable to anglers in the ENP (Fig. 3.3.5). Because juveniles eventually disperse from the mangrove habitats to offshore and older fish would not be available to anglers, a selectivity / vulnerability function that decreased with increasing age such as a gamma or double logistic curve (among others) was chosen to model this function. Because there is no size information of angler catches for releases, weighted average weights for juveniles in the catch for the 1990-2015 period were estimated by using the growth curve average total length by age at mid-year, the average weight corresponding to this TL, and the vulnerability curve for estuarine habitats (Table 3.3.5). For estuarine catches in the ENP, the weighted average weight of Goliaths was estimated as 5.26 kg (whole weight), which compares well to the weighted average weight of 5.37 kg estimated from the observed lengths of Goliaths landed by anglers in the ENP from 1974-1990. This ENP vulnerability curve and average weight for releases (since all catch of Goliaths is assumed to be released) was also applied to the MRFSS/MRIP catch index from estuarine areas.

For offshore Goliaths, few measurements of size and even fewer ages are available from recreationally caught fish, and there are no measurements for released fish. But recently, Koenig and Coleman (2013) presented some age measurements using fin rays (method developed by Murie et al. 2009) of adult fish captured using hook-and-line gear in 2012 at spawning sites off southeast Florida (Fig. 3.3.8). The ages estimated from these fin rays were used to construct a vulnerability curve for offshore Goliaths, and fit to a single logistic curve (Fig. 3.3.9). When additional ages of adult fish become available, the information available to construct selectivity / vulnerability curves or priors for this portion of the population will be on more solid footing. Approximately 800 specimens (fin ray samples) have been sampled from offshore adults and are undergoing age determinations. If this proves to be valid method for age determinations for older fish, better age composition information should be available for future assessments. For offshore catches (Table 3.3.5), the weighted average weight of Goliaths was estimated as 59.39 kg (whole weight), which does not compare well to the average weight of 6.6 kg estimated from the MRFSS/MRIP landings by anglers in offshore areas from 1984-1988. However, the sizes (and ages) of Goliaths in offshore catches is currently unknown, and the sizes in the MRFSS/MRIP catches over 1984-1988 may not be representative of the current size and age structure in this recovering population. Additionally, it is possible that most recreational anglers use lighter fishing tackle and Goliaths would be vulnerable to hooking but not necessarily being brought to the surface and identified as part of the catch. Therefore, until better information on recreational catches becomes available, the estimates for the vulnerability curve (Table 3.3.5) and average weight for offshore areas will have to suffice.

An additional vulnerability curve was constructed from the estimated annual numbers released by anglers in the MRFSS/MRIP survey (Table 3.3.1) by area and the estimated age composition of the releases (using the vulnerability curves) by area to produce a weighted average number of fish at age in the catch (Fig. 3.3.10). A single logistic curve was fit to this curve to use as starting values or priors for fishery selectivities in the catch-free and SSRA models.

3.4 Total estimated harvest

The catch-free model does not use estimates of harvest, but the SSRA model (and other types of surplus production models) needs these estimates over the time series to estimate management reference points.

There are significant gaps in the harvest information that need to be filled. The time series of commercial landings (reported or adjusted) was available, but there are no estimates of total harvests (which would include dead discards especially in years after the 1990 prohibition on retention). Commercial discards are set to 0, though there is information from the commercial logbooks and at-sea observations that there is some level of discards that occur with vertical line and long line gears (Tables 3.2.1 and 3.2.2). Recreational landings and releases (with adjustments; Table 3.3.1) were available for 1981-2015, but not for 1950-1980 because the MRFSS/MRIP survey was not in operation during those years. To fill in some level of recreational harvests for those years, they were set to the average estimated for 1981 to 1989 (Table 3.4.1).

The estimated harvests for 1950-2015 (Fig. 3.4.1) show a significant reduction starting in 1990, but have climbed significantly after 2000 because of the number of estimated releases and the assumed 5% release mortality. Estimated harvests have declined with recreational catch rates after 2008, which is suspected to be a result of the cold kills in 2008 and 2010. The magnitude of the estimated harvest due to release mortality (even though set at 5%) over the 1990-2015 is a product of the assumptions made about the vulnerability-at-age of estuarine and offshore fish and their corresponding average weights (see discussion in previous section).

4. Indices of Abundance

Guidance in many stock assessment models is provided by trends over time in catch rates or other types of measures that are intended to track the population abundance of the species of interest (e.g., Lo et al. 1992). Indices may apply to the entire population or some subset by age, area fished, type of gear, fishery sector, or other appropriate factor. The indices proposed and used in Goliath assessments (Table 4.1) have been changed, replaced, or modified through updates of the time series and re-grouping of data for the index in each assessment. The approach to indices taken in this assessment is to reduce (through consolidation) the number of indices used in the past based upon the type of index (fishery or fishery independent) and the portion of the age structure thought to comprise the majority of individuals described by the index.

There can be differences in the rates of catch or other measure employed to track abundance through time in the areas in which they apply [e.g., REEF SE (southeast FL and the Keys) and REEF SW (West FL), MRFSS estuarine (EFL, WFL), MRFSS offshore (EFL, WFL)]. The usual way indices are entered into models is to scale each one individually by their mean level over time so that it is the trend in the index rather than the raw magnitude that informs the model. These differences in catch rates by coast are ignored because the trends have been re-scaled. There can be conflicting advice given to the model if the trends in the catch rates or other measures of abundance are different by coast. For example, catch rates observed from the MRFSS/MRIP (Fig. 3.3.2) differ by coast (generally lower in southeast FL and Keys and higher in west FL), and the patterns in catch rates for the offshore (adult) population differ somewhat in trend over time possibly due to red tide impacts off west FL. The MRFSS/MRIP estuarine re-scaled catch rates by coast (Fig. 3.3.5) are more similar in trend than that of the MRFSS/MRIP offshore catch rates (Fig. 3.3.6). If two indices, for example) are equally weighted and are similar in variability (the catch-free model allows each index to have each year of the index to have a measure of variability), the model will likely attempt to average the differences in trends of those indices in the fitting process. To reduce this effect, the indices for the REEF FL and MRFSS/MRIP were re-examined with a general linear models approach to balance the trends in sighting rates or catch rates by coast and produce a single index trend for each of those indices for the assessment model.

4.1 REEF FL Index

Few surveys or research studies are available that provide coverage for the range of this species in U.S. waters. One source of data that has been used to gauge the abundance of Goliaths in the waters around Florida is from REEF (Reef Environmental Education Foundation; Pattengill-Semmens and Semmens 2004) and is in the category now referred to as “citizen science”. REEF captures data volunteered by divers which have gone through a training program in fish identification and survey techniques taught by this organization. There is no rigid experimental design. Divers participating in the program are free to choose their dive sites and times without regard to any random or stratified design. Their observations on the habitat type, depth, duration of dive, date, species of fish observed, and ranked abundance categories are recorded as part of the surveys. For Florida, over 20,000 such surveys in southeastern Florida, the Florida Keys, and West Florida to Pensacola have been recorded since 1993. The first REEF surveys in the database were from several sites in the Florida Keys in 1993. Surveys from southeast Florida started to show up in the next year, and occasional surveys occurred sporadically on Florida's West Coast in later years.

REEF data were examined prior to analysis for consistency in habitat scoring. There are eleven categories used in REEF to classify the habitat a diver encounters at a site (Table 4.1.1). Some surveys had unknown habitats especially prior to 2000 because there was no habitat code available for artificial reefs or wrecks. For those sites, if the wreck or artificial reef existed at the time of the survey, the habitat code was reset to "artificial". In other cases, sites with surveys listing the code for unknown or mixed habitats were compared with other surveys at the same site where habitat was more specifically coded. The most frequently listed habitat was substituted in those cases, unless the most frequently coded habitat was unknown or mixed. After these revisions, the habitat scoring was re-grouped into a smaller number of codes that were appropriate for examining Goliath Grouper presence or absence. Goliaths have been noted as preferring high profile reefs, wrecks, and artificial reefs with large vertical profiles (Koenig et al. 2013, Collins 2014).

Porch and Eklund (2004) used a subset of these surveys to construct an index of abundance (REEF SE) for southeastern Florida and the Florida Keys, using it in the first assessment of Goliath Grouper (Porch et al. 2006, SEDAR 6, 2004). It was updated in the second assessment (SEDAR 23, 2010) and a second index (REEF SW) representing fewer sites and a shorter time series was developed from surveys from the West Coast of Florida.

An additional source of surveys of sites for 2010-2014 was the Great Goliath Grouper Counts (GGGC). Divers are asked to survey sites usually in late June to count the number of Goliaths seen during their dive. The protocols for the conduct of the survey are similar to REEF (Dr. A. Collins, University of Florida SeaGrant, personal communication) which are typically an artificial reef or wreck, but natural reef habitats can also be chosen. There is a significant overlap in sites in REEF and GGGC, which is fortunate because the number of surveys submitted for West Florida sites has fallen significantly in recent years. The GGGC data was re-formatted to match coding conventions for REEF surveys, and Goliath counts from the GGGC were converted to the abundance ranks used by REEF in order to compensate for the drop-off in REEF surveys. The combined REEF and GGGC surveys will be referred to simply as "REEF FL" for the rest of the discussion.

The criteria used for site selection in SEDAR 6 and 23 was modified for this assessment (Table 4.1.1) and differed slightly. The criterion of including sites where Goliaths had been observed at least once was unchanged. The second criterion used in SEDAR 6 and 23 was that sites needed surveys in at least six years for inclusion in the analysis. For SEDAR 47, this criterion was raised to requiring surveys in at least 10 years at a site. These are arbitrary criteria intended to balance the need for spatial coverage in sites (to examine the aspect of recovery in terms of presence/absence) with the need for temporal coverage for the site over the 21 years of the time period (1994-2014). All sites meeting the requirement of at least one positive sighting of Goliaths and at least one survey in each of any ten years over 1994-2014 were selected, with an additional criterion that sites were in waters adjacent to Florida. This last criterion excluded two sites in the Texas Flower Gardens from this analysis. There were 214 sites in Florida meeting the original SEDAR 6 and 23 criteria of 6 or more years of surveys at sites with at least 1 sighting of Goliaths (Table 4.1.2 a-d), and 129 sites meeting the new criteria of least 10 or more years of surveys.

The selected REEF FL data were analyzed with a generalized linear model (SAS GENMOD; SAS Institute Inc. 2008) configured as a Poisson regression (e.g., Bilder and Loughin 2015) using the abundance ranks in the surveys as the response variable, and potential classification variables: year, site (REEF site number), new_hab (re-coded habitat class, Table 4.1.1), season (Warm [June-October], Cool [November-May]), region (Atlantic, Gulf), experience level (Experienced, Novice). Variables were added to the regression using a step-wise analysis, selecting variables that were significant ($p<0.05$) and that reduced the deviance (relating to the fit of the regression) by at least 0.5%. Site, year, and new_hab were selected, and over half of the deviance was explained by the regression (Table 4.1.3). The least-square means by year were generated for the time series (Fig. 4.1.1a), and the final index, scaled to the mean over the time period, is presented in Fig. 4.1.1b.

The new REEF FL index is comprised of more sites (129) and includes data from sites along both coasts of Florida and the Florida Keys. In fact, this index has more sites (120) comprising it from the southeast coast of Florida and the Keys than sites (9) from the west coast (Table 4.1.1b). Other differences between REEF FL and SEDAR 23's REEF SE were the re-coding of the mixed habitat code (if possible), and re-coding of artificial reefs and wrecks prior to 2000 which had "unknown" for the habitat code. This caused some slight differences in the time period from 1994 to 1999 between the REEF FL and REEF SE of SEDAR 23 (Fig. 4.1.1b). Even with the addition of the GGGC data for the West Florida sites, nine of the SEDAR 23 sites in West Florida had too few years of surveys to meet the new criteria for the REEF FL index.

4.2 Everglades National Park (ENP) Angler Survey Index

This index was updated through 2014 recently (O'Hop et al. 2015; Fig. 3.3.4) and followed the methods of Cass-Calay (2010) who developed this index originally for SEDAR 23. The analysis uses a hurdle model [also referred to as a "zero-adjusted" or specifically in this case as a "delta-lognormal" (Lo et al. 1992) model] to examine data collected by the National Park Service biologists who regularly conduct a survey of anglers fishing in the ENP. This analysis employs a binomial sub-model to analyze the proportion of positive catches of the target species (Goliath Grouper), and a lognormal sub-model to examine the magnitudes of the positive catches. Potential factors for the sub-models were year, area fished (sub-area of the Ten Thousand Islands), hours fished, season (Dec-Feb, Mar-May, Jun-Aug, Sep-Nov), number of anglers, and skill level (skilled and other).

The response variable for the binomial sub-model was whether a Goliath was caught (1) or not caught (0), and a binomial distribution is used to model the proportion positives. Hours fished was treated as a categorical variable for the binomial sub-model, and were placed into these categories: 0-3, 4-5, 6-7, and 8+.

The response variable for the positives sub-model was the total catch of Goliaths reported (all were released) on the trips expressed as catch-per-unit-effort. Because there may be more than one angler on a trip, the total number of angler hours fished was the product of the number of anglers multiplied by the number of hours fished. Total numbers of Goliaths caught was divided by the total number of angler hours for the trip and multiplied by 1000 to make the response variable in terms of catch per 1000 angler-hours. These values were log-transformed for the analysis in the sub-model for the positives. Because the response variable for the positives was a CPUE measure based on number of anglers and hours fished, number of anglers and hours fished were not used as potential factors in this model.

As in SEDAR 23, surveys for 1974 were excluded from the analysis because only one Goliath was reported caught, which caused estimates to be non-estimable for that year. For this assessment, additional exclusions of surveys for which the hours fished was listed as 0 as well as those interviews on which no fish of any species was caught. Before exclusions, there were 216,210 interviews. After these exclusions, there were 193,577 interviews remaining for analyses (6,837 interviews were positive for Goliath). These exclusions should be similar to those made by Cass-Calay (2010).

Year, area fished, hours fished (as categories), and season were significant in the binomial sub-model (Table 4.2.1a). Year and season were significant in the lognormal sub-model (Table 4.2.1b). Least-square means by year were generated from each of the sub-models, and the index values were derived using a Monte Carlo simulation of draws for each of the sub-models' annual means and their associated standard errors. Because each of the sub-model's means and standard errors are in transformed space, it is necessary to back-transform them appropriately before deriving the index as the product of the proportion positives and the average catch rates (Table 4.2.2). The index, with annual values scaled to their means (Fig. 4.2.1), show an extended period of low catch rates from 1981-1993, increasing moderately to 2002, a rapid period of increase through 2007, a sharp decline in 2008 to a low point in 2010, and a slow increase in trend through 2014. There were documented cold kills that affected portions of the Everglades in January of 2008 and 2010, and mortality of Goliaths (as well as other species, especially common snook) was noted for both of these events. The 2010 cold kill was the more extensive. Because this index applies to juvenile Goliaths, and they spend the first 5 or 6 years of their life in the mangrove-lined tidal creeks, the cold kills would be expected to have a large impact on this portion of the population. The slow recovery in the catch rates of young Goliaths in the ENP should be cause for concern as it indicates that successful recruitment to the tidal creeks has not recovered to pre-cold kill levels, and this reduced recruitment could potentially delay or stall the recovery of the adult population offshore.

4.3 MRFSS/MRIP Indices

Survey data from the MRFSS/MRIP was available for these two indices. The usual approach for examining the catch rates of species is to subset angler interviews from the entire data set that were likely to have fished in areas and habitats where the species of interest occurs without respect to whether the species of interest was actually caught. In this way, not only are the "positives" (interviews which have Goliaths) obtained, but also a measure of the "zeroes" for calculating the proportion of positive catches so that catch rates are more meaningful. Several methods can be employed for selecting data from general surveys to obtain trips with and without the target species. Clustering (Shertzer and Williams 2008), logistic modeling (Stephens and MacCall, 2004), other multi-variate methods, and the use of caught or angler-expressed targeting criteria have all been used for this purpose.

Unfortunately, the data for Goliaths seem resistant to those methods of deriving subsets. Perhaps that will change as they become more frequently caught in the future as their population levels recover. Goliaths in estuarine habitats are caught with a different suite of species than when caught in offshore areas, and which can also be different by coast. Goliaths are uncommon in catches and too sparse in the data for 1981-1996 for this type of analysis, and there are only weak associations with the catches of other species. As a result, the method of selection used was to simply to tally the number times a species was caught with Goliaths by coast and area fished, and those species occurring on 1.5% or more of trips with Goliaths were used to select interviews by coast and area fished (Table 4.3) for the analyses.

MRFSS/MRIP Estuarine Index

This analysis employs a binomial sub-model to analyze the proportion of positive catches of the target species (Goliath Grouper), and a gamma sub-model to examine the magnitudes of the positive catches. Interviews of anglers participating in the same trip were combined for a single record per trip with catch of Goliaths (0 or more). Median hours fished and median group avidity for the trip were calculated. If hours fished or avidity was missing (a small number of records), these values were filled in from the median values for the year and coast to reduce the potential loss of positive catches from the analysis due to missing values. Potential factors for the sub-models were year, mode of fishing (shore, charter boat, private/rental boat), hours fished (0-3, 3-6, 6-9, 9+), season (Jun-Oct, Nov-May), number of anglers, and avidity (days fished in last 60 days: 0-1wk, 1-2wk, 2-3wk, 3-4wk, 5+wk), season (November-May, June-October), and coast (EFL+Keys, WFL). The response variable for the binomial sub-model was whether a Goliath was caught (1) or not caught (0), and a binomial distribution is used to model the proportion positives. The positives model used the same suite of potential factors.

Year, mode of fishing, and hours fished were significant in the binomial (proportion positives) sub-model (Table 4.3.1a), and year, mode of fishing, and coast were significant and met the 0.5% deviance reduction criteria for the gamma (positives; Table 4.3.1b) sub-model. Least-square means by year (and standard errors) were produced for each sub-model, and simulation through Monte Carlo methods generated the catch rate index from the product of draws from the distributions of each sub-model's annual means (Fig. 4.3.1).

MRFSS/MRIP Offshore Index

This index was generated using the same process as described above. A binomial sub-model analyzed the proportion positives for the trips, and a gamma sub-model analyzed the positive catches of Goliaths. Year, mode of fishing (charter boat, private/rental boat), and numbers of anglers were statistically significant and met the 0.5% reduction in deviance criteria for the binomial sub-model (Table 4.3.2a). Year, avidity and coast were significant and met the 0.5% reduction in deviance criteria for the gamma sub-model (Table 4.3.2b). Least square means by year (and standard errors) were produced for each sub-model, and the catch rate index was generated as above (Fig. 4.3.2).

4.4 A comparison of the scaled indices

When scaled to their means, the general trends being provided to the assessment models on the abundance of age classes (through the selectivity/vulnerability vectors for the index) which comprise the index are easily seen (Fig. 4.4.1). The ENP and MRFSS/MRIP estuarine indices, which inform the assessment models about the juvenile portion of the population, are in good concordance (Fig. 4.4.1a). Both show a period of increasing catch rates, and both show declines that were probably related to the cold kills. The REEF FL and MRFSS/MRIP offshore indices which pertain to the adult portion of the population, are in reasonable concordance (Fig. 4.4.1b). Given that the age structure of the offshore adults is less well-known at this time, and that the sizes and ages of fish caught by anglers in this area is uncertain, the amount of agreement between the two indices is probably better than would be expected. It is a little worrisome that both these indices are trending downward in recent years.

III. Assessment Models

5. Introduction

Conducting an assessment of data-poor species such as the case with Goliaths can be challenging and requires the use of methods that do not require more complete knowledge of size- and age-structure, or a thorough knowledge of removals or complete understanding of the species' life history. Usually there is at least some information on removals by fisheries to guide and scale an assessment model. Even though the reporting of commercial landings information on Goliaths in the southeastern U.S. has been more or less in place since at least the 80 years, and recreational fisheries landings and releases have been surveyed regularly over the last 35 years, there is still much uncertainty in the information that has been gathered (see discussion in Part II, Section 3). And, there is some uncertainty over the life history, reproductive strategies, and genetic kinship among Goliaths, and research is being conducted in those areas.

We present two age-structured surplus production models [Stochastic Stock Reduction Analysis (SSRA) and the Catch-Free model] for consideration. Although both models belong to the same general class of models, how they estimate parameters differs greatly. Each has strengths and weaknesses. Both models depend up life history parameters such as growth, natural mortality, age-at-maturity, weight-at-length, some estimate of fishery selectivity, indices of abundance, and selectivity or vulnerability vectors associated with the indices. The SSRA model also requires an estimate of removals, which we have attempted to reconstruct for the model inputs.

6. Stochastic Stock Reduction Analysis (SSRA)

6.1 Background

Age-structured production models (ASPMs) fall somewhere between catch-only methods and integrated analysis models, and are considered to be superior to simple production models and delay-difference models (ICES, 2012). ASPMs have the following features (Restrepo and Legault, 1998; Butterworth and Rademayer, 2008; ICES, 2012):

(i) they replace the estimation of production model parameters by the estimation of stock–recruit parameters, the recruitment being functionally dependent on spawner stock size;

(ii) they take direct account of the age structure of the population;

(iii) they project the population forward in time via internal age-structured simulations accounting for time-lags (e.g., periods from birth to recruitment, first capture and first reproduction) given age effects (fleets' selectivity) and age schedules of biological parameters (weight, natural mortality, maturity or fecundity); and

(iv) they can be tuned with (age-aggregated or age-structured) abundance indices, each with its unique age-selection. Unlike statistical catch-at-age and integrated analysis models, ASPMs usually do not incorporate fishery-dependent age and length compositions and age schedules must be specified by the user.

ASPMs originally were a class of models designed for fisheries without age and size compositions (Hilborn, 1990; Punt et al., 1995). Their stochastic versions through Bayesian implementations led to referring to ASPMs as (stochastic) Stock Reduction Analyses (SRAs; Walters et al., 2006), although SRAs originally were based on delay–difference (a.k.a. stage–structured production) models (e.g., Kimura, 1985). Either way, an ASPM or SRA is a removal method asking how large the stock (including recruitment) needed to be to have produced the time series of observed catches (landings + discards) and observed changes in relative abundance. In this context, the historical catches and abundance indices are the key inputs to ASPM/SRA models.

This report employed an ASPM version developed by Martell et al. (2008) to reconstruct the possible trajectories of abundance (numbers and biomass) and fishing mortality for goliath grouper in light of the estimated time series of fishery removals across 1950–2014 and available abundance indices. This model is parameterized in terms of the maximum sustainable yield, MSY, and the fishing mortality producing MSY, FMSY (i.e., MSY and FMSY are estimated parameters), on the grounds that MSY and FMSY could be management benchmarks a stock status has to be judged against. However, the management plan for goliath grouper prescribes the maximum fishing mortality threshold (MFMT) equivalent to 50% static spawning potential ratio (50% SPR) as the FMSY proxy, as well as the minimum stock size threshold (MSST), to determine when overfishing and overfished status, respectively, are occurring (GMFMC, 2015). Therefore, the second objective consisted of developing various types of SPRs to evaluate the overfishing and overfished status of goliath grouper on the basis of the MFMT and MSST.

6.2 Model Description

Martell et al.'s (2008) ASPM (reference document SEDAR47-RD-1) is a standard population dynamics model with age-structured representations of growth, survival, and recruitment, where the population simulations are carried forward in time. This model is parameterized in terms of MSY and FMSY on the ground that MSY is proportional to the unfished biomass (B0) and FMSY is a function of a population productivity metric called Goodyear recruitment compensation ratio (κ). That is, instead of searching over values of B0 and κ (e.g., Frisk et al., 2010) when fitting the model to time-series data and then determining MSY and FMSY, MSY and FMSY are treated as leading (estimated) parameters and the values of B0 and κ that would likely be consistent with the (MSY, FMSY) hypothesis are derived a posteriori, conditional on pre-specified life-history parameters and selectivity schedules.

Details of the ASPM algorithm are available in Martell et al. (2008). These authors referred to their model parameterization approach as management-oriented, and, conditional on an assumed (and implicitly reliable) stock–recruit function, considered this approach to be more transparent than the translation of population parameters (e.g., B0 and κ) to management benchmarks. Eq. A1–Eq. A34 (Appendix A) reproduce the ASPM general framework, and our implementation of this model is described in the source code detailed in SEDAR47-WP-01.

Three aspects should be noted. First, the parameter κ corresponds to the quantity that Myers et al. (1999, 2002) defined as maximum lifetime reproductive rate at low density, and is related to the steepness of a stock–recruit model (h), i.e., the fraction of the unexploited recruitment produced by 20% of the unexploited parental stock (Myers et al., 1999; Martell et al., 2008; Brooks et al., 2010). Second, when fecundity at age is available and is reliable (as measured at peak spawning), the recruitment (age-0 fish) is a function of spawning stock egg production (Eq. A27) via a stock–recruit model expressed by Eq. A28. Otherwise, the product of mean weight for both females and males at the time of peak spawning and the proportion mature (Eq. A8) is, as was the case here, commonly treated as fecundity proxy. In which case, the unfished egg per-recruit (Eq. A9) and the unfished spawning biomass per-recruit (Eq. A11) on the one hand, and on the other, the fished egg per-recruit (Eq.A10) and the fished spawning biomass per-recruit (Eq. A12) are equivalent. Likewise, the spawning stock biomass

(SSB) is a proxy of egg production (Eq. A27). Finally, Martell et al.'s (2008) ASPM can accommodate fishery independent proportions of catch at age if they are available.

The ADMB code used was written by Martell et al.'s (who employed a single age-aggregated tuning index with its related age composition and, instead of FMSY, estimated the exploitation fraction at MSY). This code was modified by Dr. W. Cooper (a former FWC/FWRI employee, stock assessment group) to estimate FMSY and accommodate multiple abundance indices, including those indices with age composition (Appendix A and SEDAR47-WP-01). Given various predicted states (Eq. A25–Eq. A30), especially the numbers of individuals by age and year (Eq. A28), the predicted index typically is the estimated population scaled by the index-specific selectivity and to a mean of one (Eq. A31). In this way, the predicted index is comparable to the observed index, which itself is preliminarily scaled to mean of one.

6.3 Model Configuration

Specification details for the goliath grouper ASPM are in Appendix A. Calculations were made for age-0 through age-37 for the period 1950–2014; there were no age composition data. Age schedules (Eq. A1–Eq. A8) included:

(i) Mean length (mm) and mean weight (kg) obtained, respectively, by employing the von Bertalanffy growth parameters and the weight–length coefficients.
(ii) A two-block fishery selectivity (logistic for the 1950–1989 block as in SEDAR 6 and quasi-logistic for the 1990–2014 block) and single-block selectivity for each index (Fig. 6.3.1). A dome-shaped selectivity was assumed for juvenile indices; a logistic selectivity was assumed for the dive reef index and the quasi-logistic selectivity of the fishery during 1990–2014 was applied to the MRFSS/MRIP offshore index.
(iii) Proportion mature: 0 for age-0–age-5 and 1 otherwise.
(iv) Natural and fished survivorships to various ages.
(v) Fecundity approximated Eq. A8.

These age schedules served the calculations of incidence functions (Eq. A9–Eq. A14), such as the equilibrium biomass, fecundity, and yield on a per-recruit basis.

F_{MSY} and MSY (Eq. A15) were the key model parameters, but annual recruitment deviations were also estimated. The lower and upper bounds for the estimation of F_{MSY} were 0.01 and 0.5, with an initial guess of 0.1. For the estimation of MSY, the lower and upper bounds were 1,000 and 200,000 kg; the initial guess was set to average of the estimated landings (i.e., 70,000 kg). Recruitment deviations were bounded between −5 and 5, and were assigned a standard deviation of 0.6 on the basis of Rose et al.'s (2001) meta-analysis results for periodic species. For the calculation of the total negative log-likelihood, equal weights of one (1) were assumed for various likelihood components.

Given the incidence functions, estimated values of F_{MSY}, MSY and an assumed Beverton–Holt stock–recruit model (see Appendix A for its functional form), the derived quantities (Eq. A16–Eq. A24) included the compensation ratio, the unfished biomass and egg production, the equilibrium recruitment and yield by fishing mortality and the classical stock–recruit parameters (i.e., α and β).

Model data were: (i) fishery removals (kg) during the period 1950–2014 (Fig. 6.3.2) and (ii) indices of abundance in number (Everglades National Park (ENP) juveniles, 1975–2014; MRIP/MRFSS offshore for adults, 1997–2014; MRIP/MRFSS shore for juveniles, 1997–2014; and Diver or Reef survey on adults, 1994–2014) and the related coefficients of variation (Fig. 6.3.3). Observed fishery removals (C_t) consisted of commercial landings (1950–1989), reported recreational landings (Type A+B1, 1981–1989) and recreational dead discards (Type B2) with an assumed release mortality of 5%; they were considered to be known without error.

In Martell et al.'s (2008) ASPM, annual fishing mortality rates (F_t) are conditioned on the Baranov catch equation (Eq. A30). F_t values are first initialized by setting them to the ratios of C_t and the annual estimated vulnerable biomass (B_t, Eq. A29; $F_t = C_t/B_t$). Then, using Newton's root finding method, F_t values are iteratively updated until the difference between the predicted removals ($\hat{C}_t$) and the observed removals are minimal (Eq. A30 and Eq. A32). A fixed number of ten iterations was used to ensure that the algorithm converged.

6.4 Likelihood

Martell et al.'s ASPM calculates the log-likelihood for each index using Eq. A33 as adapted by W. Cooper. In addition to index likelihood components, the total log-likelihood may or may not include the likelihood components associated with priors for FMSY (Eq. A34), MSY, κ, fishing mortality"-observations", and the penalty for κ being negative. The likelihood components for priors on MSY, κ, and fishing mortality"-observations" are calculated similarly as with Eq. A34. In particular, if the prior for κ is to be included, the estimate for κ is set to 0.16 with a cv of 0.3 following Shertzer and Conn (2012).

6.5 Uncertainty in model results

Running the ASPM's ADMB code under the Markov Chain Monte Carlo (MCMC) mode makes the ASPM "stochastic." In this way, uncertainty in the quantities of interest can be characterized, provided the chains converge.

Six chains were run each with 1,000,000 draws, a saving of every 1,000th ("thinning" process), and a unique seed number: 1,000 draws were therefore saved ("accepted") for each chain and the other draws were discarded. Convergence diagnostics of MCMC simulations to posterior distributions were checked visually by inspecting various plots (traces, density and autocorrelation). Higher values of lag autocorrelation suggest high degree of autocorrelation between draws and slow mixing. Such an (unwanted) outcome can be avoided by increasing the thinning interval (or, whatever the number of iterations, by reducing the proportion of saved draws). Traceplots indicate how well the chains are mixing (i.e., are moving around the parameter space): jumps in certain areas signal bad mixing, which are associated with multimodal density plots; in contrast, good mixing of chains (i.e., variations without trend across iterations) typically results in unimodal density plots.

The final marginal posterior probability density functions were summarized in terms of the mean, median, standard deviation (SD) and the 2.5th and 97.5th percentiles, which define the 95% Bayesian central interval (95%BCI). In a Bayesian context, a 95%BCI means that there is exactly a 0.95 probability that the true value of a parameter lies within that interval given the model, data, and priors (Ellison, 2004; Grosbois et al., 2008; Kéry, 2010).

Retrospective pattern has been another important issue in assessment results (Mohn, 1999; Legault, 2009). Here, a retrospective analysis was carried out by removing successive years of data from the model for 5 years. The objective was to inspect (visually) retrospective patterns in estimated time series and to evaluate the retrospective error in model results. The retrospective error (E2) was the rho statistic of Mohn (1999):

$$E2 = \sum_{t=2014-5}^{2013} (Q_t|_{data\ to\ t} - Q_t|_{data\ to\ 2014})/Q_t|_{data\ to\ t}.$$

This statistic must be zero when the assessments after removing successive (retrospective) year data match exactly with the full time series assessment, or when the differences between the (retrospective) assessments and full time series assessment are balanced both positive and negative (Cadigan and Farell, 2005; Legault, 2009. Legault (2009) adds: “The former case has no change from year to year, while the latter case would be characterized as exhibiting noise but not a retrospective pattern. The Mohn rho will become large, either positive or negative, when there is a consistent pattern of change in the (retrospective) assessments relative to the full time series assessment. Although it is a relative measure, there have not been rules of thumb developed regarding how large in absolute value Mohn rho must be before an assessment is declared to exhibit a retrospective pattern.”

6.6 Stock Status

The management plan for goliath grouper proposes two prescriptions (GMFMC, 2015). First is the maximum fishing mortality threshold (MFMT) equivalent to 50%SPR as FMSY proxy for determining whether overfishing is or is not occurring. As such, therefore, the 50%SPR measures the level of target (equilibrium and static) SPR at and beyond which the goliath grouper stock is experiencing overfishing. Second is the minimum stock size threshold (MSST) at or below which the stock is considered to be overfished.

The equilibrium and static SPR and, additionally, the time-varying static and transitional SPRs (sSPR and tSPR; Gulf of Mexico SPR Management Strategy Committee, 1996) were developed. Calculation inputs for the equilibrium and static SPR consisted of growth and maturity schedules, a selectivity schedule obtained as a number-weighted mean of the estimated fishing mortality at age during 2011–2014, and a spawning offset (i.e., fraction of the year elapsed at the time of peak spawning) of 0.67 (Table 6.6.1 for the schedules used). In addition to the previous life histories, the calculations of the sSPR and tSPR involved the matrix of fishing mortality at age generated by the ASPM run. Note that the spawning offset was based on the fact that spawning aggregations for goliath grouper occur during the months of July through September (Ellis et al. 2013), August being hypothesized as a probable month of peak spawning.

The GMFMC (2015) defines the MSST for goliath grouper as MSST = (1–M)×BMSY (or proxy, which here is the SSB associated with the MFMT) or MSST = 0.5 BMSY (or proxy), whichever is greater. To this end, Eq. A27 was refitted externally to the estimated stock–recruit data for the period 1975–2014 when indices of abundance were available and presumably captured better the population dynamics. The equilibrium SSB, recruitment and yield by fishing mortality were computed given the spawning biomass per-recruit and the estimated stock–recruit parameters; the MSST was subsequently derived.

The determination of the overfishing and overfished status was based on the ratios of current fishing mortality (Fcur) to MFMT (Fcur/MFMT) and of current SSB (Bcur) to MSST (Bcur/MSST). Fcur and Bcur consisted of the geometric means of the estimated fishing mortality and SSB across 2012–2014. When the ratio Fcur/MFMT exceeded 1, overfishing was considered to be occurring and vice-versa. The ratio Bcur/MSST smaller than 1 reflected the overfished status and vice-versa. Furthermore, the time series of sSPR and tSPR were plotted and compared with the management threshold of 50%SPR. The sSPR is related to fishing mortality and can be used as a measure of overfishing; the tSPR indicates how close the age structure of a stock is to being rebuilt, but does not necessarily correlate to absolute biomass levels (GMFC, 1996, 2015).

6.7 Sensitivity analyses

No sensitivity analyses were carried out with the ASPM.

6.8 Projections

No projection analyses were carried out with the ASPM.

6.9 Results

Goodness-of-Fit

The ASPM predicted indices of abundance mimicked the overall trends of observed values, especially for juveniles, but the standardized residuals indicated periods when the observed values were overestimated and underestimated during consecutive years (Figs. 6.9.1 and 6.9.2).

Estimated Parameters

MCMC runs of the ASPM indicate that the negative log-likelihood associated with the estimation of FMSY, MSY and 64 recruitment deviations of goliath grouper employing the ASPM averaged 1,468 (95%BCI: 1457–1480.21; Table 6.9.1; Fig. 6.9.3), out of which the fitting of juvenile indices accounted for 25%, the recruitment deviations for 14%, and the prior of "observed fishing mortality" for 40.1%. MCMC simulations converged fairly well (Fig. 6.9.3).

From MCMC simulations, mean FMSY was 0.182year^{-1} (95%BCI = 0.175–0.189year^{-1}) and mean MSY = 85,650 kg (95%BCI: 83,460–88,047 kg (Table 6.9.1).

Fishing Mortality

The fishing mortality of goliath grouper was less than 0.09year^{-1} between 1950 and 1963 except in 1953 and 1963 when its annual values were 0.11 (Fig. 6.9.4a). Since 1964, the fishing mortality was well above 0.18year^{-1} and trended up through the late 1980s when it reached values of 1.2–1.56 year^{-1} (also see Table 6.9.2 for the 1975–2014 time series). During 1963–1989, the fishing mortality excessively exceeded the MFMT.

The fishing mortality (typically incidental mortality of releases) was generally low since 1990, but amounted to 0.17–0.21year^{-1} in 1990/1991 and to 0.11–0.17year^{-1} between 2003 and 2008, during which years it exceeded the MFMT (Fig. 6.9.4a, Table 6.9.2). It was 0.02 in 2014.

Population abundance

The average number of goliath grouper from MCMC simulations amounted to 513,072 individuals in 19950 (95%BCI = 498,900–530,690). In the absence of indices of abundance to guide the population trajectory prior to 1975, the numbers of goliath grouper varied smoothly between 347,000 and 400,000 (Fig. 6.9.4b). Since 1975, the numbers of goliath grouper (Table 6.9.2) tracked the trend of relative indices of abundance especially of the ENP juvenile index: it declined from a mean of 378,164 (95%BCI = 328,257–431,329) individuals in 1975 to a mean of 82,900 (95%BCI = 59,821–107,900) individuals in 1991. Since then, the numbers of goliath grouper increased to a peak of 1,186,100 (95%BCI = 1,030,000–1,340,000) animals in 2006, but declined thereafter until 2011 (mean: 298,500 animals; 95%BCI = 266,059–337,185 fish). The estimated mean number of goliath grouper in 2014 was 345,700 (95%BCI = 299,800–397,600). During the period 1950–2014, age-0 goliath grouper represented 50–85% of the entire population; this percentage was 69% in 2014.

During 1950–1989, goliath grouper's total biomass, vulnerable biomass and SSB showed trends opposite to that of the fishing mortality (Figs. 6.9.4c, d, and e; Table 6.9.3 for the vulnerable biomass and SSB during the period 1975–2014). They amounted, respectively, to 2,331 MT, 2,120 MT and 2,060 MT in 1950, but declined steadily until 1990 when they reached mean levels of 143 MT (95%BCI = 129–160 MT), 82 MT (95%BCI = 73–93 MT), and 9 MT (95%BCI = 4–16 MT) in 1990. Since 1991, total biomass, vulnerable biomass and SSB of goliath grouper increased sharply. This increase of biomasses, even when the population number of goliath grouper was declining after 2006, suggested an increasing presence of larger and heavier individuals. Note that the population of goliath grouper may have been overfished since 1966 through 2010, because the estimated SSB was below the MFMT throughout that period (Fig. 6.9.4e).

Uncertainty in Estimated Parameters and Trajectories

Uncertainty in model results appeared small, as indicated by very narrow 95%BCIs (Tables 6.9.1–6.9.3; Fig. 6.9.4), except for the total numbers of goliath grouper prior to 1989 and between 1995 and 2006. Such precise results may largely be due to fishery data and life history inputs that were assumed to be known without error.

The retrospective analysis indicated that the estimated total numbers and recruitment of goliath grouper were more and more biased high upon removing annual data backward, but this trend was not obvious for other variables (Fig. 6.9.5). This observation was reflected in the statistic rho (Table 6.9.4): positive values of rho close to or greater than 1 for the total numbers and recruitment of goliath grouper meant that their retrospective estimates were decreasing with time. However, as indicated by Legault (1999), there is no accepted level of rho beyond which an assessment is deemed to exhibit a (strong) retrospective pattern. For other variables, the statistic rho was positive or negative but was low in absolute terms.

Stock Status

Mean Fcur 0.017year−1 (95%BCI = 0.016–0.018year−1) and mean Bcur as 324 MT (95%BCI = 284–371 MT). Results from the fitting of Eq. A28 to the stock–recruit estimates across 1975–2014 (Fig. 6.9.6; parameter $\alpha = 6.527446$; parameter $\beta = 2.32\times10^{-5}$) and from the (equilibrium) yield per-recruit (YPR) and SPR analyses (Fig. 6.9.7) indicated that:

i. The fishing mortality associated with 50%SPR (F50%SPR) equaled 0.08year^{-1}; hence, the MFMT = 0.08year^{-1}.
ii. The estimated SSB at F50%SPR was 890,508 kg (BMSY proxy). Therefore, for M = 0.18, the MSST = 730,216 kg; otherwise, the MSST could be 890,508 kg/2 = 445,254 kg. Since,

730,216 kg > 445,254 kg, the retained MSST was 730,216 kg.

Because the ratio Fcur/MFMT = 0.22 and the ratio Bcur/MSST = 1.48, overfishing was not occurring for goliath grouper and the stock of goliath grouper was not overfished in most recent years.

The time-varying SPR (sSPR) compared with the objective of maintaining the SPR at or above 50% (Fig. 6.9.8), conveyed the same message as that of the fishing mortality by year in comparison with the MFMT (Fig. 6.9.4a). They indicated that overfishing was not occurring since 1995, except perhaps during 2003–2008 when the fishing mortality was greater than the MFMT and sSPR < 50%SPR. On the other hand, the time-varying transitional SPR (tSPR; Fig. 6.9.8) showed a trend similar to those trends of biomasses (Fig. 6.9.4c–e). The age structure of goliath grouper may have been expanding since the mid-1990s, after a long period of continual contraction, from 1963 (tSPR = 48.3%) through the late 1980s–early 1990s (tSPR = 0.4–9%). However, the tSPR did not exceed the management target of 50%, except in 2013 and 2014.

6.10 Discussion

Through the use of an age-structured production model (ASPM) parameterized in terms of MSY and FMSY, this analysis attempted to reconstruct the population size and fishing mortality of goliath grouper inhabiting the U.S southeast coast during the period 1950–2014, and, ultimately, to determine the possible stock status of goliath grouper in light of estimated harvests and available indices of abundance. The goliath grouper population dynamics was simulated conditionally on the ASPM estimates of FMSY and MSY, but the overfishing and overfished status of the stock were determined by comparing results from per-recruit analyses and the fitting of a stock–recruit model with the management definitions proposed by the GMFMC (2015).

The ASPM relied heavily on indices of abundance, estimated annual harvests (landings + discards) assumed to be free of error, and on known life history and selectivity schedules. Efforts has been made to improve the development of indices of abundance, but the related selectivity by age, especially for the MRFSS/MRIP offshore index and the dive reef index were problematic. For the life history traits, (i) goliath grouper may live longer that it has been reported, so constant and age-specific natural mortality rates may have been biased high; (ii) there was lack of fecundity information; and (iii) the proportion mature at age has been anecdotal. Overall, however, the major uncertainty related to two aspects. First was historical harvests, the reconstruction of which and the selectivity associated with the corresponding fishery were rough approximations. Second was the apparent inability for the ASPM to fit adequately indices.

The stock of goliath grouper is data-poor, but the estimated fishery data, assumptions made about selectivity, and available life history information were the best inputs at hand to run the ASPM, reconstruct the plausible historical population size, and determine the current stock status of the species. It was found that after a period of decline from the 1950s through the late 1980s–early 1990s, the stock may have since been rebuilding and is not currently overfished nor experiencing overfishing.

7. Catch-free model

7.1 Model Description

The catch-free model (Porch et al. 2006; reference document SEDAR47-RD-2), like the SSRA model described in the previous section, is a standard population dynamics model with age-structured representations of growth, survival, and recruitment, where the population simulations are carried forward in time. The model uses a variety of life history parameters (e.g., growth, length-weight, age-specific M, fecundity), indices of abundance and associated vulnerabilities-at-age, an index of effort (this model uses census data for the Florida population in South Florida as a proxy for fishing effort over 1950 to 1980 and plateaus at 1 from 1980 and later years), starting values for fishing mortality (F) over certain time periods in the model, and options for specifying reference points and projections. Some of the parameters are fixed at certain values, whereas others are supplied as initial starting values and the model solves for them. Each index has a catchability parameter associated with it, and these serve to scale each index internally in the model since each index may apply to different ages in the population and have a different catch or observation rate. Because there are no data on catches, fishing mortality rates must be estimated using from the catchabilities and indices, and finding the best solution for trends in the indices in comparison to the reconstructed population biomass-at-age levels. The results are scaled to be proportional with an unfished population and are a relative rather than an absolute statement about the status of a particular stock of fish. Benchmarks or reference points are therefore relative and based on a Beverton-Holt spawner-recruit function (Porch et al. 2006). If there was some certainty about F in one or more years (perhaps from a comprehensive tag-recapture experiment or a fishery independent survey of population size throughout Florida waters), these relative measures of stock status could become absolute reference points.

7.2 Model Configuration and Parameters

The model structure allows some parameters to have specified priors (e.g., means, medians or other distributional parameters) to inform the model of not only the central tendency for one or more parameters but also the probabilities of the parameter taking a particular value based on a probability density function (e.g., a normal distribution). Uninformative priors may be used for values for which there is no information that specifies whether one value is any more likely to occur than another. Informative priors allow for the bounding of parameters and likely values based on meta-analyses of estimates from similar populations of the same species or different species, or may be constructed from existing data about the population that is being researched. For example, the prior on the fecundity parameter used for Goliaths was an informative prior. It was constructed from a meta-analyses by Porch et al. (2006) using data on the maximum reproductive rate of other demersal marine fish (Myers et al. 1999). Age-specific natural mortality (a modification to the original catch-free model provided by Dr. Porch for SEDAR 23) and the average terminal size of Goliath Grouper ("L_∞") are specified as priors, and the model is allowed to solve for these as well as other priors within specific bounds. Model parameters are shown for the proposed "base" configuration of the model (Table 7.2.1; natural mortality rate adjusted to M=0.18, index selectivities set to 0.075). Other sensitivity runs adjusted the natural mortality rate to M=0.12, and modified the index selectivity rates. A sample data file and parameter file are included in Appendix B and C.

After the prohibition (often called a "moratorium") on retention of Goliaths in 1990, the fishing mortality rate (F) should decline because harvest was no longer permitted and it is believed that release mortality is low, perhaps on the order of 5% or less. There are tag-recapture observations of juveniles (Koenig and Coleman 2009, Brusher and Schull 2009) and adults (Collins 2014; Ellis et al. 2013) that support a low release mortality rate if fish are properly treated. Therefore, estimates of F after the prohibition on harvest after 1990 is believed to be low. But there is also the possibility that some illegal take may occur, and participants in SEDAR 6 (SEDAR 2004) and SEDAR 23 (SEDAR 2010) were asked about their views on the plausible levels for the reduction in F after 1990. There are documented examples of Goliaths that have been speared after 1990, and some fishers have expressed the view that Goliaths are competitors for fish (Lorenzen et al. 2013; reference document SEDAR47-RD-3) as fishers have experienced losses of hooked or speared fish to Goliaths. There are also data (Tables 3.2.1 and 3.2.2) from commercial vertical line and long line vessel logbooks and at-sea observations that show that there is some catch from these gears which may be expected to cause some mortality of adult Goliaths.

The opinions of SEDAR 6 and 23 participants were used to develop a range of plausible levels and a central tendency for the reduction in F after the moratorium in 1990, and the opinions were summarized by constructing a distribution for the reduction in F after 1990 (Fig. 7.2.1). The model would then be supplied with a way of solving, within certain bounds, for both M and F given plausible levels (priors, sometimes called "Bayesian priors") for each of these parameters during the moratorium period. This technique of supplying priors has been employed more frequently in recent assessments and other research areas especially when the information is either unknown and is drawn from a comparison of similar parameters for other species or processes (meta-analyses), uses "expert opinion", or is based on previously observed data. For this report, the prior developed during SEDAR 23 for the reduction in F after the moratorium was used for the catch-free model runs.

7.3 Likelihood

The likelihoods in the catch-free model (Porch et al. 2006) contain all parameters (and the appropriate distributions if priors are active) that are estimated by the model. Penalties on the likelihood are used to constrain certain quantities (like estimated biomass) to positive values.

7.4 Uncertainty in model results

When a model such as the catch-free model is evaluated, the parameters are solved for simultaneously and, if there is successful convergence (from a matrix algebra sense, meaning that matrices are positive-definite and capable of being inverted and all roots (eigenvalues) in the solution are positive), a posterior distribution (means, standard errors) for each of the solved parameters results. Uncertainty (e.g., Gelman et al. 2014) from the catch-free model in the life history or other parameters and relative stock status measures is evaluated through likelihood profiling or Markov Chain Monte Carlo (MCMC). Either or both methods can be used for examining the uncertainty in model estimates.

Likelihood profiling is a partial maximization method (Millar 2011) that evaluates the model over the range of valid solutions. This method generates a probability distribution of solutions for parameters of interest by holding a profiled parameter constant and allowing the other model parameters to vary.

MCMC is a technique that uses successive random draws of samples from the posterior distributions of parameters. Because the random draws (the "Monte Carlo" process) depend upon the parameter values obtained in the preceding iteration (called a "chain"; a property of stochastic processes), they are said to result from a "Markov process". After a number of successive simulations (called "iterations"), a chain is examined for "burn-in" (the effect of the starting values on the trajectory of the solutions for each of the parameters) and autocorrelation (the correlation between successive values for a parameter in the chain). After the number of iterations where "burn-in" is eliminated, and after autocorrelation (if any) is reduced by "thinning" the samples using some lag (e.g., taking every n^{th} sample), the frequency of values occurring for each parameter in the simulations is generated. When MCMC is employed, multiple chains (i.e., different starting values) are sometimes used to more thoroughly explore parameter spaces. Multiple chains and thinning were employed for the runs of the catch-free model to reduce the time required for obtaining the samples since multiple runs could be simultaneously executing on some of our computers at FWRI. Typically, medians and 95% confidence intervals for parameters are used from either method for characterizing uncertainty. While both profile likelihood and MCMC methods were used to characterize uncertainty in the model results, only the results from the MCMC were used for this report. Eight chains of 5,001,000 samples each at a thinning rate of 9,511 were run, and a combined 4,000 samples after burn-in for each chain was removed were obtained to characterize uncertainty in the model results.

7.5 Results

With the new specification for an upper bound on M based upon maximum age ("$Hoenig_{nls}$"; Then et al. 2015), the SEDAR 23 (SEDAR, 2010) configurations were no longer current with the latest estimate for natural mortality. Two levels of natural mortality rates using the revised M were used in the model configurations, corresponding to the maximum observed age for Goliath Grouper of 37 years (M=0.18) and a maximum age of 56 years (M=0.12) as a sensitivity. The choice of 56 years was made to allow for comparisons, if desired, with results of the base model used in SEDAR 23, and can be used as a to examine the impact of this choice for the upper bound on M on the model's solution for the relative stock status and potential level of recovery of this species since 1990. The catch-free model estimates Lorenzen age-specific natural mortality values at mid-year, so appropriate adjustments were made to the priors when configuring this parameter. The model estimated natural mortality rates a little lower than the M=0.18 prior (model estimate M=0.16), and solved a little higher than the M=0.12 prior (model estimate M=0.13); Fig. 7.5.1).

The age composition data for the ENP index was probably as close a match to the ages available for anglers to encounter in the catch in tidal creeks, so selectivities for this index were fixed to the input values estimated from the research studies (Fig. 3.3.7).

Fits to the ENP index (comprised mainly of juveniles according to the research studies) and MRFSS/MRIP estuarine index, which probably pertains to juveniles because it would represent catches in estuaries and tidal rivers in areas other than the ENP, were very reasonable (Fig. 7.5.2 a,b and e,f) for either choice of M. There were fewer age classes (~5-7) in the vulnerability/selectivity curves (Fig. 3.3.7) that comprised the modeled age compositions, probably leading to a relatively close tracking of the observed index values and the model's predictions. The standardized residuals of the observed and predicted index values were under 2, indicating no serious outliers (Fig. 7.5.3 a,b and e,f).

Fits to the two offshore indices [REEF FL and MRFSS/MRIP offshore] representing the adult portion of the Goliath Grouper population were also reasonable for either natural mortality rate used

(Fig. 7.5.2 c,d and g,h). The standardized residuals for these indices were relatively modest (Fig. 7.5.3 c,d and g,h). There were more age classes (~ 20) represented in the vulnerability curves for the offshore portion of the population (Fig. 3.3.9) than for the juvenile habitats, probably resulting in looser fits to the MRFSS/MRIP offshore index. The REEF FL index fit somewhat better. Since the selectivities for the REEF FL index are based on a small number of aged fish, it is curious how well the index was fit. Perhaps the age composition is in the correct ballpark. The age compositions for the MRFSS/MRIP offshore index are unknown, and perhaps the selectivity vector for it is not quite correct. Without knowing more about the sizes and ages of Goliaths caught by offshore anglers, the current selectivity priors for this index will have to suffice until new information becomes available.

The model-estimated selectivities for both choices of M values were similar (Fig. 7.5.4). The estimated selectivities tended to reduce the spread of ages for the MRFSS/MRIP estuarine catches (the ENP index was fixed at the input values), and tended to move the age at 50% to slightly younger ages for both the REEF FL and MRFSS/MRIP offshore catch indices. The age at 50% for the model-estimated selectivities for both the pre-1980 and post-1980 periods of the fishery (Fig. 7.5.5) moved to slightly older ages for both choices of M.

Overall, fits to the indices were improved over those obtained in SEDAR 23 (Fig. 7.5.6). This may have been at least partially to separating the single MRFSS/MRIP index used in SEDAR 23 into components for estuarine and offshore habitats to better match with the Everglades National Park (estuarine habitats) and the REEF FL (offshore areas) indices, and removing the DeMaria index which has not been updated since 2002 (and was from a small number of aggregation sites). But, turning on the priors for many of the index and fishery selectivities as well as the slope of the growth curve likely allowed the model more leeway in adjusting natural mortality, growth, and selectivities to fit the indices more closely and resulted in standardized residuals of lower magnitude. Without the priors on the index selectivities that were being estimated, some of the parameters tended to hit bounds and not stay within reasonable neighborhoods.

Estimates of fishing mortality rates (Fig. 7.5.7) from the catch-free model in the moratorium period after 1990 ("$F_{moratorium}$") are "flat" because they represent an "average" rate of removals over and above what would be expected from the natural mortality rate estimated by the model. In the absence of episodic events (like 2005 red tide which was quite extensive and of long duration on the West Coast of Florida, or cold kills in late December and early January of 2008 and 2010 which impacted Goliaths), this "average" would be expected to estimate the mortality of released fish after their encounter with fishing gear, with more severe effects if hook location caused damage or if barotrauma was involved. However, because there were episodic events affecting Goliaths, the model apparently is estimating more of the removals as part of the fishing mortality rate. This can readily be seen by comparing Fig. 7.5.7 a and b. For the prior adjusted to M=0.18, the estimated F in the moratorium period is just above the line corresponding to the management reference point of $F_{50\%SPR}$. For the prior at M=0.12, the estimated F in the moratorium period is farther above the $F_{50\%SPR\ line}$. Normally, having the rate of F above the management F-reference point would indicate that overfishing was occurring. In this case, the interpretation may be that along with some low level of release mortality there has been higher mortality from the episodic events in some years than would be expected from the more typical rate of natural mortality of Goliaths. The catch-free model, as currently constructed, will not provide anything more definitive on this point.

MCMC was used to examine uncertainty in the relative SSB and "Fmoratorium" estimates. The initial model runs were configured to solve for M, growth (L-infinity, k), and index selectivities (except for the ENP) using priors. However, the MCMC runs, with all of those parameters active in the solution, led to iterates not staying in the target distribution seen through likelihood profiling. Perhaps the runs (5,001,000 iterates) were insufficient in length for iterates to converge (Gelman et al., 2014). To remedy this situation, the solutions from the initial runs were used to configure the runs for the MCMC, with growth k, alpha (lifetime reproductive rate), and index selectivity parameters turned off for estimation. The fishery selectivities and other quantities were estimated and the solutions were very close to those obtained with the phases on for the above mentioned quantities.

The MCMCs were reasonably stable as a result. Eight chains of 5 million iterates were generated at a thinning rate of 9,511 (just a large prime number) to cut down on serial correlation in the resulting 526 samples in each chain. The first 26 samples (the first 247,286 iterates generated) were discarded, leaving 500 samples per chain for examining the posterior distributions. The within-chain and between-chain variances were calculated. Gelman et al. (2014) recommend that the ratio of within-chain variance/between-chain variances be close to 1. If the ratio is not close to 1, additional samples should be added to the chains and the ratio re-assessed. Plots of the samples from the chains (e.g., Fig. 7.5.8) were inspected, and two of the eight chains from each of the M configurations (0.18 and 0.12) were significantly different (ANOVA, multiple t-test, $p<0.05$). Those chains were deleted, leaving 6 chains (3,000 samples) for the analysis of each of the M configurations. The variance ratios for each of the M configurations were 1.07-1.08, and serial correlations were usually less than 0.15 except for projections. Distributions of several quantities of interest are shown in Fig. 7.5.9.

Commonly, "phase" plots of the F-ratio versus the SSB-ratio (Fig. 7.5.10) are used to portray the current status of a population against management reference points (for Goliath Grouper, these are defined by the F and SSB predicted at 50% SPR). In this case, the F for the last year (2014, which is also the "$F_{moratorium}$" over 1990-2014) of the assessment is divided by the F corresponding to 50% SPR, and the SSB for the last year is divided by the SSB corresponding to the predicted SSB at F at 50% SPR. Reference lines for F and MSST are usually added to the plot, and the location of the F- and SSB- ratios can be easily compared with the reference values. If the F-ratio is above 1 a population is said to be undergoing overfishing. If the SSB-ratio is below MSST, the population is considered overfished. Either condition will lead to some sort of management action to reduce fishing pressure on a population.

Fig. 7.5.10a shows the phase plot of MCMC samples of the F- and SSB-ratios for the M=0.18 case, and Fig. 7.5.10b the M=0.12 case. Both of the simulations estimated that Goliaths were not overfished [more than 50% of the samples of simulated relative SSB-ratios in 2014 exceeded MSST (i.e., were to the right of MSST on the plot)]. The simulations for the F-ratios in both cases exceeded the reference line (i.e., were above an F-ratio=1), which would normally be interpreted as the stock was undergoing overfishing.

Trajectories of relative spawning stock biomass (SSB) over the time series (Fig. 7.5.11) shows an initial decrease and low SSB through the 1978-1995 period, with a marked upward trend thereafter which peaked around 2012. Relative SSB was predicted to have passed the MSST reference line (below which the population is considered overfished) either in 2008 (higher natural mortality rate M=0.18; Fig. 7.5.11a) or in 2011 (lower M=0.12; Fig 7.5.11b). The confidence intervals for each of the runs, as estimated through MCMC simulations, provides a way of examining the degree of uncertainty associated with the model's predictions. But in both runs, relative stock status at the 50% SPR level was sufficiently above the MSST line to conclude that the population was no longer in the overfished condition in 2014.

With the declines in the indices noted after 2007 and 2010, relative SSB projections from both runs show marked declines in predicted SSB particularly over at least the next decade if there are future episodic events and the "$F_{moratorium}$" rate (0.09 for the M=0.18 prior, 0.10 for the M=0.12 prior) is appropriate. The downward trends in the estuarine indices after 2007 are the primary drivers for these predictions as they are indicating relatively poor recovery in recruitment after 2010. From the ENP catch rate index (Fig. 4.2.1) it does appear that recruitment has been slow to recover after the 2010 cold kill, and if so could indicate that SSB may decline over the short term. In the M=0.18 configuration, the population would not be predicted to be overfished over the next decade (dashed line stays above MSST; Fig. 7.5.11a). In the M=0.12 configuration, the model projections are for the SSB to drop below MSST perhaps in 2017 (dashed line falls below MSST; Fig. 7.5.11b).

If the fishing mortality rate was at the $F_{50\%SPR}$ reference point which is estimated to be around 0.06 (M=0.18 prior) to 0.05 (M=0.12 prior) by the catch-free model, the projections take a slightly different and less pessimistic trajectory (Fig. 7.5.12). Both M configurations stay above the overfished (MSST) limit.

Finally, if the fishing mortality rate is set to the 2012-2014 geometric mean of the F's from the SSRA model (natural mortality is currently a fixed quantity in this model and corresponds to the M=0.18 rate) which was about 0.2, the projections are even more optimistic (Fig. 7.5.13). However, because certain quantities are fixed in the SSRA model and estimated using priors in the catch-free model, it may be advisable to use some of the solutions for parameters like M, growth (L-infinity, k), selectivities, etc., from the catch-free model and substitute these values into the SSRA model to see how that affects the estimation of F and management reference points.

8. Discussion

Normally in assessments a more definitive statement of the status of a stock is usually possible. For data-poor stocks such as Goliath Grouper, where there is potential uncertainty with its longevity in that it is probable that they may live longer than we know at this point, historical commercial landings are suspected to be inaccurate, no independent estimate of population abundance across its distribution exists, knowledge of the size structure of former catches by commercial and recreational fishers is poorly known, and the current age structure vulnerable to fishing activities is unknown, the results of the modeling should be treated as having relatively high uncertainty. The model itself needs some work to properly handle episodic mortality events which appear to be as important in interpreting patterns in recruitment and juvenile abundances for Goliaths as it is for Common Snook. Episodic events like cold-kills should be considered when contemplating management actions on species that show susceptibility to these types of events.

The catch-free model relies heavily on indices of abundance, and it is very important to have these indices track population abundance for the model to properly solve for its estimate of stock status. We have re-analyzed the indices used in previous SEDAR assessments on Goliaths, and we believe that the current ones we are using are an improvement. The exploration of the SSRA model proved useful, though there are differences between it and the catch-free model and they are not directly comparable. The SSRA is also rather limited in that, while capable of handling multiple indices with their associated selectivities, it uses total fishery removals rather than removals by area (which would have been helpful with Goliaths), gear, fleet, or some other aspect of fisheries that would be useful in characterizing the age compositions of removals. There are other models that could be configured as age-structured surplus production models that could be worth exploring now that estimates of fishery removals (Tables 3.1.1 and 3.3.1) have been constructed.

Assessments such as this one depend upon the effective monitoring of a species throughout its distribution. The abundance of juveniles of Goliaths, particularly in estuaries, should be monitored routinely to detect signs of potential recruitment problems. The Everglades National Park Angler Survey is the best existing way to monitor juvenile Goliaths since it is already being conducted and has a long time series of data available. For other estuaries and offshore areas, the MRFSS/MRIP survey may produce time series of catches that are potentially useful. In offshore areas, it may be possible to acoustically monitor for Goliaths to detect spawning aggregations, and perhaps for protections from harvest during times when they aggregate should be discussed. It may also be possible to take advantage of modern genetic techniques that could potentially be used to estimate population size (e.g., see review article by Schwartz et al. 2007).

IV. Research Recommendations

The Florida Fish and Wildlife Conservation Commission held a workshop on March 14-16, 2016 to discuss recent research findings about Goliath Grouper in Florida waters. Before the close of the workshop, the participants provided their recommendations about additional research that should be conducted on this species to improve our understanding of this species.

Monitoring activities

- Genetics: sample from fish from around Florida, and particularly the Florida West Coast. Samples could be from removal of a few scales, fin clips, or needle biopsy. Consider training at-sea observers/samplers to collect these samples. Eggs could also be collected and analyzed. A repeat of the recent kinship analysis (Tringali) on a periodic basis (5-10 years) would help monitor for changes in the degree of relatedness in the Florida Keys and southeast Florida.
- Spawning aggregations – locate additional sites where aggregations occur, using a combination of sound and Didson sonar imaging to verify spawning activity. This is work currently in progress. Monitor currently known spawning sites for trends over time.
- Mark-recapture data needs to be analyzed from the acoustic tagging data and about 800 sampled and visually tagged fish on the east and west coast of Florida. Investigate the possibility of using genetic mark-recapture methods.
- Expand sampling for nursery habitat and targeted juvenile sampling, possibly using an existing fishery-independent sampling program. Recommend to the NMFS Cooperative Research Program the possible funding of projects to work with the blue crab trap fishermen to collect fin clips (for genetics) when there is bycatch of Goliaths.
- Annual age sampling on the level of 400-500 specimens to monitor age structure of adults. The fin ray-age validation work is in progress.
- Fecundity research – in progress.
- Investigate the use of wildlife models like occupancy modelling. This may require more regular, systematic sampling than is currently available.
- Use visual data from the REEF survey, NMFS-UM Reef Visual Census (though they do not sample artificial reefs and wrecks), and expand the Great Goliath Grouper Counts from once a year in June to twice a year (June and September) to help identify locations with larger fish to sample.
- Drop cam video from FWRI's FIM program could expand the coverage of visual surveys, but would need to expand sampling to artificial reefs/wrecks.
- Investigate feasibility of mounting video cameras on charter and head boats to obtain information on bycatch (some preliminary work by Mote Marine Lab may be useful).
- Discuss with the FWC Artificial Reef Program the possibility of grant funding for Goliath work.
- Promote the collection of Goliath lengths from anglers (Snook and Game Fish Foundation app)
- Use GIS artificial reef data to identify all artificial reef structures and related data (materials, heights) in the Gulf of Mexico for developing a sampling plan.
- Extract dates and locations from log book data especially during spawning season that may identify new aggregations/spawning sites.

V. References

Bilder, C. R. and T. M. Loughin. 2015. Analysis of Categorical Data with R. CRC/Taylor and Francis Group, Boca Raton, FL. xiii + 533p.

Brice, J.J. 1897. The fish and fisheries of the coastal waters of Florida. Part 6, Report on the Fish and Fisheries of the Coastal Waters of Florida. pp 263-342. *In*: Report of the Commissioner for 1896. U.S. Commission on Fish and Fisheries, Bureau of Commercial Fisheries. U.S. Government Printing Office, Washington, D.C.

Brooks, E.N, Powers, J.E., and Cortés, E. 2010. Analytical reference points for age-structured models: application to data-poor fisheries. ICES. J. Sci. 67: 165–175.

Brusher, J.H. and J. Schull. 2009. Non-lethal age determination for juvenile goliath grouper *Epinephelus itajara* from southwest Florida. Endang. Species. Res. 7: 205-212.

Bullock L.H., M.D. Murphy. M.F. Godcharles, and M.E. Mitchell. 1992. Age, growth, and reproduction of jewfish *Epinephelus itajara* in the eastern Gulf of Mexico. Fish Bull 90: 243–249.

Bullock, L.H. and G.B. Smith. 1991. Seabasses (Pisces: Serranidae). Pages 1-243. Memoirs of the Hourglass Cruises. Florida Marine Research Institute. Department of Natural Resources, St. Petersburg, FL.

Butterworth, S.D., and Rademeyer, R.A, 2008. Statistical catch-at-age analysis vs. ADAPT-VPA: the case of Gulf of Maine cod. ICES J. Mar. Sci. 65: 1717–1732.

Cadigan, N.G., and Farrell, P.G. 2005. Local influence diagnostics for the retrospective problem in sequential population analysis. ICES J. Mar. Sci. 62: 256–265.

Cass-Calay, S.L. 2010. Monitoring changes in the catch rates and abundance of juvenile Goliath Grouper using the ENP Creel Survey, 1973-2009. SEDAR 23-DW-02. http://sedarweb.org/s23dw02-monitoring-changes-catch-rates-and-abundance-juvenile-goliath-grouper-using-enp-creel-survey

Collins, A. 2014. An investigation into the habitat, behavior and opportunistic feeding strategies of the protected Goliath grouper (*Epinephelus itajara*). Dissertation for the degree of Doctor of Philosophy, April 8, 2014, Department of Integrative Biology, College of Arts and Sciences, University of South Florida. http://scholarcommons.usf.edu/etd/5002

Collins, A.B. and L.R. Barbieri. 2010. Behavior, habitat, and abundance of Goliath Grouper, *Epinephelus itajara*, in the Central Eastern Gulf of Mexico. NOAA Award Number NA07NMF4540085 for award period: August 1, 2007 – April 30, 2010.

Craig, M.T., R.T. Graham, R.A. Torres, J.R. Hyde, M.O. Freitas, B.P. Ferreira, M. Hostim-Silva, L.C. Gerhardinger, A.A. Bertoncini, and D.R. Robertson. 2009. How many species of Goliath Grouper are there? Cryptic genetic divergence in a threatened marine fish and the resurrection of a geopolitical species. Endangered Species Research 7:167-174.

Deuel, D.G. and J.R. Clark. 1968. The 1965 Salt-Water Angling Survey. United States Fish and Wildlife Survey, Bureau of Sport Fisheries and Wildlife Resource Publication 67. Department of the Interior. U.S. Government Printing Office, Washington, DC. iii +51p.

Deuel, D.G. 1973. The 1970 Salt-Water Angling Survey. Statistics and Market News Division, Current Fishery Statistics No. 6200. National Oceanic and Atmospheric Administration, U. S. Department of Commerce. U.S. Government Printing Office, Washington, DC. iv+54p.

Ellis, R., Koenig, C., and F. Coleman. 2013. Spawning-related movement patterns of Goliath Grouper (*Epinephelus itajara*) off the Atlantic Coast of Florida. Proc. 66th Gulf and Caribbean Fisheries Institute, 66: 396-400.

Ellison, A. M. 2004. Bayesian inference in ecology. Ecol. Lett. 7:509–520.

Evermann, B.W. and B.A. Bean. 1897. Indian River and its fishes. Part 5, Report on the Fisheries of the Indian River, Florida. pp 227-248. *In*: Report of the Commissioner for 1896. U.S. Commission on Fish and Fisheries, Bureau of Commercial Fisheries. U.S. Government Printing Office, Washington, D.C.

Evers, D.C., R.T. Graham, C.R. Perkins, R. Michener, T. Divoll. 2009. Mercury concentrations in the Goliath Grouper of Belize: an anthropogenic stressor of concern. Endang. Species Res. 7: 249-256.

Fennessy, S.T. and Y. Sadovy. 2002. Reproductive biology of a diandric protogynous hermaphrodite, the Serranid *Epinephelus andersoni*. Mar. Freshwater Res. 53: 147-158.

Frias-Torres, S. 2006. Habitat use by juvenile goliath grouper, *Epinephelus itajara*, in the Florida Keys, USA. Endang. Species Res. 7: 249-256.

Frisk, M.G., Martell, S.J.D., Miller, T.J., and Sosebee, K. 2010. Exploring the population dynamics of winter skate (*Leucoraja ocellata*) in the Georges Bank region using a statistical catch-at-age model incorporating length, migration, and recruitment process errors. Can. J. Fish. Aquat. Sci. 67: 774–792.

Gelman, A., J.B. Carlin, H.S. Stern, D.B. Dunson, A. Vehtari, D.B. Rubin. 2014. Bayesian Data Analysis. Third edition. Chapman & Hall/CRC Press. Boca Raton, FL.

Gould, R.G., and J.W. Atz. 1996. The trouble with "jewfish" or what's in a name? Tropical Fish Hobbyist 44: 172-182.

Grosbois, V., Gimenez, O., Gaillard, J. -M., Pradel, R., Barbraud, C., Clobert, J., Møller, A. P., and Weimerskirch, H. 2008. Assessing the impact of climate variation on survival in vertebrate populations. Biol. Rev. 83:357–399.

Gulf of Mexico Fishery Management Council. 1990. Amendment 2 to the Fishery Management Plan for Reef Fish. February, 1990. Tampa, FL.

Gulf of Mexico Fishery Management Council 1996. SPR Management Strategy Committee. An evaluation of the use of SPR levels as the basis for overfishing definitions in Gulf of Mexico finfish fishery management plans, Gulf of Mexico Fishery Management Council, Final Report.

Gulf of Mexico Fishery Management Council. 2015. Minimum stock size threshold (MSST) and maximum sustainable yield (MSY) proxy for reef fish stocks. Options paper for an amendment to the Fishery Management Plan for the Reef Fish Resources of the Gulf of Mexico. October

2015. http://gulfcouncil.org/council_meetings/BriefingMaterials/BB-10-2015/B%20-%2010%20Options%20Paper%20-%20MSST%20for%20GOM%20Reef%20Fish.pdf .

Hallac, D, J. Kline, J. Sadle, S. Bass, T. Ziegler, and S. Snow. 2010. Preliminary effects of the January 2010 cold weather on flora and fauna in Everglades National Park. February 2, 2010. Biological Resources Branch, South Florida Natural Resources Center, Everglades and Dry Tortugas National Parks, Homestead, Florida.

Hilborn, R. 1990. Estimating the parameters of a full age-structured model from catch and abundance data. Bull. Int. N. Pac. Fish. Comm. 50: 207–2013.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. 82: 898-903.

ICES, 2012. Report on the classification of stock assessment methods developed by SISAM. ICES CM 2012/ACOM/SCICOM: 01. 15pp.

Jordan, D.S. 1884. The fishes of the Florida Keys. In: Bulletin of the U. S. Fish Commission, Vol. IV, for 1884. U.S. Government Printing Office, Washington, D.C.

Kéry, M. 2010. Introduction to WinBUGS for ecologists: a Bayesian approach to regression, ANOVA, mixed models and related analyses, 302 p. Academic Press, Burlington, MA.

Kimura, D.K. 1985. Changes to stock reduction analysis indicated by Schnute's general theory. Can. J. Fish. Aquat. Sci. 42: 2059–2060.

Koenig CC, F.C.Coleman. Eklund. A.M., Schull. J, Ueland. J. 2007. Mangroves as essential nursery habitat for goliath grouper, *Epinephelus itajara*. Bull. Mar. Sci. 80:567–586.

Koenig, C.C. and F.C. Coleman. 2009. Population density, demographics and predation effects of adult goliath grouper. MARFIN Project (NA05NMF4540045) NOAA/NMFS Final Report. 79 pp.

Koenig, C.C. and F.C. Coleman. 2013. The recovering goliath grouper population of the southeastern US: non-consumptive investigations for stock assessment. NOAA MARFIN Project Final Report (Project NA10NMF4330123; FSU Project No. 027054). 70 pp.

Legault, C.M. 2009. Report of the Retrospective Working Group, January 14-16, 2008, Woods Hole, Massachusetts. NEFSC Reference Doc. 09-01.

Lo, N.C., L.D. Jackson, and J.L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Can. J. Fish. Aquat. Sci. 49: 2515-2526.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: A comparison of natural ecosystems and aquaculture. Journal of Fish Biology 49: 627-647.

Lorenzen, K. 2005. Population dynamics and potential of fisheries stock enhancement: practical theory of assessment and policy analysis. Philosophical Trans. of the Royal Society of London B 360: 171-189.

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

Martell, S.J.D., Pine III, W.E., and Walters, C.J. 2008. Parameterizing age-structured models from a fisheries management perspective. Can. J. Fish. Aquat. Sci. 65: 1586–1600.

McClenachan, L. 2009a. Documenting loss of large trophy fish from the Florida Keys with historical photographs. Conservation Biology 23:636-643.

McClenachan, L. 2009b. Historical declines of goliath grouper populations in South Florida, USA. Endang Species Res 7: 175–181.

Millar, R.B. 2011. Maximum Likelihood Estimation and Inference with examples in R, SAS, and ADMB. John Wiley & Sons, LTD. West Sussex, UK.

Mohn, R. 1999. The retrospective problem in sequential population analysis: an investigation using cod fishery and simulated data. ICES J. Mar. Sci. 56: 473–488.

Murie, D.J. D.C. Parkyn, C.C. Koenig, F.C. Coleman, J. Schull, and S. Frias-Torres. 2009. Evaluation of finrays as a non-lethal ageing method for protected goliath grouper *Epinephelus itajara*. Endang. Species Res. Vol. 7: 213–220, doi: 10.3354/esr00146.

Myers, R.A., Barrowman, N.J., Hilborn, R., and Kehler, D.G. 2002. Inferring Bayesian priors with limited directed data: application to risk analysis. N. Am. J. Fish. Manage. 22: 351–364.

Myers, R.A., K.G. Bowen, and N.J. Barrowman. 1999. Maximum reproductive rate of fish at low population sizes. Can. J. Fish. Aquat. Sci. 56: 2404-2419.

NMFS (National Marine Fisheries Service) (2006) Status report on the continental United States distinct population segment of the goliath grouper (*Epinephelus itajara*). January 12, 2006. NMFS, St.Petersburg, FL. http://sero.nmfs.noaa.gov/pr/pdf/Final_Status_Report_on_the_Goliath_Grouper.pdf

O'Hop, J., D.T. Addis, and J. Munyandorero. 2015. Stock assessment update of Goliath Grouper in Florida, 2015. Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute. St. Petersburg, FL. FWC Report IHR2015-002, revised August 3, 2015.

Page, L.M., Héctor Espinosa-Pérez, L.T. Findley, C.R. Gilbert, R.N. Lea, N.E. Mandrak, R.L. Mayden, and J.S. Nelson. 2013. Common and Scientific Names of Fishes from the United States, Canada, and Mexico. Seventh Edition. American Fisheries Society Special Publication 34. Bethesda, MD.

Pattengill-Semmens, C.V and B.X. Semmens. 2004. Conservation and management applications of the REEF volunteer fish monitoring program. Environmental Monitoring 81: 43-50.

Phelan, M.J. 2009. Report on Goliath Grouper aggregations at Jupiter, Florida. October, 2009. Report by M. J. Phelan, 4465 SE Graham Drive, Stuart, FL 34997.

Phelan, M.J. 2010. 2010 Goliath Grouper Aggregation Monitoring Report. Jupiter, Florida, USA. December 2010. Report by M. J. Phelan. http://www.scrfa.org/images/stories/pdf/scrfa/goliath_grouper_aggregation_report_2010.pdf

Porch, C.E., and A-M. Eklund. 2004. Standardized visual counts of goliath grouper off South Florida and their possible use as indices of abundance. Gulf Mex. Sci. 22:155-163.

Porch, C.E., A-M. Eklund and G.P. Scott. 2006. A catch-free stock assessment model with application to goliath grouper (*Epinephelus itajara*) off southern Florida. Fish. Bull. 104:89-101.

Punt, A.E., Butterworth, D.S., and Penney, A.J. 1995. Stock assessment and risk analysis for the south Atlantic population of Albacore *Thunnus alalunga* using an age-structured production model. S. Afr. J. mar. Sci. 16: 287–310.

Restrepo, V.R., and Legault, C.M. 1998. A stochastic implementation of an age-structured production model. P. 435-450 in Symposium on Fishery Stock Assessment Models. Alaska Sea Grant College Program. AK-SG-98-01.

Rose, K.A., Cowan Jr., J.H., Winemiller, K.O., Myers, R.A., and Hilborn, R. 2001. Compensatory density dependence in fish populations: importance, controversy, understanding and prognosis. Fish and Fish. 2: 293–327.

SAS Institute Inc. 2008. SAS/STAT[R] 9.2 User's Guide. The GENMOD Procedure (book excerpt). SAS Institute Inc., Cary, NC.

Schroeder, W.C. 1924. Fisheries of Key West and the clam industry of southern Florida. Appendix XII to the Report of the U.S. Commissioner of Fisheries for 1923. Bureau of Fisheries Document No. 962. U.S. Government Printing Office, Washington, D.C.

Schwartz, M.K., G. Luikart, and R.S. Waples. 2007. Genetic monitoring as a promising tool for conservation and management. Trends in Ecology and Evolution 22: 25-33.

Shertzer, K.W. and P.B. Conn. 2012. Spawner-recruit relationships of demersal marine fishes: prior distribution of steepness. Bulletin of Marine Science 88: 39-50.

Shertzer, K.W. and E.H. Williams. 2008. Fish assemblages and indicator species: reef fishes off the southeastern United States. Fisheries Bulletin 106: 257-269.

SEDAR. 2003. The goliath grouper in southern Florida: assessment review and advisory report. Report prepared for the South Atlantic Fishery Management Council, the Gulf of Mexico Fishery Management Council, and the National Marine Fisheries Service. vi + 15 pp.

SEDAR, 2004. Complete Stock Assessment report of SEDAR 6 Goliath Grouper. SEDAR 6–SAR1. South Atlantic Fishery Management Council. Charleston, SC.

SEDAR. 2010. South Atlantic and Gulf of Mexico Goliath Grouper. SEDAR 23 Stock Assessment Report. South Atlantic Fishery Management Council. 4055 South Faber Place Drive, Suite 201. North Charleston, SC 29405. http://sedarweb.org/sedar-23-final-goliath-grouper-stock-assessment-report

South Atlantic Fishery Management Council. 1990. Amendment 2 to the Fishery Management Plan for the Snapper Grouper Fishery. Charleston, SC.

Stephens, A. and A. MacCall. 2004. A multispecies approach to subsetting logbook data for purposes of estimating CPUE. Fisheries Research 70: 299-310

Then, A.Y., J.M. Hoenig, N.G. Hall, and D.A. Hewitt. 2015. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES Journal of Marine Science 72:82-92.

Tremain, D.K. and D.H. Adams. 2012. Mercury in groupers and sea basses from the Gulf of Mexico: relationships with size, age, and feeding ecology. Trans. Am. Fish. Soc. 141: 1274-1286.

Tzadik, O.E., E. A. Goddard, D. J. Hollander, C. C. Koenig, and C. D. Stallings. 2015. Non-lethal approach identifies variability of δ^{15}N values in the fin rays of Atlantic Goliath Grouper, *Epinephelus itajara*. PeerJ 3:e1010: DOI 10.7717/peerj.1010.

Walters, C.J., S.J D. Martell, and J. Korman 2006. A stochastic approach to stock reduction analysis. Can. J. Fish. Aquat. Sci. 63: 212–223.

Wilcox, W.A. 1897. The Fisheries of Indian River, Florida. pp 249-262. *In:* Report of the Commissioner for 1896. U.S. Commission on Fish and Fisheries, Bureau of Commercial Fisheries. U.S. Government Printing Office, Washington, D.C.

VI. Tables

Table 3.1.1. Commercial landings (pounds whole weight) of Goliath Grouper in the Southeastern U.S. states from Texas to North Carolina. Adjusted landings for 1964 to May, 1984 from West Florida are highlighted in yellow.

Year	TX	LA	MS	AL	WFL	EFL	GA	SC	NC	TX-NC
1950	20,800	0	0	7,400	74,200	23,300	0	0	0	125,700
1951	73,900	500	500	0	65,200	54,400	0	0	0	194,500
1952	31,500	400	200	53,600	44,200	40,000	0	0	0	169,900
1953	24,600	3,400	0	123,000	97,500	35,700	0	0	0	284,200
1954	22,600	5,700	0	0	55,600	31,500	0	0	0	115,400
1955	3,500	0	0	2,000	53,200	24,100	0	0	0	82,800
1956	2,200	1,100	0	1,000	36,500	17,300	0	0	0	58,100
1957	1,000	0	0	5,600	27,200	24,300	0	0	0	61,500
1958	30,400	600	0	7,000	51,800	34,400	0	0	0	132,600
1959	20,200	18,300	0	18,500	65,100	9,000	0	0	0	131,700
1960	0	20,000	0	4,400	66,800	11,000	0	0	0	102,200
1961	0	9,500	0	24,900	50,600	16,200	0	0	0	101,900
1962	300	4,100	0	15,500	48,500	21,400	0	0	0	89,800
1963	7,800	8,300	0	41,400	65,500	16,700	0	0	0	139,700
1964	2,700	2,200	0	118,400	86,200	31,700	0	0	0	241,200
1965	0	1,300	0	134,200	50,179	40,100	0	0	0	225,779
1966	0	1,700	0	100,300	30,041	38,700	0	0	0	170,741
1967	200	200	0	76,500	46,530	55,800	0	0	0	179,230
1968	0	200	0	115,600	45,086	50,800	0	0	0	211,686
1969	0	2,900	0	49,900	29,363	46,100	0	0	0	128,263
1970	0	6,500	0	73,300	35,689	21,200	0	0	0	136,689
1971	0	2,400	0	41,500	40,195	3,300	0	0	0	87,395
1972	0	0	0	80,000	37,126	7,600	0	0	0	124,726
1973	0	5,500	0	59,400	45,375	15,800	0	0	0	126,075
1974	0	300	0	29,200	51,703	46,400	0	0	0	127,603
1975	0	0	0	22,900	57,690	40,500	0	0	0	121,090
1976	0	0	0	15,900	37,906	53,200	0	0	0	107,006
1977	0	0	0	22,500	75,483	50,800	0	0	0	148,783
1978	0	32	0	4,551	62,151	17,185	0	0	0	83,919
1979	0	0	0	2,690	38,394	18,064	0	0	0	59,148
1980	0	0	0	2,887	47,303	19,423	0	0	0	69,613
1981	0	0	0	6,062	56,469	12,397	1,154	0	0	76,082
1982	0	0	0	12,827	50,571	6,131	0	0	0	69,529
1983	0	0	0	13,536	66,569	12,293	0	0	0	92,398
1984	0	0	0	7,240	67,427	11,440	0	0	0	86,107
1985	0	0	0	0	101,539	9,367	0	0	0	110,906
1986	0	0	0	0	108,952	10,492	0	0	0	119,444
1987	24	1,146	0	0	99,540	17,911	0	0	0	118,621
1988	491	0	0	0	135,715	12,931	0	0	0	149,137
1989	0	0	0	0	93,066	8,669	0	0	0	101,735
1990	0	2,272	0	0	7,488	1,814	0	0	0	11,574
1991	0	798	0	0	0	0	0	0	0	798

Table 3.2.1. NMFS Coastal Fisheries Logbook Program reports of discards of Goliath Grouper from commercial vessels using vertical line (bandit rigs, hook-and-line) and long line gears from areas where this species is likely to be encountered. Confidential cells are indicated by an asterisk.

	Vertical Line			Long Line		
Year	Trips with catch of Goliaths	Percentage of trips with Goliaths	Number of Goliaths	Trips with catch of Goliaths	Percentage of trips with Goliaths	Number of Goliaths
2002	14	0.85	22	6	4.69	23
2003	8	0.30	8	25	14.04	512
2004	4	0.19	4	14	8.92	101
2005	17	0.91	19	7	6.36	60
2006	24	1.60	27	4	4.21	10
2007	45	1.41	53	19	9.41	118
2008	34	0.61	55		0.00	
2009	24	0.76	38	5	4.20	48
2010	37	0.80	57	*	*	*
2011	24	0.44	50	4	1.23	4
2012	14	0.28	19	6	2.93	12
2013	35	0.64	52	*	*	*
2014	46	0.92	87	*	*	*

Table 3.2.2. NMFS at-sea observer program reports of catches of Goliath Grouper from commercial vessels employing vertical line (VL) and bottom long line (BLL) gears. RFOP=Reef Fish Observer Program, SBLOP=Shark Bottom Longline Observer Program.

	RFOP, 2006-2015		SBLOP, 2007-2015
	VL	BLL	BLL
% of trips	3.6	7.5	11
number of trips w/ Goliaths	39	26	51
number of Goliaths discarded	59	28	78

Table 3.3.1. Recreational harvests and releases for the NMFS MRFSS (1981-2003), MRIP (2004-2015), harvests from the Head Boat Survey, and Total Recreational harvests (direct harvests and releases with a 5% release mortality applied) in kilograms. Data for 2015 are preliminary through wave 6 (Nov-Dec).

	Estuarine MRFSS/MRIP				Offshore MRFSS/MRIP				Head Boat Survey		
Year	Harvest (A+B1, fish)	Harvest (A+B1, kg)	Releases (B2,fish)	Dead (5%) Releases (B2, kg) [a]	Harvest (A+B1, fish)	Harvest (A+B1, kg)	Releases (B2,fish)	Dead (5%) Releases (B2, kg) [a]	No. of Fish landed	Weight (kg)	Total Rec. Harvest + 5% dead releases (kg)
1981	1,173	587	0	0	22,871	150,316[b]	0	0	27	772	151,675[d]
1982	0	0	0	0	9,643	63,382[c]	0	0	88	3,430	66,812[d]
1983	0	0	0	0	0	0	120	2	54	1,843	1,845
1984	0	0	0	0	5,979	35,917	2,805	44	17	725	36,685
1985	0	0	0	0	7,238	85,408	1,754	27	17	247	85,682
1986	0	0	0	0	5,932	15,489	395	6	94	4,945	20,440
1987	0	0	0	0	4,469	35,933	0	0	57	2,274	38,207
1988	0	0	0	0	3,212	3,592	0	0	32	1,986	5,578
1989	0	0	6,260	97	2,120	13,936[b]	0	0	140	4,127	18,161[d]
1990	0	0	0	0	0	0	1,928	5,726	6	208	5,933
1991	0	0	0	0	0	0	5,722	16,992	0	0	16,992
1992	0	0	799	210	0	0	2,263	6,720	1	91	7,021
1993	0	0	2,135	562	0	0	3,181	9,446	1	0	10,008
1994	0	0	539	142	0	0	3,865	11,476	3	341	11,959
1995	0	0	11,202	2,946	0	0	2,682	7,963	0	0	10,909
1996	0	0	1,752	461	0	0	849	2,521	0	0	2,982
1997	0	0	5,079	1,336	0	0	3,163	9,393	0	0	10,728
1998	0	0	4,048	1,065	0	0	4,256	12,639	0	0	13,704
1999	0	0	6,021	1,584	0	0	2,205	6,549	1	11	8,144
2000	0	0	24,817	6,527	0	0	8,477	25,171	0	0	31,698
2001	0	0	34,018	8,947	0	0	7,376	21,902	0	0	30,849
2002	0	0	25,129	6,609	729	4,790[b]	5,124	15,215	0	0	26,615[d]
2003	0	0	33,991	8,940	0	0	15,363	45,619	8	80	54,639
2004	0	0	28,130	7,398	0	0	13,104	38,913	16	218	46,530
2005	0	0	44,088	11,596	0	0	18,500	54,934	17	29	66,558
2006	0	0	95,053	25,000	0	0	16,571	49,206	0	0	74,205
2007	0	0	80,032	21,049	0	0	23,989	71,235	18	0	92,284
2008	1,666	1,238	19,806	5,209	0	0	19,980	59,330	0	0	65,777
2009	0	0	26,587	6,993	0	0	9,119	27,079	0	0	34,072
2010	0	0	6,596	1,735	0	0	5,495	16,316	0	0	18,051
2011	0	0	3,917	1,030	0	0	5,278	15,674	0	0	16,704
2012	0	0	1,106	291	0	0	2,920	8,671	0	0	8,962
2013	0	0	18,305	4,814	0	0	7,819	23,218	1	1	28,034
2014	0	0	4,291	1,128	0	0	5,174	15,363	0	0	16,491
2015	0	0	10,382	2,731	0	0	5,229	15,526	0	0	18,257

[a] The weight of released fish was not estimated by the MRFSS/MRIP. An average of 5.26 kg/fish was used for Estuarine releases, and 59.39 kg/fish for Offshore releases. A release mortality of 5% was applied to estimate the weight of dead releases.

[b] weight was not estimated. The 1984-1988 average weight of 6.6 kg/fish was used for estimate.

[c] weight was reported as 1.14 million pounds. The 1984-1988 average weight of 6.6 kg/fish was used instead.

[d] indicates that an adjustment to harvest weights (other than releases) was made.

Table 3.3.2. Measured sizes of Goliaths from angler catches in the Everglades National Park Survey, 1974-1990. Years with no measured Goliaths were not included on this table. Estimated average weight of Goliaths in angler catches in this matrix is 5.37 kg. Legal sized fish averaged 5.47 kg, and sub-legal size fish (<12" TL prior to 1990) averaged 0.31 kg. The maximum value recorded for lengths of fish in this survey was 999 mm TL.

TL_mm	1974	1975	1976	1977	1978	1982	1983	1984	1986	1987	1988	1989	1990	Total	estimated avg. wt (kg)
51-100														0	0.01
101-150														0	0.03
151-200														0	0.09
201-250		2												2	0.19
251-300		3	2	1										6	0.35
301-350	3	10	2	2										17	0.58
351-400	2	14	9	11				1						37	0.91
401-450		21	8	11	1								1	42	1.34
450-499	1	11	12	6			1					1	1	33	1.89
501-550	2	14	11	11			1	1			2			42	2.57
551-600	1	14	8	9					1		1			34	3.41
601-650	1	19	16	5		1				1		1		44	4.41
651-700	2	9	6	5	2									24	5.59
701-750	1	28	4	7										40	6.97
751-800	1	10	3	6	2									22	8.57
801-850	2	5	1	2			1	1						12	10.39
851-900	1	5	1	4	1	1								13	12.46
901-950		5	1	3			1							10	14.80
951-999+	2	10	5	8	1		6		2					34	17.41
Total	19	180	89	91	7	2	10	3	3	1	3	2	2	412	5.37

Table 3.3.3. Measured sizes and ages from mangrove-lined rivers and islands of the Ten Thousand Islands (Everglades National Park), 1998-2000. (from Table 1 in Koenig et al. 2007).

	Age							
TL (mm)	0	1	2	3	4	5	6	Total
0-100								0
101–200	1	8	3	25				37
201–300	3	90	107	108	3			311
301–400		52	239	100	9			400
401–500		1	81	48	17	2		149
501–600			8	21	36	3		68
601–700			4	8	34	11	1	58
701–800				3	22	17	2	44
801–900					15	17	2	34
901–1000					6	7	2	15
Total n	4	151	442	313	142	57	7	1116
proportion	0.004	0.139	0.408	0.289	0.131	0.053	0.006	1.030

Table 3.3.4. Measured sizes and ages from a research study of juvenile Goliath Grouper in ENP tidal river mangrove habitats from Brusher and Schull (2009).

	Age							
TL_mm	0	1	2	3	4	5	6	total
101-150								0
151-200	3	3						6
201-250	27	15	4	1				47
251-300	57	78	30	3				168
301-350	31	106	70	17		1		225
351-400	7	78	79	12				176
401-450	1	40	63	20	1			125
451-500	1	17	41	13	3			75
501-550		4	32	19	2			57
551-600		2	11	15	5			33
601-650		2	13	17	4			36
651-700		1	6	13	12	1		33
701-750			4	11	8	1		24
751-800		1	3	8	11	2		25
801-850			3	7	11	2		23
851-900			0	2	9	1		12
901-950			1	5	4	1	1	12
951-1000			1	1	3			5
1001-1050					1			1
Total	127	347	361	164	74	9	1	1083
proportion	0.117	0.320	0.333	0.151	0.068	0.008	0.001	1.000

Table 3.3.5. Mid-year estimated total length (TL, mm) and weight (kg) at age, and vulnerability at age for estuarine and offshore catches of Goliaths.

	mid-year		vulnerability vectors	
Age	TL(mm)	Wt. (kg)	Estuarine	Offshore
0	233	0.21	0.0124	0.0008
1	411	1.21	0.2437	0.0008
2	573	3.37	0.3674	0.0018
3	720	6.84	0.2281	0.0038
4	855	11.59	0.0985	0.0079
5	977	17.52	0.0349	0.0163
6	1088	24.45	0.0109	0.0329
7	1189	32.19	0.0031	0.0628
8	1282	40.55	0.0008	0.1088
9	1366	49.34	0.0002	0.1597
10	1442	58.39	0.0001	0.1856
11	1512	67.55		0.1652
12	1575	76.70		0.1155
13	1633	85.72		0.0679
14	1686	94.54		0.0359
15	1734	103.09		0.0179
16	1777	111.32		0.0087
17	1817	119.18		0.0041
18	1853	126.67		0.0020
19	1886	133.75		0.0009
20	1916	140.43		0.0004
21	1943	146.70		0.0002
22	1968	152.58		0.0001
23	1991	158.06		0.0001
24	2011	163.17		0.0000
25	2030	167.92		0.0000
26	2047	172.33		0.0000
27	2063	176.40		0.0000
28	2077	180.17		0.0000
29	2090	183.65		0.0000
30	2102	186.86		0.0000
31	2112	189.82		0.0000
32	2122	192.53		0.0000
33	2131	195.03		0.0000
34	2139	197.32		0.0000
35	2146	199.43		0.0000
36	2153	201.35		0.0000
37	2159	203.12		0.0000
38	2165	204.74		0.0000
39	2170	206.22		0.0000
40	2174	207.57		0.0000

Table 3.4.1. Total reported commercial landings (reported and adjusted), and recreational harvests (landings and estimated dead releases). Re-estimated recreational landings are shown in bright yellow. Recreational landings from 1950-1980 (in gold) are set to the average over 1981-1989.

Year	Total SE Comm. Landings (**Reported**) (kg)	Total SE Comm. Landings (***Adjusted***) (kg)	Total Rec. Harvest (MRFSS/MRIP + HB) + 5% dead releases (kg)	Total SE Comm. **Reported** Landings, Rec. Harvest + 5% dead releases (kg)	Total SE Comm. ***Adjusted*** Landings, Rec. Harvest + 5% dead releases (kg)
1950	57,017	57,017	35,303	92,320	92,320
1951	88,224	88,224	35,303	123,527	123,527
1952	77,065	77,065	35,303	112,368	112,368
1953	128,911	128,911	35,303	164,214	164,214
1954	52,345	52,345	35,303	87,648	87,648
1955	37,557	37,557	35,303	72,861	72,861
1956	26,354	26,354	35,303	61,657	61,657
1957	27,896	27,896	35,303	63,199	63,199
1958	60,146	60,146	35,303	95,449	95,449
1959	59,738	59,738	35,303	95,041	95,041
1960	46,357	46,357	35,303	81,660	81,660
1961	46,221	46,221	35,303	81,524	81,524
1962	40,733	40,733	35,303	76,036	76,036
1963	63,367	63,367	35,303	98,670	98,670
1964	109,406	109,406	35,303	144,710	144,710
1965	107,501	102,412	35,303	142,805	137,715
1966	82,826	77,447	35,303	118,129	112,750
1967	90,764	81,297	35,303	126,067	116,600
1968	120,565	96,019	35,303	155,868	131,322
1969	91,081	58,179	35,303	126,384	93,482
1970	104,961	62,001	35,303	140,264	97,304
1971	88,949	39,642	35,303	124,253	74,945
1972	108,091	56,575	35,303	143,394	91,878
1973	109,860	57,187	35,303	145,163	92,490
1974	107,320	57,880	35,303	142,623	93,183
1975	112,899	54,925	35,303	148,202	90,229
1976	115,212	48,537	35,303	150,516	83,840
1977	123,876	67,487	35,303	159,179	102,790
1978	97,076	38,065	35,303	132,380	73,368
1979	82,021	26,829	35,303	117,324	62,132
1980	101,689	31,576	35,303	136,992	66,879
1981	92,091	34,510	151,675	243,767	186,185
1982	79,739	31,538	66,812	146,550	98,349
1983	90,886	41,911	1,845	92,731	43,756
1984	49,014	39,057	36,685	85,699	75,742
1985	50,306	50,306	85,682	135,989	135,989
1986	54,179	54,179	20,440	74,619	74,619
1987	53,806	53,806	38,207	92,012	92,012
1988	67,647	67,647	5,578	73,225	73,225
1989	46,146	46,146	18,161	64,307	64,307
1990	5,250	5,250	5,933	11,183	11,183
1991	362	362	16,992	17,354	17,354
1992	0	0	7,021	7,021	7,021
1993	0	0	10,008	10,008	10,008
1994	0	0	11,959	11,959	11,959
1995	0	0	10,909	10,909	10,909
1996	0	0	2,982	2,982	2,982
1997	0	0	10,728	10,728	10,728
1998	0	0	13,704	13,704	13,704
1999	0	0	8,144	8,144	8,144
2000	0	0	31,698	31,698	31,698
2001	0	0	30,849	30,849	30,849
2002	0	0	26,615	26,615	26,615
2003	0	0	54,639	54,639	54,639
2004	0	0	46,530	46,530	46,530
2005	0	0	66,558	66,558	66,558
2006	0	0	74,205	74,205	74,205
2007	0	0	92,284	92,284	92,284
2008	0	0	65,777	65,777	65,777
2009	0	0	34,072	34,072	34,072
2010	0	0	18,051	18,051	18,051
2011	0	0	16,704	16,704	16,704
2012	0	0	8,962	8,962	8,962
2013	0	0	28,034	28,034	28,034
2014	0	0	16,491	16,491	16,491
2015	0	0	18,257	18,257	18,257

Table 4.1. Indices used in Goliath assessments.

Index	SEDAR 6 2006	SEDAR 23 2010	FWC Update 2015	SEDAR 47 2016
DeMaria	√			
Interviews	√			
ENP	√	√	√	√
REEF SE	√	√	√	
REEF SW		√		
REEF FL (both)				√
MRFSS (PR, % positives)		√		
MRFSS (WFL, offshore boats)			√	
MRFSS (EFL, offshore boats)			√	
MRFSS (WFL, estuarine)			√	
MRFSS (EFL, estuarine)			√	
MRFSS/MRIP (offshore boats)				√
MRFSS/MRIP (estuarine)				√

Table 4.1.1. Classification of habitats for the REEF surveys.

Habitat description	REEF Habitat	Hab[a]	New_Hab[b]
Unknown	0	0	0
Mixed	1	1	5
High profile reef, coral structures 4' or more above bottom	2	2	2
Low profile reef, coral structures < 4' above bottom	3	3	3
Sloping drop-off into open water	4	1	3
Wall - a shear drop-off of over 25' facing open water	5	2	2
Ledge - a single or few sharp drops in bottom topography of 3' or more	6	2	2
Seagrass	7	1	1
Sand	8	1	1
Rubble	9	1	1
Artificial	10	4	4
Open water	11	1	1

[a] re-classification of habitat score used for REEF SE index in SEDAR 6 and REEF SE and SW in SEDAR 23

[b] re-classification of habitat score used for REEF FL index in SEDAR 47. If habitat for a survey was unknown, the most frequently observed habitat score for surveys at that site was substituted unless a site was only coded as unknown or mixed. In the case of artificial reefs and wrecks, the "artificial" category does not appear in the database until the year 2000 (there were a few 1999 surveys coded as "artificial", and these may have been entered after the code for "artificial" became available). So, artificial reefs or wrecks which were surveyed prior to 2000 were re-coded to "artificial" if they existed as such at the time of the survey.

Table 4.1.2 a. Legend for REEF and Great Goliath Grouper Count Surveys examined for SEDAR 47.

Cell Color Key	Years with surveys recorded	Used for SEDAR 23 Index	Used for SEDAR 47 Index
White	6 to 9 years	No	No
Peach	6 to 9 years	Yes	No
Blue	10 or more years	No	Yes
Yellow	10 or more years	Yes	Yes

Numbers highlighted in blue in the “Years Surveyed” column are from the “Great Goliath Grouper Count” surveys.

Data for grey-shaded years in the “Years Surveyed” column were not used for indices.

Table 4.1.2 b. Number of REEF sites with survey data using various criteria.

	1994-2014	
Criteria	East Florida and Florida Keys	West Florida
All sites* with 6 or more years of surveys	173	41
All sites* with 6-9 years of surveys	46	23
SEDAR 23** sites dropped (<10 yrs of record)	7	9
SEDAR 23 and SEDAR 47 sites (10+ yrs of record)	53	8
Additional sites with 10+ yrs of record for SEDAR 47	67	1
SEDAR 47 Total Sites in index (10+yrs of record)	120	9
Index time period	***1994-2014***	***1999-2014***

*Sites must have had at least one survey with a Goliath Grouper sighting over the index period.

** The SEDAR 23 Southeast FL index was comprised of 1994-2009 survey data for 60 sites, and the Southwest FL index used 1999-2009 survey data from 17 sites.

Table 4.1.2 c. REEF sites in southeast Florida and the Florida Keys where Goliath Grouper have been observed at least once and with 6 or more years where surveys were recorded over the 1994-2014 time period. Index included sites with 10 or more years where surveys were conducted from ***1994-2014***.

Location	REEF geozone	Number of years with surveys[1]	Number of surveys	Years surveyed and max. abundance rank[2] (1993, 1995, 2000, 2005, 2010, 2014)	Abundance Ranks and no. surveys by rank: 0: None seen	1: One seen	2: 2-10 seen	3: 11-100 seen	4: 101+ seen	Latitude DD	Longitude DD
PM site South Tug #1	31010018	6	24	-----01----10---10----	20	4	0	0	0	30.3302	-81.1830
1997 concrete culverts (Volusia County Site 2)	31010022	6	14	------00200-0---------	12	1	1	0	0	29.1550	-80.6770
Northside Jupiter Inlet	32010005	15	936	-------201110111110000	903	31	2	0	0	26.9455	-80.0743
Esso Bonaire Wreck	32010006	13	46	-01----0-11---32331233	18	8	13	7	0	26.9642	-80.0080
Loggerhead Reef	32010017	14	76	--------00000201212121	58	14	4	0	0	26.9467	-80.0250
St. Lucie Inlet Preserve Site A	32010019	7	45	------00-000-01-------	43	2	0	0	0	27.1632	-80.1392
St. Lucie Inlet Preserve Site B	32010020	12	205	---------003-102021120	189	8	7	1	0	27.0993	-80.1110
The Tunnels	32010023	12	131	---------012323333333-	20	12	57	42	0	26.9464	-80.0313
Julie's Reef	32010025	7	20	----------0--1010--0-0	18	2	0	0	0	26.9569	-80.0174
Lobster Reef (Jupiter)	32010027	7	9	----------00-2-000-0--	8	0	1	0	0	26.9167	-80.0500
Jupiter Ledge	32010028	6	11	----------00---1-22-0-	7	2	2	0	0	26.9440	-80.0220
Tug Boat Reef (Curly, Larry, Moe)	32010032	6	16	-------0---0---112--1-	10	5	1	0	0	26.9763	-80.0162
Zion Train	32010033	12	98	----------202323333423	7	4	30	55	2	26.9628	-80.0075
McGill/MG111 Barge (artificial)	32010036	12	65	------0-0-222--3333333	9	4	24	28	0	26.9778	-80.0248
Loran Tower Ledge (was 33010295)	32010061	8	27	--------1--0-0-22312--	9	7	9	2	0	27.0420	-80.0506
Commercial Pier Reefs/Datura Ave. 1st and 2nd Reef	33010001	18	1473	--0--00000000010000000	1472	1	0	0	0	26.1872	-80.0842
Juno Ledge	33010005	18	91	-0--00001020-210223222	53	10	27	1	0	26.8730	-80.0133
Princess Anne	33010006	15	54	----0-00211202-220-000	37	9	8	0	0	26.7933	-80.0037
Mizpah	33010007	13	24	--0--0--1221-20-32-332	7	4	6	7	0	26.7860	-80.0163
Breakers Reef (Elevator,4th Window,King Neptune)	33010009	21	286	-000000000100001010000	283	3	0	0	0	26.7092	-80.0160
Captain Dan/Capt Dan Garnsey	33010010	12	26	------00-0000-00--0220	24	0	2	0	0	26.2310	-80.0660
Mercedes I (Channel Islands)	33010012	8	28	-----01-1000-1-------0	25	3	0	0	0	26.1562	-80.0752
Middle Tenneco Tower	33010014	12	27	-----000010--0021--00-	24	2	1	0	0	25.9823	-80.0854
Finks' Grouper Hole (Boynton Beach)	33010022	16	50	-0-0-0000020000000--0-	49	0	1	0	0	26.4115	-80.0513
Shark Reef	33010023	13	41	--0---000000--1100-10-	38	3	0	0	0	26.1935	-80.0727
Amaryllis Wreck, West Palm	33010026	7	11	-0----0-0-0--1-01-----	8	3	0	0	0	26.7883	-80.0160
Scarface (Jupiter)	33010033	15	93	--0-----00000212221202	63	22	8	0	0	26.9167	-80.0183
Opal Tower/Hillsborough Domes (Pompano Beach)	33010038	14	69	--0--02002000000-00---	67	0	2	0	0	26.2927	-80.0685
Delray Ledge	33010042	16	81	-0--0-002000001000-00-	79	1	1	0	0	26.4695	-80.0440
Honeycombs (Boca Raton)	33010043	16	90	---0--000000000000010-	89	1	0	0	0	26.3545	-80.0557
Briney Breeze, Boynton Beach	33010047	9	25	----0-0--20--002-0--0-	23	0	2	0	0	26.5100	-80.0343
The Trench (WPB)	33010050	12	32	----00000--200-0--0-10	30	1	1	0	0	26.7052	-80.0170
Gulf Stream Ledge (Boynton Beach)	33010051	12	37	----0-000000-000-0--1-	36	1	0	0	0	26.4903	-80.0413
Boynton Ledge	33010052	13	49	----0-0000000-01-0-00-	45	4	0	0	0	26.5008	-80.0365
Rybovich Artificial Reef (WPB)	33010054	8	29	-----0-010-1-1------00	25	4	0	0	0	26.7505	-80.0432

Table 4.1.2 c. REEF sites in southeast Florida and the Florida Keys where Goliath Grouper have been observed at least once and with 6 or more years where surveys were recorded over the 1994-2014 time period. Index included sites with 10 or more years where surveys were conducted from ***1994-2014***.

				Years surveyed and max. abundance rank[2]	Abundance Ranks and no. surveys by rank						
Location	REEF geozone	Number of years with surveys[1]	Number of surveys	1993 1995 2000 2005 2010 2014	0: None seen	1: One seen	2: 2-10 seen	3: 11-100 seen	4: 101+ seen	Latitude DD	Longitude DD
Playpen/Tri County Reef (WPB)	33010055	13	41	-----10000101000-2--2-	35	3	3	0	0	26.7630	-80.0215
Horseshoe Reef (WPB)	33010057	13	33	-----0000000-200--002-	31	0	2	0	0	26.6073	-80.0087
Habitat Corridors North (WPB)	33010061	10	44	-----100001------010-0	39	5	0	0	0	26.7888	-80.0163
Hillsboro Ledge	33010062	17	147	-----00000000000001000	145	2	0	0	0	26.3011	-80.0685
Cross Current Reef (WPB)	33010071	10	60	-------1012010--0--0-0	55	4	1	0	0	26.7615	-80.0210
Hog Heaven	33010072	11	31	-----0000100----0-2-00	28	2	1	0	0	26.1350	-80.0798
Sea Emperor / AquaZoo Wreck (Boca Raton)	33010073	16	107	------2221222220022020	49	23	35	0	0	26.3243	-80.0615
Copenhagen Wreck	33010079	15	72	-----000000000000-0-10	71	1	0	0	0	26.2058	-80.0852
Moray Bend (Boca Raton)	33010081	16	88	------0000000000010001	85	3	0	0	0	26.3342	-80.0582
Separated Rocks (Deerfield Beach)	33010082	17	115	-----00000010000000000	114	1	0	0	0	26.3130	-80.0663
Boca Raton N. Beach Ledge/Boca Ledges 3rd Reef	33010083	14	84	------0000000100000-0-	83	1	0	0	0	26.3587	-80.0555
Chalfonte (Boca Raton)	33010084	13	107	------0000000000-111--	103	4	0	0	0	26.3498	-80.0563
PEP Reef (WPB)	33010086	8	70	------0-101000-----0--	66	4	0	0	0	26.6787	-80.0288
Sugar Sands Ledges	33010087	7	51	------00101--2---2----	46	3	2	0	0	26.7935	-80.0448
Habitat Corridors South	33010088	6	34	------00001------0----	33	1	0	0	0	26.7873	-80.0160
Larson's Valley (WPB)	33010090	10	35	------0---00-00-00-110	33	2	0	0	0	26.7908	-80.0123
Jolly Jacks Reef	33010093	7	14	------0-02---0-00----0	12	1	1	0	0	26.8373	-80.0180
Wreck of the Tracey/Ken Vitale Wreck	33010095	10	17	------0-0-0000----0011	15	2	0	0	0	26.1593	-80.0793
Palm Beach Triangle (Eidsvag,Rolls,Philips,Mid Ree	33010096	11	20	------00000000-00--1--	19	1	0	0	0	26.7670	-80.0123
Boca Trench/Boca Outfall Trench	33010099	11	34	------0-0000000----100	33	1	0	0	0	26.3503	-80.0553
Beck Wreck/Captain Tony Wreck	33010103	11	26	------00-0022---01002-	20	2	4	0	0	26.4812	-80.0392
Jim Atria Wreck	33010109	7	10	------1100---0---0---1	7	3	0	0	0	26.1645	-80.0703
Crab Cove (Deerfield Beach)	33010110	14	45	------0000000000-0030-	44	0	0	1	0	26.3120	-80.0597
Noula Express	33010119	8	25	-------1-01-000--11---	19	6	0	0	0	26.3213	-80.0575
Ancient Mariner	33010122	14	93	--0---012210000-010--0	86	5	2	0	0	26.3020	-80.0623
Boca Ledge Artificial (Boca Raton)	33010124	15	130	-------010100000010000	127	3	0	0	0	26.3278	-80.0580
United Caribbean	33010130	13	66	-------00111000-01222-	51	11	4	0	0	26.3212	-80.0590
Royal Park Bridge / Atlantis / Spud Barge (West Pa	33010146	11	56	-------02011-22-22--12	40	7	9	0	0	26.7955	-80.0175
Boynton Corridors	33010147	8	25	-------0--0102---1-00-	21	3	1	0	0	26.4782	-80.0395
Rodeo 25	33010150	7	13	--0----010--0---00----	12	1	0	0	0	26.2313	-80.0635
NW Double Ledges / Shark Canyon (WPB)	33010169	10	21	--------00000---002-21	16	3	2	0	0	26.8628	-80.0180
Castor Wreck (Boynton Beach)	33010183	8	18	--------0-20-2----3333	8	0	6	4	0	26.4788	-80.0372
Governor's Riverwalk Reef	33010198	10	41	---------10101010---20	34	6	1	0	0	26.7520	-80.0103
Oakland Ridge Moorings	33010204	10	26	---------00000-10-0-00	25	1	0	0	0	26.1503	-80.0898
Double Ledges (WPB)	33010222	7	14	---------00-0-0-01--0-	13	1	0	0	0	26.7510	-80.0133
Hole in the Wall	33010236	13	65	---------2123232033300	33	12	12	8	0	26.8940	-79.9862
Juno High Reef Ledge	33010246	7	23	-----------0----2130-21	12	6	4	1	0	26.8705	-80.0188

Table 4.1.2 c. REEF sites in southeast Florida and the Florida Keys where Goliath Grouper have been observed at least once and with 6 or more years where surveys were recorded over the 1994-2014 time period. Index included sites with 10 or more years where surveys were conducted from ***1994-2014***.

Location	REEF geozone	Number of years with surveys[1]	Number of surveys	Years surveyed and max. abundance rank[2] (1993, 1995, 2000, 2005, 2010, 2014)	Abundance Ranks and no. surveys by rank: 0: None seen	1: One seen	2: 2-10 seen	3: 11-100 seen	4: 101+ seen	Latitude DD	Longitude DD
ShaSha Boekanier Wreck	33010256	6	9	-----------020000-----	8	0	1	0	0	26.7508	-80.0098
Genesis	33010272	6	8	--------100---0-0--1--	6	2	0	0	0	26.4778	-80.0397
Mike's Reef	33010279	11	98	-----------0122222232-	21	19	56	2	0	26.8462	-80.0203
Captain Kirle's / Jupiter (was 32010040)	33010296	14	107	--------01222021221212	57	28	22	0	0	26.9258	-80.0200
The Bluffs (was 32010042)	33010297	13	79	--------0011-122222110	52	19	8	0	0	26.9037	-80.0175
Leigh's Reef	33010298	6	10	--0-----000--------01-	9	1	0	0	0	26.9000	-80.0167
Area 51 (was 32010041)	33010299	13	111	---------0010232222220	56	26	28	1	0	26.8810	-80.0140
Spadefish Point (was 32010039)	33010301	13	55	--------0-020211222212	28	16	11	0	0	26.8945	-80.0155
Area 29 (Jupiter - south of Inlet)	33010325	10	33	-----------0101102002-	26	5	2	0	0	26.8890	-80.0028
Scarf-out (E of Scarface, S of Jupiter Inlet)	33010326	7	8	-----------00111--00--	5	3	0	0	0	26.9167	-80.0000
Center Street (S of Jupiter Inlet)	33010327	6	10	------------0-20200---	8	0	2	0	0	26.7500	-80.0167
Gorgeous Gorge (S of Jupiter Inlet)	33010328	9	14	----------000-100000--	13	1	0	0	0	26.8797	-80.0170
Paul's Reef (northern end) - WPB (was 32010038)	33010383	13	28	----0000100-000---000-	27	1	0	0	0	26.6527	-80.0208
The Wall	33020002	7	25	----000-1-0--0---0----	24	1	0	0	0	25.3055	-80.1548
Anchor Chain E6	34030001	18	203	0000000001011000-0--00	199	4	0	0	0	25.1450	-80.2563
South Ledges/Undersea Highway E3	34030003	15	130	-000000010000-0-0----0	129	1	0	0	0	25.1403	-80.2590
Grecian Rocks	34030004	21	475	-000001010002000020000	468	4	3	0	0	25.1098	-80.3042
Key Largo Dry Rocks (Christ Statue)	34030005	21	492	0000000201000000000010	489	2	1	0	0	25.1225	-80.2975
Carysfort Reef	34030006	17	264	000-000001100000000---	262	2	0	0	0	25.2195	-80.2108
South Carysfort Reef	34030007	19	140	-10-00000000001001000-	137	3	0	0	0	25.2105	-80.2172
French Reef	34030008	21	1098	-000000111120111111000	1056	41	1	0	0	25.0353	-80.3473
Molasses Reef	34030009	21	2178	-100112202111222221221	2057	94	27	0	0	25.0090	-80.3737
Benwood Wreck	34030011	21	704	0000000101100110010010	687	17	0	0	0	25.0527	-80.3337
Mike's Wreck / Hannah Bell / Seneca E6/7	34030013	21	205	-000000000010000100000	198	7	0	0	0	25.1446	-80.2566
City of Washington Wreck (Elbow) E9/10	34030014	21	336	-000000001211211122200	281	45	10	0	0	25.1460	-80.2558
Train Wheel Wreck E4	34030017	13	76	-0-0000---0-02000---00	73	2	1	0	0	25.1420	-80.2578
Horseshoe Reef	34030018	21	154	-001111001200000000100	143	10	1	0	0	25.1383	-80.3117
Carysfort Deep Ledge	34030021	6	30	--00-0---00---1-------	29	1	0	0	0	25.2300	-80.2123
North North Dry Rocks (Double North)	34030023	21	314	-000000001000000010000	312	2	0	0	0	25.1363	-80.2903
Wellwood Grounding Site M12	34030024	15	231	--0-000-0003000---0100	228	2	0	1	0	25.0105	-80.3728
Duane Wreck	34030026	20	131	-200001012210110-22000	108	16	7	0	0	24.9880	-80.3805
Bibb Wreck	34030027	10	21	-0-----02-1120---2-0-0	12	6	3	0	0	24.9960	-80.3795
Minnow Caves / North Dry Rocks	34030028	20	254	-000000000000010001-00	252	2	0	0	0	25.1307	-80.2943
Sand Island	34030030	19	117	-0--010000000010000000	115	2	0	0	0	25.0183	-80.3677
The Elbow Reef	34030031	21	158	-100010002102000000000	152	4	2	0	0	25.1388	-80.2610
Banana Reef	34030032	14	29	-0000-00-000001-0----0	27	2	0	0	0	25.1077	-80.3073
The Slab	34030033	9	12	--0-0---0-1---111--10-	6	6	0	0	0	24.8333	-80.6667

Table 4.1.2 c. REEF sites in southeast Florida and the Florida Keys where Goliath Grouper have been observed at least once and with 6 or more years where surveys were recorded over the 1994-2014 time period. Index included sites with 10 or more years where surveys were conducted from ***1994-2014***.

Location	REEF geozone	Number of years with surveys[1]	Number of surveys	Years surveyed and max. abundance rank[2] (1993 1995 2000 2005 2010 2014)	Abundance Ranks and no. surveys by rank: 0: None seen	1: One seen	2: 2-10 seen	3: 11-100 seen	4: 101+ seen	Latitude DD	Longitude DD
Dixie Ledge	34030036	9	88	---0-----000010-----00	82	6	0	0	0	25.0702	-80.3162
Spiegel Grove Wreck	34030038	14	286	---0-----1211221200221	238	35	13	0	0	25.0667	-80.3108
White Banks	34030045	15	119	----000000-2000000-0-0	118	0	1	0	0	25.0417	-80.3700
Cannon Patch/Garret's Reef	34030046	15	124	----000000000001-000--	123	1	0	0	0	25.1118	-80.3417
Alyssa Rocks	34030064	7	15	-------0-00001-------0	13	2	0	0	0	25.0453	-80.3950
Snapper Ledge	34030071	16	197	----0--001000010000000	194	3	0	0	0	24.9820	-80.4217
Red Can Ledge	34030075	7	68	---------010110------0	59	9	0	0	0	25.0718	-80.3152
Alligator Reef	34040002	19	326	-00-0000010-0000000010	323	3	0	0	0	24.8512	-80.6202
Conch Reef	34040004	20	293	-000000012000022030-00	270	8	14	1	0	24.9518	-80.4595
Hens and Chickens Reef	34040006	19	210	-10000000000-00-000001	208	2	0	0	0	24.9317	-80.5483
Wreck of the Eagle	34040007	19	101	-01-100222222-22201022	59	21	21	0	0	24.8695	-80.5702
Tennessee Reef Research	34040008	13	134	-1--00000000-00-0----0	132	2	0	0	0	24.7662	-80.7542
Crocker Ridges / Baby Grand	34040010	11	31	--100-000000---0----0-	30	1	0	0	0	24.9028	-80.5295
Pleasure Reef	34040011	12	38	--0-000000--0--01-0-0-	36	2	0	0	0	24.9135	-80.5158
Crocker Reef	34040019	11	29	----0--000102--0---000	26	2	1	0	0	24.9073	-80.5250
Aquarium Reef/A&B Patch	34040020	14	82	----000000010-000--00-	81	1	0	0	0	24.8912	-80.5555
Cheeca Rocks	34040022	14	108	----00000000-1020--00-	105	2	1	0	0	24.9045	-80.6155
The Pillars	34040024	13	94	-----0-0000010000---00	90	4	0	0	0	24.9922	-80.4085
Conch Reef Research Only/Aquarius Habitat	34040100	13	72	-----0-0-2002212100--0	41	9	22	0	0	24.9332	-80.4548
Tennessee Reef (Open - near tower)	34040116	9	76	-------0000--0-20-0--0	74	0	2	0	0	24.7457	-80.7810
Sombrero Reef	34050001	20	340	-000100000201000000-00	326	11	3	0	0	24.6253	-81.1122
Samantha's Ledge	34050002	15	158	-0-000000200000-01----	156	1	1	0	0	24.6577	-81.0067
Coffins Patch	34050004	16	187	-0-000000000100-00-0--	184	3	0	0	0	24.6857	-80.9635
Looe Key - East	34050005	18	264	-00-00012010-101010-21	245	16	3	0	0	24.5460	-81.4035
Looe Key - Research	34050006	10	97	-0--000101-0-0-------0	91	6	0	0	0	24.5670	-81.3903
Herman's Hole	34050007	7	23	--000---0-------10---0	22	1	0	0	0	24.6505	-81.0313
Delta Shoals	34050013	12	109	----00001001-0000-----	107	2	0	0	0	24.6327	-81.0900
R/V Thunderbolt	34050015	11	27	----0--211100-2--2--21	12	9	6	0	0	24.6580	-80.9650
Barge	34050021	7	9	-------00-1---0-00---0	7	2	0	0	0	24.6445	-81.0718
Newfound Harbor Spa	34050026	12	112	----00000000-100-----0	108	4	0	0	0	24.6138	-81.3953
Adolphus Busch Wreck	34060002	10	106	-------122222-20-0--1-	59	24	23	0	0	24.5180	-81.4610
Looe Key West Deep Reef	34060003	8	80	-------01000-0---01---	77	3	0	0	0	24.5418	-81.4153
Middle Looe Key	34060004	12	103	-------0010120001--0-0	89	12	2	0	0	24.5450	-81.4083
Looe Key - Buoy 14	34060006	6	15	-----------0-0--10-3-0	12	2	0	1	0	24.5458	-81.4063
Looe Key Marker 16	34060008	6	15	------------021--0--20	8	4	3	0	0	24.5450	-81.4043
Western Sambo	34080001	21	463	-000000011201010000000	443	19	1	0	0	24.4792	-81.7163
Eastern Sambo	34080002	12	150	-00-00000100-0--0-----	144	6	0	0	0	24.4912	-81.6640

Table 4.1.2 c. REEF sites in southeast Florida and the Florida Keys where Goliath Grouper have been observed at least once and with 6 or more years where surveys were recorded over the 1994-2014 time period. Index included sites with 10 or more years where surveys were conducted from ***1994-2014***.

Location	REEF geozone	Number of years with surveys[1]	Number of surveys	Years surveyed and max. abundance rank[2] (1993, 1995, 2000, 2005, 2010, 2014)	Abundance Ranks and no. surveys by rank: 0: None seen	1: One seen	2: 2-10 seen	3: 11-100 seen	4: 101+ seen	Latitude DD	Longitude DD
Rock Key	34080003	20	327	-00000000202212101000-	309	14	4	0	0	24.4490	-81.8563
Sand Key	34080004	20	333	-00000000100010011111-	323	10	0	0	0	24.4508	-81.8778
Middle Sambo	34080005	13	131	-00-0001000100-0------	128	3	0	0	0	24.4883	-81.6733
Eastern Dry Rocks Shallow	34080008	20	329	-00000-000211111111100	307	21	1	0	0	24.4592	-81.8445
Nine Foot Stake	34080009	17	146	--00--0-01000000000000	145	1	0	0	0	24.4725	-81.7650
Joe's Tug	34080010	16	172	--01--10011000-01000-0	157	15	0	0	0	24.4638	-81.7373
Cayman Salvor	34080014	15	95	------101112221112012-	65	24	6	0	0	24.4608	-81.7668
Trinity Cove	34080016	10	44	---0--1--0220100-1----	37	5	2	0	0	24.4338	-81.9330
Western Dry Rocks	34080018	18	233	-0--00200100000000000-	231	1	1	0	0	24.4452	-81.9378
Lost Reef/High Rocks	34080019	13	100	----0-0-0010010-101-0-	95	5	0	0	0	24.4433	-81.9325
Marker 32 (Toppino Buoy) Shallow	34080023	16	177	-----00-00000010011000	173	4	0	0	0	24.4723	-81.7455
Ball & Chain	34080040	6	26	--------0-00------010-	25	1	0	0	0	24.4710	-81.7748
Vandenberg (Hoyt Vandenberg Artificial Reef)	34080097	6	139	----------------222100	121	15	3	0	0	24.4600	-81.7375
Texas Rock	34100004	12	137	-0--0101102000-0------	128	8	1	0	0	24.6750	-82.8860
Pulaski	34100005	8	90	-0--000-110----0------	88	2	0	0	0	24.6955	-82.7713
Riley's Hump	34100008	10	116	-1----200122111-------	89	18	9	0	0	24.4918	-83.1205
Sherwood Forest	34100013	11	108	----0100000001-0------	103	5	0	0	0	24.7115	-83.0468
Windjammer Site (French Wreck)	34100015	9	61	-0--0-21120-11--------	43	15	3	0	0	24.6212	-82.9430
G-Spot / Hidden Paradise	34100016	11	106	----0011100001--0-----	95	11	0	0	0	24.6538	-83.0333
Wreck Reef/Awesome	34100017	9	112	----000-211100--------	96	12	4	0	0	24.6792	-83.0255
Playmate Rock	34100030	8	79	------12222221--------	26	29	24	0	0	24.6867	-82.9070
Loggerhead Ledge	34100036	8	68	-------0110000------1-	64	4	0	0	0	24.6300	-82.9173
SeaClusive Sanctuary	34100041	6	56	-------00200-1--------	47	6	3	0	0	24.6563	-83.0357
Fort Jefferson	34100046	7	30	------0-02--100----0--	25	4	1	0	0	24.6273	-82.8722
Little Africa	34100073	6	35	--------1000-0-0------	34	1	0	0	0	24.6400	-82.9200
Rileys Hump Station 12	34100205	6	17	--------------01001-0-	15	2	0	0	0	24.4907	-83.1214
MM 82 - Founder's Park - Petey's Beach	34110005	7	28	----------0----010000-	27	1	0	0	0	24.9630	-80.5701

[1] – Number of survey years excludes any data collected during 1993. [2] – The maximum abundance rank is the highest rank observed at a site in a year.

Table 4.1.2 d. REEF sites in West Florida where Goliath Grouper have been observed at least once and with 6 or more years where surveys were recorded over the 1994-2014 time period. Index included sites with 10 or more years where surveys were conducted for the ***1999-2014*** time period.

				Years surveyed and max. abundance rank[2]	Abundance Ranks and no. surveys by rank						
Location	REEF geozone	years with surveys[1]	Number of surveys	1 1 2 2 2 2 9 9 0 0 0 0 9 9 0 0 1 1 3 5 0 5 0 4	0: None seen	1: One seen	2: 2-10 seen	3: 11-100 seen	4: 101+ seen	Latitude DD	Longitude DD
Black Bart (Panama City)	21010008	9	33	---0--1-0000-0-0-----1	30	3	0	0	0	30.0607	-85.8238
Bridge Span 14 (Panama City)	21010009	7	13	---0--0--00--0-0-----2	11	1	1	0	0	30.0715	-85.8146
Miss Louise Tugboat (Destin)	21010027	6	13	------00-0-10-------0-	6	7	0	0	0	30.3717	-86.4215
USS Oriskany	21010060	8	21	-------------02000000-	20	0	1	0	0	30.0426	-87.0066
Clearwater Wreck	23010007	12	45	---1--0-2323211-10--1-	15	9	19	2	0	27.9532	-83.1217
Dunedin Reef	23010009	6	9	--0-0-------------2100	6	2	1	0	0	28.0570	-82.9108
Cable Barge (aka Indian Shores)	23010013	8	15	----1-22210------1-1--	8	4	3	0	0	27.8567	-83.0292
Masthead Ledge	23010014	7	14	----0---001---01-0----	11	3	0	0	0	28.0623	-83.1907
Tug Sheridan	23010016	10	25	----0---222-----221212	8	5	12	0	0	27.8760	-83.1863
Rube Allen (Pinellas #1)	23010018	13	43	----0-0-1221-22221-02-	19	11	13	0	0	27.9267	-83.0233
Airplane Barge at Veterans' Creek	23010033	7	10	---------0-0--212---20-	3	3	4	0	0	28.0475	-83.0118
Veteran's Reef	23010043	12	26	----------001-20221222 2	11	6	9	0	0	28.0500	-83.0125
Boulder Reef	23010064	7	12	----------0--00-21-00-	9	2	1	0	0	28.0000	-83.0000
Seven mile north reef	23020004	6	10	-------------2-0-212-2	5	1	4	0	0	27.5382	-82.8783
Palm Island Ferry Reef	23040001	8	28	-------332-------22232	4	1	18	5	0	26.8208	-82.5330
Alligator Reef in Charlotte County	23040002	6	10	-------0---0-----22-01	7	1	2	0	0	26.8585	-82.0885
Edison Artificial Reef	23050001	11	39	-----3222222022----1--	7	7	24	1	0	26.3092	-82.2222
Doc Kline Artificial Reef	23050002	6	13	-----222-22--0--------	1	4	8	0	0	26.3360	-82.0892
Belton Johnson Artificial Reef	23050004	7	39	-----222-2-2-22-------	4	2	33	0	0	26.4220	-82.1952
Boxcar Artificial Reef	23050007	10	22	-----222202------2221-	8	2	12	0	0	26.7037	-82.6003
Shermans Artificial Reef Culverts	23050008	6	13	-----221-----00--2----	6	4	3	0	0	26.5457	-82.4103
Charlie's Artificial Reef (Pegasus)	23050009	13	28	-----3222222-20--22-22	4	4	19	1	0	26.5583	-82.7188
Redfish Pass Barge #2	23050010	7	12	-----210-2---22---2---	2	3	7	0	0	26.5592	-82.2363
Boca Grande, Phosphate Pier	23050012	17	60	----333323033233-33033	5	0	18	37	0	26.7200	-82.2555
Bay Ronto	23050013	7	12	-----3-3323--30-------	1	3	3	5	0	26.7658	-82.8468
Mary's Artificial Reef/ Mary's Rubble	23050014	13	23	-----212222--2-1-22100	8	6	9	0	0	26.7697	-82.3058
ARC Barge	23050017	6	13	------2222-2-----3----	1	2	9	1	0	26.4150	-82.4115
School Bus Pilings 2	23050023	6	6	------2-0--1--2--2-2--	1	1	4	0	0	26.5995	-82.4728
Charlie's Reef Hopper Cars	23050024	9	16	------232222-22--2----	0	1	14	1	0	26.5562	-82.7228
Pace's Place Reef	23050028	6	11	-------22-2222--------	0	2	9	0	0	26.5177	-82.2835
ARC Reef Pilings	23050035	6	7	-------111010---------	3	4	0	0	0	26.4155	-82.4135
Pace's Place Barge & Crane	23050036	7	10	-------122222----2----	2	1	7	0	0	26.5193	-82.2825
Doc Kline Pilings	23050037	6	8	-------1222-10--------	1	2	5	0	0	26.3392	-82.0900
ARC Rubble	23050038	6	8	--------222112--------	0	2	6	0	0	26.4135	-82.4113
ARC Tetrahedrons	23050039	7	15	--------2110-00--1----	8	5	2	0	0	26.4142	-82.4105
Twin Barges	23050041	7	8	--------232------22-22	0	0	7	1	0	26.4995	-82.7245
ARC Towers	23050048	11	23	---------3323322-3-323	0	0	12	11	0	26.4160	-82.4103
Pace's Place Tetrahedrons	23050050	6	11	---------20110--------0	6	3	2	0	0	26.5208	-82.2833
South Reef Rock	23050056	6	18	---------122212-------	8	5	5	0	0	26.4210	-82.3170
Paces Place Limerock	23050063	6	7	-------------200-2-2-1	3	1	3	0	0	26.5183	-82.2817
Air Force Radio Tower	23060006	6	9	--------03--302-2-----	3	0	4	2	0	26.0500	-83.0750

[1] – Number of survey years excludes any data collected during 1993. [2] – The maximum abundance rank is the highest rank observed at a site in a year.

Table 4.1.3. Step-wise selection of variables for the Poisson regression model of the REEF FL survey data of Goliath Grouper rank abundances based upon the percentage reduction in deviance. Rows highlighted in green were significant in the model, and reduced the deviance in the model by at least 0.5%.

Source	levels	Df	Deviance	Mean Deviance	Δ Mean Deviance	% change	Cum %	Full Log likelihood	Δ log likelihood	-2 Δ log likelihood	df	Prob Ho	AIC	AICc
intercept	1	21024	15090.0	0.7177				-9803.2	-9803.2	36125.1	21024	<0.0001	19608.5	19608.5
Year	21	21004	13441.4	0.6399	0.07781	10.84%		-8978.9	-824.3	1648.6	20	<0.0001	17999.9	17999.9
Geozone	129	20896	7363.8	0.3524	0.36535	50.90%	50.90%	-5940.1	-3863.1	7726.2	128	<0.0001	12138.3	12139.9
New_hab	4	21021	13245.3	0.6301	0.08765	12.21%		-8880.9	-922.3	1844.6	3	<0.0001	17769.8	17769.8
Season	2	21023	15024.3	0.7147	0.00309	0.43%		-9770.4	-32.8	65.6	1	<0.0001	19544.8	19544.8
Experience	2	21023	14718.0	0.7001	0.01766	2.46%		-9617.3	-186.0	371.9	1	<0.0001	19238.5	19238.5
Region	2	21023	13843.3	0.6585	0.05927	8.26%		-9179.9	-623.3	1246.7	1	<0.0001	18363.8	18363.8
with Geozone														
Year	21	20876	6977.4	0.3342	0.01817	2.53%	53.43%	-5747.0	-193.2	386.3	20	<0.0001	11791.9	11794.1
New_hab	4	20893	7249.3	0.3470	0.00543	0.76%		-5882.9	-57.2	114.5	3	<0.0001	12029.8	12031.4
Season	2	20895	7360.9	0.3523	0.00012	0.02%		-5938.7	-1.4	2.8	1	0.0924	12137.4	12139.1
Experience	2	20895	7355.4	0.3520	0.00038	0.05%		-5936.0	-4.2	8.3	1	0.0039	12131.9	12133.6
Region	2	20895	7363.8	0.3524	-0.00002	0.00%		-5940.1	0.0	0.0	1	1.0000	12140.3	12141.9
with Geozone, Year														
New_hab	4	20873	6887.0	0.3299	0.00428	0.60%	54.03%	-5701.7	-45.2	90.4	3	<0.0001	11707.5	11709.7
Season	2	20875	6976.8	0.3342	0.00001	0.00%		-5746.6	-0.3	0.6	1	0.4307	11793.3	11795.5
Experience	2	20875	6976.4	0.3342	0.00003	0.00%		-5746.4	-0.5	1.0	1	0.3121	11792.9	11795.1
Region	2	20875	6977.4	0.3342	-0.00002	0.00%		-5747.0	0.0	0.0	1	1.0000	11793.9	11796.1
with Geozone, Year, New_hab														
Experience	2	20872	6886.7	0.3299	0.00000	0.00%		-5701.6	-0.1	0.3	1	0.5918	11709.2	11711.5
Region	2	20872	6886.0	0.3299	0.00003	0.00%		-5701.2	-0.5	1.0	4	0.9046	11708.5	11710.7

Table 4.2.1 a,b. Everglades National Park (ENP) Angler Survey Catch Index for Goliaths, 1973-2014. Variables that were significant factors in the analysis and accounted for more than 0.5% reduction in deviance were selected for the final model, and are shaded in green.

a. Deviance table for the binomial sub-model of the proportion positive catches of Goliaths in the ENP.

Variable	df	full log likelihood	Δ log likelihood	Chi-sq	Chi-sq df	Prob Ho	AIC	Δ AIC	deviance	Mean Dev	Δ Mean Dev	% change
	193,576	-29573.1					59,148.3		59146.3	0.3055		
Year	193,536	-26385.9	3187.2	6374.5	40	<0.0001	52,853.8	-6294.5	52771.8	0.2727	0.033	10.8%
Area fished	193,532	-25500.0	885.9	1771.9	4	<0.0001	51,089.9	-1763.9	50999.9	0.2635	0.009	3.0%
Hours fished	193,529	-25171.5	328.4	656.9	3	<0.0001	50,439.0	-650.9	50343.0	0.2601	0.003	1.1%
Season	193,526	-24991.6	179.9	359.8	3	<0.0001	50,085.3	-353.8	49983.3	0.2583	0.002	0.6%
Skill level	193,525	-24898.4	93.2	186.5	1	<0.0001	49,900.8	-184.5	49796.8	0.2573	0.001	0.3%
Num_anglers	193,522	-24797.9	100.5	201.0	3	<0.0001	49,705.8	-195.0	49595.8	0.2563	0.001	0.3%
										cumulative%		15.5%

b. Deviance table for the lognormal (positives) sub-model for catches of Goliaths in the ENP.

Variable	df	full log_like	Δ log likelihood	Chi-sq	Chi-sq df	Prob Ho	AIC	Δ AIC	deviance	Mean Dev	Δ Mean Dev	% change
	6,836	-7392.2					14,788.3		3479.4	0.5090		
Year	6,796	-7277.5	114.7	229.3	40	<0.0001	14,639.0	-149.3	3364.7	0.4951	0.014	2.7%
Season	6,793	-7256.9	20.6	41.3	3	<0.0001	14,603.7	-35.3	3344.4	0.4923	0.003	0.5%
Num_anglers	6,790	-7243.4	13.4	26.9	3	<0.0001	14,582.8	-20.9	3331.3	0.4906	0.002	0.3%
Area fished	6,786	-7232.1	11.4	22.7	4	0.0001	14,568.1	-14.7	3320.2	0.4893	0.001	0.3%
Skill level	6,785	-7231.3	0.7	1.4	1	0.2302	14,568.7	0.6	3319.5	0.4892	0.000	0.0%
										cumulative%		3.9%

Table 4.3. Species, by coast and area fished, occurring on MRFSS/MRIP angler interviews used for the selection of trips.

Estuarine		Offshore	
East Florida (Nassau-Miami-FL Keys)	West Florida (Collier-Levy)	East Florida (Nassau-Miami-FL Keys)	West Florida (Collier-Levy)
GOLIATH GROUPER	GOLIATH GROUPER	GOLIATH GROUPER	GOLIATH GROUPER
COMMON SNOOK	COMMON SNOOK	GAG	GAG
GRAY SNAPPER	GRAY SNAPPER	GRAY SNAPPER	GRAY SNAPPER
RED DRUM	RED DRUM	RED GROUPER	RED GROUPER
GAG	GAG	WHITE GRUNT	WHITE GRUNT
SPOTTED SEATROUT	SPOTTED SEATROUT	SPANISH MACKEREL	SPANISH MACKEREL
CREVALLE JACK	CREVALLE JACK	COMMON SNOOK	COMMON SNOOK
LADYFISH	LADYFISH	CREVALLE JACK	CREVALLE JACK
PINFISH	PINFISH	SPOTTED SEATROUT	SPOTTED SEATROUT
HARDHEAD CATFISH	HARDHEAD CATFISH	BLUE RUNNER	BLUE RUNNER
	GAFFTOPSAIL CATFISH	LADYFISH	LADYFISH
SHEEPSHEAD	SHEEPSHEAD	LANE SNAPPER	LANE SNAPPER
SPANISH MACKEREL	SPANISH MACKEREL	RED DRUM	RED DRUM
	SCALED SARDINE	PINFISH	PINFISH
BLUEFISH		COBIA	COBIA
PIGFISH		KING MACKEREL	KING MACKEREL
BLACK DRUM		GREAT BARRACUDA	GREAT BARRACUDA
		YELLOWTAIL SNAPPER	YELLOWTAIL SNAPPER
		MUTTON SNAPPER	
		BLACK GROUPER	
		TARPON	
		NURSE SHARK	
		BLUEFISH	
		SHEEPSHEAD	

Table 4.3.1 a,b. MRFSS/MRIP Estuarine (juveniles) index, 1997-2014. Variables that were significant factors in the analysis and accounted for more than 0.5% reduction in deviance were selected for the model, and are shaded in green.

a. Deviance table for the binomial sub-model of the proportion positive catches of Goliaths.

Variable	levels	DF	Deviance	Mean Deviance	%deviance reduction	Cum %	Full Likelihood	Chi-Square	Chi-square DF	Pr>ChiSq	AIC	AICc	BIC
	1	108075	6502.3	0.06017	.		-3251.15		.	.	6504.3	6504.3	6513.9
year	1	108058	6200.7	0.05738	4.62	4.6	-3100.34	301.6	17	<.0001	6236.7	6236.7	6409.3
year mode_fx	2	108056	6086.3	0.05633	1.76	6.4	-3043.16	114.4	2	<.0001	6126.3	6126.3	6318.1
year mode_fx hr_fish	3	108053	6040.2	0.05590	0.71	7.1	-3020.1	46.1	3	<.0001	6086.2	6086.2	6306.8
year mode_fx hr_fish avidity	4	108048	6010.7	0.05563	0.45		-3005.34	29.5	5	<.0001	6066.7	6066.7	6335.2
year mode_fx hr_fish num_angl	4	108048	6018.2	0.05570	0.33		-3009.11	22.0	5	0.0005	6074.2	6074.2	6342.7
year mode_fx hr_fish season	4	108052	6020.1	0.05572	0.31		-3010.06	20.1	1	<.0001	6068.1	6068.1	6298.3
year mode_fx hr_fish coast	4	108052	6022.5	0.05574	0.27		-3011.26	17.7	1	<.0001	6070.5	6070.5	6300.7

b. Deviance table for the gamma sub-model of the positive catches of Goliaths.

Variable	levels	DF	Deviance	Mean	%deviance	Cum %	Full	Chi-Sq	Chi-DF	PrChiSq	AIC	AICc	BIC
	1	511	230.8	0.45165	.		-713.25	510.0	.	.	1430.5	1430.5	1439.0
year	1	494	209.5	0.42409	6.10	6.1	-686.84	52.8	17	<.0001	1411.7	1413.2	1492.2
year mode_fx	2	492	202.0	0.41064	2.98	9.1	-676.97	19.7	2	<.0001	1395.9	1397.8	1484.9
year mode_fx coast	3	491	199.9	0.40720	0.76	9.8	-674.13	5.7	1	0.0172	1392.3	1394.3	1485.5
year mode_fx coast avidity	4	486	196.7	0.40471	0.55		-669.69	8.9	5	0.1139	1393.4	1396.5	1507.8
year mode_fx coast num_angl	4	486	197.4	0.40615	0.23		-670.65	7.0	5	0.2233	1395.3	1398.4	1509.7
year mode_fx coast season	4	490	199.3	0.40673	0.11		-673.26	1.7	1	0.1873	1392.5	1394.8	1490.0
year mode_fx coast hr_fish	4	488	198.8	0.40743	-0.05		-672.63	3.0	3	0.3892	1395.3	1397.9	1501.2

Table 4.3.2 a,b. MRFSS/MRIP Offshore (adult) index, 1997-2014. Variables that were significant factors in the analysis and accounted for more than 0.5% reduction in deviance were selected for the model, and are shaded in green.

a. Deviance table for the binomial sub-model of the proportion positive catches of Goliaths.

Variable	levels	DF	Deviance	Mean Deviance	%deviance reduction	Cum %	Full Likelihood	Chi-Square	Chi-square DF	Pr>ChiSq	AIC	AICc	BIC
	1	59841	4338.1	0.07249	.		-2169.03		.	.	4340.1	4340.1	4349.1
year	1	59824	4190.0	0.07004	3.39	3.4	-2095.01	148.0	17	<.0001	4226.0	4226.0	4388.0
year mode_fx	2	59823	4041.0	0.06755	3.44	6.8	-2020.49	149.0	1	<.0001	4079.0	4079.0	4250.0
year mode_fx num_angl	3	59818	3994.5	0.06678	1.07	7.9	-1997.24	46.5	5	<.0001	4042.5	4042.5	4258.5
year mode_fx num_angl hr_fish	4	59815	3977.3	0.06649	0.39		-1988.64	17.2	3	0.0006	4031.3	4031.3	4274.3
year mode_fx num_angl avidity	4	59813	3980.5	0.06655	0.32		-1990.24	14.0	5	0.0156	4038.5	4038.5	4299.5
year mode_fx num_angl coast	4	59817	3992.8	0.06675	0.04		-1996.4	1.7	1	0.1959	4042.8	4042.8	4267.8
year mode_fx num_angl season	4	59817	3993.9	0.06677	0.01		-1996.93	0.6	1	0.4302	4043.9	4043.9	4268.8

b. Deviance table for the gamma sub-model of the positive catches of Goliaths.

Variable	levels	DF	Deviance	Mean Deviance	%deviance reduction	Cum %	Full Likelihood	Chi-Square	Chi-square DF	Pr>ChiSq	AIC	AICc	BIC
	1	353	131.1	0.37140	.		-426.84	379.0	.	.	857.7	857.7	865.4
year	1	336	117.4	0.34951	5.89	5.9	-406.29	41.1	17	0.0009	850.6	852.8	924.1
year avidity	2	331	112.3	0.33920	2.78	8.7	-397.93	16.7	5	0.0051	843.9	847.5	936.7
year avidity coast	3	330	109.4	0.33159	2.05	10.7	-393.15	9.6	1	0.002	836.3	840.3	933.0
year avidity coast hr_fish	4	327	107.4	0.32840	0.86		-389.66	7.0	3	0.0727	835.3	840.3	943.7
year avidity coast num_angl	4	325	107.0	0.32920	0.64		-388.98	8.4	5	0.1379	838.0	843.7	954.0
year avidity coast season	4	329	108.7	0.33031	0.35		-391.87	2.6	1	0.1094	835.7	840.0	936.3
year avidity coast mode_fx	4	329	108.9	0.33088	0.19		-392.19	1.9	1	0.166	836.4	840.7	937.0

Table 6.6.1. Inputs to the calculation of the yield per-recruit and various spawning potential ratios

Von Bertalanffy	L_{inf} (mm)	2221	K =	0.0937	to =	-0.6842
Length-weight	a =	1.011E-08	b =	3.09		
Spawning offset from Jan 1		0.67				

Age	M	Selectivity	Maturity
0	1.64	0.01	0
1	0.77	0.18	0
2	0.53	0.43	0
3	0.41	0.59	0
4	0.35	0.69	0
5	0.30	0.69	0
6	0.27	0.60	1
7	0.25	0.77	1
8	0.23	0.75	1
9	0.22	0.76	1
10	0.21	0.83	1
11	0.20	0.90	1
12	0.19	0.90	1
13	0.18	0.93	1
14	0.18	0.95	1
15	0.17	0.96	1
16	0.17	0.96	1
17	0.17	0.93	1
18	0.16	0.93	1
19	0.16	0.96	1
20	0.16	0.97	1
21	0.16	0.97	1
22	0.16	0.93	1
23	0.15	0.96	1
24	0.15	0.94	1
25	0.15	0.92	1
26	0.15	0.94	1
27	0.15	1.00	1
28	0.15	0.93	1
29	0.15	0.91	1
30	0.15	0.92	1
31	0.15	0.94	1
32	0.14	0.93	1
33	0.14	0.94	1
34	0.14	0.95	1
35	0.14	0.96	1
36	0.14	0.94	1
37	0.14	0.94	1

Table 6.9.1. Empirical a) mean and standard deviation (SD) for selected parameters plus standard error (SE) of the mean; b) quantiles for those parameters.

a

	Mean	SD	Naive SE	Time-series SE
negLL	1468.00	5.84	0.18	0.19
Fmsy	0.1822	0.0035	0.0001	0.0001
MSY	85650	1206	38	45
h	0.93	0.01	0.00	0.00

b

	2.50%	25%	50%	75%	97.50%
negLL	1457.00	1464.00	1467.00	1471.00	1480.21
Fmsy	0.1753	0.1799	0.1821	0.1846	0.1890
MSY	83460	84840	85630	86420	88047
h	0.910	0.921	0.927	0.932	0.942

Table 6.9.2. MCMC summary statistics of the fishing mortality and numbers of goliath grouper off the U.S southeast coast, estimated using the ASPM over 1975–2014 (L95% and U95% are lower and upper values of the 95% Bayesian Central Interval).

	Fishing mortality				**Numbers**			
Year	Median	Mean	L95%	U95%	Median	Mean	L95%	U95%
1975	0.263	0.264	0.240	0.295	376,920	378,164	329,257	431,329
1976	0.254	0.256	0.232	0.284	367,607	367,594	323,043	422,718
1977	0.333	0.334	0.303	0.372	360,935	361,885	315,416	412,499
1978	0.250	0.251	0.227	0.279	346,958	347,323	303,593	397,505
1979	0.206	0.206	0.188	0.227	322,915	324,365	284,660	367,522
1980	0.212	0.213	0.196	0.231	302,038	302,753	266,316	344,331
1981	0.702	0.705	0.639	0.778	294,976	296,185	261,896	333,641
1982	0.498	0.500	0.445	0.563	288,547	289,127	251,218	330,317
1983	0.232	0.233	0.207	0.261	279,592	280,524	245,513	319,829
1984	0.399	0.399	0.358	0.443	277,814	278,690	241,203	318,702
1985	0.931	0.934	0.827	1.058	287,098	287,185	248,563	331,210
1986	0.721	0.725	0.626	0.844	286,512	286,850	245,446	332,288
1987	1.197	1.204	1.014	1.440	245,790	247,456	216,648	281,656
1988	1.378	1.383	1.130	1.691	207,938	208,259	181,492	239,936
1989	1.555	1.561	1.258	1.911	159,596	159,855	134,249	185,356
1990	0.173	0.173	0.151	0.197	115,854	116,082	92,016	141,929
1991	0.212	0.212	0.186	0.239	81,832	82,899	59,821	107,868
1992	0.073	0.073	0.064	0.083	130,323	130,846	102,177	162,639
1993	0.089	0.090	0.078	0.103	235,343	236,247	200,850	274,700
1994	0.094	0.095	0.082	0.109	341,513	342,523	291,351	396,374
1995	0.073	0.073	0.064	0.084	339,039	340,428	300,713	387,082
1996	0.016	0.016	0.014	0.018	295,331	295,654	261,621	335,283
1997	0.046	0.046	0.042	0.051	273,398	274,144	243,864	309,243
1998	0.049	0.049	0.045	0.054	273,523	274,761	241,930	311,509
1999	0.025	0.025	0.023	0.027	291,088	291,432	256,336	330,828
2000	0.089	0.089	0.082	0.095	304,875	305,926	269,375	348,743
2001	0.081	0.081	0.075	0.087	339,989	341,015	297,074	393,332
2002	0.065	0.065	0.060	0.070	473,919	474,887	407,866	545,160
2003	0.126	0.126	0.118	0.135	521,436	521,154	448,899	598,354
2004	0.102	0.102	0.096	0.110	535,073	535,921	449,584	629,132
2005	0.138	0.138	0.129	0.147	785,117	791,645	631,238	975,685
2006	0.146	0.146	0.137	0.156	1,180,000	1,186,102	1,030,000	1,340,000
2007	0.170	0.170	0.159	0.182	590,289	591,311	536,410	656,317
2008	0.109	0.109	0.102	0.116	425,013	425,201	383,543	467,857
2009	0.050	0.050	0.046	0.053	333,084	334,243	302,659	369,407
2010	0.023	0.023	0.022	0.025	303,905	304,274	275,159	336,864
2011	0.020	0.020	0.019	0.021	297,287	298,506	266,059	337,185
2012	0.010	0.010	0.009	0.011	304,812	306,250	272,672	349,073
2013	0.030	0.030	0.028	0.031	318,342	320,259	281,286	368,084
2014	0.017	0.017	0.016	0.018	344,295	345,729	299,831	397,612

Table 6.9.3. MCMC summary statistics of the vulnerable biomass and spawning stock biomass (metric tons) of goliath grouper off the U.S southeast coast, estimated using the ASPM over 1975–2014 (L95% and U95% are lower and upper values of the 95% Bayesian Central Interval).

	Vulnerable Biomass				**Spawning Stock Biomass**			
Year	Median	Mean	L95%	U95%	Median	Mean	L95%	U95%
1975	436	436	395	473	335	335	290	378
1976	418	418	379	453	318	318	276	360
1977	405	405	368	439	309	308	265	347
1978	373	372	338	405	278	277	238	316
1979	376	376	344	408	271	271	233	307
1980	394	393	365	424	281	281	244	315
1981	404	404	375	434	301	300	266	334
1982	277	277	251	304	192	192	165	222
1983	238	238	215	264	154	154	127	183
1984	257	257	235	281	168	169	142	197
1985	241	241	221	262	159	159	134	186
1986	157	157	139	175	87	88	69	107
1987	136	136	120	152	62	63	46	80
1988	96	96	82	111	32	32	21	46
1989	77	77	65	89	16	17	9	26
1990	82	82	73	93	9	9	4	16
1991	104	104	93	117	25	26	16	38
1992	116	116	102	132	66	66	51	84
1993	134	134	117	153	115	116	97	136
1994	152	152	131	173	153	153	131	177
1995	177	178	155	202	173	174	150	199
1996	218	218	194	245	184	184	157	213
1997	275	275	250	303	192	192	160	227
1998	327	327	301	357	216	217	182	254
1999	373	374	346	405	280	280	246	318
2000	423	423	394	454	383	383	346	423
2001	450	450	419	483	446	446	408	488
2002	479	479	447	513	481	482	444	521
2003	518	518	485	552	508	508	472	547
2004	541	541	505	576	506	506	468	547
2005	581	581	547	618	515	515	477	556
2006	614	614	576	652	510	510	469	550
2007	666	666	626	707	509	510	468	551
2008	728	728	685	775	538	538	492	583
2009	807	807	760	858	594	594	546	644
2010	890	891	841	946	678	678	628	738
2011	964	965	911	1,020	873	874	797	953
2012	1,020	1,022	967	1,080	1,220	1,222	1,150	1,300
2013	1,080	1,076	1,020	1,140	1,290	1,293	1,220	1,370
2014	1,110	1,106	1,050	1,170	1,300	1,299	1,230	1,370

Table 6.9.4. Calculation of the statistic rho (E2) of Mohn (1999) for the abundance in number (N), recruitment (Rec), fishing mortality (F), total abundance (TB), vulnerable biomass (VB) and spawning stock biomass (SSB) of goliath grouper off the U.S southeast coast, based on retrospective analyses starting from 2009.

	N	Rec	F	TB	VB	SSB
2009-14	0.23	0.31	-0.04	0.05	0.03	0.01
2010-14	0.20	0.26	-0.01	0.02	0.01	-0.02
2011-14	0.17	0.22	-0.01	0.02	0.01	-0.01
2012-14	0.11	0.15	0.04	-0.03	-0.04	-0.04
2013-14	0.11	0.13	-0.05	0.05	0.04	0.05
E2	0.82	1.07	-0.06	0.09	0.05	-0.02

Parameter	Parameter name	Function Type	Starting value (median of prior)	lower bound	upper bound	Phase for estimation (- = off, + = on)	probability density function	SE = +, cv = - [active if phase on]	comment
1	f_ph (1)	polynomial	0	-0.01	0.5	-2	normal	-1	f in "prehistoric" times, constant 1.
2	f_ph (2)	polynomial	0	-0.01	0.5	1	normal	-1	f in "prehistoric" times constant 2.
3	f_modern (1) before change in regulations	footnote [a]	1	0.02	10	1	normal	-1	
4	f_modern (2) expected after change in regulations	footnote [b]	0.16464	0.01	0.9	3	gamma	-0.4	
5	natural mortality rate intercept (Lorenzen "natural")	power	0.5746	0.01	0.7	3	normal	-0.25	Estimated adjustment factor
6	natural mortality rate slope (Lorenzen "natural")	power	-0.288	-1	-0.1	-3	none	-0.4	Estimated
7	alpha-1	gamma	2.648087	0.01	150	2	lognormal	1.310438	Estimated lifetime
8	growth eqn L-infinity	von Bertalannfy	2221	150	3000	5	normal	-0.11	Estimated
9	growth eqn slope (k)	von Bertalannfy	0.0937	0	10	3	lognormal	0.00295	Estimated
10	growth eqn t0	von Bertalannfy	-0.6842	-5	10	-1	none	0.1	fixed
11	growth eqn cv	von Bertalannfy	1	0	10	-1	none	0.1	fixed [if cv ≠ 1,
12	length(mm)-wt(kg) intercept	power	1.011E-08	0	10	-1	none	0.1	fixed
13	length(mm)-wt(kg) slope	power	3.09	0	10	-1	none	0.1	fixed
14	q - DeMaria index	constant	0.5	0.01	10	-1	normal	-2	excluded (q off)
15	q - REEF FL index	constant	0.5	0.01	10	1	normal	-2	included
16	q - ENP index	constant	0.5	0.01	10	1	normal	-2	included
17	q - MRFSS/MRIP index - offshore	constant	0.5	0.01	10	1	normal	-2	included
18	q - MRFSS/MRIP index - estuarine	constant	0.5	0.01	10	1	normal	-2	included
19	selectivity "prehistoric" a50	logistic	2.5	2	15	4	normal	-2	Estimated
20	selectivity "prehistoric" slope	logistic	0.8	0.5	3	4	normal	-0.5	Estimated
21	selectivity "modern" a50	logistic	2.5	2	15	4	normal	-2	Estimated
22	selectivity "modern" slope	logistic	0.8	0.5	3	4	normal	-0.5	Estimated
23	selectivity DeMaria index a50	logistic	9.5644	4	15	-4	normal	-0.075	Excluded
24	selectivity DeMaria index slope	logistic	1.3303	0.5	3	-4	normal	-0.250	Excluded
25	selectivity REEF FL a50	logistic	9.5644	4	15	4	normal	-0.075	Estimated
26	selectivity REEF FL index slope	logistic	1.3303	0.5	3	4	normal	-0.250	Estimated
27	selectivity ENP index a100	gamma	1.7857	0	7	-4	normal	-0.075	Fixed
28	selectivity ENP cv	gamma	0.4948	0.01	2	-4	normal	-0.250	Fixed
29	selectivity MRFSS/MRIP offshore a50	logistic	9.5644	4	15	4	normal	-0.075	Estimated
30	selectivity MRFSS/MRIP offshore slope	logistic	1.3303	0.5	3	4	normal	-0.250	Estimated
31	selectivity MRFSS/MRIP estuarine a50	gamma	1.7857	0	7	4	normal	-0.075	Estimated
32	selectivity MRFSS/MRIP estuarine cv	gamma	0.4948	0.01	2	4	normal	-0.25	Estimated
33	index variance	constant	1	0	10	1	constant	0.1	Estimated
34	overall variance	constant	-0.2	-1	-0.01	5	normal	-0.5	cv value input

Table 7.2.1 Input parameters and priors for SEDAR 47, M=0.179, cv for index selectivities set to 0.075 based upon sensitivity runs. (see: S_47_M18_base.prm)

[a] F = parameter*F(last year of historical period)

[b] F = parameter*F(last year before change in regulations

VII. Figures

Figure 2.6.1. Estimates of natural mortality based on maximum age.

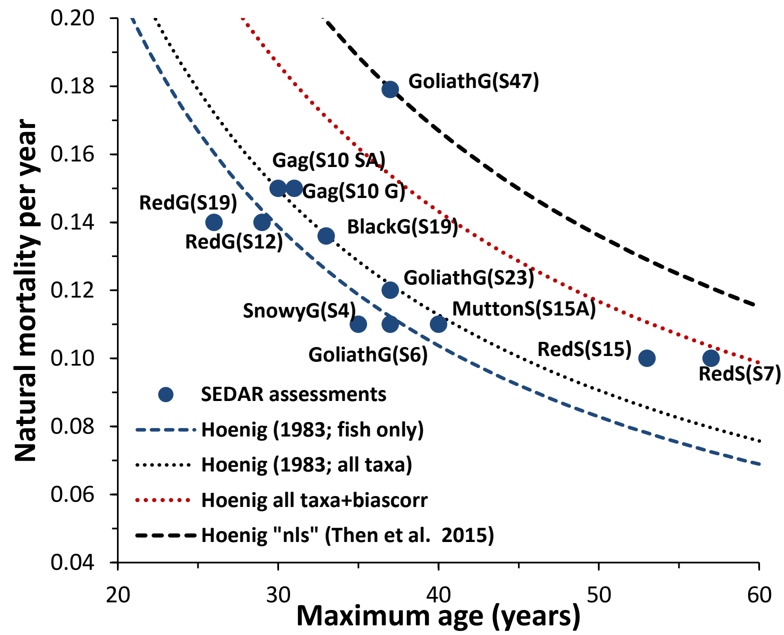


Figure 2.6.2. Maximum ages presently known for some groupers.

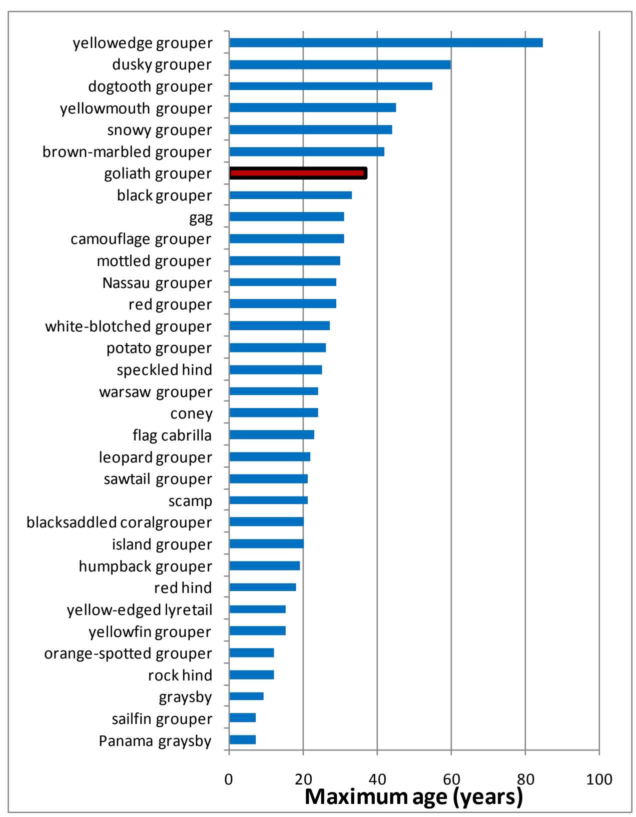


Figure 2.6.3. Revised growth curve for Goliath Grouper in waters of the Southeastern U.S. [Growth equation: $L_{age} = L_{\infty} * \left(1 - e^{-k*(age-t0)}\right), L_{\infty} = 2221.1, K = 0.0937, t0 = -0.6842$]

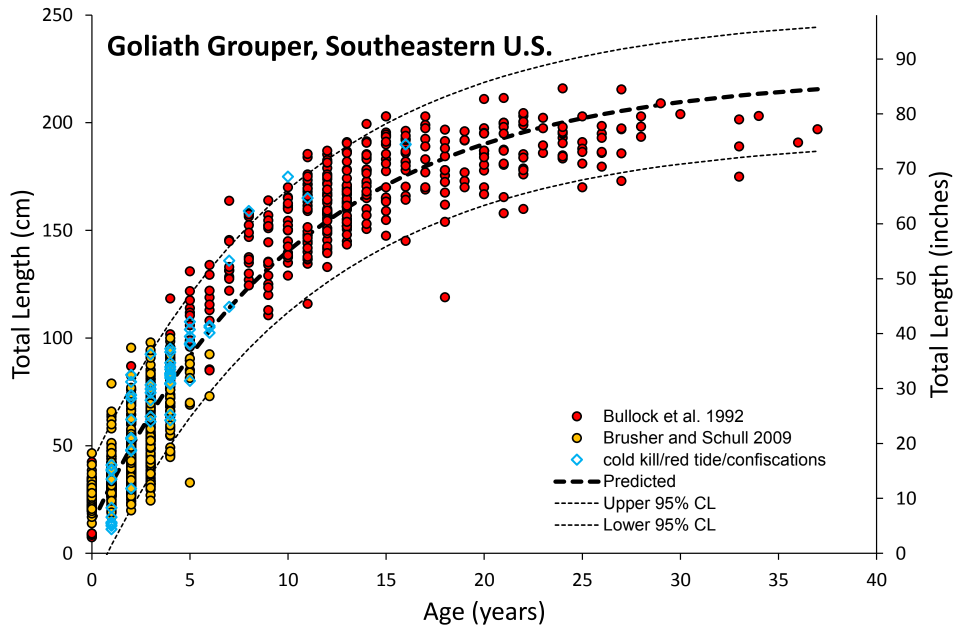


Figure 2.6.4. Total Length versus Total Weight for Goliath Grouper. (Weight-Length formula: $\text{Whole Weight (kg)} = \log_e(a) + b * \log_e[\text{Total Length(mm)}]$, a=-18.853, b=3.151, MSE=0.01526, r^2 = 0.99, n=1,211.

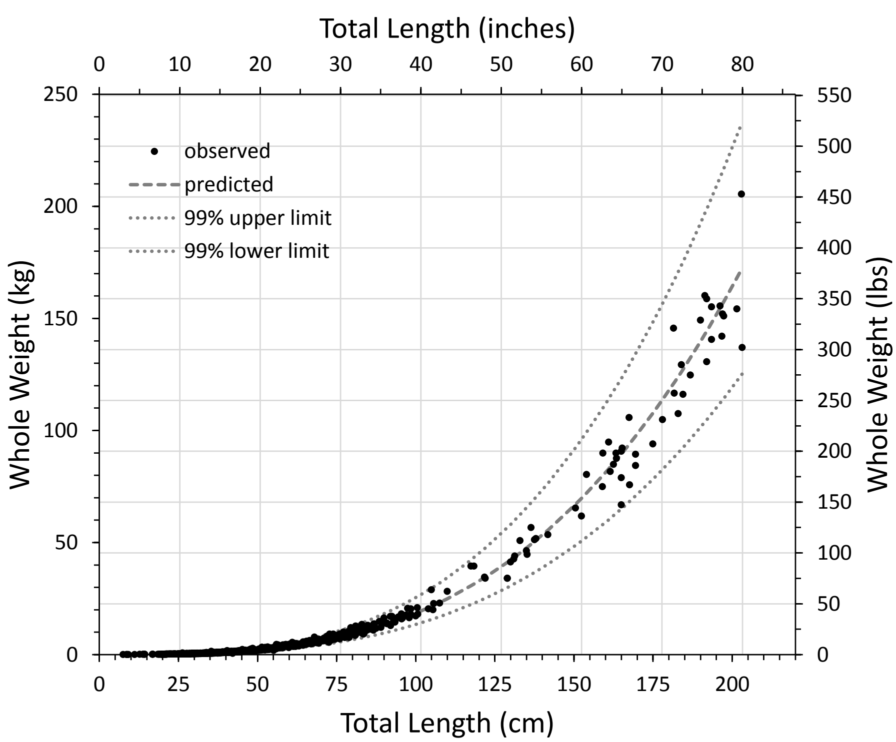


Fig. 3.1.1. Reported and adjusted Florida commercial landings of Goliath Grouper, 1918-2014.

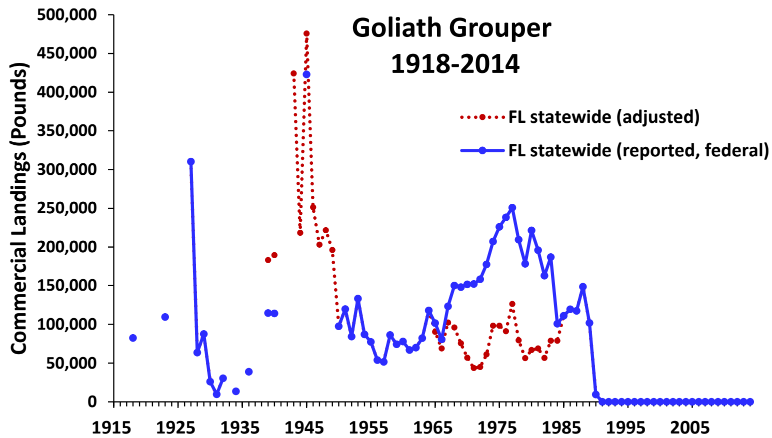


Fig. 3.3.1. Recreational total catch of Goliath Grouper in thousands of fish for the West Coast and East Coast of Florida, 1981-2014. Nearly all Goliaths caught after 1989 were released by anglers. (data from the National Marine Fisheries Service, 2015).

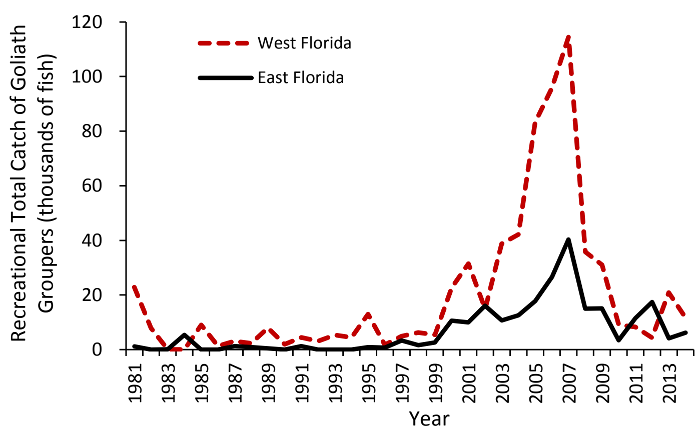
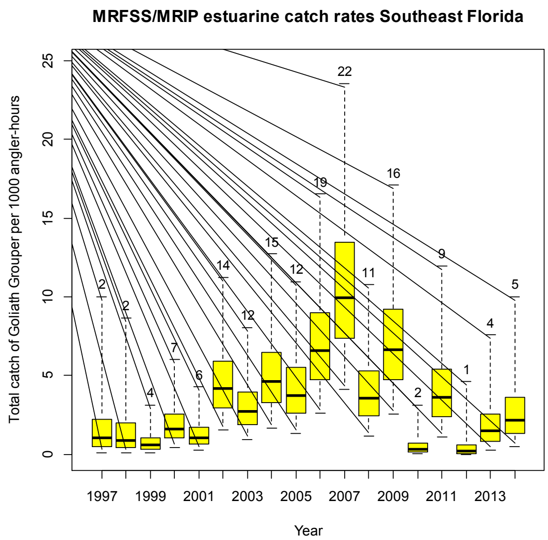
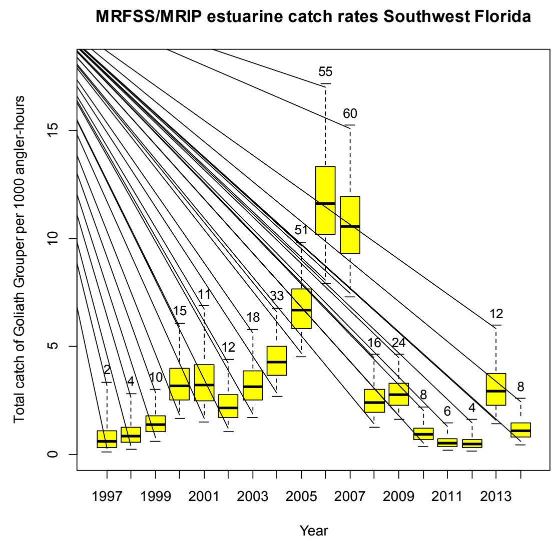


Fig. 3.3.2. Estimated total catch rates of Goliath Grouper by anglers intercepted by the MRFSS/MRIP samplers in Florida by coast of Florida and estuarine or offshore habitat fished. Goliaths in estuarine habitats are mostly juveniles, whereas in offshore waters they are mostly adults. Yellow bars are inter-quartile ranges (25-75% of data), the dark bar in the center is the median (50% of the data are above the line, and 50% are below), and the error bars are 95% confidence limits on the catch rates. The numbers above the error bars represent the number of positive catches of Goliaths.

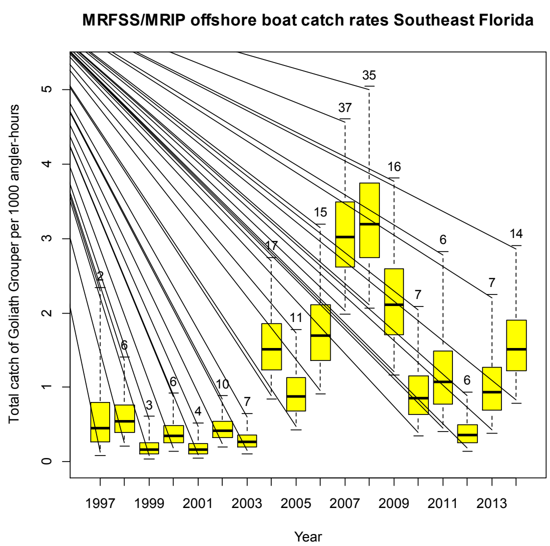
a. Southeast and Florida Keys, estuarine, juveniles



b. Southwest Florida, estuarine, juveniles



c. Southeast and Florida Keys, offshore, adults



d. Southwest Florida, offshore, adults

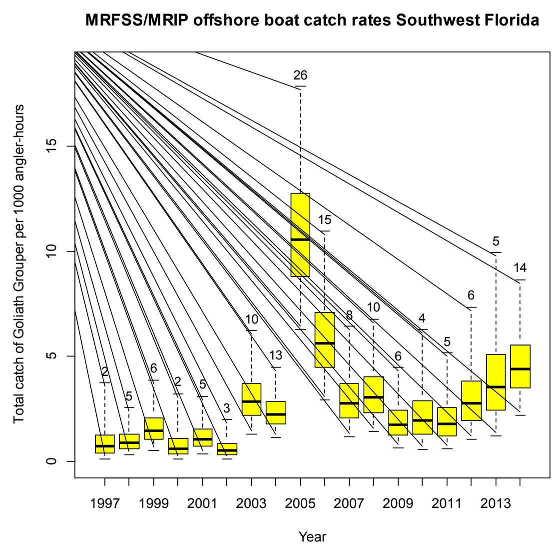


Figure 3.3.3. Cold-killed Goliath Grouper in the Everglades National Park in 2008. (photo by Peter Frezza)

Figure 3.3.4. Catch rates of juvenile goliath grouper from the Everglades National Park Angler Survey. Yellow bars are inter-quartile ranges (25-75% of data), the dark bar in the center is the median (50% of the data are above the line, and 50% are below), and the error bars are 95% confidence limits on the catch rates. The numbers above the error bars represent the number of positive catches of Goliaths.

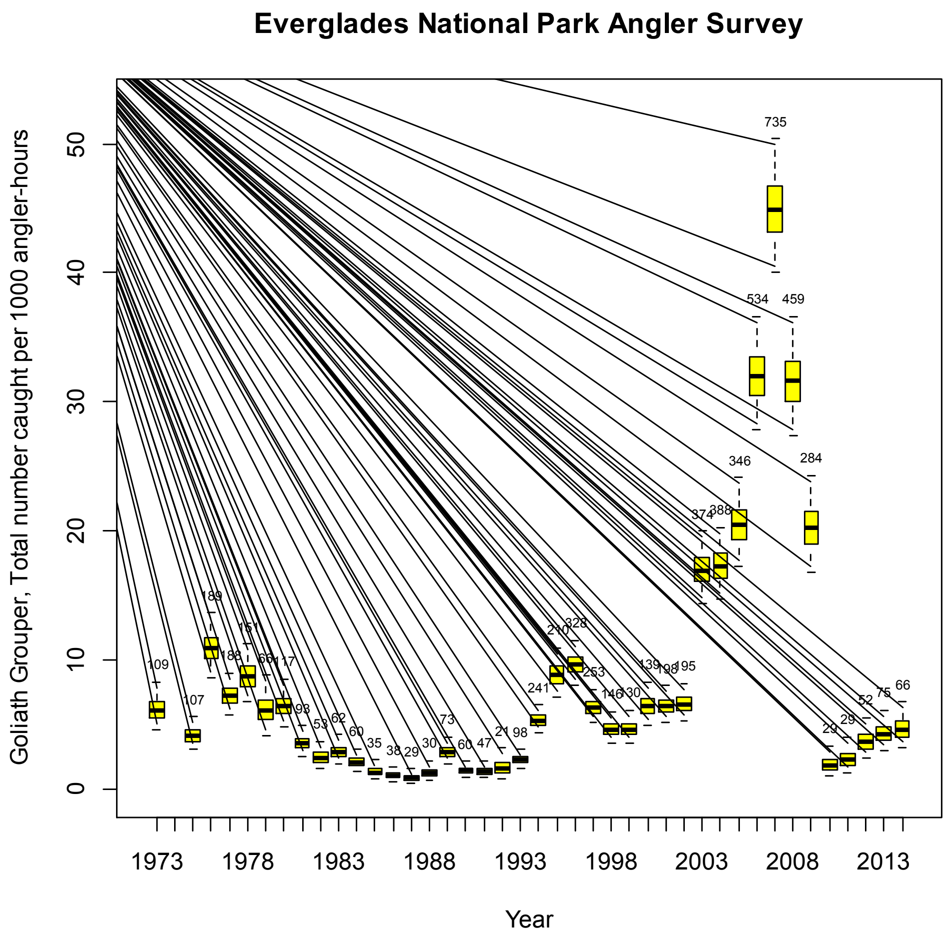


Figure 3.3.5. Standardized catch rates of juvenile Goliath Grouper caught in estuarine habitats from the Everglades National Park and the MRFSS/MRIP angler surveys.

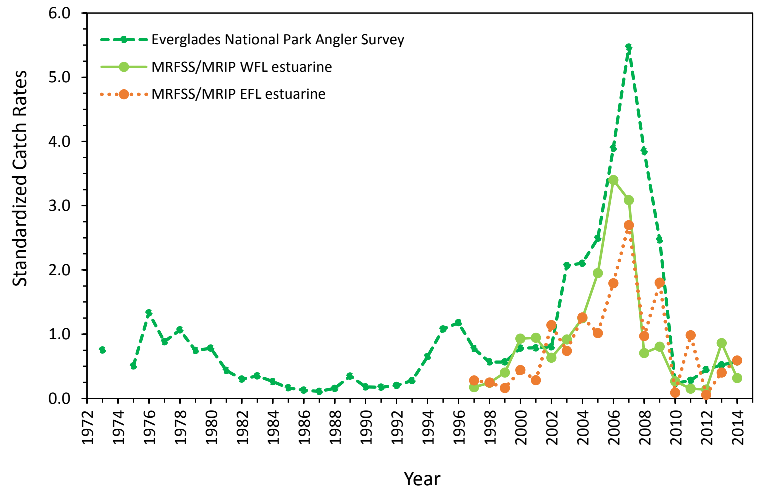


Figure 3.3.6. Standardized catch rates of adult Goliath Grouper caught in offshore habitats from the East and West Coasts of Florida, and underwater observations by divers in southeast Florida and the Florida Keys participating in the REEF program. Also shown is the DeMaria index that was developed from underwater observations by Mr. Don DeMaria of Goliaths at selected sites in the Florida Keys and southwest Florida which was not used in this analysis.

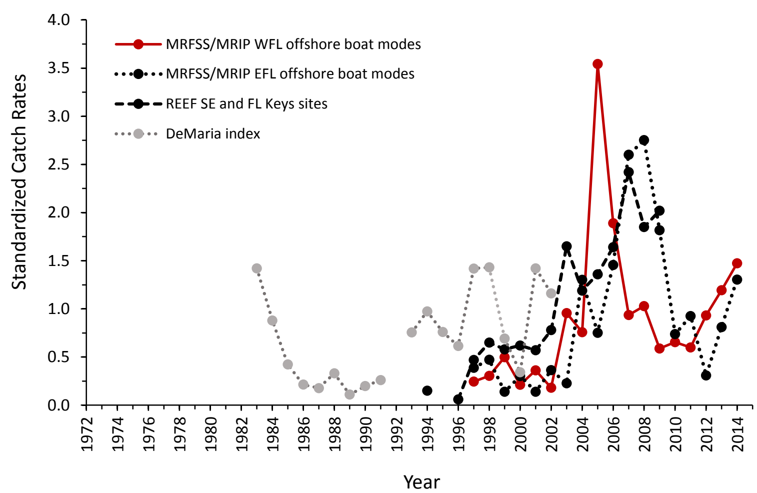


Fig. 3.3.7. Estimated vulnerability curve for juvenile and sub-adult Goliath Grouper. Aged specimens from two research studies which employed hook and line gears were combined to estimate the ages vulnerable to anglers in the Everglades National Park.

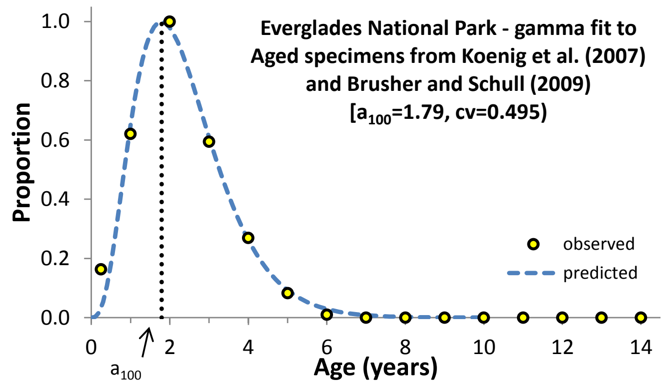


Fig. 3.3.8. Proportion of specimens by age caught in 2012 at offshore sites which are known or suspected to be in spawning areas off southeast Florida. (After Fig. 15 in Koenig et al. 2013).

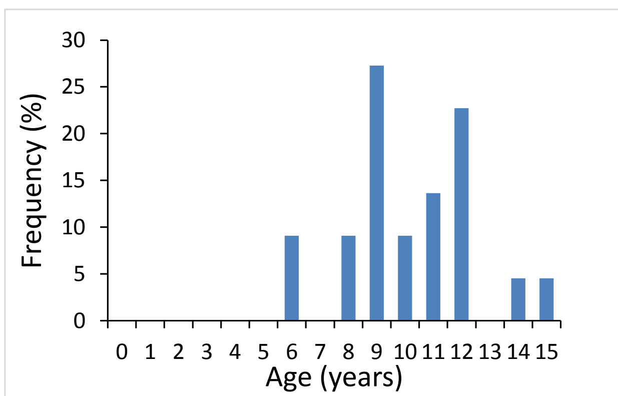


Fig. 3.3.9. Estimated vulnerability curve for offshore Goliath adults fit to cumulative proportions at age (specimens in Fig. 3.3.8. from Koenig et al. 2013).

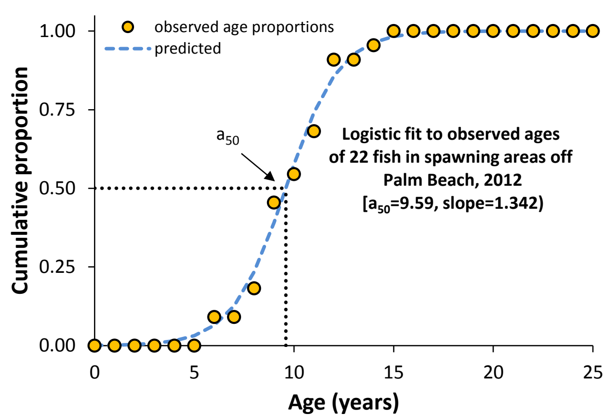


Fig. 3.3.10. Proportions at age estimated for released fish weighted by the estimated MRFSS/MRIP numbers of fish released in estuarine and offshore areas.

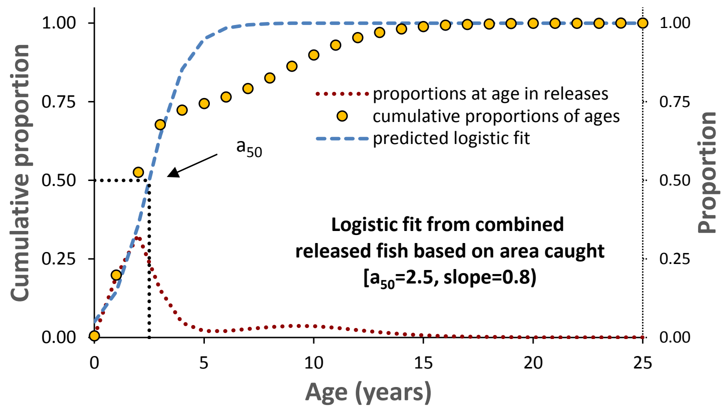


Figure 3.4.1. Commercial landings (reported and adjusted) and estimated recreational harvests in kilograms whole weight, 1950-2015.

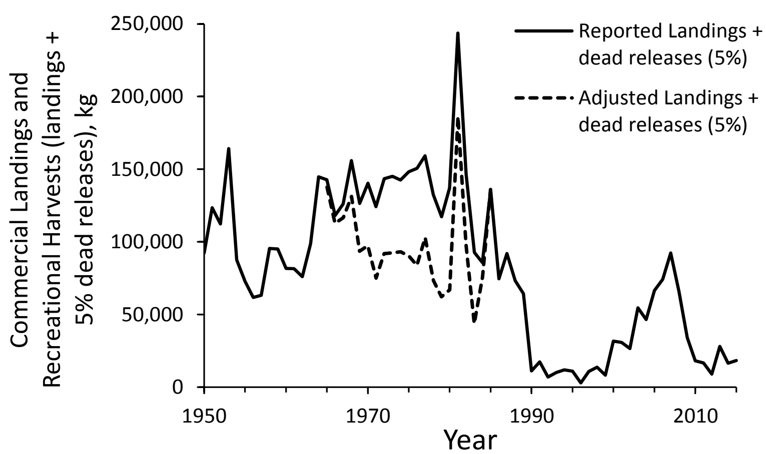
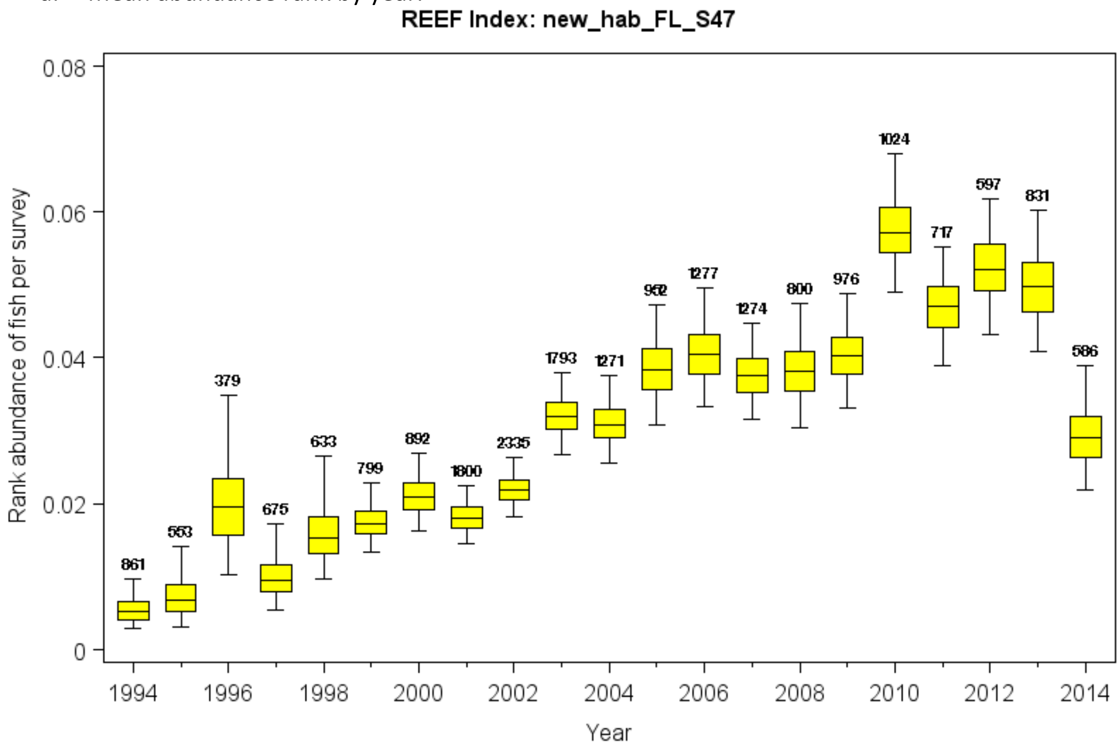


Fig. 4.1.1. a,b. REEF FL Index. a.) Plot of least square means of the abundance ranks by year for the REEF FL survey data based on 21,025 surveys at 214 sites in Florida waters with a sighting of at least one Goliath grouper and at least 10 years or record. The number of surveys at sites meeting the criteria are shown above the error bar for each year. The error bars are the 95% confidence limits, the yellow boxes are bounded by the first and third quartiles of the data, and the line in the middle of the box is the median value. b.) REEF FL index scaled to its mean, with a comparison to the scaled nominal ranks and to the REEF SE index from SEDAR 23.

a. Mean abundance rank by year.



b. Standardized Index of abundance ranks, with a comparison to nominal ranks and to the REEF SE index from SEDAR 23 (2010).

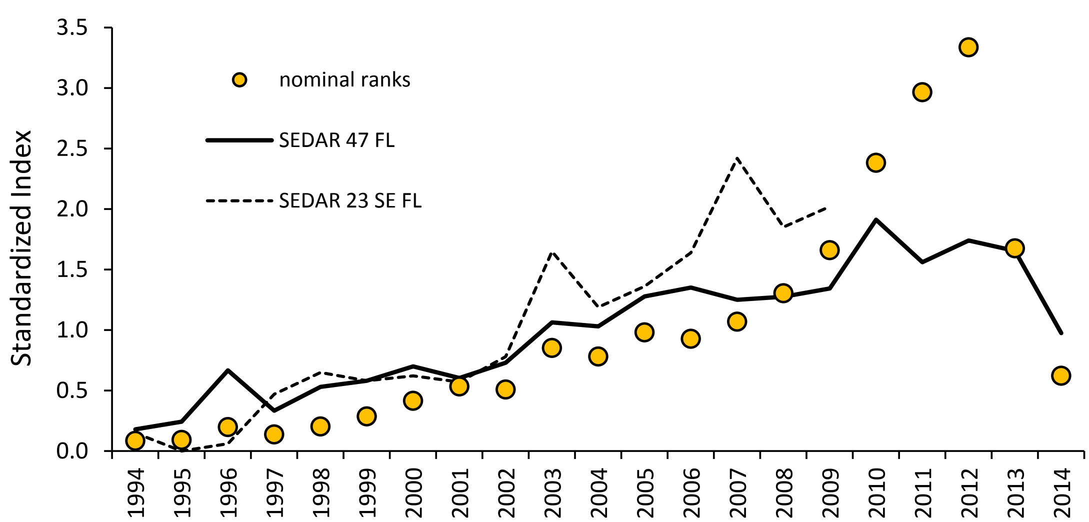


Fig. 4.2.1 Everglades National Park (ENP) Angler Survey Index. Annual index values are standardized to their mean. The number of positive (Goliath caught) surveys are shown above the error bar for each year. The error bars are the 95% confidence limits, the yellow boxes are bounded by the first and third quartiles of the data, and the bar in the middle of the box is the median value.

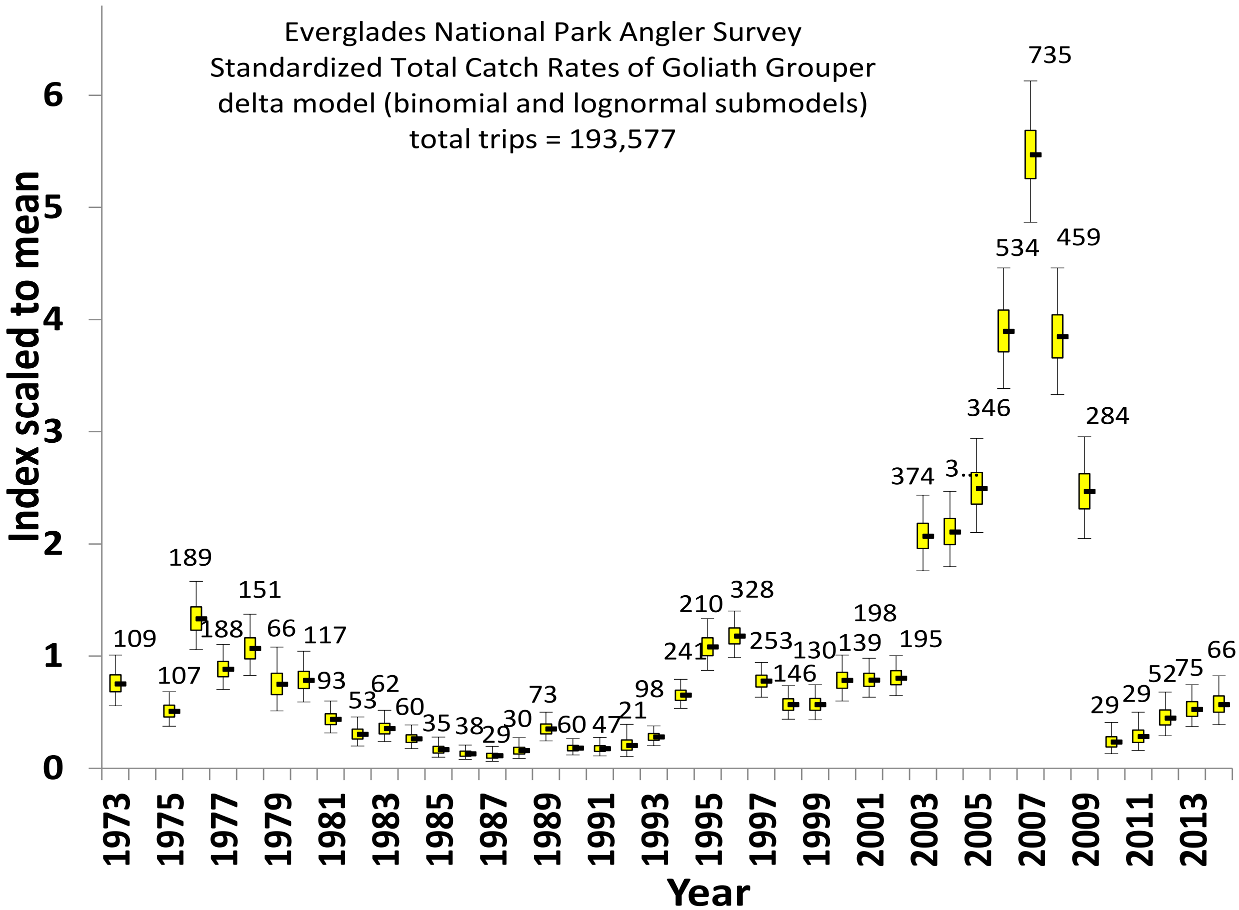


Fig. 4.3.1 MRFSS/MRIP Estuarine Index, 1997-2014. Distribution of the number of Goliath Grouper caught per trip. Error bars denote the 95% confidence limits, the yellow box shows the location of the first and third quartiles, the bar in the middle of the box is the median value, and the numbers over the tops of the error bars are the number of trips on which the annual mean is based.

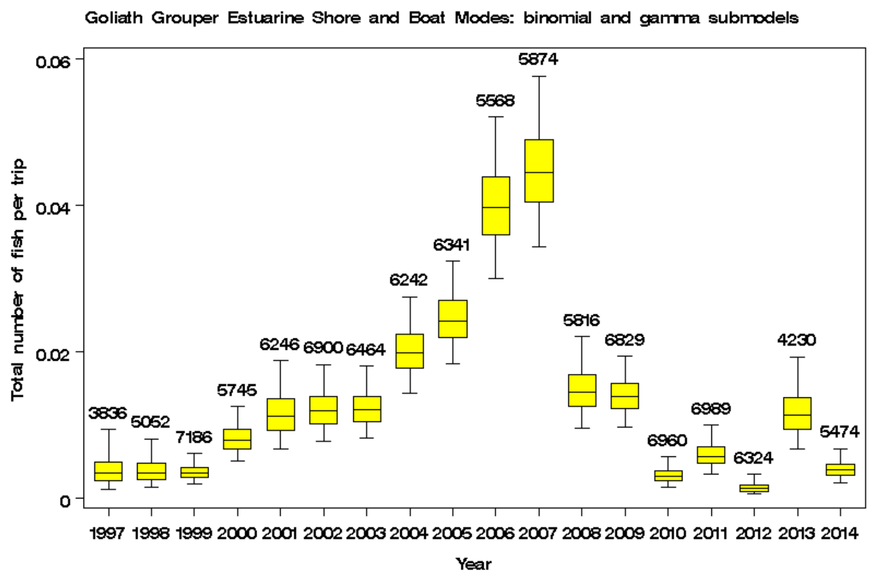


Fig. 4.3.2 MRFSS/MRIP Offshore Index, 1997-2014. Distribution of the number of Goliath Grouper caught per trip. Error bars denote the 95% confidence limits, the yellow box shows the location of the first and third quartiles, the bar in the middle of the box is the median value, and the numbers over the tops of the error bars are the number of trips on which the annual mean is based.

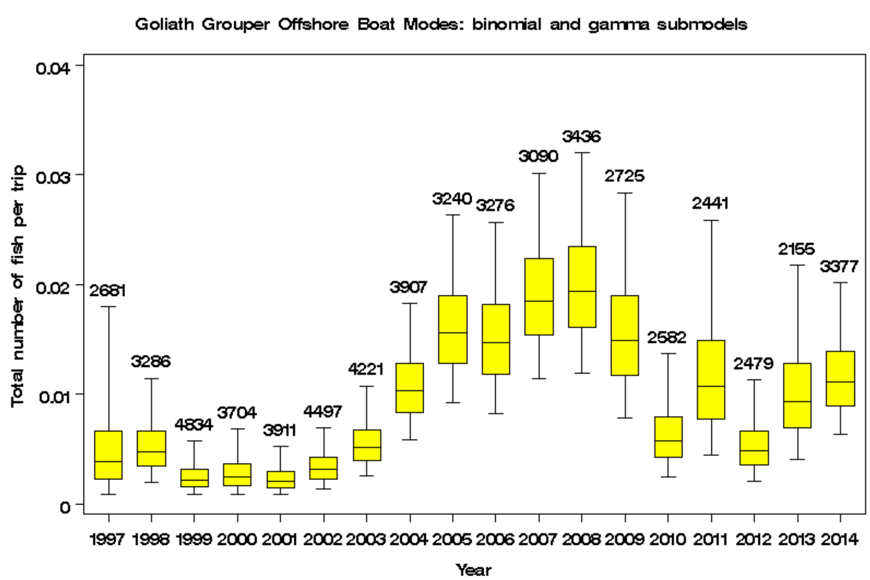
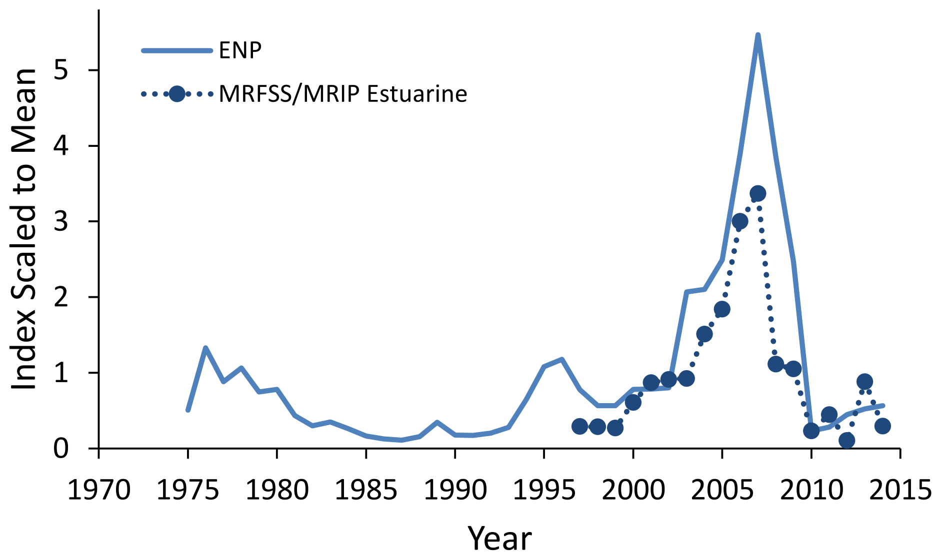


Fig. 4.4.1 a,b. A comparison of the scaled indices prepared for this assessment.

a. Estuarine (juvenile) indices.



b. Offshore (adult) indices

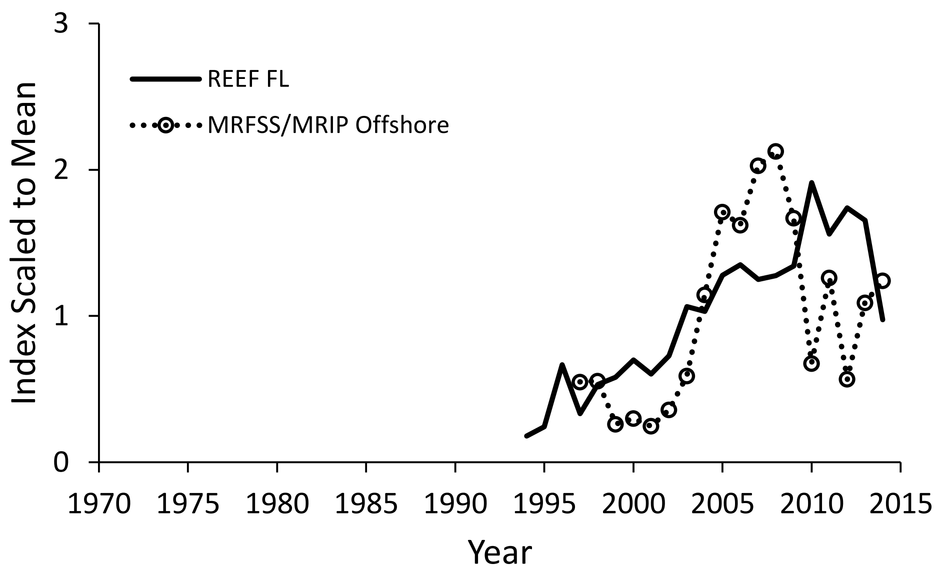
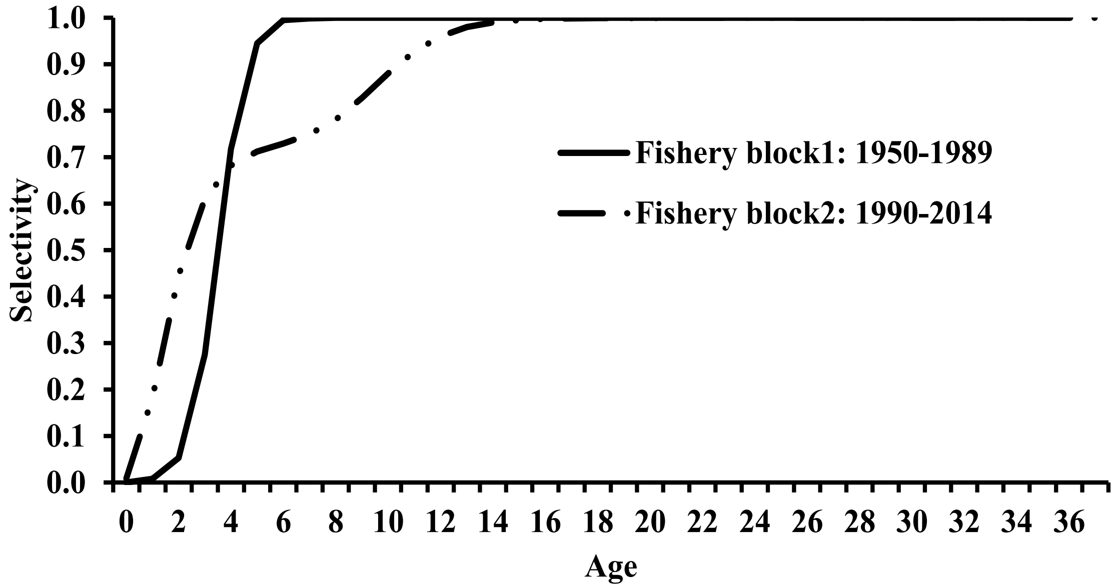


Fig. 6.3.1. Assumed selectivity schedules for fisheries, with two blocks (top), and for various indices of abundance (bottom) of goliath grouper off the U.S. southeast coast.



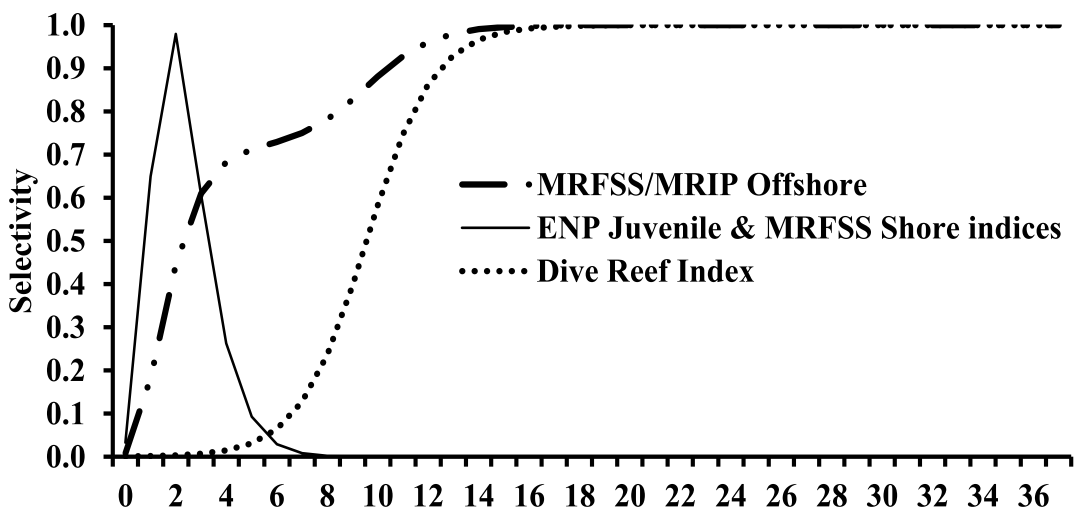


Fig. 6.3.2. Estimated harvests of goliath grouper off the U.S. southeast coast, 1950–2014.

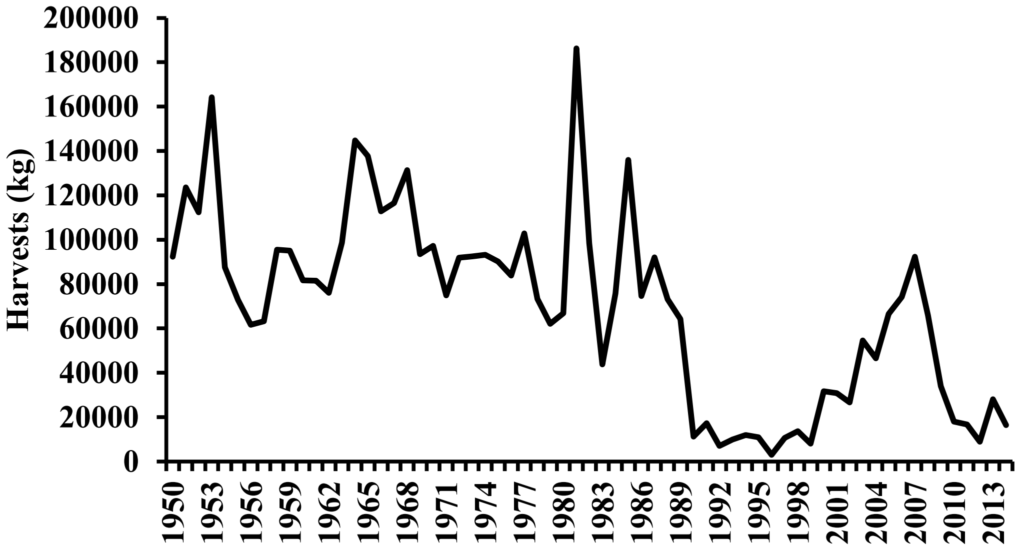


Fig. 6.3.3. Estimated indices of abundance along with the corresponding coefficients of variation (CV) for goliath grouper off the U.S. southeast coast.

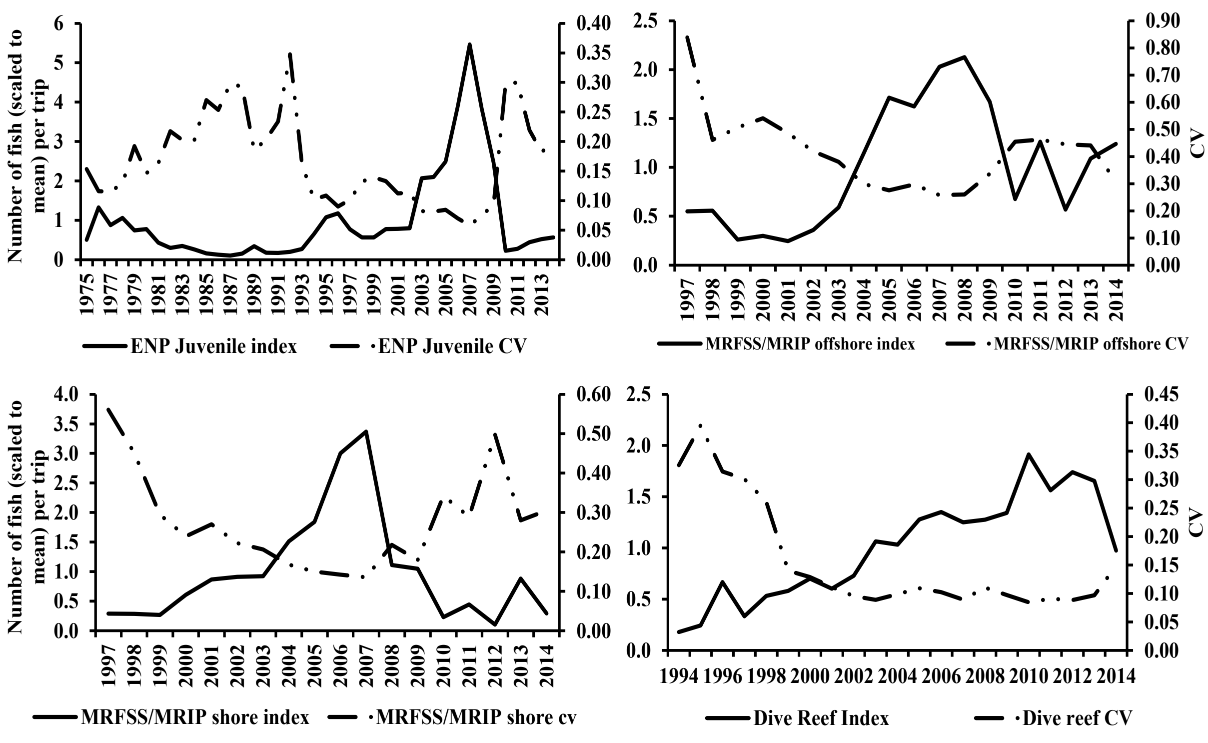


Fig. 6.9.1. Observed versus ASPM predicted indices of abundance for goliath grouper off the U.S. southeast coast.

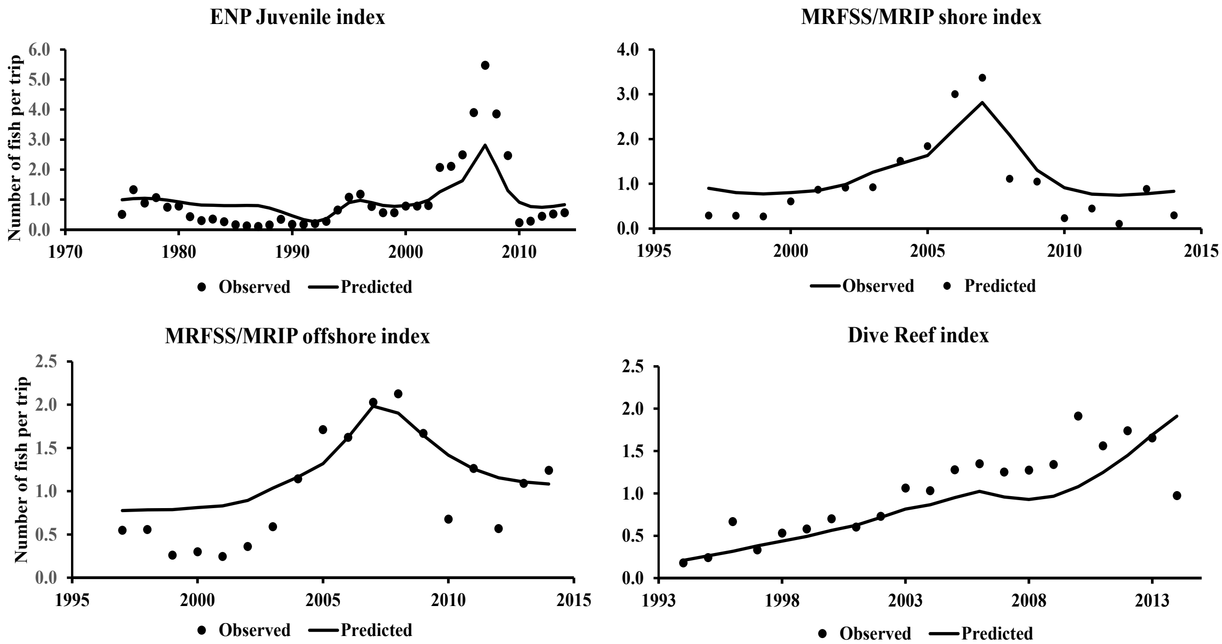


Fig. 6.9.2. Standardized residuals from the ASPM run for various indices of abundance of goliath grouper off the U.S. southeast coast.

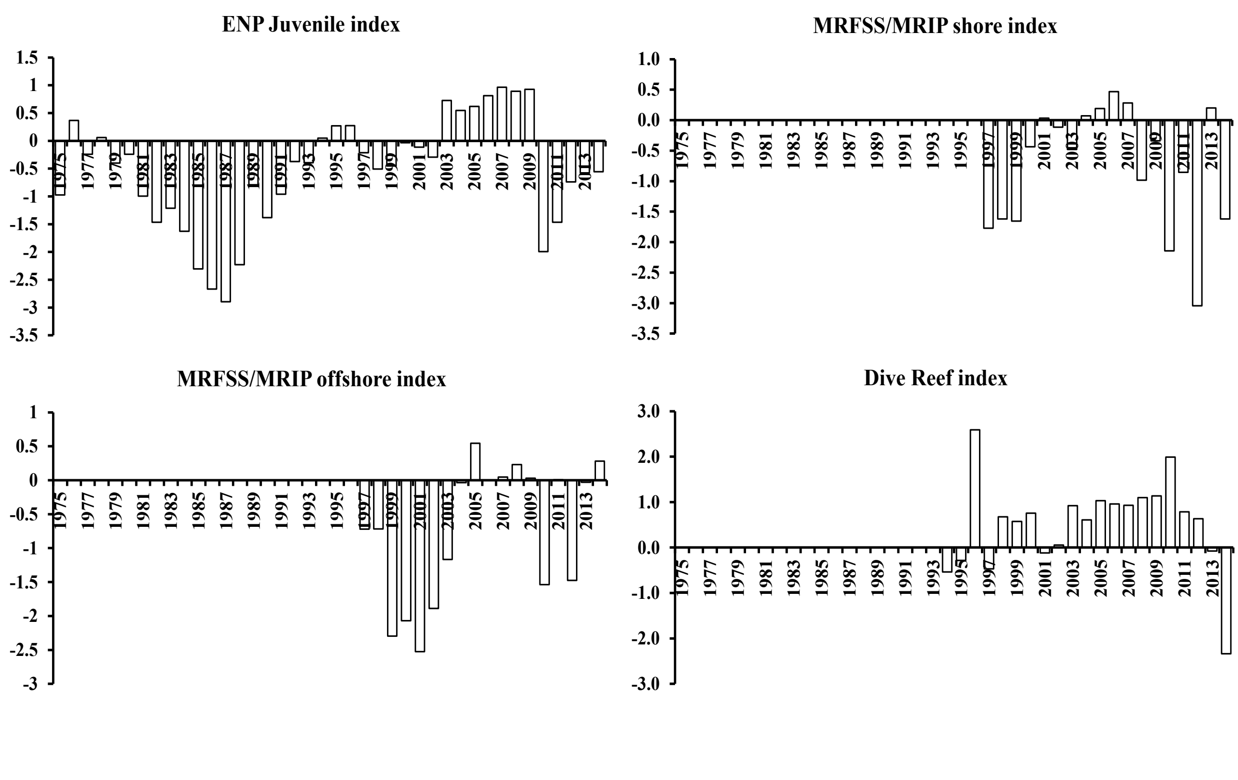


Fig. 6.9.3. Diagnostic plots based on MCMC simulations for the negative log-likelihood and the estimated F_{MSY}, MSY and steepness (h) upon applying the ASPM to goliath grouper off the U.S. southeast coast. Note: various chains produced similar plots.

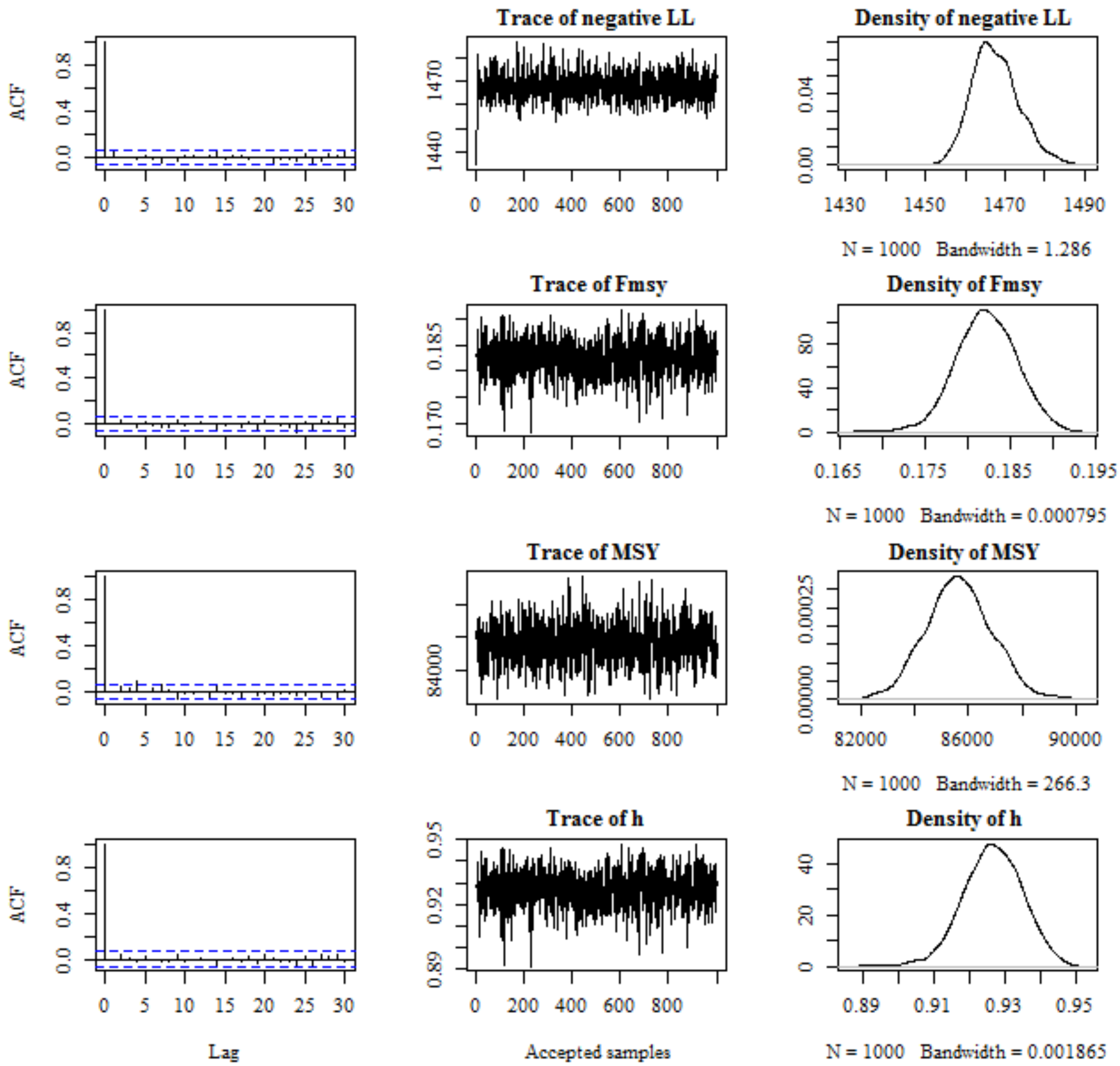


Fig. 6.9.4. Trajectories of median (solid black line), mean (red line) and 95% Bayesian central interval (95% BCI; gray band) of (a) fishing mortality, (b) numbers, (c) total biomass, (d) vulnerable biomass, and (e) spawning stock biomass (SSB) of goliath grouper off the U.S. southeast coast, 1950–2014, as estimated from the ASPM. The plots of fishing mortality and SSB also show the estimated levels of the maximum fishing mortality threshold (MFMT) equivalent to 50%SPR as F_{MSY} proxy and of the minimum stock size threshold, MSST (horizontal green lines). The accepted MCMC results were so close that various summary statistics are undistinguishable.

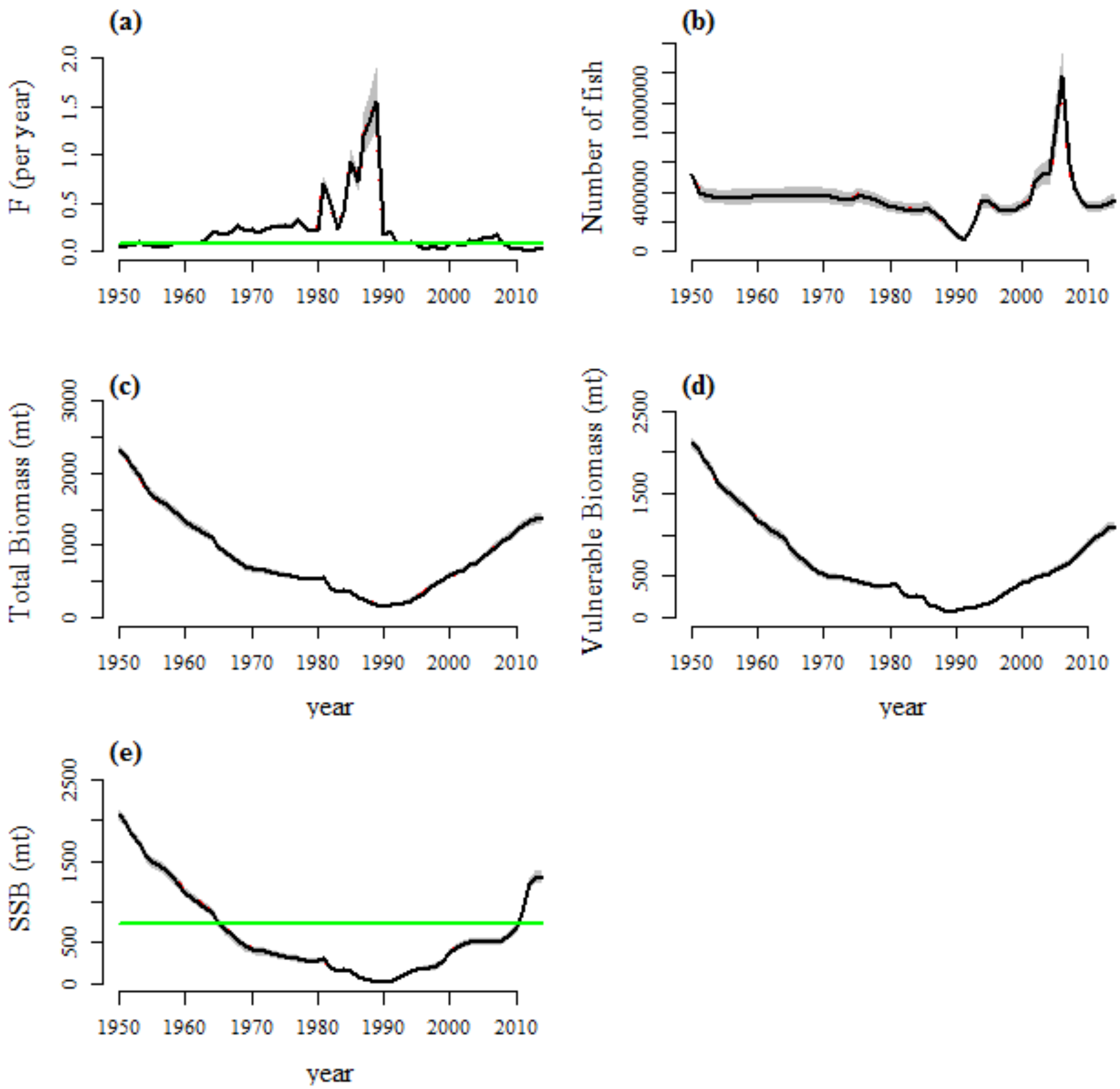


Fig. 6.9.5. Plots of retrospective analyses for various variables estimated by the ASPM for goliath grouper off the U.S. southeast coast.

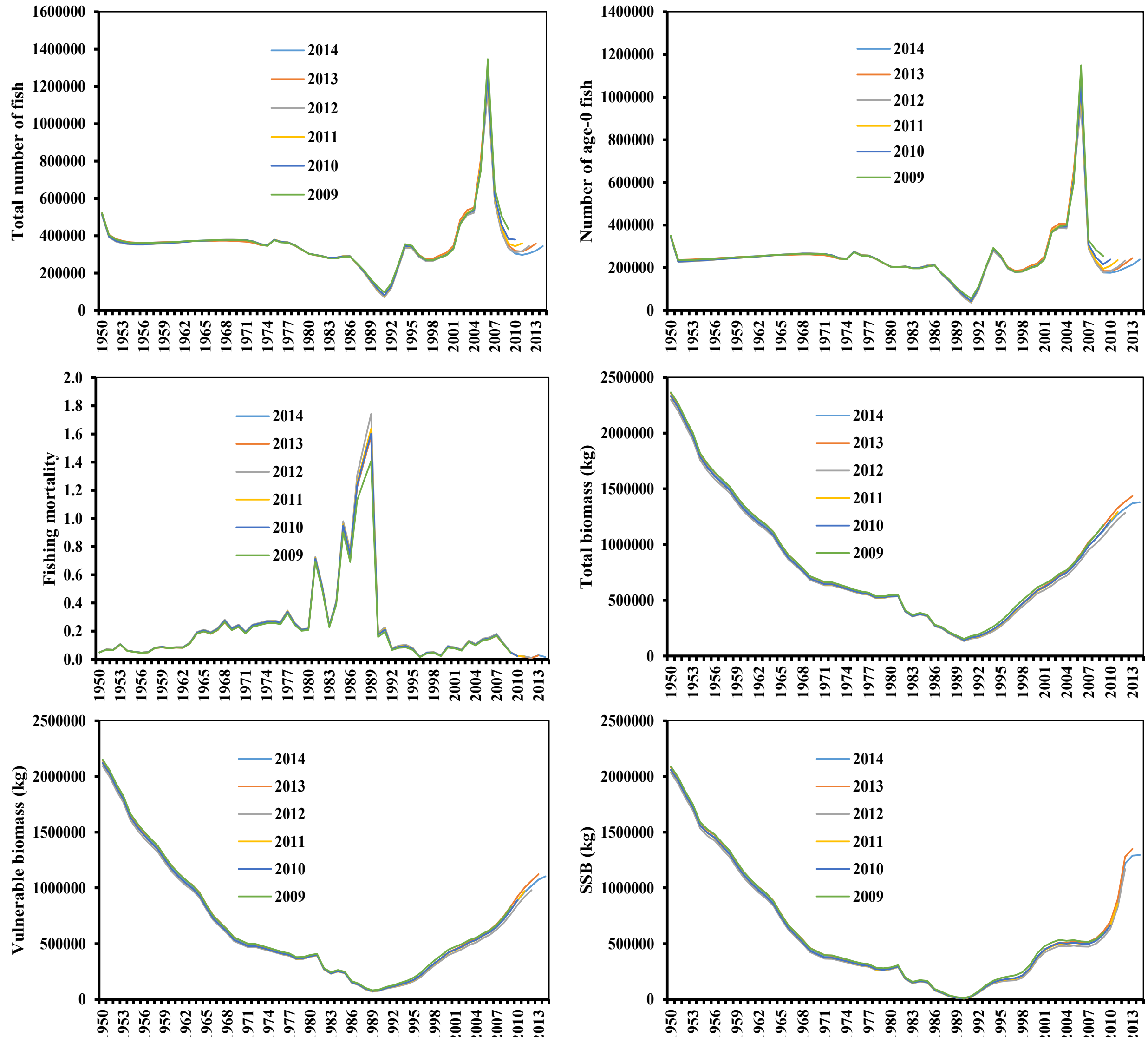


Fig. 6.9.6. Beverton–Holt stock–recruit relationship for goliath grouper from the ASPM, 1975–2014.

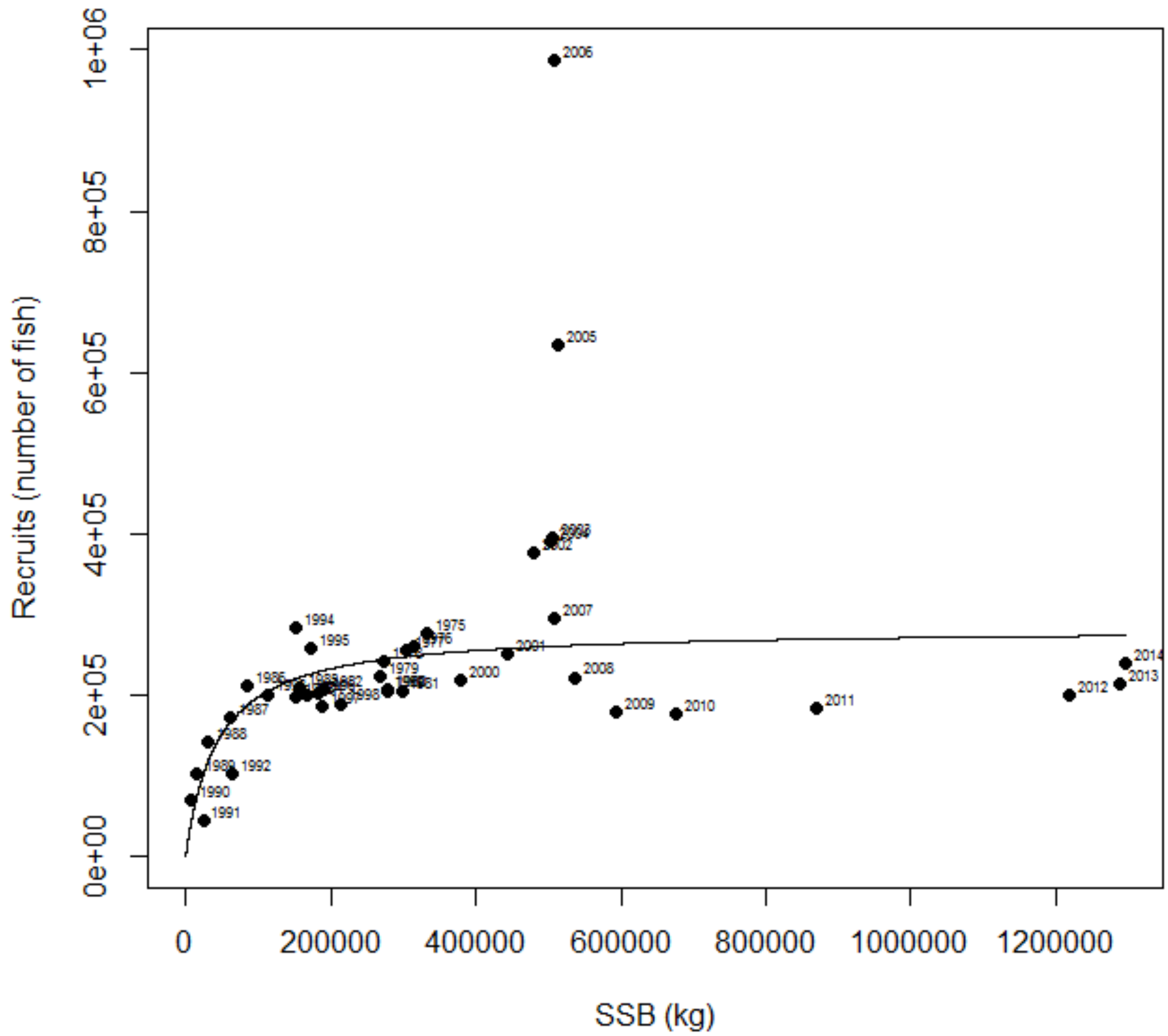


Fig. 6.9.7. Plot of the equilibrium yield per-recruit (YPR, solid black line) and spawning potential ratio (SPR, dash-dot black line) of goliath grouper off the U.S. southeast coast. The open circle indicates the pair ($F_{50\%SPR}$, 50%SPR); $F_{50\%SPR}$ = 0.08year^{-1}.

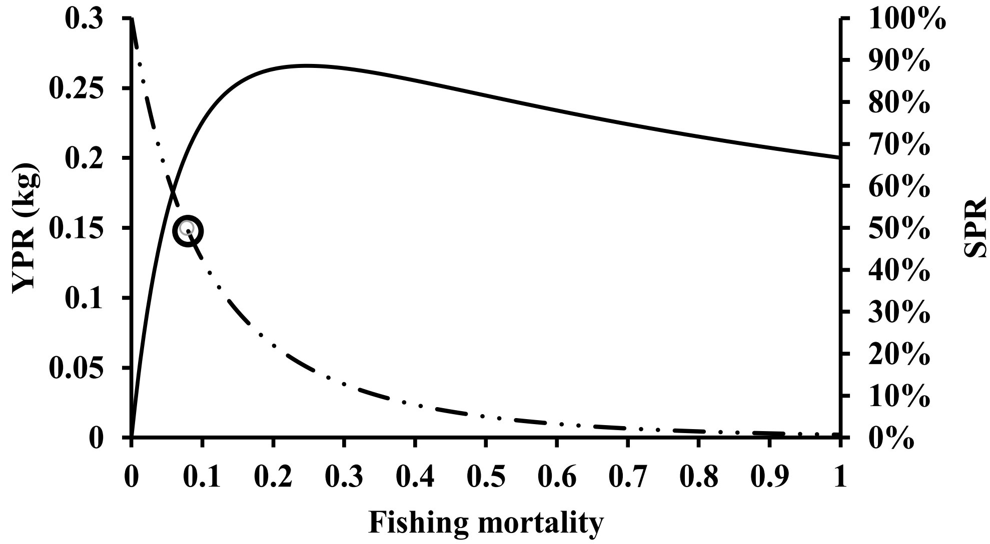


Fig. 6.9.8. Trajectories of the transitional SPR (tSPR), static SPR (sSPR) and target SPR off goliath grouper off the U.S. southeast coast, 1950–2014.

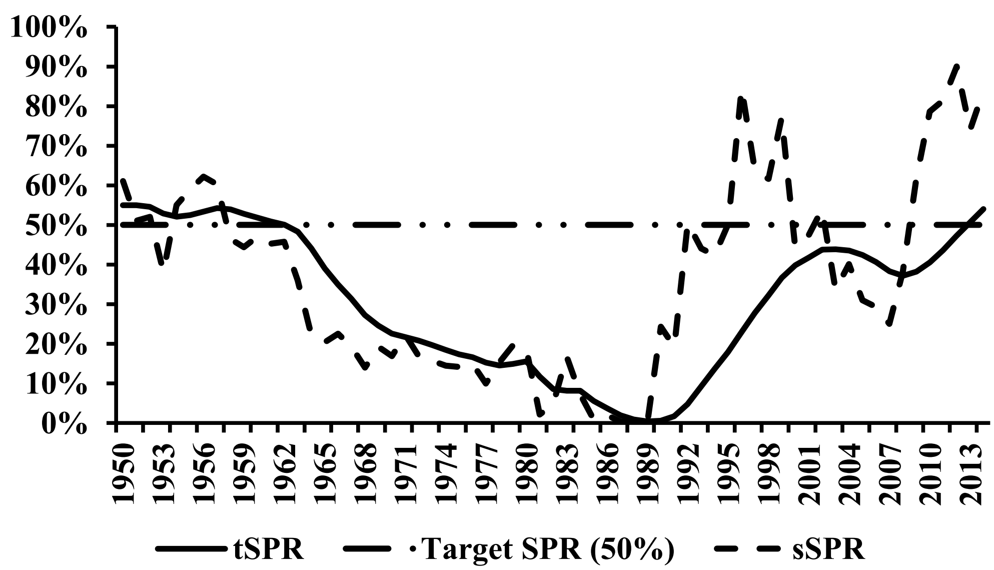


Fig. 7.2.1. Priors for the effectiveness of the moratorium on harvest in reducing the level of fishing mortality (F) formed from opinions of participants at the SEDAR 6 and 23 data workshops.

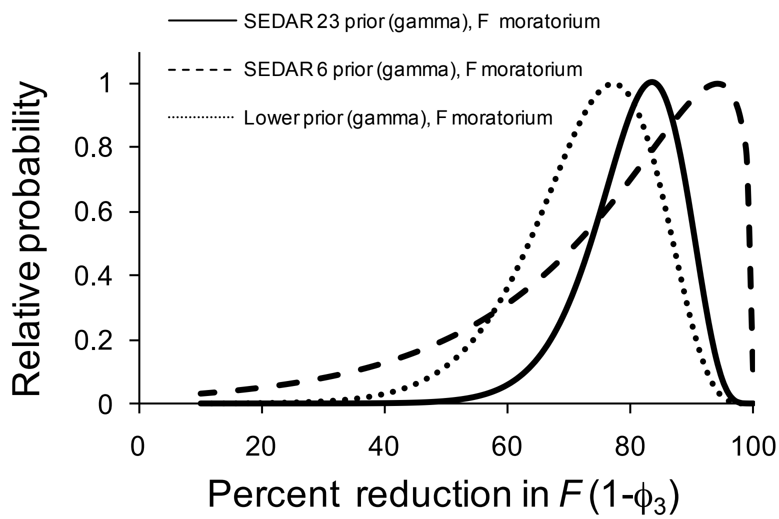


Fig. 7.5.1. Age-specific natural mortality estimates estimated by the catch-free model. The base run assumed the starting value for M corresponding to 0.179 from the Hoenig$_{nls}$ equation at a maximum observed age of 37 years for Goliaths. M=0.12 corresponds to a maximum age of 56 years.

a.) Estimates for the proposed "base" configuration with priors corresponding to M=0.18.

b.) Estimates for the age-specific natural mortality prior adjusted to M=0.12.

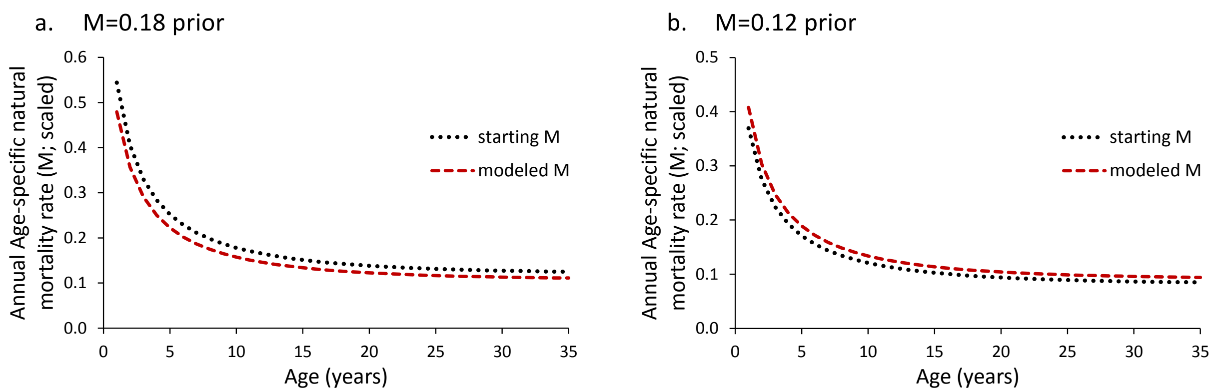
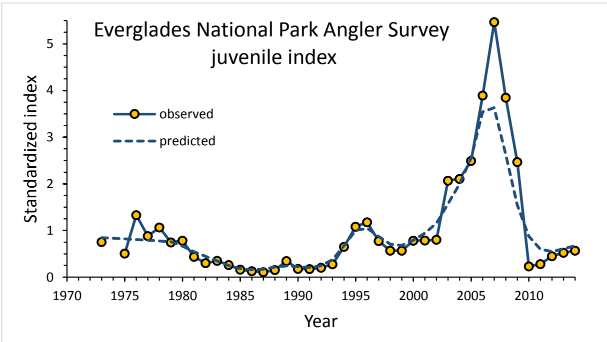


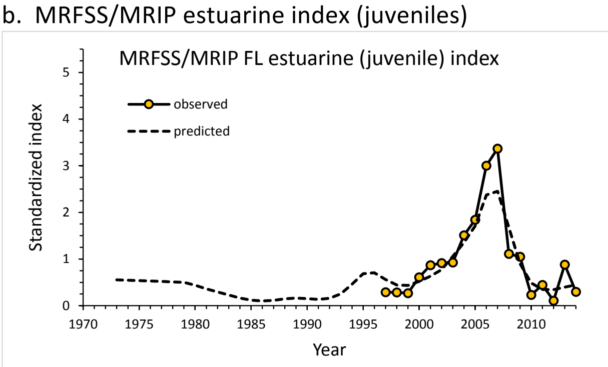
Fig. 7.5.2. Catch-free model fits to indices. a-d.) Priors for M adjusted to 0.18. e-f.) Priors adjusted to M=0.12.

a. M=0.18

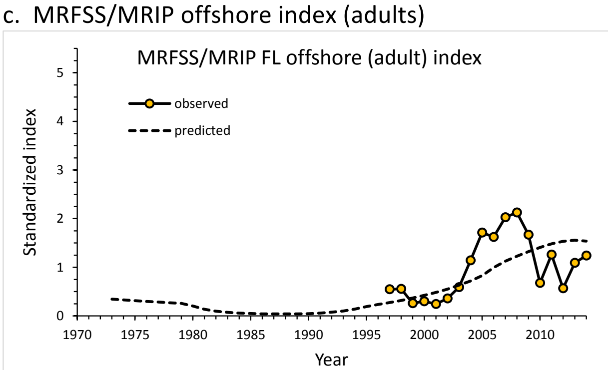
ENP index



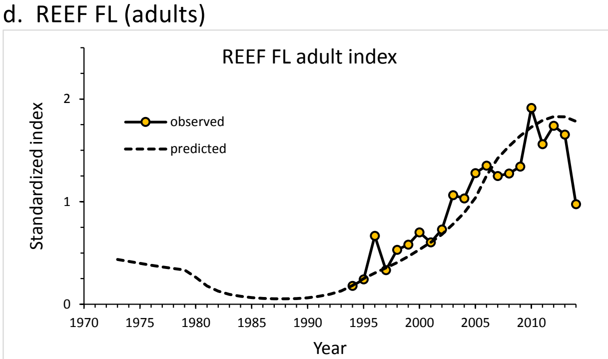
b. MRFSS/MRIP estuarine index (juveniles)



c. MRFSS/MRIP offshore index (adults)

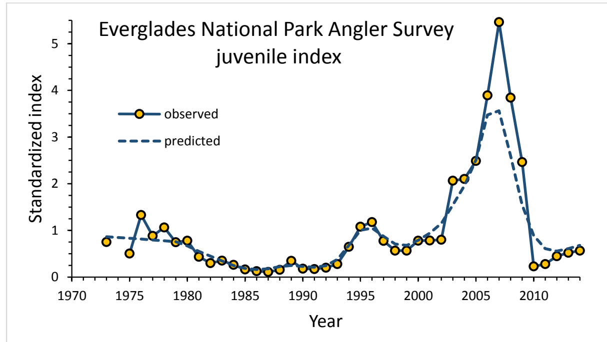


d. REEF FL (adults)

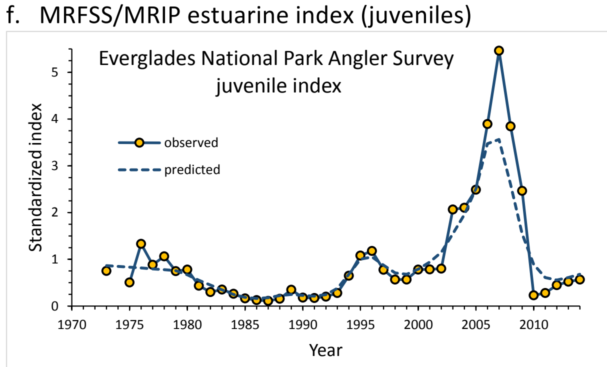


e. M=0.12

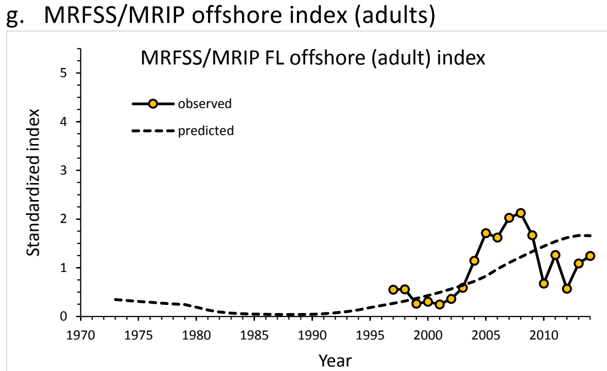
ENP index



f. MRFSS/MRIP estuarine index (juveniles)



g. MRFSS/MRIP offshore index (adults)



h. REEF FL (adults)

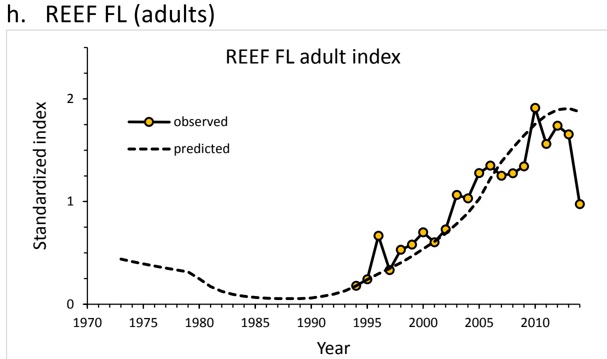
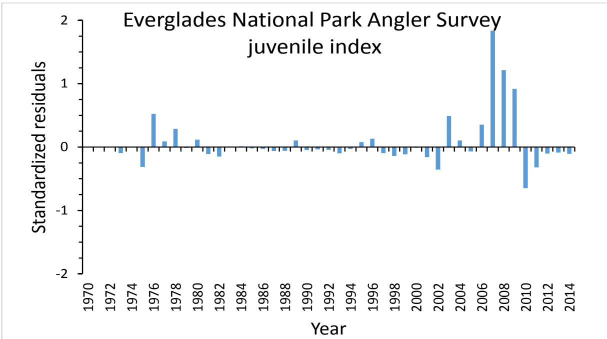


Fig. 7.5.3. Standardized residuals of index fits. a-d.) Priors for M adjusted to 0.18. e-f.) Priors adjusted to M=0.12.

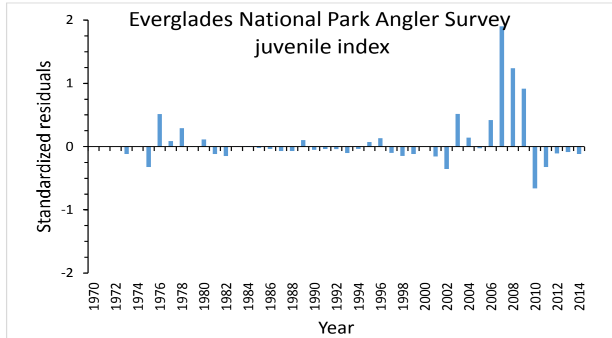
a. M=0.18

ENP index

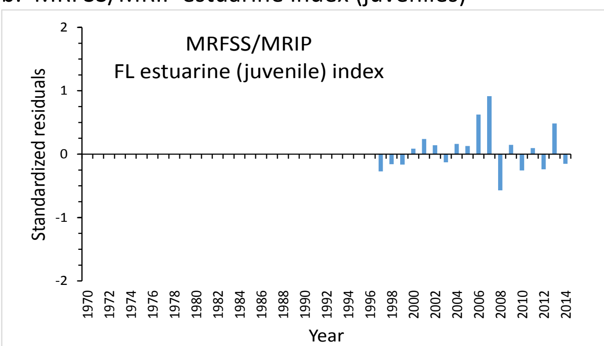


e. M=0.12

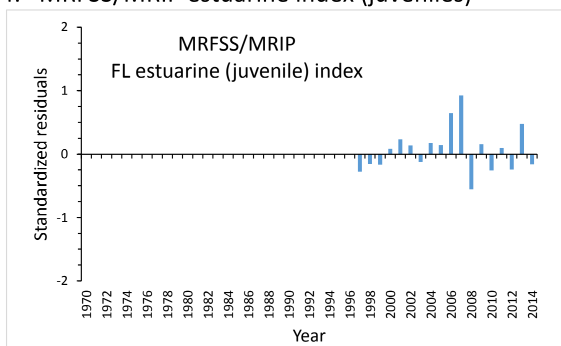
ENP index



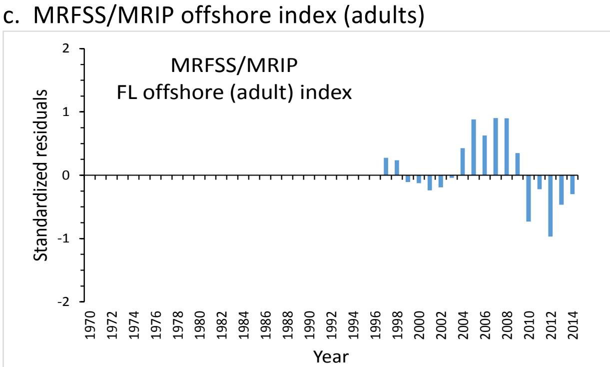
b. MRFSS/MRIP estuarine index (juveniles)



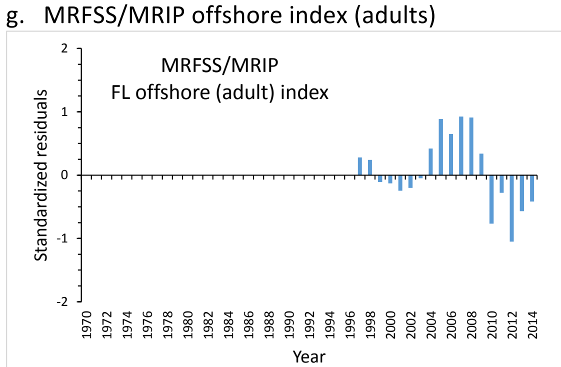
f. MRFSS/MRIP estuarine index (juveniles)



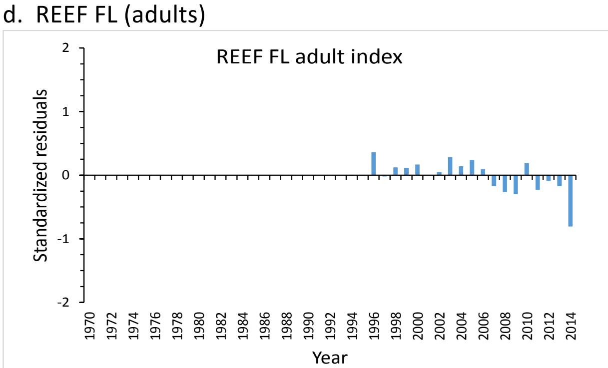
c. MRFSS/MRIP offshore index (adults)



g. MRFSS/MRIP offshore index (adults)



d. REEF FL (adults)



h. REEF FL (adults)

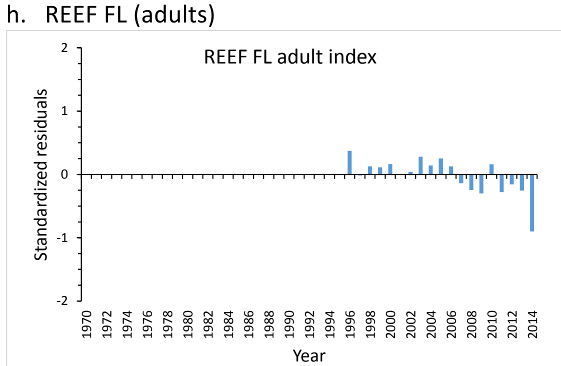
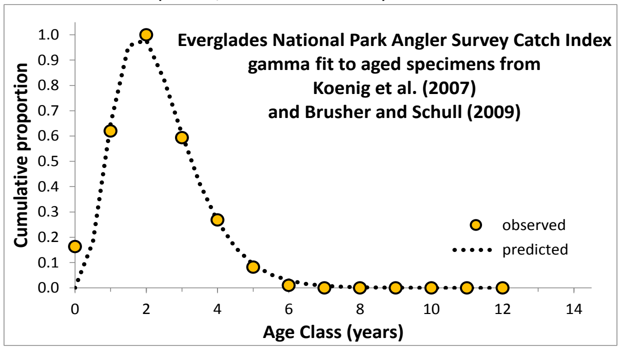


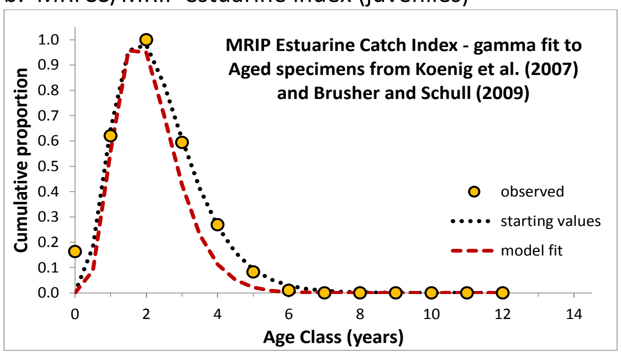
Fig. 7.5.4. Selectivity priors for indices and model-estimates. a-d.) Priors for M adjusted to 0.18. e-f.)

a. M=0.18

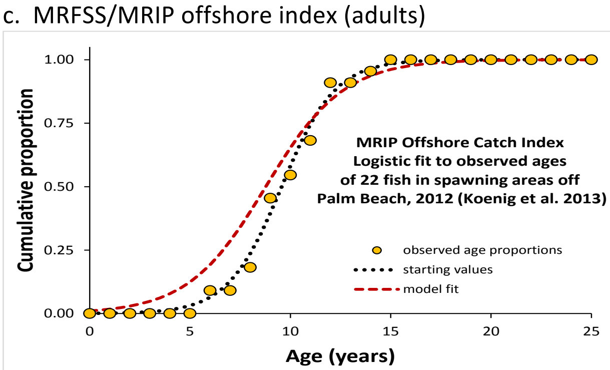
ENP index (fixed, not estimated)



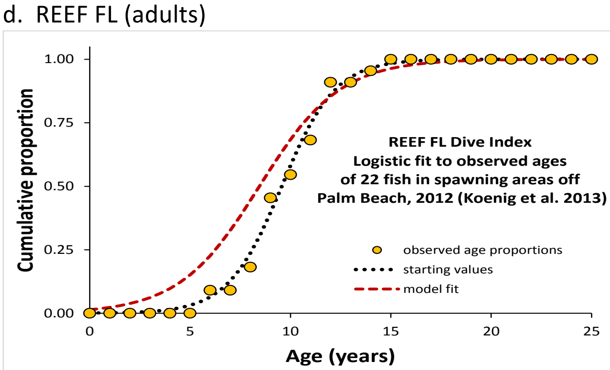
b. MRFSS/MRIP estuarine index (juveniles)



c. MRFSS/MRIP offshore index (adults)

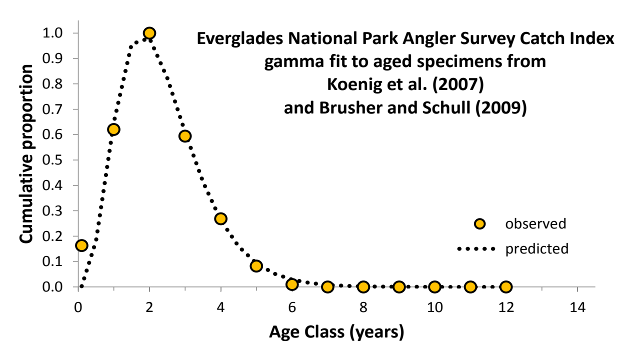


d. REEF FL (adults)

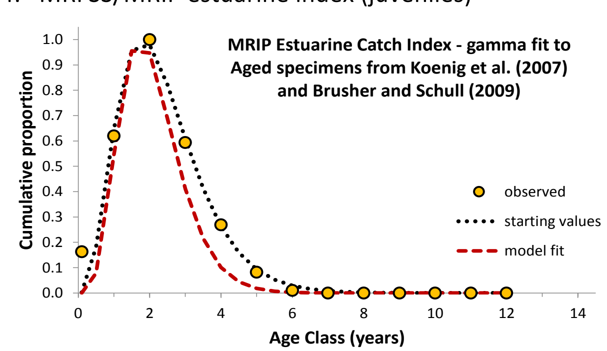


e. M=0.12

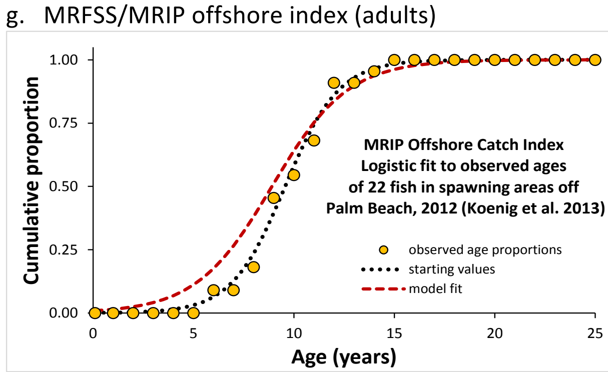
ENP index (fixed, not estimated)



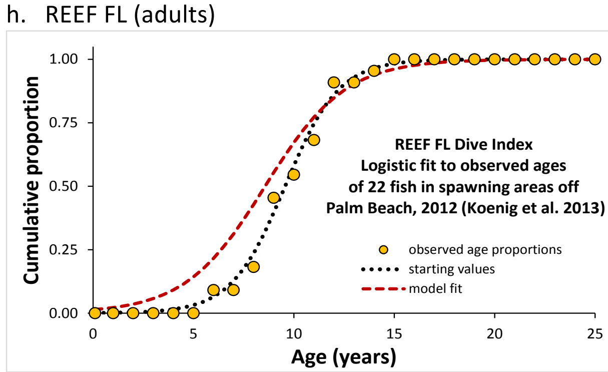
f. MRFSS/MRIP estuarine index (juveniles)



g. MRFSS/MRIP offshore index (adults)



h. REEF FL (adults)

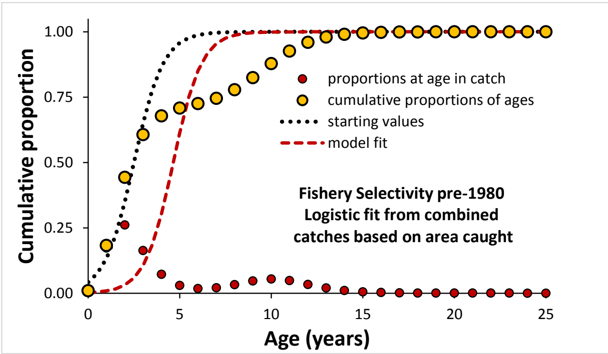


Priors adjusted to M=0.12.

Fig. 7.5.5. Selectivity priors for fishery and model-estimates for: a.) M=0.18 Pre-1980; b.) M=0.18 Post-1980; c.) M=0.12 Pre-1980; d.) M=0.12 Post-1980.

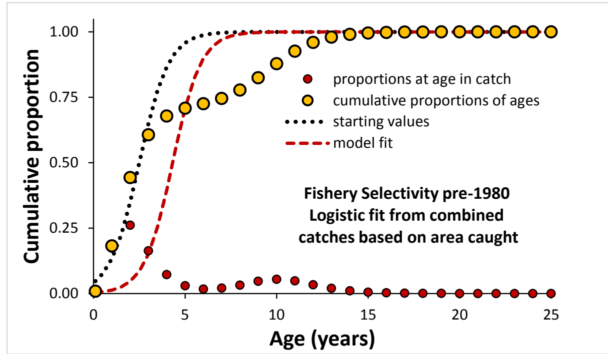
a. M=0.18

Pre-1980

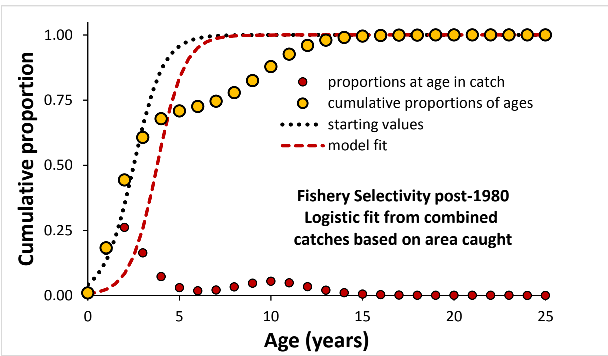


c. M=0.12

Pre-1980



b. Post-1980



d. Post-1980

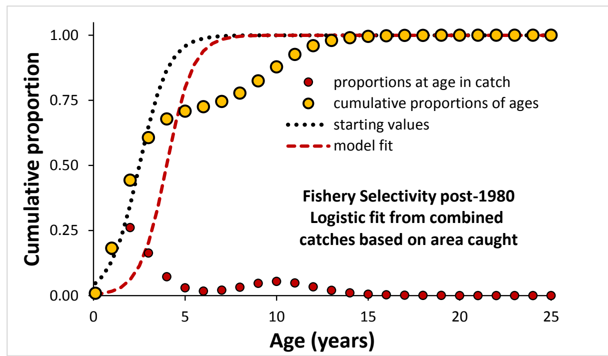
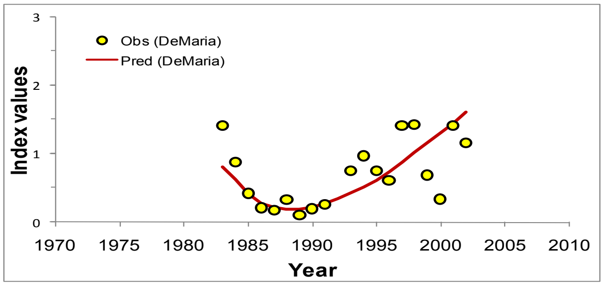
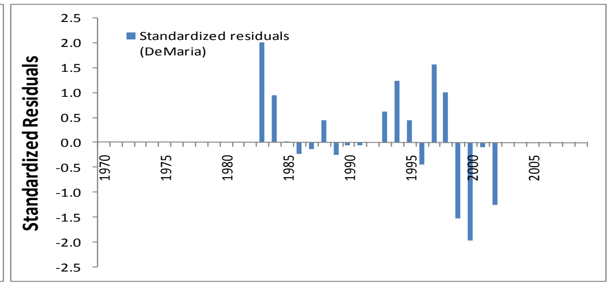


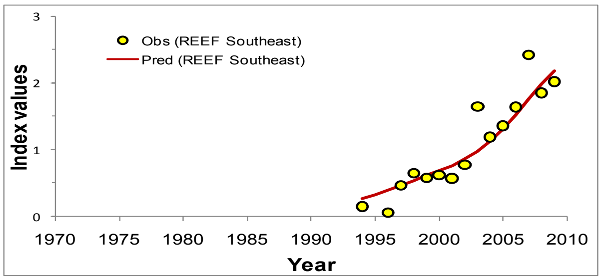
Fig. 7.5.6. Index fits and standardized residuals from Fig. 3.3.5 in SEDAR 23 base run, M=0.12.



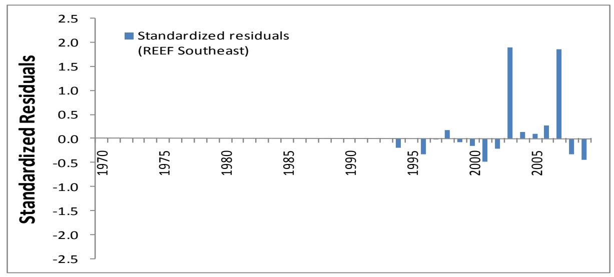
a. Fit, DeMaria index.



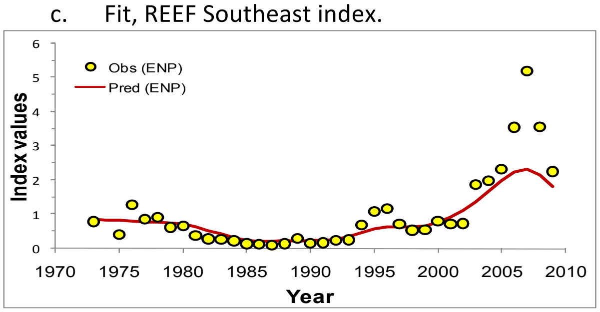
b. Standardized residuals, DeMaria index.



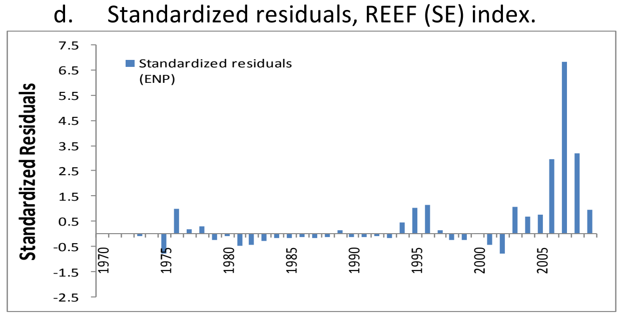
c. Fit, REEF Southeast index.



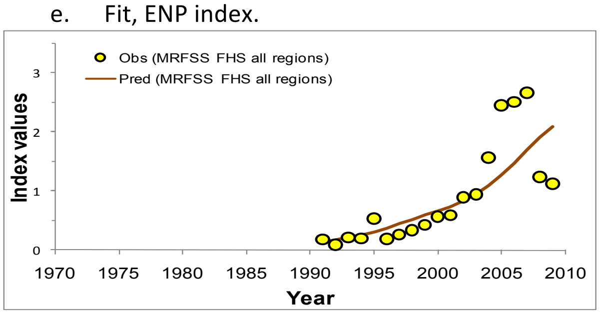
d. Standardized residuals, REEF (SE) index.



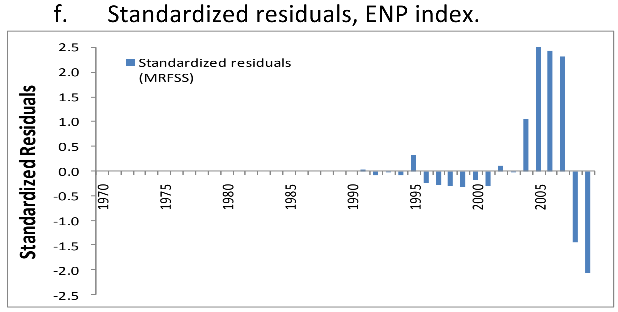
e. Fit, ENP index.



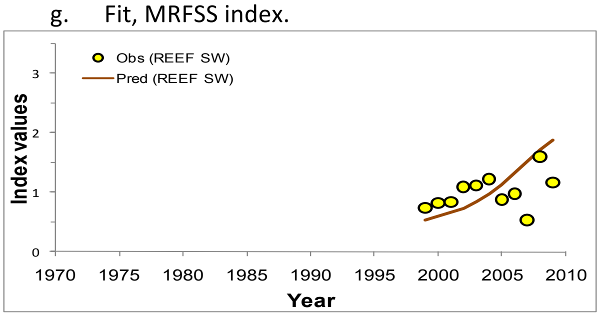
f. Standardized residuals, ENP index.



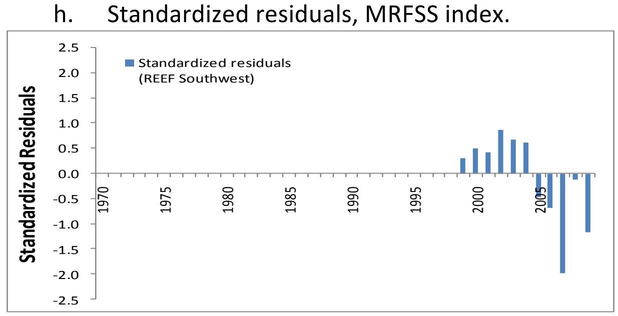
g. Fit, MRFSS index.



h. Standardized residuals, MRFSS index.



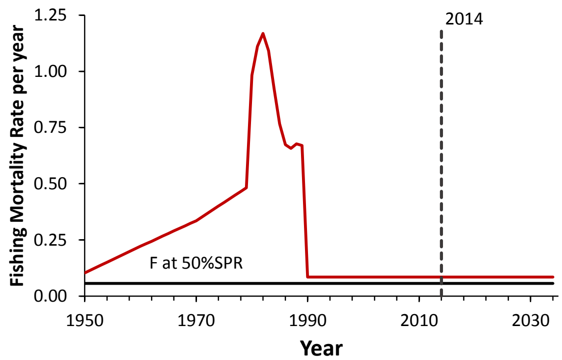
i. Fit, REEF Southwest index.



j. Standardized residuals, REEF (SW) index.

Fig. 7.5.7. Estimated fishing mortality rates. a.) for priors adjusted to M=0.18; b.) for priors adjusted to M=0.12.

a. M=0.18 prior



b. M=0.12 prior

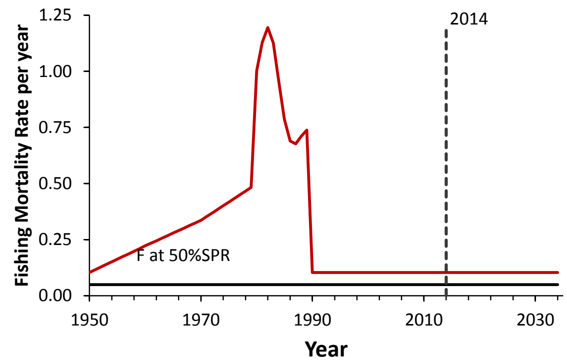
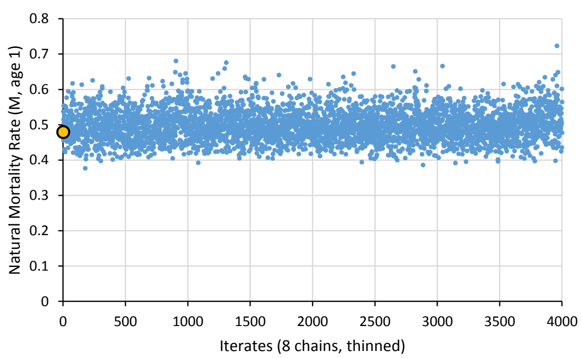
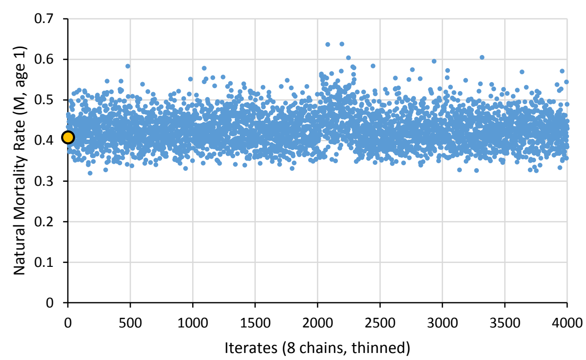


Fig. 7.5.8. Examples from different chains from MCMC runs which were unsuitable for examining posterior distributions of some variables of interest.

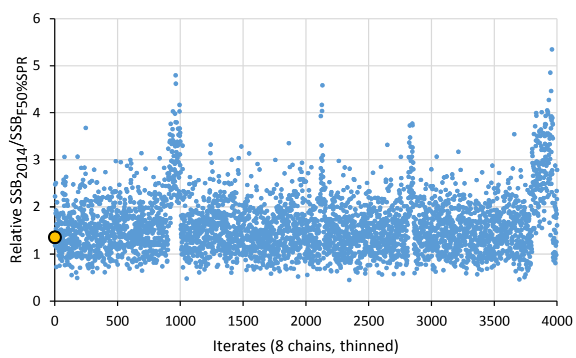
a. M=0.18 prior
Natural Mortality, Age 1



b. M=0.12 prior,
Natural Mortality, Age 1



c. $SSB_{2014}/SSB_{F50\%SPR}$



d. $SSB_{2014}/SSB_{F50\%SPR}$

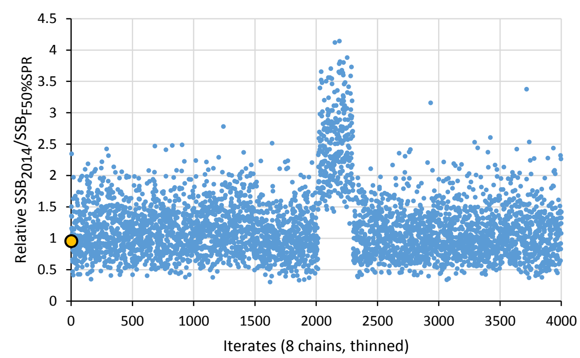
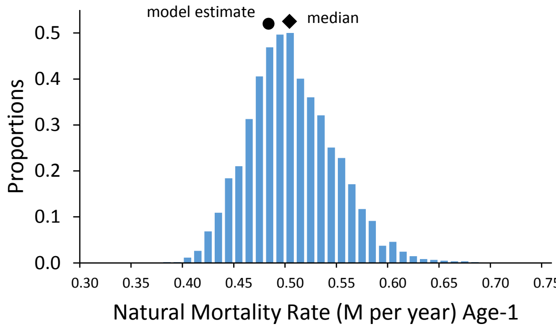


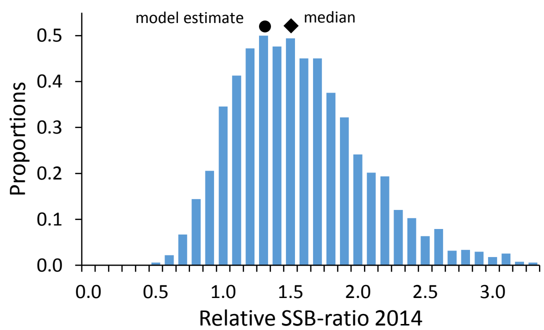
Fig. 7.5.9. Distributions of MCMC samples for some variables of interest. a-d.) Priors for M adjusted to 0.18. e-f.) Priors adjusted to M=0.12.

a. M=0.18

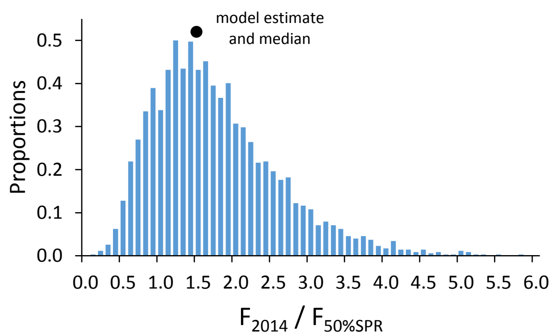
Natural Mortality Rate, Age 1



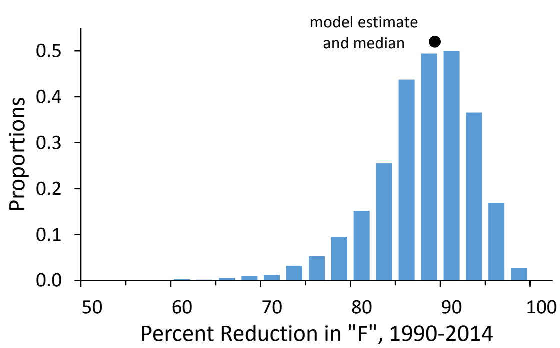
b. SSB-ratio ($SSB_{2014}/SSB_{F50\%SPR}$)



c. $F_{\text{"moratorium"}}/F_{50\%SPR}$

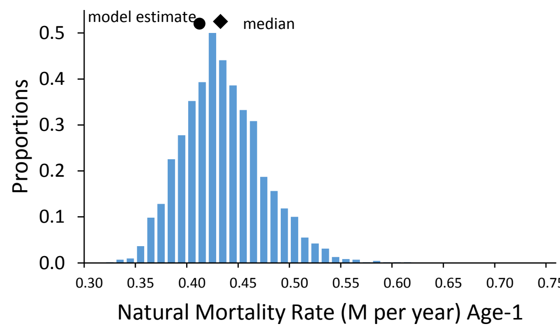


d. Percent reduction in F, 1990-2014

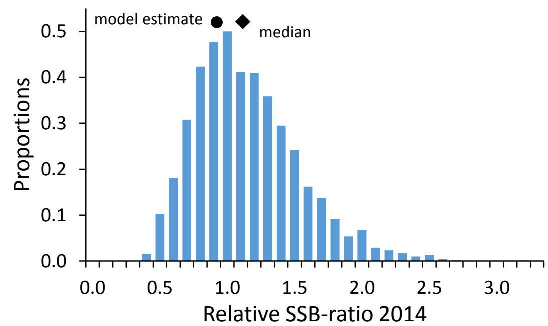


e. M=0.12

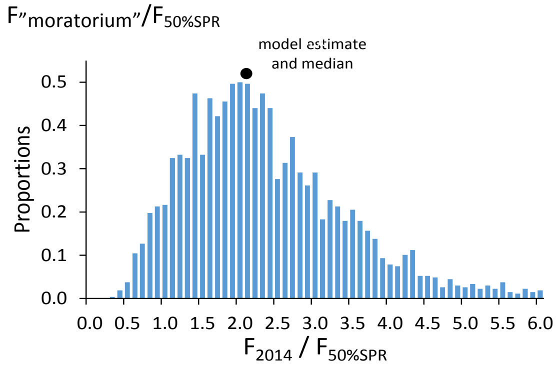
Natural Mortality Rate, Age 1



f. SSB-ratio ($SSB_{2014}/SSB_{F50\%SPR}$)



g. $F_{\text{"moratorium"}}/F_{50\%SPR}$



h. Percent reduction in F, 1990-2014

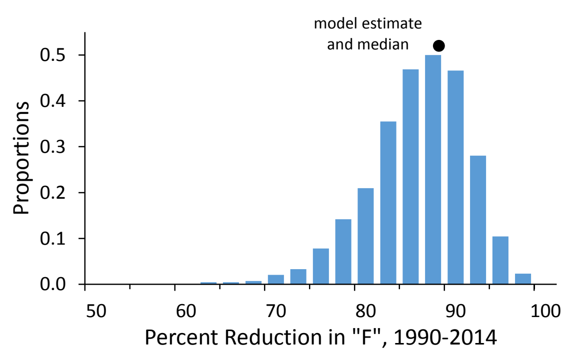
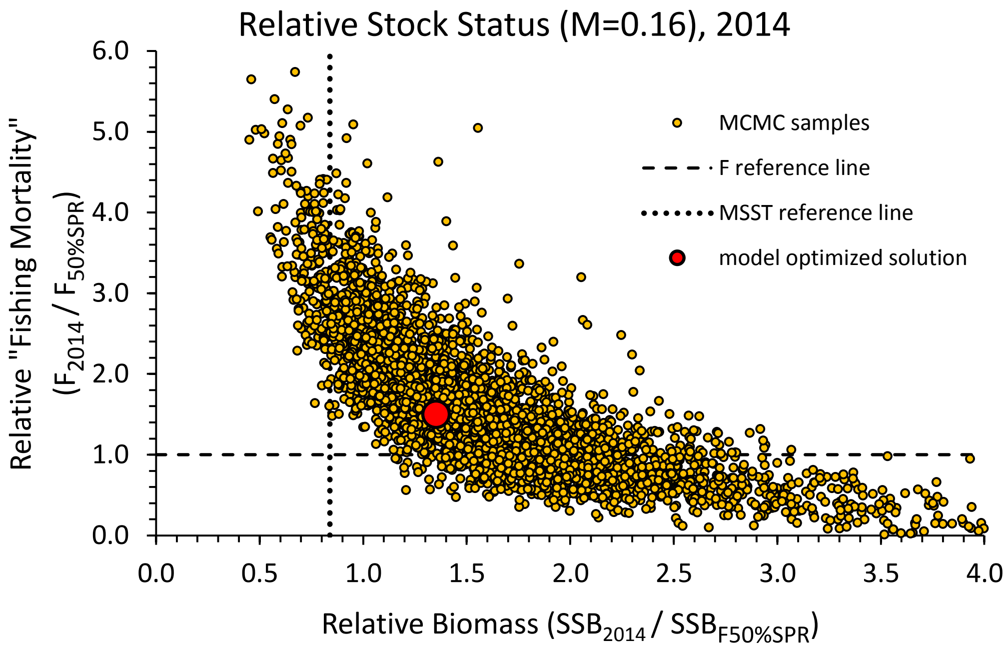


Fig. 7.5.10. Phase plots of the F-ratio ($F_{\text{"moratorium"}}/F_{50\%SPR}$) versus SSB-ratio ($SSB_{2014}/SSBF_{50\%SPR}$)

a. M=0.18 prior



b. M=0.12 prior

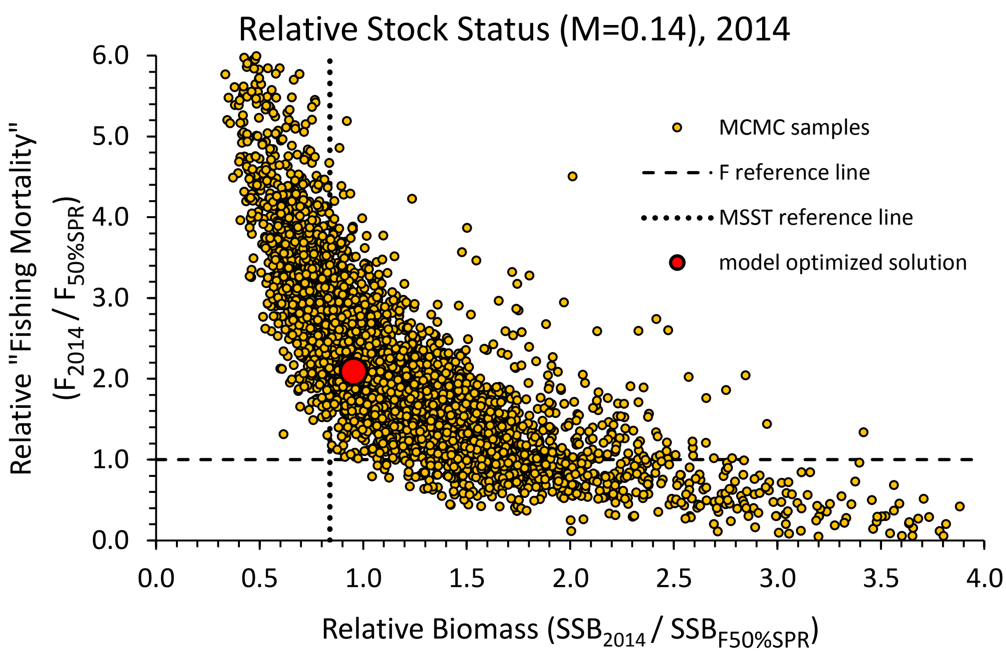
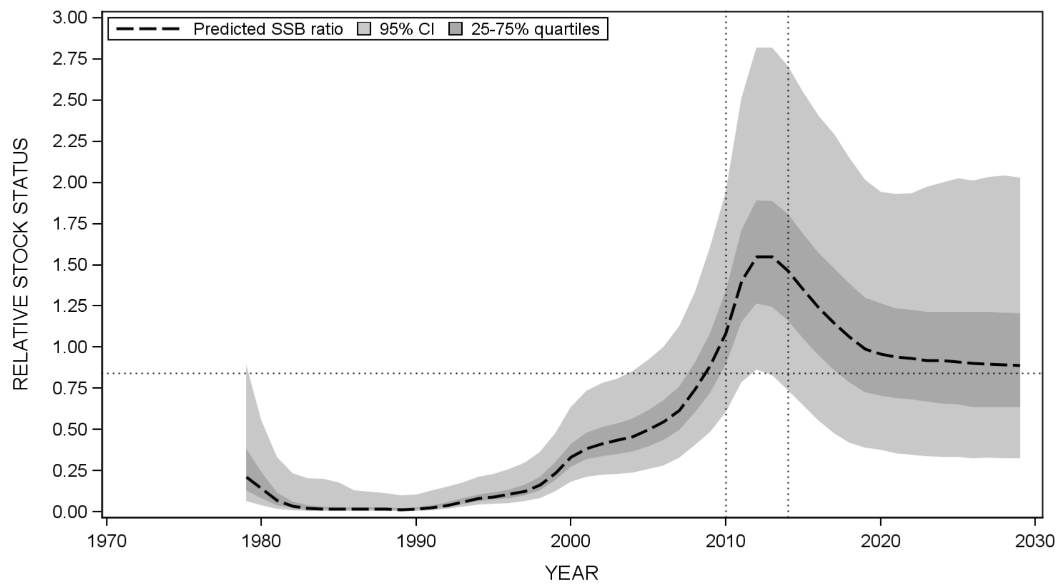
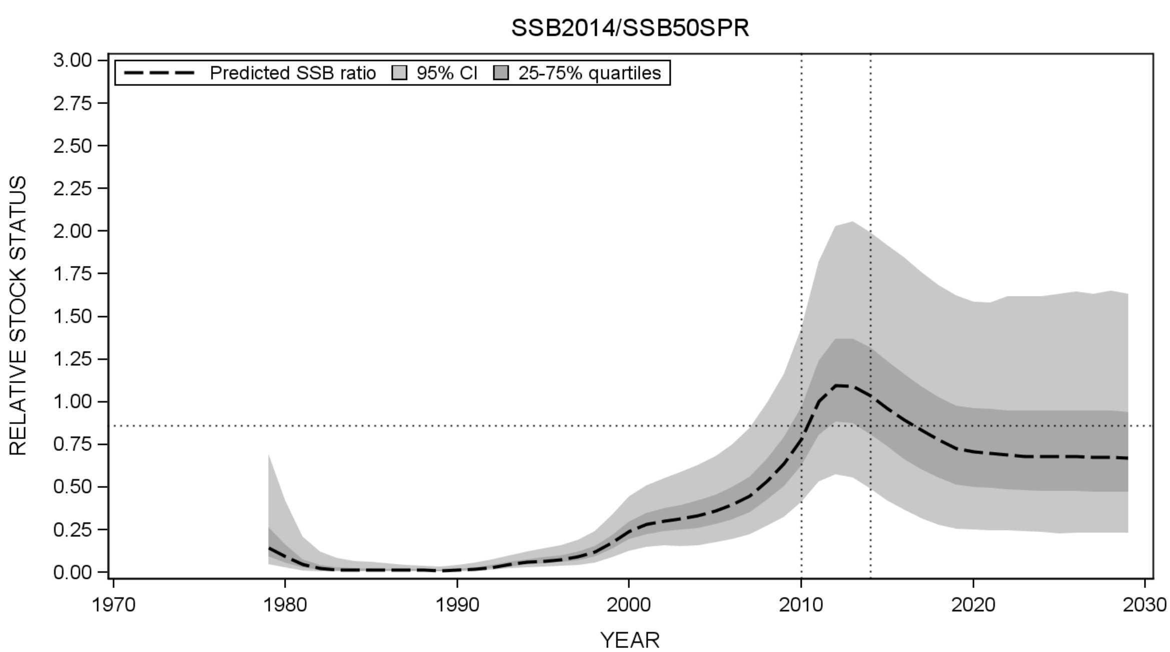


Fig. 7.5.11. Estimated relative spawning stock biomass at current "$F_{moratorium}$" (the average rate of removals above the expected natural mortality rate over 1990-2014) with 95% confidence intervals as light-gray shaded area and 25-75% quartiles as the inner dark gray shaded area. The minimum stock size threshold (1-M) is shown as the horizontal dotted line. Dashed line are the medians of the estimates and projections. a.) for priors adjusted to M=0.18; b.) for priors

a. M=0.18 prior



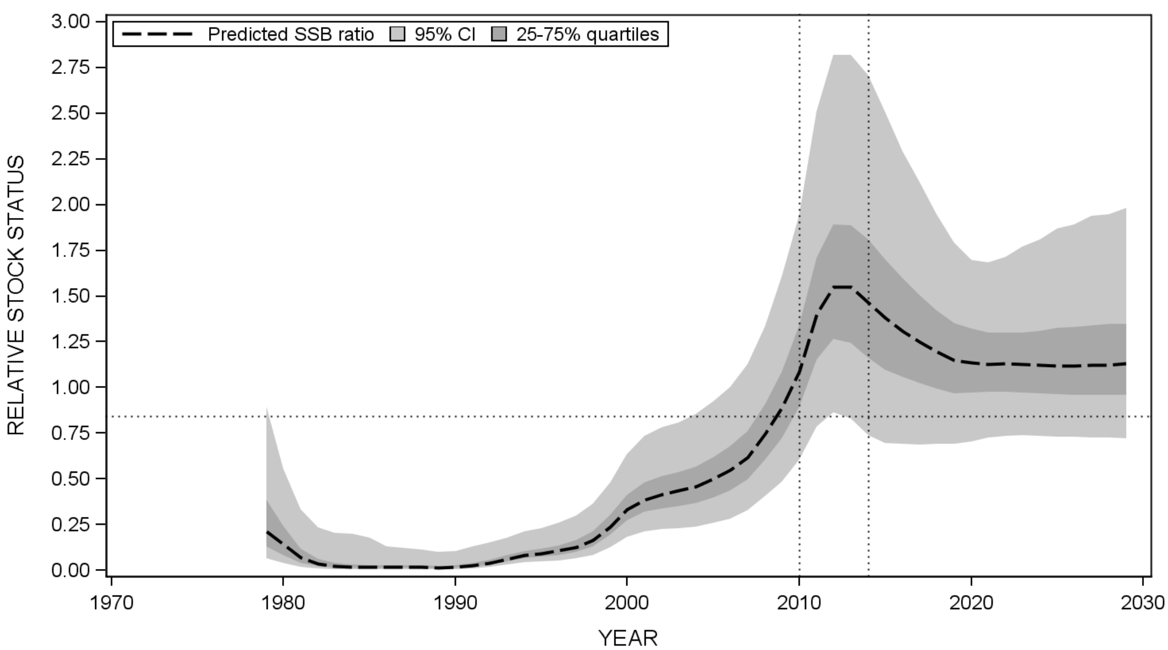
b. M=0.12 prior



adjusted to M=0.12.

Fig. 7.5.12. Estimated relative spawning stock biomass at F50%SPR (the proxy for the management reference point for MSY and OY) with 95% confidence intervals as light-gray shaded area and 25-75% quartiles as the inner dark gray shaded area. The minimum stock size threshold (1-M) is shown as the horizontal dotted line. Dashed line are the medians of the estimates and projections. a.) for priors adjusted to M=0.18; b.) for priors adjusted to M=0.12.

a. M=0.18 prior



b. M=0.12 prior

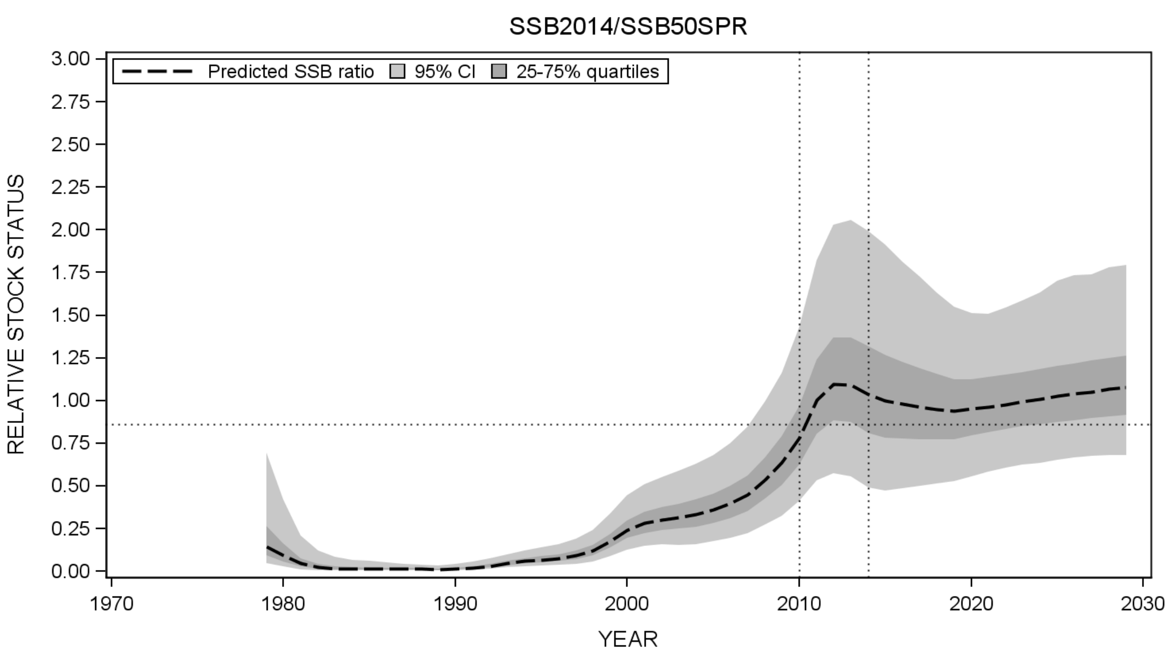
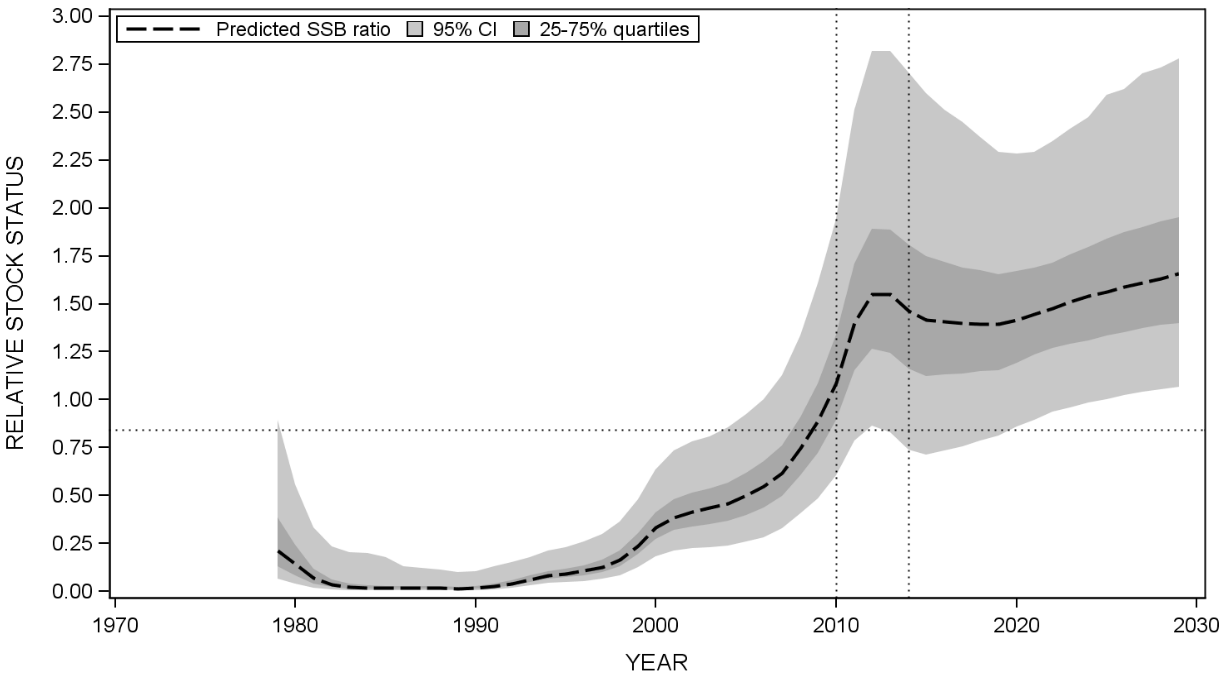
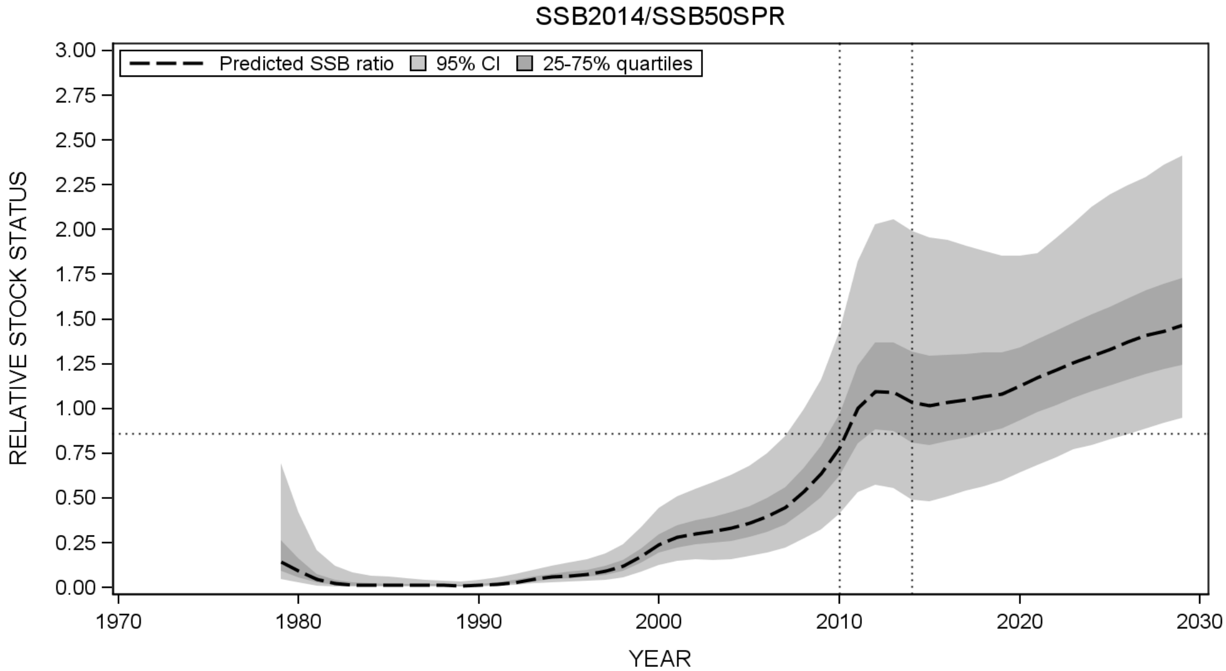


Fig. 7.5.13. Estimated relative spawning stock biomass at Fgeo 2012-2014 (the geometric mean of the F estimates for 2012-2014 from the SSRA mode)l with 95% confidence intervals as light-gray shaded area and 25-75% quartiles as the inner dark gray shaded area. The minimum stock size threshold (1-M) is shown as the horizontal dotted line. Dashed line are the medians of the estimates and projections. a.) for priors adjusted to M=0.18; b.) for priors adjusted to M=0.12.

a. M=0.18 prior



b. M=0.12 prior


SSB2014/SSB50SPR
Predicted SSB ratio
95% CI
25-75% quartiles
RELATIVE STOCK STATUS
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1970
1980
1990
2000
2010
2020
2030
YEAR

Appendix A - SSRA Parameters

Parameters and relationships of Martell et al.'s (2008) age–structured production model and specifications for goliath grouper inhabiting the US south Atlantic coast.

Eq.	Quantity	Notation	Description/Specifications
	Index for age	a	Ages 0–37
	Index for years	t	Years 1950–2014
Age schedules			
A1	Length at age	L_a	$L_a = L_\infty[1-e^{-K(a-a_0)}]$ where L_∞ (2221 mm), K (0.0937 year^{-1}), and a_0 (−0.6842 year) are von Bertalanffy growth parameters
A2	Weight at age	W_a	$W_a = AL_a^B$ where A (1.13×10^{-8}) is the scale and B (3.09) the exponent
A3	Fishery selectivity at age	$S_a^{(f)}$	Two blocks: logistic (1950–1989 block), "quasi-logistic" (1990–2014 block)
A4	Index selectivity at age	$S_a^{(I)}$	Dome-shaped for juvenile indices; logistic or quasi-logistic for adult indices (single block)
A5	Proportion mature at age	m_a	$m_a = 0$ for a = 0–5 and $m_a = 1$ otherwise
A6	Unfished survivorship to age a on January 1	l_a	$l_a = 1$ for $a = 0$; $l_a = l_{a-1}\, exp(-M_{a-1})$ for $a > 0$; M_a is natural mortality at age calculated using Lorenzen's (1996) equation for oceanic species, where target $M = 4.899\times37^{-0.916}$ (Then et al., 2015) and full selectivity is for fish of age 4+.
A7	Fished survivorship to age a on January 1	$l_a^{(f)}$	$l_a^{(f)} = 1$ for a = 0; $l_a^{(f)} = l_{a-1}^{(f)} exp\left[-\left(M_{a-1} + S_{a-1}^{(f)}F_e\right)\right]$ for $0 < a \le 36$; $l_a^{(f)} = l_a^{(f)}/(1 - exp\left[-\left(M_a + S_a^{(f)}F_e\right)\right]$ for $a = 37$; F_e is equilibrium fishing mortality.
A8	Fecundity at age	f_a	$f_a = W_{a+\pi}\times m_a$; $W_{a+\pi}$ is mean weight at age a+π, calculated by combining Eq. A1 and Eq. A2, π is fraction of the year elapsed at the time of spawning, and m_a is proportion mature.
Incidence functions (i.e., steady-state expressions of population units such as biomass, fecundity) on a per-recruit basis			
A9	Unfished egg per-recruit	ϕ_e	$\phi_e = \sum_{a=0}^{37} l_{a+\pi} f_a$; $l_{a+\pi}$ is the unfished survivorship to age a+π: l_a = exp $(-M(0)\times\pi)$ for $a = 0$ and $l_{a+\pi} = l_{a-1+\pi}\, exp(-M_{a-1}\times\pi)$ for $a > 0$
A10	Fished egg per-recruit	ϕ_f	$\phi_f = \sum_{a=0}^{37} l_a^{(f)} f_a$
A11	Unfished spawning biomass per-recruit	ϕ_B	$\phi_B = \sum_{a=0}^{37} l_{a+\pi} W_{a+\pi} m_a$

A12	Fished spawning biomass per-recruit	$\phi_B^{(f)}$	$\phi_B^{(f)} = \sum_{a=0}^{37} l_a^{(f)} W_{a+\pi} m_a$
A13	Vulnerable biomass per-recruit	ϕ_Q	$\phi_Q = \sum_{a=0}^{37} \frac{l_a^{(f)} S_a^{(f)} W_a}{M_a + S_a^{(f)} F_e}\left[1 - exp\left(-\left(M_a + S_a^{(f)} F_e\right)\right)\right]$
A14	Yield per-recruit	YPR	$YPR = F_e \phi_Q$
Model Leading Parameters			
A15	Estimated parameters	Θ	Θ = {F_{MSY}, MSY, w_t}: where MSY is maximum sustainable yield, F_{MSY} is fishing mortality producing MSY, and w_t are annual recruitment deviations
Derived steady-state parameters assuming a Beverton–Holt stock (*S*)–recruit (*R*) model $R_{t+1} = \frac{\alpha S}{1+\beta S_t}$; α is the slope of the stock–recruit curve at the origin (density-independent parameter) and β the density-dependent term (α > 0 and β > 0).			
A16	Compensation ratio	κ	$\kappa = \frac{\phi_e}{\phi_f} - \frac{F_{MSY}\phi_Q \frac{\phi_e}{\phi_f^2}\frac{\partial \Phi_f}{\partial F_{MSY}}}{\phi_Q + F_{MSY}\frac{\partial \Phi_Q}{\partial F_{MSY}}}$ where ϕ_f and ϕ_Q are evaluated at F_{MSY}.
A17	Unfished biomass	B_0	$B_0 = \frac{MSY \phi_B (\kappa - 1)}{F_{MSY}\phi_Q\left(\kappa - \frac{\phi_e}{\phi_f}\right)}$ where ϕ_f and ϕ_Q are evaluated at F_{MSY}
A18	Unfished recruitment	R_0	$R_0 = B_0/\phi_B$
A19	Unfished egg production	E_0	$E_0 = R_0\phi_e$; note: $R_0/E_0 = 1/\phi_e$ is juvenile survival
A20	Equilibrium Recruitment (at *F*)	Re	$R_e = R_0 \frac{\kappa - \frac{\phi_e}{\phi_f}}{\kappa - 1}$
A21	Equilibrium yield (at *F*)	Ye	$Y_e = R_e F_e \phi_Q$
A22	Density-independent parameter	α	$\alpha = \kappa/\phi_e$
A23	Density-dependent parameter	β	$\beta = \frac{\kappa - 1}{R_0 \phi_e}$
A24	Stock–recruit steepness	h	$h = \frac{\kappa}{4+\kappa}$
Model Data for goliath grouper			
	Fishery removals (Kg)	C_t	Commercial landings (1950–1981), Commercial & recreational landings and dead discards (Types AB1 and B2; 1981–1989), and recreational dead discards (1990–2014)
	4 Abundance indices (number)	I_t	ENP (juveniles, 1975–2014), MRIP/MRFSS (offshore, 1997–2014), MRIP/MRFSS (shore, 1997–2014), and Dive reef survey (1994–2014)
Unobserved (equilibrium) state			

A25	Initial (virgin) state (t < 1950)	N_{at}	$N_{at} = R_0 l_a$
State dynamics (1950–2014)			
A26	Total fishing mortality at age	Z_{at}	$Z_{at} = M_a + S_a^{(f)} F_t$; F_t is year-specific ("fully selected") fishing mortality
A27	Egg production	E_t	$E_t = \sum_a N_{at} \exp(-\pi Z_{at}) \times f_a$; given how f_a is calculated (Eq. A8), egg production is herein approximated by the spawning stock biomass.
A28	Numbers at age	$N_{a,t}$	$N_{at} = \frac{\alpha E_{t-1}}{1+\beta E_{t-1}}$ for a = 0; $N_{a,t} = N_{a-1,t-1} \exp\left(-Z_{a-1,t-1}\right)$ for a >0
A29	Total and vulnerable biomass	B_t; vB_t	$B_t = \sum_a N_{a,t} W_a$; $vB_t = \sum_a N_{a,t} W_a S_a^{(f)}$
A30	Predicted removals (weight)	$\hat{C}_t$	$\hat{C}_t = \sum_a \frac{N_{at} W_a S_a^{(f)} F_t [1-\exp(-Z_{at})]}{Z_{at}}$
A31	Predicted index by year	$\hat{I}_t$	$\hat{I}_t = W_a S_a^{(I)} \mathbf{N}^T / \frac{1}{n} \sum_a W_a S_a^{(I)} \mathbf{N}^T$ (biomass); $\hat{I}_t = S_a^{(I)} \mathbf{N}^T / \frac{1}{n} \sum_a S_a^{(I)} \mathbf{N}^T$ (numbers) where $\mathbf{N}^\mathbf{T}$ is a transpose matrix of $N_{a,t}$ predicted over an index period.
A32	Iteration (i)-specific rate of the annual fishing mortality	F_{ti+1}	$F_{ti+1} = F_{ti} - \frac{\hat{C}_t - C_t}{C'_t}$; C'_t is the first derivative of Eq. A29.
Likelihoods and priors			
A33	Log-likelihood for each index observation	LI_t	$LI_t = \lambda_I \{0.5 \log(2\pi) + 0.5 \log(\sigma_{I,t}^2) + [\log(I_t) - \log(\hat{I}_t)]^2 / \sigma_{I,t}^2\}$ where λ_I is the index weight and $\sigma_{I,t}^2$ is the index variance by year
A34	Log-likelihood for F_{MSY} prior ($F_{MSY}P$)	LF_{MSY}	$LF_{MSY} = \lambda F_{MSY} \{0.5 \log(2\pi) + 0.5 \log(\sigma_{FMSY}^2 P) + [\log(F_{MSY}P) - \log(F_{MSY})]^2 / \sigma_{FMSY}^2 P\}$ where, for the F_{MSY} prior, λF_{MSY} is weight and $\sigma_{FMSY}^2 P$ is variance

Appendix B - SEDAR 47 data input file (catch-free model)

(S_47_noDeMaria_proj_Fcurrent.dat) for the catch-free model, projections set to Fcurrent.

```
#/////////////////////////////////////////////////////////////////////////////////////////////
#/////////////////////////////////////////////////////////////////////////////////////////////
#// INPUT DATA FILE FOR PROGRAM DATAPOOR_S_47p
#// * rev - months elapsed for the MRFSS index set to mid-year (6)
#//   Important notes:
#//    (1) Comments may be placed BEFORE or AFTER any line of data, however they MUST begin
#//        with a # symbol in the first column.
#//    (2) No comments of any kind may appear on the same line as the data (the #
#//        symbol will not save you here)
#//    (3) Blank lines without a # symbol are not allowed.
#//
#// old==> Manufactured data - updated indices - removed REEF SE, added 4 MRFSS, updated ENP, no update to REEF SE
#// SEDAR 47 test run with new indices for REEF FL, MRFSS FL (offshore bt), and MRFSS FL (estuarine), turned off DeMaria, MRFSS EFL offshore,
MRFSS EFL estuarine
#/////////////////////////////////////////////////////////////////////////////////////////////
#/////////////////////////////////////////////////////////////////////////////////////////////
#
#####################################################
# GENERAL INFORMATION
#####################################################
# first year in simulation (beginning of historical period)
# |     last year of historical period
# |     |     last year when data are available
# |     |     |     end of simulation (year to project to)
# |     |     |     |
  1950  1979  2014  2034
# year when fishing mortality rate in modern period becomes relatively constant so that no f_devs are estimated from that point on
# (enter negative value if no such period exists)
1990
# first and last age in the simulation
1
# scale of variance parameters (1 = log scale variance, 2 = observation scale variance, 0=force equal weighting)
1
# method of modifying variance parameters (0= do not modify, 1 = add annual values to variance, -1 = multiply annual values by variance)
1
# spawning season (integer representing number of months elapsed when spawning occurs)
7
# maturity schedue (fraction m of each age class that is sexually mature
0
# fecundity schedule (index of per capita fecundity of each age class)
-1
#####################################################
# INDICES OF ABUNDANCE (e.g., CPUE) If there are no series, there should be no entries between the comment lines.
#####################################################
# number of index data series
5
# pdf of observation error for each series (1) lognormal, (2) normal
1       1       1       1       1
# units (1=numbers, 2=weight, 10=number relative to virgin levels, 20=weight relative to virgin levels (in case of 10 or 20, you should fix the
corresponding q to 1)
1       1       1       1       1
# months elapsed at time index observed
6       6       6       6       6
# option to (1) scale or (0) not to scale index observations
0       0       0       0       0
# set of index variance parameters each series is linked to
1       1       1       1       1
```

```
# set of q parameters each series is linked to
1       2       3       4       5
# set of s parameters each series is linked to
3       4       5       6       7
# observed indices by series )
# DeMaria
#       REEF SE
#           |   ENP (juv)
#           |       |   MRFSS (offshore bt)
#           |       |       |   MRFSS (estuarine)
#           |       |       |       |
#           |       |       |       |
#           |       |       |       |       year
-1      -1      -1      -1      -1      1950
-1      -1      -1      -1      -1      1951
-1      -1      -1      -1      -1      1952
-1      -1      -1      -1      -1      1953
-1      -1      -1      -1      -1      1954
-1      -1      -1      -1      -1      1955
-1      -1      -1      -1      -1      1956
-1      -1      -1      -1      -1      1957
-1      -1      -1      -1      -1      1958
-1      -1      -1      -1      -1      1959
-1      -1      -1      -1      -1      1960
-1      -1      -1      -1      -1      1961
-1      -1      -1      -1      -1      1962
-1      -1      -1      -1      -1      1963
-1      -1      -1      -1      -1      1964
-1      -1      -1      -1      -1      1965
-1      -1      -1      -1      -1      1966
-1      -1      -1      -1      -1      1967
-1      -1      -1      -1      -1      1968
-1      -1      -1      -1      -1      1969
-1      -1      -1      -1      -1      1970
-1      -1      -1      -1      -1      1971
-1      -1      -1      -1      -1      1972
-1      -1      0.751   -1      -1      1973
-1      -1      -1      -1      -1      1974
-1      -1      0.506   -1      -1      1975
-1      -1      1.33    -1      -1      1976
-1      -1      0.882   -1      -1      1977
-1      -1      1.065   -1      -1      1978
-1      -1      0.746   -1      -1      1979
-1      -1      0.781   -1      -1      1980
-1      -1      0.435   -1      -1      1981
-6.42   -1      0.299   -1      -1      1982
-1.42   -1      0.351   -1      -1      1983
-0.88   -1      0.261   -1      -1      1984
-0.424  -1      0.163   -1      -1      1985
-0.214  -1      0.128   -1      -1      1986
-0.177  -1      0.109   -1      -1      1987
-0.331  -1      0.155   -1      -1      1988
-0.11   -1      0.347   -1      -1      1989
-0.198  -1      0.178   -1      -1      1990
-0.261  -1      0.173   -1      -1      1991
-1      -1      0.201   -1      -1      1992
-0.755  -1      0.277   -1      -1      1993
-0.974  0.179   0.649   -1      -1      1994
-0.761  0.243   1.08    -1      -1      1995
-0.615  0.667   1.177   -1      -1      1996
```

```
-1.419	0.333	0.774	0.549	0.289	1997
-1.431	0.531	0.566	0.556	0.285	1998
-0.691	0.581	0.566	0.261	0.269	1999
-0.342	0.7	0.782	0.3	0.608	2000
-1.421	0.603	0.785	0.246	0.868	2001
-1.161	0.729	0.802	0.36	0.913	2002
-1	1.064	2.067	0.59	0.924	2003
-1	1.031	2.104	1.144	1.511	2004
-1	1.278	2.491	1.712	1.841	2005
-1	1.351	3.894	1.622	3.001	2006
-1	1.251	5.466	2.027	3.368	2007
-1	1.275	3.847	2.126	1.112	2008
-1	1.342	2.465	1.669	1.05	2009
-1	1.913	0.231	0.676	0.232	2010
-1	1.561	0.28	1.262	0.445	2011
-1	1.739	0.447	0.568	0.106	2012
-1	1.654	0.522	1.091	0.882	2013
-1	0.975	0.566	1.241	0.295	2014
# annual scaling factors for variance (use this option to account for annual differences in the variance, e.g., to down-weight observations based on very little data)
# DeMaria
#	REEF SE
#	|	ENP (juv)
#	|	|	MRFSS (offshore bt)
#	|	|	|	MRFSS (estuarine)
#	|	|	|	|
#	|	|	|	|
#	|	|	|	|	year
0	0	0	0	0	1950
0	0	0	0	0	1951
0	0	0	0	0	1952
0	0	0	0	0	1953
0	0	0	0	0	1954
0	0	0	0	0	1955
0	0	0	0	0	1956
0	0	0	0	0	1957
0	0	0	0	0	1958
0	0	0	0	0	1959
0	0	0	0	0	1960
0	0	0	0	0	1961
0	0	0	0	0	1962
0	0	0	0	0	1963
0	0	0	0	0	1964
0	0	0	0	0	1965
0	0	0	0	0	1966
0	0	0	0	0	1967
0	0	0	0	0	1968
0	0	0	0	0	1969
0	0	0	0	0	1970
0	0	0	0	0	1971
0	0	0	0	0	1972
0	0	0.151	0	0	1973
0	0	0	0	0	1974
0	0	0.153	0	0	1975
0	0	0.116	0	0	1976
0	0	0.115	0	0	1977
0	0	0.13	0	0	1978
0	0	0.192	0	0	1979
0	0	0.147	0	0	1980
0	0	0.163	0	0	1981
```

```
0.089	0	0.218	0	0	1982
0.066	0	0.203	0	0	1983
0.046	0	0.203	0	0	1984
0.031	0	0.27	0	0	1985
0.047	0	0.254	0	0	1986
0.067	0	0.298	0	0	1987
0.059	0	0.293	0	0	1988
0.09	0	0.185	0	0	1989
0.114	0	0.204	0	0	1990
0.078	0	0.234	0	0	1991
0	0	0.348	0	0	1992
0.249	0	0.162	0	0	1993
0.113	0.326	0.102	0	0	1994
0.077	0.395	0.109	0	0	1995
0.055	0.314	0.09	0	0	1996
0.092	0.301	0.102	0.838	0.561	1997
0.133	0.261	0.132	0.461	0.451	1998
0.075	0.14	0.139	0.507	0.294	1999
0.215	0.129	0.133	0.541	0.24	2000
0.082	0.111	0.113	0.486	0.27	2001
0.11	0.095	0.113	0.419	0.223	2002
0	0.089	0.082	0.38	0.207	2003
0	0.099	0.081	0.299	0.168	2004
0	0.109	0.085	0.276	0.15	2005
0	0.102	0.07	0.297	0.142	2006
0	0.089	0.058	0.257	0.136	2007
0	0.11	0.075	0.26	0.218	2008
0	0.097	0.093	0.337	0.18	2009
0	0.084	0.298	0.454	0.343	2010
0	0.091	0.3	0.462	0.289	2011
0	0.088	0.22	0.445	0.498	2012
0	0.097	0.183	0.44	0.28	2013
0	0.148	0.193	0.308	0.306	2014
#####################################################
# INDEX OF RELATIVE EFFORT (you must enter values for each year, even if they are only dummy values)
#####################################################
# how to treat effort data (0) do not use values below, instead replace with a default of 1.0 for all years
# |		(1) use values below
# |		(-1)use values below, then rescale relative to maximum value
1
# value	year
0.207	1950
0.231	1951
0.255	1952
0.278	1953
0.302	1954
0.326	1955
0.35	1956
0.373	1957
0.397	1958
0.421	1959
0.445	1960
0.468	1961
0.49	1962
0.513	1963
0.536	1964
0.559	1965
0.582	1966
0.604	1967
0.627	1968
```

```
0.65	1969
0.673	1970
0.706	1971
0.738	1972
0.771	1973
0.804	1974
0.836	1975
0.869	1976
0.902	1977
0.935	1978
0.967	1979
1	1980
1	1981
1	1982
1	1983
1	1984
1	1985
1	1986
1	1987
1	1988
1	1989
1	1990
1	1991
1	1992
1	1993
1	1994
1	1995
1	1996
1	1997
1	1998
1	1999
1	2000
1	2001
1	2002
1	2003
1	2004
1	2005
1	2006
1	2007
1	2008
1	2009
1	2010
1	2011
1	2012
1	2013
1	2014
####################################################
# Projection specifications
####################################################
# selectivity for reference points (1=fishery, 2=use maturity vector)
1
# non-negative=input reference (should have value between 0 and 1)
# otherwise, -0.1=B at F0.1, -1=B at msy, -2=B at Fmax, -20=Bspr20, -30=Bspr30, -40=Bspr40, -50=Bspr50, -60=Bspr60, -999=Bcurrent)
-50
# control for recruitment deviations (0=none, + = variance, - = -cv)
-0.6
# projected F values (non-negative=input F, -0.1=F0.1, -1=Fmsy, -2=Fmax, -20=Fspr20, -30=Fspr30, -40=Fspr40, -50=Fspr50, -60=Fspr60, -
999=Fcurrent)
#	| Std. error (or negative CV) of implementation uncertainty (not being used at present)
#	|	|	year
```

```
#    |       |         |
  -999   -0.10     2015
  -999   -0.10     2016
  -999   -0.10     2017
  -999   -0.10     2018
  -999   -0.10     2019
  -999   -0.10     2020
  -999   -0.10     2021
  -999   -0.10     2022
  -999   -0.10     2023
  -999   -0.10     2024
  -999   -0.10     2025
  -999   -0.10     2026
  -999   -0.10     2027
  -999   -0.10     2028
  -999   -0.10     2029
  -999   -0.10     2030
  -999   -0.10     2031
  -999   -0.10     2032
  -999   -0.10     2033
  -999   -0.10     2034
```

Appendix C - SEDAR 47 parameter file (catch-free model)

(datapoor_S_47_base_M18_revM57_selcv075.prm) for the catch-free model, natural mortality prior adjusted to M=0.179 (Hoenig "nls" estimate), and index selectivity cv priors set to 0.075 based on sensitivity runs.

```
#/////////////////////////////////////////////////////////////////////////////////////////////
#/////////////////////////////////////////////////////////////////////////////////////////////
#// PARAMETER FILE FOR PROGRAM DATAPOOR - Lorenzen M, max age=37, M=0.1217 old Hoenig "lm", or max age=56.48, M=0.179 Hoenig "nls"
#// Hoenig "nls", max age=37 years, M=0.179322, re-scale to grams = 0.5746 (parameter 5) rev, re-scale ages 1-35
#// Hoenig "nls", max age=56.48236 years, M=0.179322, re-scale to grams = 0.3901 (parameter 5) rev, re-scale ages 1-35
#// Hoenig "lm"(old), max age=37 years, M=0.121718, re-scale to grams = 0.3901 (parameter 5)
#// Hoenig "lm"(old), max age=56.48236 years, M=0.080354, re-scale to grams = 0.2575 (parameter 5) rev, re-scale ages 1-35
#// * rev q5 - turned it on.
#//   Important notes:
#//    (1) Comments may be placed BEFORE or AFTER any line of data, however they MUST begin
#//        with a # symbol in the first column.
#//    (2) No comments of any kind may appear on the same line as the data (the #
#//        symbol will not save you here)
#//    (3) Blank lines without a # symbol are not allowed.
#//       Updated growth curve, f2 (moratorium effectiveness), survey index distribution parms adjusted for Lorenzen M and F, Clay's method,
#//       new length-weight, Clay's new Lorenzen parms,
#//       Hoenig "nls" M, added new MRFSS indices, deleted REEF SW index, revised offshore selectivities based on Angela's underwater measurements.
#//       This run used max age=56.48236 years (M=0.121718)
#// SEDAR 47 with new indices for REEF FL, ENP, MRFSS FL (offshore bt), and MRFSS FL (estuarine)
#//  re-calc selectivity indices 3Apr16 JRO
#//  turned on several priors and selectivities, growth and M, index variances
#//  kept ENP selectivities static - age comps look sufficient to keep these at their estimates
#//  estimating the other selectivities and holding them near their estimated values with the priors
#//  the prehistoric and modern selectivities were the compromise between estuarine and offshore catches I derived for Joseph M.
#//  they do not really follow a single logistic, but the ascending limb up to a50 is not bad.
#/////////////////////////////////////////////////////////////////////////////////////////////
#/////////////////////////////////////////////////////////////////////////////////////////////
#
##########################################################
# DIMENSION ARRAYS
##########################################################
# total number of process parameters - count the number of entries in the process parameter section
 34
# number of sets of each parameter type
#        catchabilities q        selectivity vectors     index variances
         5                       7                       1
##########################################################
# SPECIFICATIONS FOR PROCESS PARAMETERS
##########################################################
#        nature of function (1=constant, 2-3=polynomials, 12=power, 13=process correlation, 14=process variance scaling parameter
#        |        best guess of parameter value (median of prior)
#        |        |        lower bound for parameter
#        |        |        |        upper bound for parameter
#        |        |        |        |        phase of estimation (enter -1 to fix at best guess and not estimate)
#        |        |        |        |        |        probability density function of prior (0=none, 1=lognormal, 2=normal)
#        |        |        |        |        |        |        negative value is read as CV, positive value is read as standard error (must be on logscale if overall_pdf=1, arithmetic scale otherwise) of prior
#        |        |        |        |        |        |   |
#f_ph parameters for expected F during prehistoric era
         2        0.0   -0.010   0.5    -2  2       -1.0
         2        0.3   -0.010   0.5     1  2       -1.0
```

#f parameters for expected F during modern era before change in regulations- note if nature=-1 then F=parameter*F(last year of historical period))
-1 1.0 0.02 10.0 1 2 -1.0
#f2 parameters for expected F during modern era after change in regulations- note if nature=-1 then F=parameter*F(last year before change))
-1 0.16464 0.01 0.9 3 5 -0.40
#m natural mortality rate - Lorenzen M parameters modified for ages 4-37 in terms of weight (Lorenzen 1996, eqn for "Natural", M=alpha*wt(grams)^-0.288, alpha=3)
length-wt equation is in kg, so M(Lorenzen) = (1000 grams/kilogram)^-0.288 * adjustment factor for target ages * 3 * wt[kg]^(-0.288)
12 0.5746 0.01 0.7 3 2 -0.25
12 -0.288 -1 -.1 -3 0 -0.4
#r parameter alpha minus 1
10 2.648087 0.01 150.0 2 1 1.310438
#w (by record) for vonBertalannfy equation (Linf, k, t0, cv) and length-weight equation (intercept in kilograms, slope)
8 0.2221E+04 150 3000 5 2 -0.11
8 0.0937E-00 0 10 3 1 0.00295
8 -0.6842E+00 -5.00 10 -1 0 0.1
8 0.1000E+01 0 10 -1 0 0.1
8 1.0110E-08 0 10 -1 0 0.1
8 3.0900E+00 0 10 -1 0 0.1
#q (linked to survey indices 1-DeMaria, 2-REEF (FL), 3-ENP, 4-MRFSS (FL offshore bt), 5-MRFSS (FL estuarine) turn off phase if index is to be ignored.
1 0.5000E+00 .01 10 -1 2 -2
1 0.5000E+00 .01 10 1 2 -2
1 0.5000E+00 .01 10 1 2 -2
1 0.5000E+00 .01 10 1 2 -2
1 0.5000E+00 .01 10 1 2 -2
#s_prehistoric
6 2.5E+00 2 15 4 2 -2.0
6 0.8E+00 0.5 3 4 2 -0.5
#s_modern
6 2.5E+00 2 15 4 2 -2.0
6 0.8E+00 0.5 3 4 2 -0.5
#_s_survey 1 DeMaria Lorenzen M adjusted, WFL offshore diver measurements, ages for selectivity from Koenig et al. 2013 fig. 15
6 9.5644E+00 4 15 -4 2 -0.075
6 1.3303E+00 0.5 3 -4 2 -0.25
#_s_survey 2 REEF Combined coasts Lorenzen M adjusted, WFL offshore diver measurements plus GGGC, ages for selectivity from Koenig et al. 2013 fig. 15
6 9.5644E+00 4 15 4 2 -0.075
6 1.3303E+00 0.5 3 4 2 -0.25
#_s_survey 3 ENP Angler Creel Survey, Lorenzen M adjusted, ENP angler creel survey, ages for selectivity from Koenig et al. 2007 and Brusher and Schull 2009
7 1.7857E+00 0 7 -4 2 -0.075
7 0.4948E+00 0.01 2 -4 2 -0.25
#_s_survey 4 MRFSS Lorenzen M adjusted, combined coasts FL offshore boat catch rates, ages for selectivity from Koenig et al. 2013 fig. 15

6 9.5644E+00 4 15 4 2 -0.075
6 1.3303E+00 0.5 3 4 2 -0.25
#_s_survey 5 MRFSS Lorenzen M adjusted, combined coasts FL estuarine (all modes) catch rates, ages for selectivity from Koenig et al. 2007 and Brusher and Schull 2009
7 1.7857E+00 0 7 4 2 -0.075
7 0.4948E+00 0.01 2 4 2 -0.25
#idv
14 1.0000E+00 0 10 1 0 0.1
#overall var
1 -0.2 -1 -0.01 5 2 -0.5
###
SPECIFICATIONS FOR PROCESS DEVIATION PARAMETERS
###
best guess of parameter value (central tendency of prior)
| lower bound for parameter

```
#               |               |             upper bound for parameter
#               |               |             |             phase of estimation (enter -1 to fix at best guess and not estimate)
#               |               |             |             |             probability density function of prior
#               |               |             |             |             |             standard error or negative CV of prior (superfluous in case of deviations)
#_f_____|       |          |             |             |             |
    0.50   -0.001    1.0      -1     0  0.1
    0.15       0   1000.     -1     0   0.1
    0.000     -5      5       5     1    0.1
#_r_____|       |          |             |             |             |
    0.5    -0.001    1.0      -1     0   0.1
    0.15       0   100.0      -1     0   0.1
    0.0000    -5      5       4     1    0.1
#_q_____|       |          |             |             |             |
    0.0    -0.001    1.0      -1     0   0.1
    0.10       0   100.0      -1     0   0.1
    0.0000    -5      5      -1     1    0.1
# End of file #
```

Appendix D - SEDAR 47 Catch-free model tpl file (source code)

```
////////////////////////////////////////////////////////////////////////////////
DATA_SECTION
 ////////////////////////////////////////////////////////////////////////////////
 // Catch-free model (see Porch, C. E., A-M. Eklund, and G.P. Scott.  2006.  A catch-free stock assessment model with application to goliath grouper (Epinephelus itajara) off southern Florida.  Fishery Bulletin 104:  89-101.)
// datapoor_S_47pM.exe - added vars to MCMC output for index selectivities 16Apr2016 JRO, changed index sel. to likeprofs 19Apr2016, using ADMB vers. 10.1 and compiled and linked using gcc452-win64 in safe mode.
 // added M to MCMC outputs 7May2016
 // --------------- read data file -------------------------------------------------------
 // general information
 !! cout << "general information " << endl;
  init_ivector year(1,4)
  init_int year_change
  init_ivector age(1,2)
  init_int variance_scale            // controls how variance terms are represented (1=log scale, 2=arithmetic scale)
  init_int variance_modify           // + value = add annual modifiers to variance terms, - value = multiply annual modifiers by variance terms
  int year_prehistoric               // last year of historical period (hist. period is the time span from virgin levels to when data becomes available)
  int year_modern                    // last year of modern period (when data are available)
  int nyears_modern                  // number of years in the modern period (when F can vary from trend indicated by effort data)
  int nyears_prehistoric             // number of years in the prehistoric period (when F varies only as function of effort since little data)
  int nyears_past                    // number of years in the prehistoric and modern periods combined
  int nyears_proj                    // number of years to project into future
  int nyears                         // number of years in simulation, past and future
  int n_eras                         // number of time periods when F or q can vary from overall expectations(nyears_modern+1)
  int nyears_b4_change               // number of years between prehistoric period and the time during the modern period when F is suspected to change (for example, when a moratoroium was instituted)
  int nages                          // number of age classes
  int nqs                            // (n)umber of (s)ets of (q) catchability-related parameters
  int nss                            // (n)umber of (s)ets of (s) selectivity-related parameters
  int nids                           // (n)umber of (s)ets of (i) index data-related parameters
 LOCAL_CALCS
  year_prehistoric  =year(2); year_modern=year(3);
  nyears_prehistoric= year_prehistoric - year(1)+1;
  nyears_modern     = year_modern - year_prehistoric;
  nyears_proj       = year(4) - year_modern;
  nyears_past       = nyears_prehistoric + nyears_modern;
  nyears                                        = nyears_past + nyears_proj;
  if(year_change<0 || year_change>year_modern) nyears_b4_change = nyears_past;
  else nyears_b4_change=year_change-year(1);
  n_eras=nyears_modern+1;
  nages=age(2)-age(1)+1;
 END_CALCS

 // spawning information
  init_number spawn_season
  init_vector maturity(1,nages)
  init_vector fecundity_input(1,nages)

 // index (survey) information

 !! cout << "reading indices " << endl;
  init_int     n_index_series
  init_ivector index_pdf(1,n_index_series)
  init_ivector index_units(1,n_index_series)
  init_vector  index_season(1,n_index_series)
  init_ivector index_scale(1,n_index_series)
  init_ivector ivs(1,n_index_series)             // integer vector indexing the set of variance parameters used by each index of abundance
  init_ivector iqs(1,n_index_series)             // integer vector indexing the set of q parameters used by each index of abundance
  init_ivector iss(1,n_index_series)             // integer vector indexing the set of selectivity parameters used by each index of abundance
  init_matrix  index_obs(1,nyears_past,1,n_index_series+1)
  init_matrix  index_cv(1,nyears_past,1,n_index_series+1)
```

```
 init_int     effort_pdf
 init_matrix  effort_inp(1,nyears_past,1,2)

!! cout << "reading projection specifications " << endl;
 init_int    reference_selectivity      // specifies selectivity vector to use when calculating reference points (1 = fishery vector, 2 = maturity vector
 init_number Bref                      // specifies biomass reference point
 init_number estimate_r_dev_proj               // determines whether to estimate recruitment deviations in projections
 init_matrix in_prj(1,nyears_proj,1,3)                    // projection specifications for F

// --------------- read parameter file ----------------------------------------------------

!! ad_comm::change_datafile_name("datapoor_S_47.prm");
!! cout << "reading parameter specifications " << endl;
 init_int n_par                                              // number of process parameters
 init_ivector n_sets(1,3)                                    // number of sets of each type of process parameter
!! nqs=n_sets(1); nss=n_sets(2); nids=n_sets(3);
 init_matrix par_specs(1,n_par,1,7)                          // specifications for process parameters
 init_vector f_rho_specs(1,6)                                // specifications for f process error correlation coefficient
 init_vector f_var_specs(1,6)                                // specifications for f process error variance
 init_vector f_dev_specs(1,6)                                // specifications for f process error deviations
 init_vector r_rho_specs(1,6)                                // specifications for r process error correlation coefficient
 init_vector r_var_specs(1,6)                                // specifications for r process error variance
 init_vector r_dev_specs(1,6)                                // specifications for r process error deviations
 init_vector q_rho_specs(1,6)                                // specifications for q process error correlation coefficient
 init_vector q_var_specs(1,6)                                // specifications for q process error variance
 init_vector q_dev_specs(1,6)                                // specifications for q process error deviations

// --------- derived variables pertaining to parameters that are constant (don't need to be differentiated)----------//

 int i
 int ie
 int jj // added counter
 int y
 int n_series
 int n_par_phase
 ivector n_calls(1,1000)
 ivector npf(1,50)
 ivector nature(1,n_par);
 vector  best_guess(1,n_par);
 number  f_rho_best_guess;
 number  f_var_best_guess;
 number  f_dev_best_guess;
 number  r_rho_best_guess;
 number  r_var_best_guess;
 number  r_dev_best_guess;
 number  q_rho_best_guess;
 number  q_var_best_guess;
 number  q_dev_best_guess;
 number  F_best_guess;
 ivector iph(1,n_par);
 int     f_rho_iph;
 int     f_var_iph;
 int     f_dev_iph;
 int     r_rho_iph;
 int     r_var_iph;
 int     r_dev_iph;
 int     q_rho_iph;
 int     q_var_iph;
 int     q_dev_iph;
 int     r_dev_proj_iph;
 int     last_iph;
 ivector pdf(1,n_par);
 int     f_rho_pdf;
 int     f_var_pdf;
```

```
 int    f_dev_pdf;
 int    r_rho_pdf;
 int    r_var_pdf;
 int    r_dev_pdf;
 int    q_rho_pdf;
 int    q_var_pdf;
 int    q_dev_pdf;
 int    Trecover;
 vector  cv(1,n_par);
 number  f_rho_cv;
 number  f_var_cv;
 number  f_dev_cv;
 number  r_rho_cv;
 number  r_var_cv;
 number  r_dev_cv;
 number  q_rho_cv;
 number  q_var_cv;
 number  q_dev_cv;
 number  r_dev_proj_cv;
 number spawn_time;
 vector index_time(1,n_index_series);
 vector effort_obs(1,nyears_past);
 vector F_proj_cv(1,nyears_proj);
LOCAL_CALCS
 cout << "reformat parameter control matrices" << endl;
 if(effort_pdf != 0) effort_obs=column(effort_inp,1); else effort_obs=1.0;
 if(effort_pdf != -1) effort_obs/=max(effort_obs);
 if(nyears_proj > 0) F_proj_cv=column(in_prj,2);
 best_guess=column(par_specs,2);  iph=ivector(column(par_specs,5)); pdf=ivector(column(par_specs,6)); cv=column(par_specs,7);
nature=ivector(column(par_specs,1));
 f_rho_best_guess=f_rho_specs(1); f_rho_iph=int(f_rho_specs(4));    f_rho_pdf=int(f_rho_specs(5));    f_rho_cv=f_rho_specs(6);
 f_var_best_guess=f_var_specs(1); f_var_iph=int(f_var_specs(4));    f_var_pdf=int(f_var_specs(5));    f_var_cv=f_var_specs(6);
 f_dev_best_guess=f_dev_specs(1); f_dev_iph=int(f_dev_specs(4));    f_dev_pdf=int(f_dev_specs(5));    f_dev_cv=f_dev_specs(6);
 r_rho_best_guess=r_rho_specs(1); r_rho_iph=int(r_rho_specs(4));    r_rho_pdf=int(r_rho_specs(5));    r_rho_cv=r_rho_specs(6);
 r_var_best_guess=r_var_specs(1); r_var_iph=int(r_var_specs(4));    r_var_pdf=int(r_var_specs(5));    r_var_cv=r_var_specs(6);
 r_dev_best_guess=r_dev_specs(1); r_dev_iph=int(r_dev_specs(4));    r_dev_pdf=int(r_dev_specs(5));    r_dev_cv=r_dev_specs(6);
 q_rho_best_guess=q_rho_specs(1); q_rho_iph=int(q_rho_specs(4));    q_rho_pdf=int(q_rho_specs(5));    q_rho_cv=q_rho_specs(6);
 q_var_best_guess=q_var_specs(1); q_var_iph=int(q_var_specs(4));    q_var_pdf=int(q_var_specs(5));    q_var_cv=q_var_specs(6);
 q_dev_best_guess=q_dev_specs(1); q_dev_iph=int(q_dev_specs(4));    q_dev_pdf=int(q_dev_specs(5));    q_dev_cv=q_dev_specs(6);
 F_best_guess=0.2;
 spawn_time=spawn_season/12.0; index_time=index_season/12.0;
 npf=1; for (int j=1; j<=4;j++) npf(j)=j; // constants and polynomials
 npf(5)=1; npf(6)=2; npf(7)=2; // knife-edge, logistic and gamma selectivity curves
 npf(8)=6; npf(9)=3; // Chapman-Richards and Gompertz growth curves
 npf(12)=2; // power
 for (ie=1; ie<=n_par; ie++) { lower(ie)=par_specs(ie,3); upper(ie)=par_specs(ie,4);}  // JRO:  this should probably be changed to lower(ie)=par_specs(ie,3) and
upper(ie)=par_specs(ie,4)
 last_iph=max(iph);
 if(last_iph<f_rho_iph) last_iph=f_rho_iph; if(last_iph<f_var_iph) last_iph=f_var_iph; if(last_iph<f_dev_iph) last_iph=f_dev_iph;
 if(last_iph<r_rho_iph) last_iph=r_rho_iph; if(last_iph<r_var_iph) last_iph=r_var_iph; if(last_iph<r_dev_iph) last_iph=r_dev_iph;
 if(last_iph<q_rho_iph) last_iph=q_rho_iph; if(last_iph<q_var_iph) last_iph=q_var_iph; if(last_iph<q_dev_iph) last_iph=q_dev_iph;
 last_iph+=1;
 if((estimate_r_dev_proj<=0.000001 && estimate_r_dev_proj>=-0.000001) || nyears_proj<=0) r_dev_proj_iph=-1; else { r_dev_proj_iph=last_iph;
r_dev_proj_cv=estimate_r_dev_proj; }
 cout << r_dev_proj_cv << " " << estimate_r_dev_proj << endl;
 if(nyears_b4_change<=nyears_prehistoric) f_dev_iph=-1;
END_CALCS

// --------- derived variables pertaining to the data that are constant (don't need to be differentiated)----------//

 vector index_avg(1,n_index_series+1)
 vector index_min(1,n_index_series+1)
 vector n_index_points(1,n_index_series+1)
 vector one_vector_age(1,nages)
```

```
 number aic
 number temp_dble
 number n_data
LOCAL_CALCS
 cout << "Averaging and scaling index data" << endl;
 n_index_points=0.0; index_avg=0.0; index_min=1000.0;
 for (series=1; series<=n_index_series;series++) {
   for (y=1; y<=nyears_past;y++) {
     if(index_obs(y,series)>=0) {
       if(index_obs(y,series)>0.0 && index_obs(y,series)<index_min(series)) index_min(series)=index_obs(y,series);
       n_index_points(series) += 1.0 ;
     }
   }
   for (y=1; y<=nyears_past;y++) {
     if(index_pdf(series)==1 && index_obs(y,series)>=0 && index_obs(y,series)<index_min(series)) index_obs(y,series)=index_min(series)/1000.0; // no zero indices for lognormal
     if(index_obs(y,series)>=0) index_avg(series) += index_obs(y,series)/n_index_points(series);
   }
   for (y=1; y<=nyears_past;y++) if(index_units(series)<9 && index_scale(series)>0)  index_obs(y,series) /=  index_avg(series);
 }
 n_data=sum(n_index_points); n_series=n_index_series;
 zero=0.0; one=1.0; n_calls=0; i_zero=0; i_one=1; i_two=2; one_vector_age=one;
END_CALCS

////////////////////////////////////////////////////////////////////////////////
PARAMETER_SECTION
// Warning: all variables in this section must be floating point, not integers
//         integers may be declared locally by use of !! int i   etc..., but these will
//         not apply outside the parameter section (whereas the ADMB types number, vector
//         and matrix are global)
////////////////////////////////////////////////////////////////////////////////

// --------- specify estimated parameters --------------------------------------------------//

// get parameter bounds
LOCAL_CALCS
  cout << "specifying parameter bounds " << endl;
  dvector lb(1,n_par); lb=column(par_specs,3); dvector ub(1,n_par); ub=column(par_specs,4);
  double lb_f_rho; lb_f_rho=f_rho_specs(2); double ub_f_rho; ub_f_rho=f_rho_specs(3);
  double lb_f_var; lb_f_var=f_var_specs(2); double ub_f_var; ub_f_var=f_var_specs(3);
  double lb_f;     lb_f=f_dev_specs(2);     double ub_f;     ub_f=f_dev_specs(3);
  double lb_r_rho; lb_r_rho=r_rho_specs(2); double ub_r_rho; ub_r_rho=r_rho_specs(3);
  double lb_r_var; lb_r_var=r_var_specs(2); double ub_r_var; ub_r_var=r_var_specs(3);
  double lb_r;     lb_r=r_dev_specs(2);     double ub_r;     ub_r=r_dev_specs(3);
  double lb_q_rho; lb_q_rho=q_rho_specs(2); double ub_q_rho; ub_q_rho=q_rho_specs(3);
  double lb_q_var; lb_q_var=q_var_specs(2); double ub_q_var; ub_q_var=q_var_specs(3);
  double lb_q;     lb_q=q_dev_specs(2);     double ub_q;     ub_q=q_dev_specs(3);
  double lb_0;     lb_0=0.0001;             double ub_2;     ub_2=2.0;
END_CALCS

// set parameter vector to be estimated
!! cout << "specifying parameters " << endl;
!! cout << "par_est " << n_par << lb << endl ;
!! cout << "par_est " << n_par << ub << endl ;

 init_bounded_number_vector par_est(1,n_par,lb,ub,iph)
!!cout << "f_rho " << lb_f_rho << " " << ub_f_rho << " " << f_rho_iph << endl ;
 init_bounded_number f_rho(lb_f_rho,ub_f_rho,f_rho_iph)
!!cout << "f_var " << lb_f_var << " " << ub_f_var << " " << f_var_iph << endl ;
 init_bounded_number f_var(lb_f_var,ub_f_var,f_var_iph)
 init_bounded_vector f_devs(nyears_prehistoric+1,nyears_b4_change,lb_f,ub_f,f_dev_iph)
 init_bounded_number r_rho(lb_r_rho,ub_r_rho,r_rho_iph)
 init_bounded_number r_var(lb_r_var,ub_r_var,r_var_iph)
 init_bounded_vector r_devs(2,n_eras,lb_r,ub_r,r_dev_iph)
```

```
 init_bounded_number q_rho(lb_q_rho,ub_q_rho,q_rho_iph)
 init_bounded_number q_var(lb_q_var,ub_q_var,q_var_iph)
 init_bounded_matrix q_devs(1,nqs,2,n_eras,lb_q,ub_q,q_dev_iph)
 init_bounded_number Fspr20(lb_0,ub_2,last_iph)
 init_bounded_number Fspr30(lb_0,ub_2,last_iph)
 init_bounded_number Fspr40(lb_0,ub_2,last_iph)
 init_bounded_number Fspr50(lb_0,ub_2,last_iph)
 init_bounded_number Fspr60(lb_0,ub_2,last_iph)
 init_bounded_vector r_devs_proj(1,nyears_proj,lb_r,ub_r,r_dev_proj_iph)

// --------- derived variables that are functions of the parameters and therefore need derivatives ----------//

!! cout << "declaring state variables " << endl;
 vector f_apical(1,nyears_past)
 vector r(1,nyears)
 matrix q(1,nqs,1,n_eras)

!! cout << "state (process) expectations (deterministic part)" << endl;
 vector f_process(1,nyears_past)
 vector r_process(1,nyears_past)
 matrix q_process(1,nqs,1,n_eras)
 vector m(1,nages)
 vector w(1,nages)
 vector fecundity(1,nages)
 matrix s(1,nss,1,nages)

!! cout << "declare observation error parameters" << endl;
 vector i_d_var(1,nids)
 number overall_var

!! cout << "declare likelihoods and priors" << endl;
 vector index_lklhd(1,n_index_series+1)
 number f_lklhd
 number r_lklhd
 vector q_lklhd(1,nqs)
 number f_prior
 number f_hist_prior
 number m_prior
 number r_prior
 number w_prior
 number v_prior
 vector q_prior(1,nqs)
 vector s_prior(1,nss)
 vector i_d_prior(1,nids)
 number q_process_prior
 number r_process_prior
 number penalty
 number equilibrium_penalty
 number projection_penalty

!! cout << "declare misc. temporary variables" << endl;
 number pred
 number slope0
 number sprtemp
 number yprtemp
 number yprold
 number ytemp
 number yold
 number var
 number spr0
 number survive
 number plus_age
 number spr20
 number spr30
```

```
number spr40
number spr50
number spr60
number spr01
number sprmax
number sprmsy
number sprmat
number ypr20
number ypr30
number ypr40
number ypr50
number ypr60
number ypr01
number yprmax
number yprmsy
number yprmat
number Rspr20
number Rspr30
number Rspr40
number Rspr50
number Rspr60
number R01
number Rmax
number Rmsy
number Rmat
number Bmsy
number Bmat
number Bmax
number B01
number Bspr20
number Bspr30
number Bspr40
number Bspr50
number Bspr60
vector function_parameter(1,10)
vector recruitment_parameter(1,10)
vector f_hist_parameter(1,10)
vector growth_parameter(1,10)
vector M_parameter(1,10)
vector s_latest(1,nages)
vector s_equilibrium(1,nages)
vector ssb(1,nyears)
vector virgin_pred(1,n_index_series)
matrix index_pred(1,nyears_past,1,n_index_series)
matrix wbyage(1,nages,1,nyears)
matrix f(1,nages,1,nyears)
matrix n(1,nages+1,1,nyears+1)
vector F_proj(1,nyears_proj)
objective_function_value obj_func;

!! cout << "declare standard deviation report variables" << endl;
likeprof_number alpha
likeprof_number nat_mort
likeprof_number ban_effect
sdreport_number Fmsy
sdreport_number Fmat
sdreport_number Fmax
sdreport_number F01
sdreport_number Bcurrent
sdreport_number Fcurrent
sdreport_number BoverBspr20
sdreport_number BoverBspr30
sdreport_number BoverBspr40
sdreport_number BoverBspr50
```

```
sdreport_number BoverBspr60
sdreport_number BoverBmsy
sdreport_number BoverBmat
sdreport_number BoverBmax
sdreport_number BoverB01
sdreport_number FoverFspr20
sdreport_number FoverFspr30
sdreport_number FoverFspr40
sdreport_number FoverFspr50
sdreport_number FoverFspr60
sdreport_number FoverFmsy
sdreport_number FoverFmat
sdreport_number FoverFmax
sdreport_number FoverF01
sdreport_vector B(1,nyears)
sdreport_vector BoverBref(1,nyears)
sdreport_vector log_F_apex(1,nyears)
likeprof_number  Bpro_35
likeprof_number  Bpro_34
likeprof_number  Bpro_33
likeprof_number  Bpro_32
likeprof_number  Bpro_31
likeprof_number  Bpro_30
likeprof_number  Bpro_29
likeprof_number  Bpro_28
likeprof_number  Bpro_27
likeprof_number  Bpro_26
likeprof_number  Bpro_25
likeprof_number  Bpro_24
likeprof_number  Bpro_23
likeprof_number  Bpro_22
likeprof_number  Bpro_21
likeprof_number  Bpro_20
likeprof_number  Bpro_19
likeprof_number  Bpro_18
likeprof_number  Bpro_17
likeprof_number  Bpro_16
likeprof_number  Bpro_15
likeprof_number  Bpro_14
likeprof_number  Bpro_13
likeprof_number  Bpro_12
likeprof_number  Bpro_11
likeprof_number  Bpro_10
likeprof_number  Bpro_9
likeprof_number  Bpro_8
likeprof_number  Bpro_7
likeprof_number  Bpro_6
likeprof_number  Bpro_5
likeprof_number  Bpro_4
likeprof_number  Bpro_3
likeprof_number  Bpro_2
likeprof_number  Bpro_1
likeprof_number  Bpro0
likeprof_number  Bpro1
likeprof_number  Bpro2
likeprof_number  Bpro3
likeprof_number  Bpro4
likeprof_number  Bpro5
likeprof_number  Bpro6
likeprof_number  Bpro7
likeprof_number  Bpro8
likeprof_number  Bpro9
likeprof_number  Bpro10
likeprof_number  Bpro11
```

```
 likeprof_number  Bpro12
 likeprof_number  Bpro13
 likeprof_number  Bpro14
 likeprof_number  Bpro15
 matrix  sel_parm3(1,nss,1,2) ;           // selectivity parms (active and inactive) for S_47 MCMC output ;
 sdreport_vector  sel_parms(1,nss*2) ;
 likeprof_number  sFpre_a
 likeprof_number  sFpre_b
 likeprof_number  sFmod_a
 likeprof_number  sFmod_b
 likeprof_number  sREEF_a
 likeprof_number  sREEF_b
 likeprof_number  sOff_a
 likeprof_number  sOff_b
 likeprof_number  sEst_amx
 likeprof_number  sEst_cv
 likeprof_number  M_const
!! cout << "Initialize parameters" << endl;
////////////////////////////////////////////////////////////////////////////////
INITIALIZATION_SECTION
////////////////////////////////////////////////////////////////////////////////
  par_est best_guess

  f_rho   f_rho_best_guess
  f_var   f_var_best_guess
  f_devs  f_dev_best_guess
  r_rho   r_rho_best_guess
  r_var   r_var_best_guess
  r_devs  r_dev_best_guess
  q_rho   q_rho_best_guess
  q_var   q_var_best_guess
  q_devs  q_dev_best_guess
  Fspr20  F_best_guess
  Fspr30  F_best_guess
  Fspr40  F_best_guess
  Fspr50  F_best_guess
  Fspr60  F_best_guess
  r_devs_proj  r_dev_best_guess

////////////////////////////////////////////////////////////////////////////////
PROCEDURE_SECTION
////////////////////////////////////////////////////////////////////////////////
 define_parameters();
 calculate_biomass();
 calculate_the_objective_function();
 if(mceval_phase()) outputMCMC();

////////////////////////////////////////////////////////////////////////////////
// FUNCTION SECTION
////////////////////////////////////////////////////////////////////////////////

//--------------------------------------------------------------------------------
FUNCTION define_parameters
// defines process parameters and computes priors
//--------------------------------------------------------------------------------
  int j, y, inow, i_in, ihist;
  if(n_calls(1)==1) cout << "Define parameters" << endl;
  current_ph=current_phase(); n_calls(current_ph) += 1;
  i=1;                    // counters for keeping track of fixed (i) and estimated (ie) parameters, respectively

 //-------------compute expectations of state variables----------------//

 // apical fishing mortality rate during prehistoric period
   inow=i; f_hist_prior=0.; ihist=i;
```

```
   for ( j=1; j<=npf(nature(inow)); j++) {
 //    cout << "def parm " << "j= " << j << " inow= " << inow << " i_in= " << i_in << " ihist= " << ihist << " nature(inow)= " << nature(inow) << endl ;
     function_parameter(j)=get_function_parameters(i,i_in,iph(i),current_ph,par_est(i),pdf(i));
 //    cout << "func_parm(j)= " << function_parameter(j) << endl ;
 //    cout << "iph(i)= " << iph(i) << " current_ph= " << current_ph << " par_est(i)= " << par_est(i) << " pdf(i)= " << pdf(i) << endl ;
     if(pdf(i-1)>0 && iph(i-1)>0 && iph(i-1)<=current_ph) f_hist_prior+=neg_log_lklhd(f_hist_parameter(j),best_guess(i-1),one,one,zero,cv(i-1),zero,pdf(i-
1),variance_scale,i_zero,i_in);
   }
   for ( y=1; y<=nyears_prehistoric; y++) f_process(y)=function_value(nature(ihist),function_parameter,effort_obs(y));

 // apical fishing mortality rate during first modern period
   inow=i; f_prior=0.;
   for ( j=1; j<=npf(abs(nature(inow))); j++) {
     function_parameter(j)=get_function_parameters(i,i_in,iph(i),current_ph,par_est(i),pdf(i));
     if(pdf(i-1)>0 && iph(i-1)>0 && iph(i-1)<=current_ph) f_prior+=neg_log_lklhd(function_parameter(j),best_guess(i-1),one,one,zero,cv(i-1),zero,pdf(i-
1),variance_scale,i_zero,i_in);
   }
   if(nature(inow)<=-1) {
      // compute average F over last value[nature(inow)] years prior to modern period
      pred=0;
      for ( j=nyears_prehistoric+nature(inow)+1; j<=nyears_prehistoric; j++) pred+=f_process(j);
      pred=pred/double(-nature(inow));
   }
   for ( y=nyears_prehistoric+1; y<=nyears_b4_change; y++) {
     if(nature(inow)<=-1) f_process(y)=pred*function_parameter(1); // fishing mortality is proportional to average mortality rate in last years of historic time period
     else               f_process(y)=function_value(nature(inow),function_parameter,effort_obs(y)); // fishing mortality is a function of input effort
   }
    // add process errors to apical fishing mortality rates
   f_apical=f_process; f_lklhd=0.;
   if(active(f_devs)) {
     for (y=nyears_prehistoric+1; y<=nyears_b4_change;y++) {
       if(f_dev_pdf==1) f_apical(y)=f_process(y)*mfexp(f_devs(y)); else f_apical(y)=f_process(y)+f_devs(y);
     }
   }

 // expected apical fishing mortality rate after change during modern period (e.g., moratorium)
   inow=i;
   for ( j=1; j<=npf(abs(nature(inow))); j++) {
     function_parameter(j)=get_function_parameters(i,i_in,iph(i),current_ph,par_est(i),pdf(i));
     if(pdf(i-1)>0 && iph(i-1)>0 && iph(i-1)<=current_ph) f_prior+=neg_log_lklhd(function_parameter(j),best_guess(i-1),one,one,zero,cv(i-1),zero,pdf(i-
1),variance_scale,i_zero,i_in);
   }
   if(nature(inow)<=-1) {
      // compute average F over last value[nature(inow)] years prior to modern period
      pred=0;
      for ( j=nyears_b4_change+nature(inow)+1; j<=nyears_b4_change; j++) pred+=f_apical(j);
      pred=pred/double(-nature(inow));
   }
   for ( y=nyears_b4_change+1; y<=nyears_past; y++)  {
     if(nature(inow)<=-1) f_apical(y)=pred*function_parameter(1); // fishing mortality is proportional to mortality rate in last year of first modern time period
     else               f_apical(y)=function_value(nature(inow),function_parameter,effort_obs(y)); // fishing mortality is a function of input effort
   }
   ban_effect=100*(1-function_parameter(1)); // created for goliath grouper formulation

 // expected natural mortality rate by age
   inow=i; m_prior=0.; imn=i;
   for ( j=1; j<=npf(nature(inow)); j++) {
     M_parameter(j)=get_function_parameters(i,i_in,iph(i),current_ph,par_est(i),pdf(i));
     if(pdf(i-1)>0 && iph(i-1)>0 && iph(i-1)<=current_ph) m_prior+=neg_log_lklhd(M_parameter(j),best_guess(i-1),one,one,zero,cv(i-1),zero,pdf(i-
1),variance_scale,i_zero,i_in);
   }

 // expected relative recruitment
   inow=i; r_prior=0.; irn=i;
```

```
   for ( j=1; j<=npf(nature(inow)); j++) {
     recruitment_parameter(j)=get_function_parameters(i,i_in,iph(i),current_ph,par_est(i),pdf(i));
     if(pdf(i-1)>0 && iph(i-1)>0 && iph(i-1)<=current_ph) r_prior+=neg_log_lklhd(recruitment_parameter(j),best_guess(i-1),one,one,zero,cv(i-1),zero,pdf(i-
1),variance_scale,i_zero,i_in);
   }

  // expected growth
   inow=i; w_prior=0.; iwn=i;
   for ( j=1; j<=npf(nature(inow)); j++) {
     growth_parameter(j)=get_function_parameters(i,i_in,iph(i),current_ph,par_est(i),pdf(i));
     if(pdf(i-1)>0 && iph(i-1)>0 && iph(i-1)<=current_ph) w_prior+=neg_log_lklhd(growth_parameter(j),best_guess(i-1),one,one,zero,cv(i-1),zero,pdf(i-
1),variance_scale,i_zero,i_in);
   }
   for ( a=1; a<=nages; a++) {
     w(a)=function_value(nature(i-1),growth_parameter,double(age(1)+a)-1+0.5);
     if(fecundity_input(a)>=0) fecundity(a)=fecundity_input(a); else fecundity(a)=function_value(nature(i-1),growth_parameter,double(age(1)+a)-1+spawn_time);
     m(a)=function_value(nature(imn),M_parameter,w(a)); //cout << m(a) << M_parameter(1) << endl;
   }
   if(m(nages)>0) plus_age=age(2)+mfexp(-m(nages))/(1-mfexp(-m(nages))); else plus_age=2*age(2);
   w(nages)=function_value(nature(iwn),growth_parameter,plus_age+0.5);
   if(fecundity_input(nages)>=0) fecundity(nages)=fecundity_input(nages); else fecundity(nages)=function_value(nature(i-
1),growth_parameter,plus_age+spawn_time);

  // virgin spawner-per recruit
   spr0=spr(maturity,fecundity,m,one_vector_age,zero,spawn_time,nages);

  // expected q
   q_prior=0.;
   for (set=1; set<=nqs; set++) {
     inow=i;
     for ( j=1; j<=npf(nature(inow)); j++) {
       function_parameter(j)=get_function_parameters(i,i_in,iph(i),current_ph,par_est(i),pdf(i));
       if(pdf(i-1)>0 && iph(i-1)>0 && iph(i-1)<=current_ph) q_prior(set)+=neg_log_lklhd(function_parameter(j),best_guess(i-1),one,one,zero,cv(i-1),zero,pdf(i-
1),variance_scale,i_zero,i_in);
     }
     for ( y=1; y<=n_eras; y++) {
       q_process(set,y)=function_value(nature(i-1),function_parameter,one);
     }
   }

  // expected selectivity/vulnerability
   s_prior=0.;
   for (set=1; set<=nss; set++) {
     inow=i;
     for ( j=1; j<=npf(nature(inow)); j++) {
       function_parameter(j)=get_function_parameters(i,i_in,iph(i),current_ph,par_est(i),pdf(i));
       sel_parm3(set,j)=function_parameter(j) ; // S_47 save selectivity estimates for MCMC output ;
       if(pdf(i-1)>0 && iph(i-1)>0 && iph(i-1)<=current_ph) s_prior(set)+=neg_log_lklhd(function_parameter(j),best_guess(i-1),one,one,zero,cv(i-1),zero,pdf(i-
1),variance_scale,i_zero,i_in);
      }
     for ( a=1; a<=nages; a++) s(set,a)=function_value(nature(i-1),function_parameter,double(age(1)+a-1));
    }
    jj=1 ;
    for (set=1; set<=nss; set++) {
      sel_parms(jj)   = sel_parm3(set,1) ; // S_47 save selectivity parameters estimates for MCMC output ;
      sel_parms(jj+1) = sel_parm3(set,2) ;
      jj=jj+2 ;
    }
                                                        sFpre_a  = sel_parms(1) ;
                                                        sFpre_b  = sel_parms(2) ;
                                                        sFmod_a  = sel_parms(3) ;
                                                        sFmod_b  = sel_parms(4) ;
                                                        sREEF_a  = sel_parms(7) ;
                                                        sREEF_b  = sel_parms(8) ;
```

```
                                                      sOff_a   = sel_parms(11) ;
                                                      sOff_b   = sel_parms(12) ;
                                                      sEst_amx = sel_parms(13) ;
                                                      sEst_cv  = sel_parms(14) ;

  // index observation variance
    i_d_prior=0.;
    for (set=1; set<=nids; set++) {
      i_d_var(set)=get_function_parameters(i,i_in,iph(i),current_ph,par_est(i),pdf(i));
      if(pdf(i-1)>0 && iph(i-1)>0 && iph(i-1)<=current_ph) i_d_prior(set)+=neg_log_lklhd(i_d_var(set),best_guess(i-1),one,one,zero,cv(i-1),zero,pdf(i-
1),variance_scale,i_zero,i_in);
    }

  // overall variance
    overall_var=get_function_parameters(i,i_in,iph(i),current_ph,par_est(i),pdf(i));
    if(best_guess(i-1)<0) i_in = -i_in; // special case for negative cv's
    if(pdf(i-1)>0 && iph(i-1)>0 && iph(i-1)<=current_ph) v_prior=neg_log_lklhd(overall_var,best_guess(i-1),one,one,zero,cv(i-1),zero,pdf(i-
1),variance_scale,i_zero,i_in);

  //-------------incorporate process errors----------------//

  // priors for apical fishing mortality rate process parameters
    if(active(f_rho)) f_prior+=neg_log_lklhd(f_rho,f_rho_best_guess,one,one,zero,f_rho_cv,zero,f_rho_pdf,variance_scale,i_zero,i_in);
    if(active(f_var)) f_prior+=neg_log_lklhd(f_var,f_var_best_guess,one,one,zero,f_var_cv,zero,f_var_pdf,variance_scale,i_zero,i_in);

  // priors for recruitment process parameters
    r_process_prior=0.;
    if(active(r_rho)) r_process_prior+=neg_log_lklhd(r_rho,r_rho_best_guess,one,one,zero,r_rho_cv,zero,r_rho_pdf,variance_scale,i_zero,i_in);
    if(active(r_var)) r_process_prior+=neg_log_lklhd(r_var,r_var_best_guess,one,one,zero,r_var_cv,zero,r_var_pdf,variance_scale,i_zero,i_in);

  // priors for q process parameters
    q_process_prior=0.;
    if(active(q_rho)) q_process_prior+=neg_log_lklhd(q_rho,q_rho_best_guess,one,one,zero,q_rho_cv,zero,q_rho_pdf,variance_scale,i_zero,i_in);
    if(active(q_var)) q_process_prior+=neg_log_lklhd(q_var,q_var_best_guess,one,one,zero,q_var_cv,zero,q_var_pdf,variance_scale,i_zero,i_in);

  // historical (1) and subsequent modern-era catchability coefficients
    q=q_process; q_lklhd=0.;
    if(active(q_devs)) {
      for (set=1; set<=nqs; set++) {
        for (y=2; y<=n_eras; y++) {
          if(q_dev_pdf==1) q(set,y)=q_process(set,y)*mfexp(q_devs(set,y)); else q(set,y)=q_process(set,y)+q_devs(set,y);
        }
      }
    }

 //-----------------------------------------------------------------------------------
FUNCTION calculate_biomass
 //-----------------------------------------------------------------------------------

  if(n_calls(1)==1) cout << "Calculate biomass" << endl;
  index_pred=zero ; ssb=zero; r_process=one; r_lklhd=zero;

  // calculate_fishing_mortality on all age classes (first two selectivity sets designated for historical and modern era fisheries)
  for (y=1; y<=nyears_past; y++) {
    if(y<=nyears_prehistoric) set=1; else set=2;
    for (a=1; a<=nages; a++) f(a,y)=f_apical(y)*s(set,a);
  }

  // initial population structure assuming population at virgin levels (process errors assumed to average OUT)
  if(n_calls(1)==1) cout << "Calculating virgin abundance" << endl;
  n(1,1)=one;
  for (a=2; a<=nages; a++) {
    n(a,1)=n(a-1,1)*mfexp(-m(a-1));
    if(a==nages) n(a,1)=n(a,1)/(one-mfexp(-m(a)));
```

```
 }

 // time trajectory of population structure
 if(n_calls(1)==1) cout << "Calculating subsequent abundance" << endl;
 for (y=1; y<=nyears_past; y++)  {
  // distinguish historical period (no process errors) from modern epoch (has process errors)
  if(y<=nyears_prehistoric) t=1;
  else t=y-nyears_prehistoric+1;

  // update recruitment
  if(y>age(1)) r_process(y)=function_value(nature(irn),recruitment_parameter,ssb(y-age(1))); // x-year-olds in year x+1 were produced in year 1 (for which one can compute the ssb),
  if(active(r_devs) && t>1) {
   if(r_dev_pdf==1) r(y)=r_process(y)*mfexp(r_devs(t)); else r(y)=r_process(y)+r_devs(t);
  }
  else r(y)=r_process(y);
  n(1,y)=r(y);

  virgin_pred=0.0;
  for (a=1; a<=nages; a++) {

   // average fecundity of plus-group during spawning season
   if(a==nages) {
    w(a)=function_value(nature(iwn),growth_parameter,plus_age+0.5);
    if(fecundity_input(a)>=0) fecundity(a)=fecundity_input(a); else fecundity(a)=function_value(nature(iwn),growth_parameter,plus_age+spawn_time);
   }
   wbyage(a,y)=w(a);

  // predicted indices
   for (series=1; series<=n_index_series; series++) {
    if(index_pdf(series)>0) {
     if(index_units(series)==1)         index_pred(y,series) +=      q(iqs(series),t)*s(iss(series),a)*n(a,y)*mfexp(-(m(a)+f(a,y))*index_time(series));
     else if(index_units(series)==2)    index_pred(y,series) += w(a)*q(iqs(series),t)*s(iss(series),a)*n(a,y)*mfexp(-(m(a)+f(a,y))*index_time(series));
     else if(index_units(series)==10) { index_pred(y,series) +=      q(iqs(series),t)*s(iss(series),a)*n(a,y)*mfexp(-(m(a)+f(a,y))*index_time(series));
                                 virgin_pred(series)  +=                    s(iss(series),a)*n(a,1)*mfexp(-(m(a))*index_time(series)); }
     else if(index_units(series)==20) { index_pred(y,series) += w(a)*q(iqs(series),t)*s(iss(series),a)*n(a,y)*mfexp(-(m(a)+f(a,y))*index_time(series));
                                 virgin_pred(series)  += w(a)*               s(iss(series),a)*n(a,1)*mfexp(-(m(a))*index_time(series)); }
    }
   }

   // relative spawning biomass
   ssb(y)+=maturity(a)*fecundity(a)*n(a,y)*mfexp(-(m(a)+f(a,y))*spawn_time)/spr0;

   // abundance at beginning of next year
   n(a+1,y+1)=n(a,y)*mfexp(-m(a)-f(a,y)); // t=1 in historical period, t=year in modern period
  } //age

  // plus group age and abundance
  plus_age=(age(2)*n(nages,y+1)+(plus_age+1)*n(nages+1,y+1))/(n(nages,y+1)+n(nages+1,y+1));
  n(nages,y+1) += n(nages+1,y+1);

  // scale indices
  for (series=1; series<=n_index_series; series++)
   if(index_pdf(series)>0 && index_units(series)>9) index_pred(y,series) /= virgin_pred(series);

 } //year

 // Projections and equilibrium statistics based on overall selectivity during last year
 if (sd_phase) {
  if(n_calls(1)==1) cout << "starting projections" << endl;
  for (a=1; a<=nages; a++) s_latest(a)=f(a,nyears_past);
  Fcurrent=max(s_latest); Bcurrent=ssb(nyears_past); if(Fcurrent>0) s_latest=s_latest/Fcurrent;
  for (y=1; y<=nyears_past; y++) { if(f_apical(y)>0) log_F_apex(y)=log(f_apical(y)); else log_F_apex(y)=-999; }
  alpha=recruitment_parameter(1)+1; nat_mort=m(1); Trecover=-1; M_const=sum(m) ;
```

```
if(reference_selectivity==1) s_equilibrium=s_latest;
else s_equilibrium=maturity;

if (last_phase()) {

 // Compute equilibrium statistics
  if(n_calls(1)==1) cout << "Calculating equilibrium statistics" << endl;
  F01=goldensection(3, Fspr30, w, m, s_equilibrium, nages, maturity, fecundity, spawn_time, spr0, nature(irn),recruitment_parameter );
  Fmax=goldensection(i_one, Fspr20, w, m, s_equilibrium, nages, maturity, fecundity, spawn_time, spr0, nature(irn),recruitment_parameter );
  Fmsy=goldensection(i_two, Fspr40, w, m, s_equilibrium, nages, maturity, fecundity, spawn_time, spr0, nature(irn),recruitment_parameter );
  Fmat =goldensection(i_two, Fspr40, w, m, maturity, nages, maturity, fecundity, spawn_time, spr0, nature(irn),recruitment_parameter );
  sprmat=spr(maturity,fecundity,m,maturity,Fmat,spawn_time,nages)/spr0;
  spr01=spr(maturity,fecundity,m,s_equilibrium,F01,spawn_time,nages)/spr0;
  sprmax=spr(maturity,fecundity,m,s_equilibrium,Fmax,spawn_time,nages)/spr0;
  sprmsy=spr(maturity,fecundity,m,s_equilibrium,Fmsy,spawn_time,nages)/spr0;
  spr20=spr(maturity,fecundity,m,s_equilibrium,Fspr20,spawn_time,nages)/spr0;
  spr30=spr(maturity,fecundity,m,s_equilibrium,Fspr30,spawn_time,nages)/spr0;
  spr40=spr(maturity,fecundity,m,s_equilibrium,Fspr40,spawn_time,nages)/spr0;
  spr50=spr(maturity,fecundity,m,s_equilibrium,Fspr50,spawn_time,nages)/spr0;
  spr60=spr(maturity,fecundity,m,s_equilibrium,Fspr60,spawn_time,nages)/spr0;
  yprmat=ypr(w,m,maturity,Fmat,nages);
  ypr01=ypr(w,m,s_equilibrium,F01,nages);
  yprmax=ypr(w,m,s_equilibrium,Fmax,nages);
  yprmsy=ypr(w,m,s_equilibrium,Fmsy,nages);
  ypr20=ypr(w,m,s_equilibrium,Fspr20,nages);
  ypr30=ypr(w,m,s_equilibrium,Fspr30,nages);
  ypr40=ypr(w,m,s_equilibrium,Fspr40,nages);
  ypr50=ypr(w,m,s_equilibrium,Fspr50,nages);
  ypr60=ypr(w,m,s_equilibrium,Fspr60,nages);
  Bmat  =equilibrium_ssb(nature(irn),recruitment_parameter,sprmat);    Rmat=Bmat/sprmat;
  Bspr20=equilibrium_ssb(nature(irn),recruitment_parameter,spr20);    Rspr20=Bspr20/spr20;
  Bspr30=equilibrium_ssb(nature(irn),recruitment_parameter,spr30);    Rspr30=Bspr30/spr30;
  Bspr40=equilibrium_ssb(nature(irn),recruitment_parameter,spr40);    Rspr40=Bspr40/spr40;
  Bspr50=equilibrium_ssb(nature(irn),recruitment_parameter,spr50);    Rspr50=Bspr50/spr50;
  Bspr60=equilibrium_ssb(nature(irn),recruitment_parameter,spr60);    Rspr60=Bspr60/spr60;
  B01   =equilibrium_ssb(nature(irn),recruitment_parameter,spr01);    R01   =B01   /spr01;
  Bmax  =equilibrium_ssb(nature(irn),recruitment_parameter,sprmax);   Rmax  =Bmax  /sprmax;
  Bmsy  =equilibrium_ssb(nature(irn),recruitment_parameter,sprmsy);   Rmsy  =Bmsy  /sprmsy;
  if(Bspr20 >0) BoverBspr20 =Bcurrent/Bspr20 ; else BoverBspr20 =-9.0;
  if(Bspr30 >0) BoverBspr30 =Bcurrent/Bspr30 ; else BoverBspr30 =-9.0;
  if(Bspr40 >0) BoverBspr40 =Bcurrent/Bspr40 ; else BoverBspr40 =-9.0;
  if(Bspr50 >0) BoverBspr50 =Bcurrent/Bspr50 ; else BoverBspr50 =-9.0;
  if(Bspr60 >0) BoverBspr60 =Bcurrent/Bspr60 ; else BoverBspr60 =-9.0;
  if(B01    >0) BoverB01    =Bcurrent/B01    ; else BoverB01    =-9.0;
  if(Bmax   >0) BoverBmax   =Bcurrent/Bmax   ; else BoverBmax   =-9.0;
  if(Bmsy   >0) BoverBmsy   =Bcurrent/Bmsy   ; else BoverBmsy   =-9.0;
  if(Bmat    >0) BoverBmat    =Bcurrent/Bmat    ; else BoverBmat    =-9.0;
  if(Fspr20 >0) FoverFspr20 =Fcurrent/Fspr20 ; else FoverFspr20 =-9.0;
  if(Fspr30 >0) FoverFspr30 =Fcurrent/Fspr30 ; else FoverFspr30 =-9.0;
  if(Fspr40 >0) FoverFspr40 =Fcurrent/Fspr40 ; else FoverFspr40 =-9.0;
  if(Fspr50 >0) FoverFspr50 =Fcurrent/Fspr50 ; else FoverFspr50 =-9.0;
  if(Fspr60 >0) FoverFspr60 =Fcurrent/Fspr60 ; else FoverFspr60 =-9.0;
  if(F01    >0) FoverF01    =Fcurrent/F01    ; else FoverF01    =-9.0;
  if(Fmax   >0) FoverFmax   =Fcurrent/Fmax   ; else FoverFmax   =-9.0;
  if(Fmsy   >0) FoverFmsy   =Fcurrent/Fmsy   ; else FoverFmsy   =-9.0;
  if(Fmat    >0) FoverFmat    =Fcurrent/Fmat    ; else FoverFmat    =-9.0;

 // Compute projections
  if(n_calls(1)==1 && nyears_proj>0) cout << "Making projections" << endl;
  for (y=nyears_past+1; y<=nyears; y++)  {
    t=y-nyears_past;
    r(y)=function_value(nature(irn),recruitment_parameter,ssb(y-age(1))); // x-year-olds in year x+1 were produced in year 1 (for which one can compute the ssb),
    if(active(r_devs_proj)) { if(r_dev_pdf==1) r(y)=r(y)*mfexp(r_devs_proj(t)); else r(y)=r(y)+r_devs_proj(t); }
    n(1,y)=r(y);
```

```
  for (a=1; a<=nages; a++) {
   // average fecundity of plus-group during spawning season
   if(a==nages) {
    w(a)=function_value(nature(iwn),growth_parameter,plus_age+0.5);
    if(fecundity_input(a)>=0) fecundity(a)=fecundity_input(a); else fecundity(a)=function_value(nature(iwn),growth_parameter,plus_age+spawn_time);
   }
   wbyage(a,y)=w(a);
   if(in_prj(t,1) >= 0)       F_proj(t)=in_prj(t,1);   // note: this approach assumes there is no implementation uncertainty
   else if(in_prj(t,1) > -0.2) F_proj(t)=F01;          //      I had a hard time getting runs with long projections to converge
   else if(in_prj(t,1) > -1)   F_proj(t)=Fmat;          //      when I treated F_proj as a random variable, even with low implementation uncertainty
   else if(in_prj(t,1) > -2)   F_proj(t)=Fmsy;
   else if(in_prj(t,1) > -3)   F_proj(t)=Fmax;
   else if(in_prj(t,1) > -21)  F_proj(t)=Fspr20;
   else if(in_prj(t,1) > -31)  F_proj(t)=Fspr30;
   else if(in_prj(t,1) > -41)  F_proj(t)=Fspr40;
   else if(in_prj(t,1) > -51)  F_proj(t)=Fspr50;
   else if(in_prj(t,1) > -61)  F_proj(t)=Fspr60;
   else                       F_proj(t)=Fcurrent;
   if(F_proj(t)>0) log_F_apex(y)=log(F_proj(t)); else log_F_apex(y)=-999;
   f(a,y)=F_proj(t)*s_latest(a);
   ssb(y)+=maturity(a)*fecundity(a)*n(a,y)*mfexp(-(m(a)+f(a,y))*spawn_time)/spr0;
   n(a+1,y+1)=n(a,y)*mfexp(-m(a)-f(a,y));
  } //age
  plus_age=(age(2)*n(nages,y+1)+(plus_age+1)*n(nages+1,y+1))/(n(nages,y+1)+n(nages+1,y+1));
  n(nages,y+1) += n(nages+1,y+1);
 } //year
 B=ssb; BoverBref=-9.0;
 if(Bref > 0)                      BoverBref = B/Bref ;
 else if(Bref > -0.2 && B01    > 0)  BoverBref = B/B01    ;
 else if(Bref > -1   && Bmat   > 0)  BoverBref = B/Bmat   ;
 else if(Bref > -2   && Bmsy   > 0)  BoverBref = B/Bmsy   ;
 else if(Bref > -3   && Bmax   > 0)  BoverBref = B/Bmax   ;
 else if(Bref > -21  && Bspr20 > 0)  BoverBref = B/Bspr20 ;
 else if(Bref > -31  && Bspr30 > 0)  BoverBref = B/Bspr30 ;
 else if(Bref > -41  && Bspr40 > 0)  BoverBref = B/Bspr40 ;
 else if(Bref > -51  && Bspr50 > 0)  BoverBref = B/Bspr50 ;
 else if(Bref > -61  && Bspr60 > 0)  BoverBref = B/Bspr60 ;
 else                              BoverBref = B/Bcurrent ;
 if(Bspr30 >0) BoverBspr30 =Bcurrent/Bspr30 ; else BoverBspr30 =-9.0;
 if(Bspr40 >0) BoverBspr40 =Bcurrent/Bspr40 ; else BoverBspr40 =-9.0;
 if(Bspr50 >0) BoverBspr50 =Bcurrent/Bspr50 ; else BoverBspr50 =-9.0;
 if(Bspr60 >0) BoverBspr60 =Bcurrent/Bspr60 ; else BoverBspr60 =-9.0;
 if(B01    >0) BoverB01    =Bcurrent/B01    ; else BoverB01    =-9.0;
 if(Bmax   >0) BoverBmax   =Bcurrent/Bmax   ; else BoverBmax   =-9.0;
 if(Bmsy   >0) BoverBmsy   =Bcurrent/Bmsy   ; else BoverBmsy   =-9.0;
 for(y=nyears_past; y<=nyears; y++) if(BoverBref(y)>=1.0) {Trecover=y+year(1)-1; break;}
 Bpro_35=BoverBref(nyears_past-35);
 Bpro_34=BoverBref(nyears_past-34);
 Bpro_33=BoverBref(nyears_past-33);
 Bpro_32=BoverBref(nyears_past-32);
 Bpro_31=BoverBref(nyears_past-31);
 Bpro_30=BoverBref(nyears_past-30);
 Bpro_29=BoverBref(nyears_past-29);
 Bpro_28=BoverBref(nyears_past-28);
 Bpro_27=BoverBref(nyears_past-27);
 Bpro_26=BoverBref(nyears_past-26);
 Bpro_25=BoverBref(nyears_past-25);
 Bpro_24=BoverBref(nyears_past-24);
 Bpro_23=BoverBref(nyears_past-23);
 Bpro_22=BoverBref(nyears_past-22);
 Bpro_21=BoverBref(nyears_past-21);
 Bpro_20=BoverBref(nyears_past-20);
 Bpro_19=BoverBref(nyears_past-19);
 Bpro_18=BoverBref(nyears_past-18);
```

```
    Bpro_17=BoverBref(nyears_past-17);
    Bpro_16=BoverBref(nyears_past-16);
    Bpro_15=BoverBref(nyears_past-15);
    Bpro_14=BoverBref(nyears_past-14);
    Bpro_13=BoverBref(nyears_past-13);
    Bpro_12=BoverBref(nyears_past-12);
    Bpro_11=BoverBref(nyears_past-11);
    Bpro_10=BoverBref(nyears_past-10);
    Bpro_9=BoverBref(nyears_past-9);
    Bpro_8=BoverBref(nyears_past-8);
    Bpro_7=BoverBref(nyears_past-7);
    Bpro_6=BoverBref(nyears_past-6);
    Bpro_5=BoverBref(nyears_past-5);
    Bpro_4=BoverBref(nyears_past-4);
    Bpro_3=BoverBref(nyears_past-3);
    Bpro_2=BoverBref(nyears_past-2);
    Bpro_1=BoverBref(nyears_past-1);
    Bpro0=BoverBref(nyears_past);
    if(nyears_proj<1) Bpro1=-BoverBref(nyears_past); else Bpro1=BoverBref(nyears_past+1);
    if(nyears_proj<2) Bpro2=-BoverBref(nyears_past); else Bpro2=BoverBref(nyears_past+2);
    if(nyears_proj<3) Bpro3=-BoverBref(nyears_past); else Bpro3=BoverBref(nyears_past+3);
    if(nyears_proj<4) Bpro4=-BoverBref(nyears_past); else Bpro4=BoverBref(nyears_past+4);
    if(nyears_proj<5) Bpro5=-BoverBref(nyears_past); else Bpro5=BoverBref(nyears_past+5);
    if(nyears_proj<6) Bpro6=-BoverBref(nyears_past); else Bpro6=BoverBref(nyears_past+6);
    if(nyears_proj<7) Bpro7=-BoverBref(nyears_past); else Bpro7=BoverBref(nyears_past+7);
    if(nyears_proj<8) Bpro8=-BoverBref(nyears_past); else Bpro8=BoverBref(nyears_past+8);
    if(nyears_proj<9) Bpro9=-BoverBref(nyears_past); else Bpro9=BoverBref(nyears_past+9);
    if(nyears_proj<10)Bpro10=-BoverBref(nyears_past); else Bpro10=BoverBref(nyears_past+10);
    if(nyears_proj<11) Bpro11=-1; else Bpro11=BoverBref(nyears_past+11);
    if(nyears_proj<12) Bpro12=-1; else Bpro12=BoverBref(nyears_past+12);
    if(nyears_proj<13) Bpro13=-1; else Bpro13=BoverBref(nyears_past+13);
    if(nyears_proj<14) Bpro14=-1; else Bpro14=BoverBref(nyears_past+14);
    if(nyears_proj<15) Bpro15=-1; else Bpro15=BoverBref(nyears_past+15);

   }// last_phase loop
  }// sd_phase loop

 //----------------------------------------------------------------------------------
FUNCTION calculate_the_objective_function
 //----------------------------------------------------------------------------------

  double penalty_wt;
  if(n_calls(1)==1) cout << "Calculating objective function" << endl;
  index_lklhd=0.; obj_func=0.; penalty=0; equilibrium_penalty=0; projection_penalty=0; penalty_wt=0.001;

 // ---------------observation errors----------------\\
 //
   for (y=1; y<=nyears_past; y++) {
    for (series=1; series<=n_index_series; series++) {
      // cout << "index " << y << " " << series << " " << index_obs(y,series) << " " << index_pred(y,series) << " " << index_cv(y,series) << endl;
     if(index_pdf(series)>0  && index_obs(y,series)>=0)

index_lklhd(series)+=neg_log_lklhd(index_obs(y,series),index_pred(y,series),one,one,zero,i_d_var(ivs(series))*overall_var,index_cv(y,series),index_pdf(series),varianc
e_scale,variance_modify,y);
      }
     }
   if(n_index_series>0) obj_func+=sum(index_lklhd);


 // ---------------process errors----------------\\
 //
     if(active(r_devs)) {
        if(variance_scale==1 && r_dev_pdf==1 && r_var<zero) var=log(1.0+square(r_var));
         else if(variance_scale==1 && r_dev_pdf==1 && r_var>zero) var=r_var;
```

```
        else if(variance_scale==2 && r_dev_pdf==2 && r_var>zero) var=r_var;
        else var=get_variance(one,r_var,zero,r_dev_pdf,variance_scale,i_zero);
        r_lklhd=square(r_devs(2));
        for(t=3; t<=n_eras; t++) r_lklhd += square(r_devs(t)-r_rho*r_devs(t-1));
        r_lklhd=0.5*(r_lklhd/var+double(n_eras-1)*log(var));
        obj_func += r_lklhd;
       }
 if(active(f_devs)) {
  if(variance_scale==1 && f_dev_pdf==1 && f_var<zero) var=log(1.0+square(f_var));
  else if(variance_scale==1 && f_dev_pdf==1 && f_var>zero) var=f_var;
  else if(variance_scale==2 && f_dev_pdf==2 && f_var>zero) var=f_var;
  else var=get_variance(f_process(nyears_prehistoric+1),f_var,zero,f_dev_pdf,variance_scale,i_zero);
  f_lklhd=square(f_devs(nyears_prehistoric+1));
  for(t=nyears_prehistoric+2; t<=nyears_b4_change; t++) f_lklhd += square(f_devs(t)-f_rho*f_devs(t-1));
  f_lklhd=0.5*(f_lklhd/var+double(nyears_b4_change-nyears_prehistoric)*log(var));
  obj_func += f_lklhd;
 }

 if(active(q_devs)) {
  for (set=1; set<=nqs; set++) {
    if(variance_scale==1 && q_dev_pdf==1 && overall_var<zero) var=log(1.0+square(q_var*overall_var));
    else if(variance_scale==1 && q_dev_pdf==1 && overall_var>zero) var=q_var*overall_var;
    else if(variance_scale==2 && q_dev_pdf==2 && overall_var>zero) var=q_var*overall_var;
    else var=get_variance(q(nyears_prehistoric+1,set),q_var*overall_var,zero,q_dev_pdf,variance_scale,i_zero);
    q_lklhd(set)=square(q_devs(2,set));
    for(t=3; t<=n_eras; t++) q_lklhd(set) += square(q_devs(t,set)-q_rho*q_devs(t-1,set));
    q_lklhd(set)=0.5*(q_lklhd(set)/var+(n_eras-1)*log(var));
  }
  obj_func += sum(q_lklhd);
 }

// ---------------Bayesian priors-------------------\\
//
 obj_func += m_prior+r_prior+f_prior+f_hist_prior+w_prior+v_prior+q_process_prior+r_process_prior+sum(q_prior)+sum(s_prior)+sum(i_d_prior);

// --------------other penalties--------------------\\
//
 for (y=1; y<=nyears_past; y++) if(r(y)<0) penalty += square(r(y))*1000.0;
 for (y=1; y<=n_eras; y++) for (set=1; set<=nqs; set++) if(q(set,y)<0) penalty += square(q(set,y))*1000.0;
 for (a=1; a<=nages; a++) {
  if(m(a)<0) penalty += square(m(a))*1000.0;
  if(w(a)<0) penalty += square(w(a))*1000.0;
  for (set=1; set<=nss; set++) if(s(set,a)<0) penalty += square(s(set,a))*1000.0;
 }
 if(current_ph<(last_iph-1)) {
  pred= max(f_apical) ;
  if(pred<0.1) penalty+=neg_log_lklhd(0.1,pred,one,one,zero,overall_var,zero,variance_scale,variance_scale,i_zero,y);
  if(pred>one) penalty+=neg_log_lklhd(one,pred,one,one,zero,overall_var,zero,variance_scale,variance_scale,i_zero,y);
 }
 else if(last_phase()) {
  //equilibrium_penalty+=neg_log_lklhd(0.2,spr20,one,one,zero,10*overall_var,zero,variance_scale,variance_scale,i_zero,y);
  equilibrium_penalty+=square(0.2-spr20)/penalty_wt;
  equilibrium_penalty+=square(0.3-spr30)/penalty_wt;
  equilibrium_penalty+=square(0.4-spr40)/penalty_wt;
  equilibrium_penalty+=square(0.5-spr50)/penalty_wt;
  equilibrium_penalty+=square(0.6-spr60)/penalty_wt;
  if(active(r_devs_proj)) {
    if(variance_scale==1 && r_dev_pdf==1 && r_dev_proj_cv<zero) var=log(1.0+square(r_dev_proj_cv));
    else if(variance_scale==1 && r_dev_pdf==1 && r_dev_proj_cv>zero) var=r_dev_proj_cv;
    else if(variance_scale==2 && r_dev_pdf==2 && r_dev_proj_cv>zero) var=r_dev_proj_cv;
    else var=get_variance(one,r_dev_proj_cv,zero,r_dev_pdf,variance_scale,i_zero);
    projection_penalty=square(r_devs_proj(1));
    for(t=2; t<=nyears_proj; t++) projection_penalty += square(r_devs_proj(t)-r_rho*r_devs_proj(t-1));
    projection_penalty=0.5*(projection_penalty/var+double(nyears_proj)*log(var));
```

```
   }
  }
  obj_func+=(penalty+equilibrium_penalty+projection_penalty);

 //----------------------------------------------------------------------------------
FUNCTION outputMCMC
 //----------------------------------------------------------------------------------
  ofstream MCMCout("MCMC.out",ios::app);
  MCMCout << alpha     << " " << nat_mort    << " " << Bpro_5     << " " << Bpro_4     << " " << Bpro_3     << " " << Bpro_2     << " " << Bpro_1     << " " << Bpro0       <<
" "
        << Bpro1     << " " << Bpro2      << " " << Bpro3      << " " << Bpro4      << " " << Bpro5      << " " << Bpro6      << " " << Bpro7      << " "
        << Bpro8     << " " << Bpro9      << " " << Bpro10     << " " << Bpro11     << " " << Bpro12     << " " << Bpro13     << " " << Bpro14     << " " << Bpro15      << " "
        << ban_effect << " " << BoverBmsy   << " " << BoverBspr20 << " " << BoverBspr30 << " " << BoverBspr40 << " " << BoverBspr50 << " " << BoverBspr60 << " "
        << Fmsy      << " " << FoverFmsy   << " " << FoverFspr20 << " " << FoverFspr30 << " " << FoverFspr40 << " " << FoverFspr50 << " " << FoverFspr60 << " "
        << yprmat    << " " << yprmsy     << " " << yprmax     << " " << ypr01      << " " << ypr20      << " "
        << ypr30     << " " << ypr40      << " " << ypr50      << " " << ypr60      << " " << Bspr50     << " " << Bmat       << " " << Bmsy       << " " << B01       << " "
        << sprmat    << " " << sprmsy     << " " << sprmax     << " " << spr01      << " " << obj_func   << " " << Bpro_35    << " " << Bpro_34    << " " << Bpro_33   << " " <<
Bpro_32 << " " << Bpro_31 << " "
        << Bpro_30   << " " << Bpro_29    << " " << Bpro_28    << " " << Bpro_27    << " " << Bpro_26    << " " << Bpro_25    << " " << Bpro_24    << " " << Bpro_23   << "
" << Bpro_22 << " " << Bpro_21 << " "
        << Bpro_20   << " " << Bpro_19    << " " << Bpro_18    << " " << Bpro_17    << " " << Bpro_16    << " " << Bpro_15    << " " << Bpro_14    << " " << Bpro_13   << "
" << Bpro_12 << " " << Bpro_11 << " "
        << Bpro_10   << " " << Bpro_9     << " " << Bpro_8     << " " << Bpro_7     << " " << Bpro_6     << " " << sel_parms   << " " << endl;
  MCMCout.close();


 ////////////////////////////////////////////////////////////////////////////////////
REPORT_SECTION   // uses regular C++ code
 ////////////////////////////////////////////////////////////////////////////////////
  n_par_phase=initial_params::nvarcalc(); // number of active parameters
  double aic=2.0*(value(obj_func-equilibrium_penalty-projection_penalty)+double(n_par_phase));
  cout << "Writing report" << endl;
  report << "Clay's Catch-free assessment model Datapoor_S_47p, SEDAR 47 modification, rev 11Apr2016 [JRO] " << endl;
  report << " added runtimes and vars. to MCMC - Start time for run: " << ctime(&start) <<  endl;

  adstring label;
  if(Bref > 0)                      label = "input value   ";
  else if(Bref > -0.2 && B01    > 0)  label = "B at F0.1     ";
  else if(Bref > -1   && Bmat   > 0)  label = "B at MSYadult ";
  else if(Bref > -2   && Bmsy   > 0)  label = "B at MSYfleet ";
  else if(Bref > -3   && Bmax   > 0)  label = "B at Fmax     ";
  else if(Bref > -21  && Bspr20 > 0)  label = "B at 20% spr  ";
  else if(Bref > -31  && Bspr30 > 0)  label = "B at 30% spr  ";
  else if(Bref > -41  && Bspr40 > 0)  label = "B at 40% spr  ";
  else if(Bref > -51  && Bspr50 > 0)  label = "B at 50% spr  ";
  else if(Bref > -61  && Bspr60 > 0)  label = "B at 60% spr  ";
  else                              label = "current level ";

  report.setf(ios::right, ios::adjustfield);
  report.setf(ios::scientific, ios::floatfield);
  report << "--------------------------------------------------------------------" << endl;
  report << "LIKELIHOOD RESULTS" << endl;
  report << "--------------------------------------------------------------------" << endl;
  report << "AIC               : " << setw(12) << setprecision(5) << aic << endl;

  if(n_data<(n_par_phase+2)) {
    report << "AICc (small sample) : " << " undefined (too few data)" << endl;
  }
  else {
    double aicc=aic+2.0*double(n_par_phase*(n_par_phase+1)/(n_data-n_par_phase-1));
    report << "AICc (small sample) : " << setw(12) << setprecision(5) << aicc << endl;
  }
  report << "                  " << endl;
  report << "OBJECTIVE FUNCTION  : " << setw(12) << setprecision(5) << obj_func << endl;
```

```
report << " Observation errors : " << endl;
report << "   Abundance indices: " ;
  for(series=1; series<=n_index_series-1; series++) report << setw(12) << setprecision(5) << index_lklhd(series) << " ";
  report << setw(12) << setprecision(5) << index_lklhd(n_index_series) << endl ;
report << " Process errors     : " << endl;
report << "   f fishing mort.  : " << setw(12) << setprecision(5) << f_lklhd  << endl;
report << "   r recruitment    : " << setw(12) << setprecision(5) << r_lklhd  << endl;
report << "   q catchability   : " ;
  for(set=1; set<=nqs-1; set++) report << setw(12) << setprecision(5) << q_lklhd(set) << " ";
  report << setw(12) << setprecision(5) << q_lklhd(nqs) << endl ;
report << " Priors             : " << endl;
report << "   F historical     : " << setw(12) << setprecision(5) << f_hist_prior  << endl;
report << "   F modern period  : " << setw(12) << setprecision(5) << f_prior  << endl;
report << "   m natural mort.  : " << setw(12) << setprecision(5) << m_prior  << endl;
report << "   r recruitment    : " << setw(12) << setprecision(5) << r_prior  << endl;
report << "   r process error  : " << setw(12) << setprecision(5) << r_process_prior  << endl;
report << "   k growth         : " << setw(12) << setprecision(5) << w_prior  << endl;
report << "   q catchability   : " ;
  for(set=1; set<=nqs-1; set++) report << setw(12) << setprecision(5) << q_prior(set) << " ";
  report << setw(12) << setprecision(5) << q_prior(nqs) << endl ;
report << "   q process error  : " << setw(12) << setprecision(5) << q_process_prior << endl;
report << "   s selectivity    : " ;
  for(set=1; set<=nss-1; set++) report << setw(12) << setprecision(5) << s_prior(set) << " ";
  report << setw(12) << setprecision(5) << s_prior(nss) << endl ;
report << "   index variances  : ";
  for(set=1; set<=nids-1; set++) report << setw(12) << setprecision(5) << i_d_prior(set) << " ";
  report << setw(12) << setprecision(5) << i_d_prior(nids) << endl ;
report << "   over-all var.    : " << setw(12) << setprecision(5) << v_prior << endl;
report << "  Penalties         : " << endl;
report << "   out-of-bounds    : " << setw(12) << setprecision(5) << penalty << endl;
report << "   equilibrium stats: " << setw(12) << setprecision(5) << equilibrium_penalty << endl;
report << "   projections      : " << setw(12) << setprecision(5) << projection_penalty << endl;
report << "              " << endl;
if(overall_var<zero) report << "OVERALL %CV        : " << setw(12) << setprecision(5) << -100.0*overall_var << endl;
else                 report << "OVERALL VARIANCE   : " << setw(12) << setprecision(5) << overall_var << endl;
report << "              " << endl; report << "              " << endl;
report << "LIFE-TIME REPRODUCTIVE RATE: " << setw(12) << setprecision(5) << alpha << endl;
report << "NATURAL MORTALITY RATE: " << setw(12) << setprecision(5) << m << endl;
report << "YEAR OF RECOVERY: " << setw(5) << setprecision(0) << Trecover << "  Cumulative_M = " << setprecision(6) << sum(m) << "      model estimated M = " <<
setw(12) << setprecision(5) << sum(m)/nages << endl;
report << "              " << endl; report << "              " << endl;
report << "NUMBER OF FUNCTION EVALUATIONS (THIS PHASE): " << setw(12) << setprecision(5) << n_calls(current_ph) << endl;
report << "NUMBER OF FUNCTION EVALUATIONS (CUMULATIVE): " << setw(12) << setprecision(5) << sum(n_calls) << endl;
report << "              " << endl; report << "              " << endl;

report << "-------------------------------------------------------------------" << endl;
report << "MANAGEMENT BENCHMARKS" << endl;
report << "Type          F          Y/R        SSB        SPR        R" << endl;
report << "-------------------------------------------------------------------" << endl;
report.setf(ios::scientific, ios::floatfield);
report << "VIRGIN   " << setw(13) << setprecision(4) << zero   << " " << zero   << " " << one    << " " << one    << " " << one    << endl;
report << "MSY adult" << setw(13) << setprecision(4) << Fmat   << " " << yprmat << " " << Bmat   << " " << sprmat << " " << Rmat   << endl;
report << "MSY fleet" << setw(13) << setprecision(4) << Fmsy   << " " << yprmsy << " " << Bmsy   << " " << sprmsy << " " << Rmsy   << endl;
report << "MAX Y/R  " << setw(13) << setprecision(4) << Fmax   << " " << yprmax << " " << Bmax   << " " << sprmax << " " << Rmax   << endl;
report << "F0.1     " << setw(13) << setprecision(4) << F01    << " " << ypr01  << " " << B01    << " " << spr01  << " " << R01    << endl;
report << "20% SPR  " << setw(13) << setprecision(4) << Fspr20 << " " << ypr20  << " " << Bspr20  << " " << spr20  << " " << Rspr20 << endl;
report << "30% SPR  " << setw(13) << setprecision(4) << Fspr30 << " " << ypr30  << " " << Bspr30  << " " << spr30  << " " << Rspr30 << endl;
report << "40% SPR  " << setw(13) << setprecision(4) << Fspr40 << " " << ypr40  << " " << Bspr40  << " " << spr40  << " " << Rspr40 << endl;
report << "50% SPR  " << setw(13) << setprecision(4) << Fspr50 << " " << ypr50  << " " << Bspr50  << " " << spr50  << " " << Rspr50 << endl;
report << "60% SPR  " << setw(13) << setprecision(4) << Fspr60 << " " << ypr60  << " " << Bspr60  << " " << spr60  << " " << Rspr60 << endl;
report << "              " << endl; report << "              " << endl;

report << "-------------------------------------------------------------------" << endl;
report << "PRESENT CONDITION OF STOCK" << endl;
```

```
report << "Type          F         SSB" << endl;
report << "-------------------------------------------------------------------" << endl;
report.setf(ios::scientific, ios::floatfield);
report << "CURRENT    " << setw(13) << setprecision(4) << Fcurrent       << " " << Bcurrent      << endl;
report << " /MSY adult" << setw(13) << setprecision(4) << FoverFmat       << " " << BoverBmat     << endl;
report << " /MSY fleet" << setw(13) << setprecision(4) << FoverFmsy       << " " << BoverBmsy     << endl;
report << " /MAX Y/R  " << setw(13) << setprecision(4) << FoverFmax       << " " << BoverBmax     << endl;
report << " /F0.1     " << setw(13) << setprecision(4) << FoverF01        << " " << BoverB01      << endl;
report << " /20% SPR  " << setw(13) << setprecision(4) << FoverFspr20     << " " << BoverBspr20   << endl;
report << " /30% SPR  " << setw(13) << setprecision(4) << FoverFspr30     << " " << BoverBspr30   << endl;
report << " /40% SPR  " << setw(13) << setprecision(4) << FoverFspr40     << " " << BoverBspr40   << endl;
report << " /50% SPR  " << setw(13) << setprecision(4) << FoverFspr50     << " " << BoverBspr50   << endl;
report << " /60% SPR  " << setw(13) << setprecision(4) << FoverFspr60     << " " << BoverBspr60   << endl;
report << "             " << endl; report << "             " << endl;

report << "-------------------------------------------------------------------" << endl;
report << "RELATIVE ABUNDANCE ESTIMATES by age" << endl;
report << "Year" << " ";
report.setf(ios::fixed, ios::floatfield);
for (a=1; a<=nages-1; a++) report << setw(8) << setprecision(0) << a+age(1)-1 << "     ";
report << setw(8) << setprecision(0) << nages+age(1)-1 << endl;
report << "-------------------------------------------------------------------" << endl;
for (y=1; y<=nyears; y++) {
  report.setf(ios::fixed, ios::floatfield);
  report << setw(4) << setprecision(0) << y+year(1)-1 << "  ";
  report.setf(ios::scientific, ios::floatfield);
  for (a=1; a<=nages-1; a++) report << setw(12) << setprecision(4) << n(a,y) << " ";
  report << setw(12) << setprecision(4) << n(nages,y) << endl;
}
report << "             " << endl; report << "             " << endl;

report << "-------------------------------------------------------------------" << endl;
report << "FISHING MORTALITY RATE ESTIMATES by age" << endl;
report << "Year" << " ";
report.setf(ios::fixed, ios::floatfield);
for (a=1; a<=nages-1; a++) report << setw(8) << setprecision(0) << a+age(1)-1 << "     ";
report << setw(8) << setprecision(0) << nages+age(1)-1 << endl;
report << "-------------------------------------------------------------------" << endl;
for (y=1; y<=nyears; y++) {
  report.setf(ios::fixed, ios::floatfield);
  report << setw(4) << setprecision(0) << y+year(1)-1 << "  ";
  report.setf(ios::scientific, ios::floatfield);
  for (a=1; a<=nages-1; a++) report << setw(12) << setprecision(4) << f(a,y) << " ";
  report << setw(12) << setprecision(4) << f(nages,y) << endl;
}
report << "             " << endl; report << "             " << endl;


report << "-------------------------------------------------------------------" << endl;
report << "RELATIVE SPAWNING BIOMASS ESTIMATES" << endl;
report << "Year" << "      " << "Spawning biomass (B) relative to" <<endl;
report << "Year" << "      " << "virgin level" << "      " << label << endl;
report.setf(ios::fixed, ios::floatfield);
report << "-------------------------------------------------------------------" << endl;
for (y=1; y<=nyears; y++) {
  report.setf(ios::fixed, ios::floatfield);
  report << setw(4) << setprecision(0) << y+year(1)-1 << "      ";
  report.setf(ios::scientific, ios::floatfield);
  report << setw(12) << setprecision(4) << ssb(y) << "      ";
  report << setw(12) << setprecision(4) << BoverBref(y) << endl;
}
report << "             " << endl; report << "             " << endl;
```

```
 report << "-------------------------------------------------------------------" << endl;
 report << "INDEX (CPUE) ESTIMATES" << endl;
 report << "Series" << "  Year" << "    Observed" << "    Predicted" << "   Variance" << "    Catchability" << endl;
 report << "-------------------------------------------------------------------" << endl;
 if(n_index_series<=0) report << "  None used" << endl;
 for(series=1; series<=n_index_series; series++) {
  report.setf(ios::fixed, ios::floatfield);
  if(index_pdf(series)==0)
   report << setw(4) << setprecision(0) << series << "    " << "Not used" << endl;
  else {
   for (y=1; y<=nyears_past; y++) {
    if(y<=nyears_prehistoric) t=1; else t=y-nyears_prehistoric+1;
    report.setf(ios::fixed, ios::floatfield);
    report << setw(4) << setprecision(0) << series << "    ";
    report << setw(4) << setprecision(0) << y+year(1)-1 << "  ";
    report.setf(ios::scientific, ios::floatfield);
    if(index_obs(y,series)>=0) report << setw(12) << setprecision(4) << index_obs(y,series); else report << setw(12) << setprecision(0) << -i_one;
    report << setw(12) << setprecision(4) << index_pred(y,series);
    if(index_obs(y,series)>=0) report  << "  " <<
get_variance(index_pred(y,series),i_d_var(ivs(series))*overall_var,index_cv(y,series),index_pdf(series),variance_scale,variance_modify) ; else report << "            ";
    report << setw(12) << setprecision(4) << q(iqs(series),t) << endl;
   }
  }
 }
 report << "              " << endl; report << "              " << endl;

 report << "-------------------------------------------------------------------" << endl;
 report << "WEIGHT ESTIMATES by age" << endl;
 report << "Year" << " ";
 report.setf(ios::fixed, ios::floatfield);
 for (a=1; a<=nages-1; a++) report << setw(8) << setprecision(0) << a+age(1)-1 << "     ";
 report << setw(8) << setprecision(0) << nages+age(1)-1 << endl;
 report << "-------------------------------------------------------------------" << endl;
 for (y=1; y<=nyears; y++) {
  report.setf(ios::fixed, ios::floatfield);
  report << setw(4) << setprecision(0) << y+year(1)-1 << "  ";
  report.setf(ios::scientific, ios::floatfield);
  for (a=1; a<=nages-1; a++) report << setw(12) << setprecision(4) << wbyage(a,y) << " ";
  report << setw(12) << setprecision(4) << wbyage(nages,y) << " " << endl;
 }
  report << "              " << endl ;
  report << endl << endl <<"starting time:  "<<ctime(&start);
  time(&finish);
  elapsed_time = difftime(finish,start);
  hour = long(elapsed_time)/3600;
  minute = long(elapsed_time)%3600/60;
  second = (long(elapsed_time)%3600)%60;
  report <<"finishing time: "<<ctime(&finish);
  report <<"This run took: ";
  report << hour <<" hours,  "<<minute<<" minutes, "<<second<<" seconds."<<endl<<endl<<endl;

  report << "that's all" << endl;

 ////////////////////////////////////////////////////////////////////////////////
RUNTIME_SECTION
 ////////////////////////////////////////////////////////////////////////////////
 convergence_criteria 1.e-2, 1.e-3, 1.e-3, 1.e-4, 1.e-6
 maximum_function_evaluations  50, 100, 200, 400, 1000

 ////////////////////////////////////////////////////////////////////////////////
TOP_OF_MAIN_SECTION
 ////////////////////////////////////////////////////////////////////////////////
 // set buffer sizes
 arrmblsize=500000;
```

```
 gradient_structure::set_MAX_NVAR_OFFSET(500);
 gradient_structure::set_NUM_DEPENDENT_VARIABLES(50000);
  time(&start); //this is to see how long it takes to run
  cout << endl << "Start time : " << ctime(&start) << endl;

 ////////////////////////////////////////////////////////////////////////////////
GLOBALS_SECTION
 ////////////////////////////////////////////////////////////////////////////////
 #include <admodel.h>
 #include <time.h>
  time_t start,finish;
  long hour,minute,second;
  double elapsed_time;

  double zero, one;
  dvector lower(1,1000);
  dvector upper(1,1000);
  int ifv,imn,imd,iwv,iwd,iwn,irv,ird,irn,i_zero,i_one,i_two,current_ph,series,set,y,a,t;

 //--------------------------------------------------------------------------------
  dvariable neg_log_lklhd(dvariable obs,dvariable pred,dvariable obs_1,dvariable pred_1,
                    dvariable rho,dvariable var,dvariable modifier,int pdf,int scale, int modify, int count)
 //--------------------------------------------------------------------------------
  {
    int oldcount;
    dvariable answer, alph, beta;

    // compute generic negative log-likelihood formulae
    if(obs<0.0 && count>=0)
      answer=0.0; // no data or process
    else {
      oldcount=count;
      if(count<0) count = -1*count;
      switch(pdf) {
        case 1: // autocorrelated lognormal
          //cout << obs << " " << pred << " " << obs_1 << " " << pred_1 << " " << var << endl;
          if(pred<=0 && oldcount>=0) pred=1.0E-10; // negative oldcount means this variable is supposed to be negative;
          if(var<0)                    var=log(1.0+square(var)) ;      // convert cv to variance on log scale
            else if(scale==2) var=log(1.0+var/square(pred)); // convert observation variance to log scale
            else if(scale==0) var=1.0;                  // automatic equal weighting
          if(modify>0) var+=modifier; else if(modify<0) var*=modifier;
          if(var<=0) cout << "Non-positive log-scale variance: " << var << " " << modifier << endl;
          if(count==1) answer= 0.5*( square(log(obs/pred+1.0E-10))/var + log(var) );
            else       answer= 0.5*( square( log(obs/pred+1.0E-10)-rho*log(obs_1/pred_1+1.0E-10) )/var + log(var) );
                                                                    break;
        case 2: // autocorrelated normal
          if(var<0)                    var=square(var*pred);      // convert cv to variance on observation scale
            else if(scale==1) var=square(pred)*(mfexp(var)-1); // convert log-scale variance to observation scale
            else if(scale==0) var=1.0;                  // automatic equal weighting
          if(modify>0) var+=modifier; else if(modify<0) var*=modifier;
          if(var<=0) cout << "Non-positive variance: " << var << " " << modifier << endl;
          if(count==1) answer= 0.5*( square(obs-pred)/var + log(var) );
            else       answer= 0.5*( square( (obs-pred)-rho*(obs_1-pred_1) )/var + log(var) );
          break;
        case 3: // uniform
          if(pred>=lower(count) && pred<=upper(count)) answer= log(upper(count)-lower(count));
          else answer=1.0e+32;
          break;
        case 4: // uniform on log-scale
          if(pred>=lower(count) && pred<=upper(count)) answer= log(log(upper(count)/lower(count)));
          else answer=1.0e+32;
          break;
        case 5: // gamma
          if(var<0)                    var=square(var*pred);      // convert cv to variance on observation scale
```

```
        else if(scale==1) var=square(pred)*(mfexp(var)-1); // convert log-scale variance to observation scale
        else if(scale==0) var=1.0;                 // automatic equal weighting
      if(modify>0) var+=modifier; else if(modify<0) var*=modifier;
      if(var<=0) cout << "Non-positive variance: " << var << " " << modifier << endl;
      alph=pred*pred/var; beta=var/pred;
      if(pred>0) answer= alph*log(beta)-(alph-1)*log(obs)+obs/beta+gammln(alph);
      else answer=1.0e+32;
      break;
    case 6: // beta
      if(var<0)                  var=square(var*pred);     // convert cv to variance on observation scale
        else if(scale==1) var=square(pred)*(mfexp(var)-1); // convert log-scale variance to observation scale
        else if(scale==0) var=1.0;                 // automatic equal weighting
      var=var/square(upper(count)-lower(count));           // rescale variance to beta (0,1) scale
      if(var<=0) cout << "Non-positive variance: " << var << endl;
      pred=(pred-lower(count))/(upper(count)-lower(count));     // rescale prediction to beta (0,1) scale
      obs=(obs-lower(count))/(upper(count)-lower(count));      // rescale observation to beta (0,1) scale
      alph=(pred*pred-pred*pred*pred-pred*var)/var; beta=alph*(1/obs-1);
      if(pred>=0 && pred<=1) answer= (1-alph)*log(obs)+(1-beta)*log(1-obs)-gammln(alph+beta)+gammln(alph)+gammln(beta);
      else answer=1.0e+32;
      break;
    default: // no such pdf accomodated
      cout << "The pdf must be either 1 (lognormal) or 2 (normal)" << endl;
      cout << "Presently it is " << pdf << endl;
      exit(0);
   }
  }
  return answer;
 }

//----------------------------------------------------------------------------------
 dvariable get_function_parameters(int &i, int &i_in, int iph, int current_phase, dvariable best, int pdf)
//----------------------------------------------------------------------------------
 {
  if(pdf==3 || pdf==4 || pdf==6) i_in=i; else i_in=i_one;
  i=i+1;
  return best;
 }

//----------------------------------------------------------------------------------
 dvariable function_value(int nature, dvar_vector par_func, dvariable obs)
//----------------------------------------------------------------------------------
 {
  dvariable answer;

  // constants
  if(nature==1 || nature==13 || nature==14 || nature==50)
    return par_func(1);

  // polynomial of degree nature-1
  else if( nature<5) {
    if(obs == zero) return par_func(1);
    else {
      answer=par_func(1);
      for(int j=2; j<nature; j++) answer=answer+par_func(j)*pow(obs,j-1);
      return answer+par_func(nature)*pow(obs,nature-1);  // trick to avoid calculating the derivative of the final sum twice
    }
  }

  // knife edge selectivity function
  else if( nature==5) {
    if(obs < par_func(1) ) return 0; else return 1;
  }

  // logisitic selectivity function
```

```
  else if( nature==6) {
    return 1/(1+mfexp(-(obs-par_func(1))/par_func(2)));
  }

  // gamma selectivity function in terms of mode and CV (assuming sel. of oldest age is constant)
  else if( nature==7) {
    return pow((mfexp(1-obs/par_func(1))*obs/par_func(1)),1.0/square(par_func(2))-1.0);
  }

  // Chapman-Richards growth function (reduces to vonB with par_func(4)=1
  else if( nature==8) {
    if(par_func(5)<=0 || par_func(1) <=0 || (1-par_func(4)*mfexp(-par_func(2)*(obs-par_func(3))))<=0) cout << "Error in growth parameters" << endl;
  // cout<<"Growth parms:  1 "<<par_func(1)<<" 2 "<<par_func(2)<<" 3 "<<par_func(3)<<" 4 "<<par_func(4)<<" 5 "<<par_func(5)<<" 6 "<<par_func(6)<<endl ;
    return mfexp(log(par_func(5))+par_func(6)*(log(par_func(1))+log(1-par_func(4)*mfexp(-par_func(2)*(obs-par_func(3))))/par_func(4))) ;
  }

  // Gompertz growth function
  else if( nature==9) {
    return par_func(1)*mfexp(-mfexp(-par_func(2)*(obs-par_func(3))));
  }

  // Beverton and Holt asymptotic function (par_func(1)=alpha-1)
  else if( nature==10) {
    return (par_func(1)+1)*obs/(1+obs*par_func(1));
  }

  // Ricker function (par_func(1)=alpha-1)
  else if( nature==11) {
    return obs*pow(par_func(1)+1,1-obs);
  }

  // power function y=a*x**b
  else if( nature==12) {
    if(obs == zero)return zero;
    else return par_func(1)*pow(obs,par_func(2));
  }

  // invalid function type
  else {
    cout << "No such function type accomodated" << endl; exit(0);
    return answer;
  }
 }

//--------------------------------------------------------------------------------
 double get_variance(dvariable pred,dvariable var,dvariable modifier, int pdf,int scale, int modify)
//-------------------------------------------------------------
 {
  switch(pdf) {
    case 1: // autocorrelated lognormal
      if(pred<0) pred=1.0E-10;
      if(var<0)                 var=log(1.0+var*var) ;      // convert cv to variance on log scale
        else if(scale==2) var=log(1.0+var/pred/pred); // convert observation variance to log scale
        else if(scale==0) var=1.0;                  // automatic equal weighting
        if(modify>0) var+=modifier; else if(modify<0) var*=modifier;
      break;
    case 2: // autocorrelated normal
      if(var<0)                 var=var*var*pred*pred;      // convert cv to variance on observation scale
        else if(scale==1) var=pred*pred*(mfexp(var)-1); // convert log-scale variance to observation scale
        else if(scale==0) var=1.0;                  // automatic equal weighting
        if(modify>0) var+=modifier; else if(modify<0) var*=modifier;
      break;
    default: // no such pdf accomodated
      exit(0);
```

```
  }
  return value(var);
 }


//---------------------------------------------------------------------------------
 dvariable spr(dvar_vector pp, dvar_vector ww, dvar_vector mm, dvar_vector ss, dvariable ff, dvariable tau ,int na)
//  Computes equilibrium spawn per recruit
//---------------------------------------------------------------------------------
 {
  dvariable answer;
  dvariable survive;
  dvariable zz;
  survive=1;
  answer=0;
  for (a=1; a<na; a++) {
   zz=mm(a)+ff*ss(a);
   answer+=pp(a)*ww(a)*mfexp(-zz*tau)*survive;
   survive=survive*mfexp(-zz);
  }
  zz=mm(na)+ff*ss(na);
  return answer+pp(na)*ww(na)*mfexp(-zz*tau)*survive/(1-mfexp(-zz));
 }

//---------------------------------------------------------------------------------
 dvariable ypr(dvar_vector ww, dvar_vector mm, dvar_vector ss, dvariable ff,int na)
//  Computes equilibrium yield per recruit
//---------------------------------------------------------------------------------
 {
  dvariable answer;
  dvariable survive;
  dvariable zz;
  survive=1;
  answer=0;
  for (a=1; a<na; a++) {
   zz=mm(a)+ff*ss(a);
   answer+=ww(a)*ss(a)*(1-mfexp(-zz))*survive/zz;
   survive=survive*mfexp(-zz);
  }
  zz=mm(na)+ff*ss(na);
  return ff*(answer+ww(na)*ss(na)*survive/zz);
 }

//---------------------------------------------------------------------------------
 dvariable equilibrium_ssb(int nature, dvar_vector par_func, dvariable spratio)
//  Computes equilibrium spawning biomass
//---------------------------------------------------------------------------------
 {
  // Beverton and Holt asymptotic function
  if( nature==10)      return ( (par_func(1)+1)*spratio-1.0 )/par_func(1);      // Beverton and Holt asymptotic function in terms of (alpha-1)
  else if( nature==11) return 1.0 + log(spratio)/log(par_func(1)+1);           // Ricker dome function in terms of (alpha-1)
 }

//---------------------------------------------------------------------------------
 dvariable goldensection(int typ, dvariable bf, dvar_vector ww, dvar_vector mm, dvar_vector ss, int na, dvar_vector mat, dvar_vector fec, dvariable tau, dvariable
spr00, int sr_nature, dvar_vector par_func)
//  Computes F's at maximum equilibrium yield per recruit and MSY
//---------------------------------------------------------------------------------
 {
  dvariable y1, y2, f0, f1, f2, f3, af, cf, sprtemp, slope0;
  double g1, g2;
  int iter;
  af=0.0001; cf=3.0; g1=0.618034; g2=0.381966;
  if(typ==i_two) {
```

```
    for (iter=1; iter<29; iter++) {
      cf=cf-0.1;
      sprtemp=spr(mat, fec, mm, ss, cf, tau, na)/spr00; y1=equilibrium_ssb(sr_nature,par_func,sprtemp)/sprtemp;
      if(y1>0) break;
    }
  }
  if(bf>(cf-0.1)) bf=bf-(bf-cf+0.1);
  f0=af; f3=cf;

  if(fabs(cf-bf)>fabs(bf-af)) { f1=bf; f2=bf+g2*(cf-bf); }
  else { f2=bf; f1=bf-g2*(bf-af); }
  y1= -ypr(ww, mm, ss, f1, na); y2= -ypr(ww, mm, ss, f2, na); // yield per recruit
  if(typ==3) { slope0=0.1*ypr(ww, mm, ss, 0.001, na); y1=fabs(slope0+y1+ypr(ww, mm, ss, f1-0.001, na)); y2=fabs(slope0+y2+ypr(ww, mm, ss, f2-0.001, na)); }
  if(typ==i_two) {
     sprtemp=spr(mat, fec, mm, ss, f1, tau, na)/spr00; y1=y1*equilibrium_ssb(sr_nature,par_func,sprtemp)/sprtemp;
     sprtemp=spr(mat, fec, mm, ss, f2, tau, na)/spr00; y2=y2*equilibrium_ssb(sr_nature,par_func,sprtemp)/sprtemp;
  }
  for (iter=1; iter<21; iter++) {
    if(y2<y1) {
      f0=f1; f1=f2; f2=g1*f1+g2*f3; y1=y2; y2= -ypr(ww, mm, ss, f2, na);
      if(typ==3) y2=fabs(slope0+y2+ypr(ww, mm, ss, f2-0.001, na));
      if(typ==i_two) {sprtemp=spr(mat, fec, mm, ss, f2, tau, na)/spr00; y2=y2*equilibrium_ssb(sr_nature,par_func,sprtemp)/sprtemp; }
    }
    else     {
      f3=f2; f2=f1; f1=g1*f2+g2*f0; y2=y1; y1= -ypr(ww, mm, ss, f1, na);
      if(typ==3) y1=fabs(slope0+y1+ypr(ww, mm, ss, f1-0.001, na));
      if(typ==i_two) {sprtemp=spr(mat, fec, mm, ss, f1, tau, na)/spr00; y1=y1*equilibrium_ssb(sr_nature,par_func,sprtemp)/sprtemp; }
    }
  }
  if(y1<y2) return f1;
  else return f2;
 }

FINAL_SECTION
 //Calculates how long is taking to run
 // this code is based on the Widow Rockfish model (from Erik H. Williams, NMFS-Santa Cruz, now Beaufort)
 time(&finish);
 elapsed_time = difftime(finish,start);
 hour = long(elapsed_time)/3600;
 minute = long(elapsed_time)%3600/60;
 second = (long(elapsed_time)%3600)%60;
 cout<<endl<<endl<<"starting time: "<<ctime(&start);
 cout<<"finishing time: "<<ctime(&finish);
 cout<<"This run took: ";
 cout<<hour<<" hours, "<<minute<<" minutes, "<<second<<" seconds."<<endl<<endl<<endl;
```

SEDAR

Southeast Data, Assessment, and Review

SEDAR 47

Southeastern U.S. Goliath Grouper

SECTION III: Research Recommendations

SEDAR
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

ASSESSMENT TEAM RESEARCH RECOMMENDATIONS

The Florida Fish and Wildlife Conservation Commission held a workshop on March 14-16, 2016 to discuss recent research findings about Goliath Grouper in Florida waters. Before the close of the workshop, the participants provided their recommendations about additional research that should be conducted on this species to improve our understanding of this species.

Monitoring activities

- Genetics: sample from fish from around Florida, and particularly the Florida West Coast. Samples could be from removal of a few scales, fin clips, or needle biopsy. Consider training at-sea observers/samplers to collect these samples. Eggs could also be collected and analyzed. A repeat of the recent kinship analysis (Tringali) on a periodic basis (5-10 years) would help monitor for changes in the degree of relatedness in the Florida Keys and southeast Florida.
- Spawning aggregations – locate additional sites where aggregations occur, using a combination of sound and Didson sonar imaging to verify spawning activity. This is work currently in progress. Monitor currently known spawning sites for trends over time.
- Mark-recapture data needs to be analyzed from the acoustic tagging data and about 800 sampled and visually tagged fish on the east and west coast of Florida. Investigate the possibility of using genetic mark-recapture methods.
- Expand sampling for nursery habitat and targeted juvenile sampling, possibly using an existing fishery-independent sampling program. Recommend to the NMFS Cooperative Research Program the possible funding of projects to work with the blue crab trap fishermen to collect fin clips (for genetics) when there is bycatch of Goliaths.
- Annual age sampling on the level of 400-500 specimens to monitor age structure of adults. The fin ray-age validation work is in progress.
- Fecundity research – in progress.
- Investigate the use of wildlife models like occupancy modelling. This may require more regular, systematic sampling than is currently available.
- Use visual data from the REEF survey, NMFS-UM Reef Visual Census (though they do not sample artificial reefs and wrecks), and expand the Great Goliath Grouper Counts from once a year in June to twice a year (June and September) to help identify locations with larger fish to sample.
- Drop cam video from FWRI's FIM program could expand the coverage of visual surveys, but would need to expand sampling to artificial reefs/wrecks.
- Investigate feasibility of mounting video cameras on charter and head boats to obtain information on bycatch (some preliminary work by Mote Marine Lab may be useful).
- Discuss with the FWC Artificial Reef Program the possibility of grant funding for Goliath work.
- Promote the collection of Goliath lengths from anglers (Snook and Game Fish Foundation app)
- Use GIS artificial reef data to identify all artificial reef structures and related data (materials, heights) in the Gulf of Mexico for developing a sampling plan.
- Extract dates and locations from log book data especially during spawning season that may identify new aggregations/spawning sites.

REVIEW PANEL RESEARCH RECOMMENDATIONS

The data used in the models mostly originated from Florida. Sparse data from elsewhere in the species (historical) range may be indicative of low population size (either as a function of natural distribution patterns or constriction of the population due to heavy fishing pressure), or poor sampling (including landings). This issue needs to be further explored as it has bearing on the geographical validity and usefulness of the assessment for regional management.

There was some concern by the RP about the method the Assessment Team used for combining the GGGC and the REEF survey as there is a potential for bias (e.g. potential for targeting sites with known high abundance of Goliath Grouper in the GGGC survey). How influential the inclusion of the GGGC data was to the outcome of the model should be explored.

Many of the research recommendations provided in the Assessment Report include research that would not necessarily improve future assessments for this species. The SEDAR 23 RW concluded that “The next benchmark assessment cannot be successfully completed without data from the research recommended by the Data, Assessment, and Review Panels.” The outcome of the SEDAR 47 benchmark assessment process indicates that much of this information is still needed in order to successfully complete an assessment for Goliath Grouper.

Specifically, research and monitoring efforts that could improve future assessments for Goliath Grouper include:

<u>Life history information</u>

Basic reproductive data is lacking throughout the species distribution. This includes size and age at maturity for each sex, sexual sequence with size and age for each sex, and fecundity. In the SEDAR 47 assessment, the reproduction functions used in the models made some strong assumptions about the maturity schedule and fecundity rates that were based on insufficient data. Greater resolution of data, especially maturity at size or age, would alleviate the impact of these assumptions for future assessments.

A limited research harvest should be considered to fill the remaining gaps in life history information for Goliath Grouper. Such a harvest should incorporate individuals from across the size spectrum, but should focus on larger individuals as they may be beneficial to ground truth the fin-ray aging techniques used for the offshore age composition, and to develop fecundity schedules.

Additional research on the age structure of the catch, especially in the offshore recreational fishery, is needed. The SEDAR 47 assessment used age composition of only 22 adult individuals that were caught by a research fishery and aged with fin rays (Koenig et al. 2013). This age composition was used for multiple parts of the assessment and may provide a large source of the assessment uncertainty. Cooperative research efforts with the recreational charter and headboat fisheries could be informative towards generating better information on the offshore recreational age composition.

Discard mortality estimates are needed across the species distribution. For the SEDAR 47 assessment, a fixed discard mortality estimate was applied to the post-moratorium harvest. However, the uncertainty around this estimate is unknown and may be substantial.

<u>Stock definition</u>

SEDAR 23 recommended that Goliath Grouper should be genetically sampled from areas across the stock range in the South Atlantic and Gulf of Mexico to allow for a more thorough examination of the current single stock definition. The SEDAR 47 RW was presented with a brief summary of these efforts, which seem to support that single stock definition. Like many other sources of information informing the

SEDAR 47 assessment, this information remains in progress or is incomplete and has not yet been vetted by peer review.

Examination of spawning aggregations over the entire distribution range should include seasonality, sex ratios, and individual fidelity.

Fishery independent sources of information are lacking or uncertain
The SEDAR 47 AT indicated that a specifically designed pre-fishery recruit survey (e.g. mangrove habitat) would help guide recruitment in the assessment model.

Develop and/or explore methods to take into account episodic mortality events.
One issue with the SEDAR 47 assessment was the use of a fixed value for natural mortality at age, despite evidence that episodic mortality events (i.e. cold-kills) have affected the Goliath Grouper population. Options to account for this mortality should be explored for future assessments. Methods used in other assessments (e.g. to address red tide events affecting red and gag grouper in the GOM) include incorporating episodic mortality events as a separate removal fleet. These methods may be appropriate for Goliath Grouper and could reduce some of the uncertainty in the estimates of natural mortality.

Reexamine methods of constructing historical removals
The use of length data from MRFSS/MRIP recreational Goliath Grouper removals need to be further examined. In SEDAR 47, the methods used to apply mean length of catch was inconsistent between years when there was missing and/or suspect data, and years with an estimate from the MRFSS/MRIP database. This introduced a significant amount of uncertainty to the harvest estimates.

Incorporate Data from Low Abundance Years into Indices
The Assessment Team discarded some of the data from index development due to very low catch rates in years adjacent to the moratorium. As a result, low abundance indices are removed from the assessment. Methods for incorporating these data into appropriate statistical models for standardization and development of indices should be explored.

SEDAR

Southeast Data, Assessment, and Review

SEDAR 47

U.S. Southeastern Goliath Grouper

SECTION IV: Review Workshop Report

June 2016

SEDAR
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

Table of Contents

1. INTRODUCTION

1.1 WORKSHOP TIME AND PLACE

The SEDAR 47 Review Workshop was held May 17-19, 2016 in St. Petersburg, Florida.

1.2 TERMS OF REFERENCE

1. Evaluate the data used in the assessment, including discussion of the strengths and weaknesses of data sources and decisions, and consider the following:
   a) Are data decisions made by the data providers and assessment analysts sound and robust?
   b) Are data uncertainties acknowledged, reported, and within normal or expected levels?
   c) Are data applied properly within the assessment model?
   d) Are input data series reliable and sufficient to support the assessment approach and findings?
2. Evaluate and discuss the strengths and weaknesses of the methods used to assess the stock, taking into account the available data, and considering the following:
   a) Are methods scientifically sound and robust?
   b) Are assessment models configured properly and used consistent with standard practices?
   c) Are the methods appropriate for the available data?
3. Evaluate the assessment findings and consider the following:
   a) Are abundance, exploitation, and biomass estimates reliable, consistent with input data and population biological characteristics, and useful to support status inferences?
   b) Is the stock overfished? What information helps you reach this conclusion?

c) Is the stock undergoing overfishing? What information helps you reach this conclusion?

d) Is there an informative stock recruitment relationship? Is the stock recruitment curve reliable and useful for evaluation of productivity and future stock conditions?

e) Are the quantitative estimates of the status determination criteria for this stock reliable? If not, are there other indicators that may be used to inform managers about stock trends and conditions?

4. Evaluate the stock projections, including discussing strengths and weaknesses, and consider the following:

   a) Are the methods consistent with accepted practices and available data?

   b) Are the methods appropriate for the assessment model and outputs?

   c) Are the results informative and robust, and useful to support inferences of probable future conditions?

   d) Are key uncertainties acknowledged, discussed, and reflected in the projection results?

5. Consider how uncertainties in the assessment, and their potential consequences, are addressed.

   - Comment on the degree to which methods used to evaluate uncertainty reflect and capture the significant sources of uncertainty in the population, data sources, and assessment methods.
   - Ensure that the implications of uncertainty in technical conclusions are clearly stated.

6. Consider the research recommendations provided and make any additional recommendations or prioritizations warranted.

   - Clearly denote research and monitoring that could improve future assessments

7. Consider whether the stock assessment constitutes the best scientific information available using the following criteria as appropriate: relevance, inclusiveness, objectivity, transparency, timeliness, verification, validation, and peer review of fishery management information.

8. Provide guidance on key improvements in data or modeling approaches that should be considered when scheduling the next assessment.

9. Prepare a Peer Review Summary summarizing the Panel's evaluation of the stock assessment and addressing each Term of Reference.

1.3 LIST OF PARTICIPANTS

Workshop Panel

Marcel Reichert, Chair .... Chair, SSC
Carolyn Belcher .... SSC
Mary Christman .... SSC

Robin Cook .... CIE Reviewer
Bob Ellis .... SSC
Desmond Kahn .... CIE Reviewer
Joel Rice .... CIE Reviewer

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Mike Murphy .... FWRI, St. Petersburg
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Staff
Julie Neer .... SEDAR
Ryan Rindone .... GMFMC Staff
Charlotte Schiaffo .... GMFMC Staff

1.4 LIST OF REVIEW WORKSHOP WORKING PAPERS AND DOCUMENTS

Documents Prepared for the Review Workshop			
SEDAR47-RW-01	The tpl file, data file, and control file for a Stochastic Stock Reduction Analysis (SSRA) program	Joseph Munyandorero	17 May 2016 Updated 24 May 2016

2. REVIEW PANEL REPORT

Review panel Report SEDAR 47 – Goliath Grouper Benchmark assessment

2. Executive Summary

The SEDAR 47 Goliath Grouper stock assessment presented to the Review Panel (RP) included two assessments models that were similar in terms of structure, but differed in the parameterization and use of the data. The assessment team acknowledged, and the RP agreed, that Goliath Grouper currently is a data poor species, and the approaches were selected accordingly. The two models were a “Stochastic Stock Reduction Analysis (SSRA)” and a “Catch Free” model. The RP concluded that the assessment does not constitute the best available scientific information and there is a significant level of uncertainty that has not been explored. Main areas of concern were the available data, treatment, and high uncertainty of the landings (catch) and the indices of relative abundance, and the structure of the chosen assessment models. As a result, the RP recommended that this assessment was not adequate to support status inferences, and as a result should not be used as a basis for management advice. However, a general increase in abundance since moratorium appears to be a reliable signal.

2.1 Terms of Reference

2.1.1. Evaluate the data used in the assessment, including discussion of the strengths and weaknesses of data sources and decisions, and consider the following:

a) Are data decisions made by the data providers and assessment analysts sound and robust?

There was no data workshop so this was difficult to evaluate; the analysts provided some detail, but the RP concluded that there are numerous issues with the data and its treatments, which are outlined below. The RP felt that this assessment could have benefitted from a data workshop (or webinars) to discuss important issues related to the data.

<u>Catch / Removals</u>
Observed fishery removals consisted of commercial landings (1950–1989), reported recreational landings (1981–1989) and recreational dead discards (1990- 2014) with an assumed release mortality of 5%; they were considered to be known without error. There are significant concerns with the removals data. Historical catch data is highly variable and discontinuous pre 1950. The assessment team also considered helpful accounts of landings back to 1884. These accounts mention a pattern of catches from U.S. waters being landed in Havana, which could be problematic for landings records. The account presents evidence of a significant commercial fishery for Goliaths averaging over 100 lbs. in the early decades of the twentieth century back to the late 19th century (see also McClenahan et al. 2009). Acknowledging the high uncertainty of historic landings, the RP suggested to assess the sensitivity of assumption of an earlier virgin stock (some time prior to 1950) to the assessment. Landings after that time period were mainly restricted to the state of Florida. These data were adjusted for the period of 1965-1984, based on suspicion of over-reporting by a single dealer in Lee County (FL); this suspicion was supported by visits from biologists to this dealer, who did not observe the amount of Goliath Grouper reported by the dealer. The reasoning behind the exact adjustment factor was explained; however, no sensitivities were given nor were alternative catch histories given. The specific percentages as chosen by the analysts were not examined in detail and subsequent analysis could result in different percentage reductions.
Commercial discards were not estimated. This is another large area of data uncertainty, with the report showing an approximate 7.5%-11% observed occurrence of Goliath Grouper in the vertical and bottom

longline fisheries in recent years. Recreational removals varied significantly in the average weight per fish and overall catch size by year, and was a source of considerable variability in the data.
The report does not present the uncertainty around the estimates of recreational catch from MRFSS and MRIP of the National Marine Fisheries Service, which are provided by MRFSS-MRIP in the form of proportional standard errors (or CV: coefficients of variation). Although they were not presented in the recreational landings in the report (Table 3.3.1), the CV values exceed 50% particularly prior to 1994, even when catch is pooled over all areas and modes of fishing. When catch estimates are partitioned out by area, as in the assessment, the CV values will probably be higher due to the partitioning of the sample size among areas. The low catches of Goliaths during the period from 1981 through 1993, may have a high uncertainty and it would have been helpful if CVs were presented in the report. The (recognized) uncertainty around the recreational catch violates the model assumption that catch is known without error (see also discussions below). The RP recommends that re-examining the Assessment Teams methods of constructing historical removals should be a research priority. This recommendation is not to reinvent the catch data using new methods, rather to try to understand the influence of plausible alternative catch streams on the assessment.

Indices of Abundance
Four indices of abundance were used in the assessments. These are addressed individually below. The details concerning general index model selection, development, and diagnostics (apart from the final deviance table) were missing from the report.

The Everglades National Park (ENP) index is a fishery index that is conducted annually by the National Park Service biologists who sample (interview) recreational anglers in the Park. The index covers important juvenile habitat, thought to be the core habitat at the beginning of the moratorium.
The raw data from the index were subjected to generalized linear modeling based on the delta distribution, which has become standard practice, and attempts to remove variation attributable to factors other than abundance. This index is valuable as a general recruitment index of immature fish and because it extends back to 1974. The fact that this index and the MRIP estuarine index show similar trends is reassuring, and suggests that both may be reliable. The ENP index is largely unable to take account of changes in the fishers behavior over time (e.g. due to the moratorium; “effort creep”), which may or may not be significant, but would relevant to explore. An important feature of this index is that it covers the period before and after the moratorium.

The REEF Dive Index is an index developed from reported sightings by volunteer divers which have gone through a training program in fish identification and survey techniques taught by the REEF organization. This index has no rigid experimental design, includes numerous reports (of sightings and non-sightings), and is generally not oriented at observing Goliath Groupers. Arbitrary criteria intended to balance the need for spatial coverage by the Assessment Team was developed to require a dive site to have at least 10 reports over the last 20 years, and at least one positive sighting of a Goliath Grouper. Data are reported as categorical variables (0, 1, 2-10, 11-100, 100+). The RP concluded that the standardization of these data which was done with a Poisson generalized linear model, is inappropriate for categorical ordinal data. The REEF data was supplemented by a targeted survey from the Great Goliath Grouper Count (GGGC) data, a targeted dive survey that is similar in method to the REEF survey conducted annually by the Florida Wildlife Commission and Florida Sea Grant from 2010 to present. The RP felt that the combination of the non-target REEF data and the targeted GGGC data was problematic for the appropriate interpretation of the index.
Another issue discussed by the RP was that divers choose which reef to visit, which could introduce bias in favor of reefs with higher abundance of Goliath Grouper.

However, overall, a diver index may have added value because Goliath Grouper will have higher "catchability", since they only need to be seen, whereas a hook-and-line-based index (e.g. MRFSS, MRIP, ENP) requires Goliath Grouper to be brought to the boat (for identification). Large Goliath Grouper can more easily break tackle and as a result, may never be reported by recreational anglers.

The MRFSS/MRIP Indices are angler intercept surveys conducted throughout Florida waters. This data set was separated to create an inshore and an offshore index. Both indices were highly variable, ad-hoc corrections for over-reporting were conducted, and estimates of mean weight per fish estimated by the Assessment Team varied an order of magnitude in the same year. As discussed above and further detailed under section 1.c., these surveys were also the data source of recreational catch estimates, and there is a potential confounding problem with recreational catch estimates and catch-per-trip indices originating from the same survey data.

Stock Structure

A single stock within US waters was assumed for the assessment and the RP considered this to be reasonable assumption. Goliath Grouper are distributed throughout the tropics, subtropics, and warm temperate coastal waters of the Atlantic Ocean. Genetic data indicate that the stocks on the western and eastern shores of Florida are related. The RP was content with the assumption of a "US only" stock in the absence of compelling data to the contrary. However, within the United States the resolution of the data is not detailed enough to determine spatial structure of the stock. Tagging data demonstrate site fidelity, but also long distance movements (~400 km), in particular related to spawning. The vast majority of the data used in the assessment originate from Florida. However, historical landings indicate a range that in the US, Goliath Grouper occurs through southern Texas in the GOM, and up to North Carolina in the South Atlantic.

Life History Information

Key decisions for the life history information were based on small sample sizes (e.g. the fecundity estimate was based on 2 fish). The maturity is assumed to be knife edge, but there is a considerable amount of uncertainty with respect to the maturity. Although current data are inconclusive, there was some discussion of unpublished report about the reproductive strategy of Goliath Grouper (diandric protogynous hermaphrodite vrs. gonochorist).

Age data

The chosen assessment models were, in essence age-based models. However, the age data for Goliath Grouper are relatively sparse and highly uncertain.

Selectivity

The selectivity of the fisheries was separated into two blocks in the assessment, before and after the moratorium. The RP agreed that, in general, this was a sound decision by the analytic team, however because commercial discards are ignored in the assessment, the assumed selectivity of sub-adult and adult age class is likely mis-specified. Furthermore it is questionable as to whether the largest fish (>2 meters) would be retained by the majority of the fishing gear.

The assumed hook-and-line selectivity for the SSRA model (report figure 6.3.1) is flat-topped, meaning that the fishery catches the oldest, largest grouper as readily as it catches those just attaining full selectivity (ages 14+). However, remarks made at the Review Workshop indicates that the larger Goliath grouper often break lines, and may also break commercial gear. This may result in a dome shaped selectivity for hook-and-line gear. As no selectivity sensitivity runs were presented, the RP recommended that the sensitivity of model output to selectivity assumptions (flat-topped vrs. dome) should be investigated.

The selectivity associated with the index of abundance for the MRFSS/MRIP and ENP estuarine indices is representative of the frequency distribution of the age of fish in the estuarine catch, rather than the proportion of fish selected by the gear from the population. Because the younger fish are more abundant in the population this “selectivity curve” will overestimate the selectivity of young fish, and underestimate the selectivity of older fish.

In general, the RP concluded that the selectivity choices and development were poorly described in the assessment report, and no sensitivity runs were presented. This hampered a thorough review of consequences of these choices for the assessment by the RP.

b) Are data uncertainties acknowledged, reported, and within normal or expected levels?

The analysts reported that this was a “data poor” assessment, and acknowledged that the uncertainties are likely at the high end of the expected level, especially those related to the catch. The CV’s for the indices of abundance were highly variable, but it was unclear to the RP what the various CV estimates represented. These CVs were used to set priors in the assessment model. The RP suggested that it would be helpful to include model diagnostics, such as plots of residuals or other portrayals of uncertainty measures from linear modeling of the indices. Also, it would be helpful to compare the indices before fitting the model (raw or nominal indices) with the results of modeling to explore how influential a-priori choices were to the model outcome.

Uncertainty in commercial landings prior to the moratorium due to the suspected over-reporting by one dealer was thoroughly discussed. The RP felt that the assessment team made a reasonable and well-explained correction, reducing the landings by almost 50% from the reported landings. As this is a major correction, the RP felt that it would be helpful to explore a model run using the uncorrected reported landings to investigate the effect of this correction.

c) Are data applied properly within the assessment model?

MRFSS/MRIP data was used to develop an index of relative abundance, and also to derive part of the catch. The way this information is used in the model resulted in the fact that the estimated errors in the catch may be correlated to those in the index. However, the RP acknowledged that this is not unusual in assessments that use the MRIP data, but the correlation should be made explicit. The RP recognized that the MRIP CPUE data was used as an input in the index of relative abundance, which is appropriate. The reported B_2 catch (recreational discards) was the only catch allowed during the moratorium beginning in 1990, and as a result was the basis for the CPUE index. This was converted into the input “catch” from the fishery, based on 5% mortality of discards. The RP raised a concern that the indices and the discard estimate were derived from the same data source, and the resulting ”catch” trend is identical, or at least (highly) correlated with the trend in the indices they were derived from. The RP recognized that this approach is not unusual, and that the impact on the model may be somewhat limited because the “catch” (discard mortality) was derived as the sum of estimated discards from the two surveys: MRIP estuarine and MRIP offshore, and catch was standardized by effort (catch-per-trip) to construct the index. Also, the index model provided a measure of uncertainty around index values portrayed in the confidence intervals (see report figures 4.3.1 and 4.3.2). Conversely, if abundance rises and effort remains roughly similar, it is reasonable to expect higher recreational catches, and thus more discards. As a result, the RP agreed that it is reasonable to expect some correlation between abundance and discards. However, the RP felt that the documentation and information provided did not allow a thorough evaluation of the indices, their use to construct catch, and the impact on the model.

d) Are input data series reliable and sufficient to support the assessment approach and findings?

The assessment approach was twofold by exploring a SSRA model and a Catch Free model. The SSRA model used catch information that was not considered reliable, and the MRIP data was used to construct an index as well as a measure of effort to get catch (see discussion above). The choice of a catch free approach seems to be supported by several indices and other information.

The MRFSS/MRIP recreational catch per trip data is available from 1981 through 2014. The analysts conducted analysis of the raw data to attempt to increase its accuracy and precision, but concluded that only data from 1997 through 2014 was adequate. This is, in part, because Goliath Grouper occurrences in the recreational catch data were sparse prior to 1997. The RP felt that it would seem helpful to the modeling process to include survey data during the period of lower abundance (from 1981 forward). A possible alternative approach could be to divide the total catch estimates by the total trips estimate for at least for the earlier period, when more refined analyses may be impractical due to sparseness or data deficiencies. Other (statistical) approaches could also be used for the earlier part of the time series. A possible sensitivity analyses extending the indices back to 1981 could be helpful for assessing model adequacy and the impact of data from time periods with lower abundances.

The analysts divided the data into two geographical area based on habitat: estuarine and off-shore. The estuarine was used as information about younger, immature fish, which is appropriate. However, employing the information by area resulted in two smaller data “components”, which increased uncertainty, especially around estimates of trips and catch. However, the RP acknowledged that, the advantage of using two areas was that the estuarine area functions as a nursery area for immature fish, which tend to move offshore as they age. As a result, the MRFSS/MRIP and ENP estuarine indices can be fortuitously employed as an index of recruitment. Conversely, the offshore area data can be employed as an index of the mature portion of the stock. As a result the RP supported that decision, in spite of it potential for increasing uncertainty.

2.1.2. Evaluate and discuss the strengths and weaknesses of the methods used to assess the stock, taking into account the available data, and considering the following:

a) Are methods scientifically sound and robust?

Two principal assessment models were presented and discussed in the assessment report. These were the “Stochastic Stock Reduction Analysis” (SSRA) (Martell et al 2009) and the “Catch Free” model (Porch et al, 2006). Both models have been published in the peer reviewed literature. The RP noted that it is important to recognise that the assessment team indicated SSRA model has been modified by FWC to allow the inclusion of multiple survey indices, and that the Catch Free model configuration was modified also (see page 33 of the assessment report). These modifications do not appear to have been reviewed externally and the RP was unable to fully evaluate the impact of these modifications for either model.

The models share some important similarities which include:

- The underlying population is model age structured
- A Beverton-Holt stock recruitment is assumed
- Recruitment deviations are treated as random effects and characterise relative year class strength

- Fishing mortality is modelled as the product of an age and year effect
- Survey indices are treated as proportional to biomass or numbers conditioned on age specific selectivity.
- Parameters are estimated by maximizing a likelihood function
- Penalty functions are used to constrain some of the model parameters. These are referred to as “priors” but are not true Bayesian priors and may result in improper posterior distributions.

Important differences between the models are:

- SSRA uses an estimate of total fishery removals (dead catch) and these are treated as error free. They do not contribute to the likelihood.
- Unlike SSRA, the Catch Free model treats selectivity, natural mortality, growth parameters and fishing mortality as parameters to be estimated.
- SSRA parameterises the stock recruitment function in terms of F_{msy} and MSY, and these are the main (“lead”) parameters to be estimated. An important consequence of this is that the stock recruitment parameters are conditioned on the assumption of selectivity and will change if the selectivity assumption is changed.

The RP noted that, while not a feature of either model, the analysts assumed different relationships between natural mortality and weight for the two models, which reduces the comparability between the models, and affects the calculation of MSY reference points.
The models are well known variants of age-structured production models and can be regarded as scientifically sound. Whether they are considered “robust” depends heavily on the data used. Here “data” may include constants, such as age at maturity, selectivity, M, etc. These do not enter the likelihood unlike observations, such as survey indices. Where data enter the model as constants, the accuracy is particularly important to avoid cumulative errors. For example, fishery removals and selectivity estimates can be critical in determining the model outcome, yet there is considerable uncertainty surrounding the values used in these assessments. The RP felt that it was not possible to conclude that the methods used are robust. This decision was largely based on various analyses reported in the assessment document (i.e. the MCMC runs for the Catch Free model) and additional model runs that were performed during the meeting (i.e. the “leave-one-index-out” survey analysis for SSR, see post RW addendum to the Assessment Report). Where priors are used, as was the case in these assessments, it is particularly important to examine whether these are updated by the observations, and to examine the sensitivity of model estimates to the priors. These diagnostics were not done, which prevented the RP from fully assessing robustness of the model.

b) Are assessment models configured properly and used consistent with standard practices?

For each model, only one or a very few model configurations were presented. The RP concluded that although these configurations were plausible, they may not necessarily represent the optimal model configuration. As mentioned under section 2.1.2-a, considerably more analysis of the prior assumptions is needed for a full evaluation of the models. More consideration should be given to the choice of indices are included. The RP expressed concern that, given the uncertainty in the catch data, these are included in the model as error-free constants. It was suggested that this could be addressed by treating the catches as observations that enter the likelihood, and would allow errors to be estimated.

c) Are the methods appropriate for the available data?

The RP concluded that the SSRA and Catch Free models are appropriate tools, but given the available data, should be used as part of a suite of alternative models, if only to better characterize model uncertainty. The available data could potentially be analysed using a variety of models, including surplus production models and other data-poor approaches. The RP recommended that considerably more thought needs to be given to the implication of handling the fishery removals as known constants and developing changes to the SSRA/Catch Free models so that this issue can be explored.

Given the significant difficulty of trying to construct abundance indices and fishery removals for Goliath Grouper, it is important to review what can be realistically derived in terms of useful reference points. Both models need age information in the data to estimate parameters, however, there is a lack of such information in the data. As a result, many assumptions have to be made to estimate age dependent parameters. Also, the VonBertalanffy (VB) growth parameters are correlated, yet in the models they can vary independently. The RP recommended that if one parameter is chosen, the other parameters should be fixed based on the age-at-length analysis (e.g. the VB model).

The RP was unable to fully evaluate how influential these assumptions were to the outcome of the assessment models. Simpler methods that consider only stock trends may be (more) useful than trying to reconstruct a fully age-structured population model. The RP felt that this assessment could have benefitted from an assessment workshop (or webinars) to discuss important issues related to the model and model parameter choices.

The RP noted that the Goliath Grouper stock attained an exponential increase, seemingly due to one or more very strong recruitment events in the 2000s. This dramatic increase was followed by a steep decline of least the estuarine pre-recruits, possibly due to an episodic natural mortality caused by some combination of red tides and severe cold snaps in 2008-2010. Since the model is informed that natural mortality is low and constant, it may not be able to appropriately account for episodes of high M. Indeed, both the SSRA and the Catch Free model show a poor fit of the indices' increase, as is illuminated by the residual pattern (see assessment report figures 6.9.1, 6.9.2, 7.5.2 and 7.5.3). This also affects model estimates of F during this period.

2.1.3. Evaluate the assessment findings and consider the following:

a) **Are abundance, exploitation, and biomass estimates reliable, consistent with input data and population biological characteristics, and useful to support status inferences?**

The RP concluded that neither the SSRA nor the Catch Free model outcomes support inferences on stock status. For the SSRA, this conclusion was largely based on the uncertainties in the data and the sensitivity to, among other things, the choice of the beginning of the time series and the REEF index. For the Catch Free models this was largely based on the uncertainties in the data and poor convergence results of the MCMC, which suggest multiple local maxima in the likelihood.

The RP was unable to fully evaluate the abundance, exploitation, and biomass estimates from both the SSRA and Catch Free models. Both models were valuable in illustrating plausible stock and exploitation trends, but neither was sufficient to support status inferences, and thus not adequate for management advice based on MSY reference points.

By definition, the Catch Free model can only provide estimates of relative abundance, exploitation, and biomass, so there is no information provided to the model to allow scaling to absolute values. The Catch Free model was previously used in SEDAR 6 and SEDAR 23, where it were adopted to provide relative estimates and guidance on the possible recovery time of Goliath Grouper. In SEDAR 23, the Catch Free model was employed again, but the context was changed with the management need to provide OFL and ABC recommendations. However, the Catch Free model cannot provide this information as it does not use data on removals to scale necessary estimates. Thus, the RP concluded that for SEDAR 47 this model is, again, not appropriate for stock status determination.

During the SEDAR 23 RW, an SSRA model was presented for exploratory purposes, but the review panel did not use it to make inferences about stock status as it had not been previously considered by the SEDAR 23 Assessment Workshop. In principle, with better quantification of removals, and with conducting various sensitivity runs, the SSRA could be used to provide more relevant information for management. However, the SEDAR 47 RP concluded that the SSRA model critically depends on credible inputs of removals, which were deemed too uncertain in the current assessment. Thus, for SEDAR 47 the RP does not consider the SSRA model appropriate for stock status determination.

(a) Is the stock overfished? What information helps you reach this conclusion?

(b) Is the stock undergoing overfishing? What information helps you reach this conclusion?

The RP did not accept either model as sufficient to infer stock status and support management decisions, thus it cannot determine if the stock is overfished or undergoing overfishing.

(c) Is there an informative stock recruitment relationship? Is the stock recruitment curve reliable and useful for evaluation of productivity and future stock conditions?

The stock recruitment curve used was estimated internal to the models and assumed to follow a Beverton-Holt relationship. The robustness of the chosen stock recruitment relationship was not explored, therefore it is not known how informative the presented stock recruitment relationship is. The estimated stock recruitment plot from the SSRA model (Figure 6.9.6) suggests that a Ricker model may be appropriate, because the highest recruitment estimates occurred at moderate values of SSB, and recruitment declines somewhat at higher SSB. In addition, Goliath Grouper biology and ecology may support a Ricker stock-recruit model choice.

(d) Are the quantitative estimates of the stock status determination criteria for this stock reliable? If not, are there other indicators that may be used to inform managers about stock trends and conditions?

The Review Panel felt that the quantitative estimates produced by both the SSRA and Catch Free models were not reliable. During the RW the Panel requested various sensitivity runs be produced from the SSRA, including starting the assessment at 1975, dropping the REEF diver data index, and including each index in isolation. The stock status determinations produced from these various sensitivity runs varied greatly and contributed to the lack of confidence that the RP had in the model's ability to reliably estimate stock status for the Goliath Grouper population (see also section 2.1.5).

One of the main sources of available data to determine the Goliath Grouper stock trends comes from diver observations collected by the REEF Foundation and, more recently, from the GGGC conducted annually by the FWC and Florida Sea Grant from 2010-2014. Positive aspects of these surveys are that they are not fishery based and have broad spatial coverage. Despite numerous concerns from the RP regarding the treatment of the REEF diver index in both models (e.g. not a random survey, variability in spatial coverage over time, and see notes above), these data might be useful as population indicators of trends in relative abundance and/or spatial distribution if standardized appropriately. At this point, the REEF foundation data extend back to 1993, and thus covers nearly the entire duration of the moratorium and subsequent population recovery. While these data may not be appropriate for use in the models presented at the RW, the Panel recommends further exploration of methods of index formation. Spatial analyses of these data may be informative in terms of the spatial extent of population trends.

2.1.4. Evaluate the stock projections, including discussing strength and weaknesses, and consider the following:

- **a) Are the methods consistent with accepted practices and available data?**
- **b) Are the methods appropriate for the assessment model and outputs?**
- **c) Are the results informative and robust, and useful to support inferences of probable future conditions?**
- **d) Are key uncertainties acknowledged, discussed, and reflected in the projection results?**

No projections were presented for SSRA. Projections from the Catch Free model give an indication of possible future biomass trends, but cannot indicate where biomass lies in relation to reference points.

2.1.5. Consider how uncertainties in the assessment, and their potential consequences, are addressed.

- **a) Comment on the degree to which methods used to evaluate the uncertainty reflect and capture the significant sources of uncertainty in the population, data sources, and assessment methods.**
- **b) Ensure the implications of uncertainty in technical conclusions are clearly stated.**

The Assessment Team indicated that in addition to the SSRA and the Catch Free models, other models were considered and rejected. However, the Assessment Team did not provide any details of the issues or sources of problems with these alternative models. Hence, the RP was unable to evaluate these efforts as potentially useful for addressing model uncertainty and assessing stock status.

Sensitivity Runs

The number of sensitivity runs provided in the assessment report was very limited, which significantly impaired the RP's ability to fully evaluate the models. Additional sensitivity analyses were performed for both models during the Review Workshop at the request of the reviewers. The SSRA model was run with and without various indices of abundance and for different time periods (1975 - 2014 vs. 1950 - 2014). The results indicated that biomass trends were strongly impacted by the changes in start date. In addition, the sensitivity runs with different indices led to further changes in the model fit and predictions. Together these provide good indications of the high degree of uncertainty in model results. For the Catch Free model, sensitivity analyses included: 1) putting prior distributions around the two levels of natural mortality (M = 0.12 and 0.18); and 2) either fixing selectivity curves or using priors on selectivity parameters. Model outputs under the different assumptions in (1) were provided as a means of assessing consistency of the conclusions. For (2), comparison of approximate catch to predicted catch from the Catch Free model was provided.
The RP was unable to fully evaluate the requested sensitivity runs (with a start year of 1975) because the models assumed a virgin stock biomass in 1975, which is likely unrealistic. As a consequence, the RP was unable to fully compare the "base" model with these sensitivity runs.
None of the sensitivity runs for either model tested whether the technical conclusions concerning overfishing were similar, regardless of model inputs and decisions. This is a serious omission making it difficult to judge the robustness of the model results.

Sources of uncertainty in the life history data sources

I) Catch Free model

Although full details for every parameter were not provided (see Table 7.2.1 in the Assessment Report for provided details), it appears that uncertainty in the life history parameters was allowed for by drawing them from a prior distribution. The RP agreed that this is a good approach to incorporating and propagating uncertainty in the model, as is the use of MCMC to obtain posterior distributions that include variability in the outputs. The use of multiple chains was helpful for checking convergence of the model and revealing the uncertainty in the model fit.

The RP was not convinced that the parameters and methods were appropriately chosen. A specific example is the use of independent prior distributions for VB model growth parameters, which should be treated as either a bivariate or tri-variate joint distribution with correlation between parameters. Use of the independent distributions leads to parameters selections that may or may not be within the valid sample space of the joint parameters. This could be part of the problem with non-convergence of the chains in the MCMC runs of the model.

The use of phase plots was a good portrayal of the uncertainties or variance around the model optimization solutions. In addition, the incorporation of an overall variance parameter to include process/unexplained error as described in Porch et al. (2006) was useful for capturing sources of variability not optimally described by CVs or variances for data inputs.

II) SSRA Model

Unlike the Catch Free model, life history parameters were assumed to be fixed (Appendix A of the Assessment Report). Uniform bounded priors were placed on F_{msy} and MSY, and a prior was placed on the compensation ratio (κ). Like the Catch Free model, MCMC was used to explore uncertainty. All other life history parameters, e.g. weight-length relationships were assumed to be fixed and known. As a result, these sources of uncertainty were not included in the model outcomes variability.

The retrospective analyses, the plots comparing observed and predicted indices, the residual plots, and the MCMC simulations were all well-done and helpful to the RP for addressing model validity and assessing uncertainty.

Sources of uncertainty in the data sources

The SSRA model did not include measures of uncertainty for the catch. The analysts appropriately raised the strong possibility of over-reporting, and used an approach to correct it. Although worthy, the adjustment to the catches may not be accurate and may influence the model outcomes. It would be helpful to run sensitivity analyses in the SSRA model to explore the impact of the range of possible corrections.

Uncertainty for the other indices (see above) were provided, but the RP was concerned about the validity of the value of the CVs. The CVs were based on only the probability distributions assumed for the data index and sample sizes, and as such may be a poor representation of the true variability. However, the RP realized that to account for this would have required adjustments to the standardization of the indices. The assessment report provided insufficient information for a full evaluation by the RP.

2.1.6. Consider the research recommendations provided and make any additional recommendations or prioritizations warranted.

a) Cleary denote research and monitoring that could improve future assessments.

The data used in the models mostly originated from Florida. Sparse data from elsewhere in the species (historical) range may be indicative of low population size (either as a function of natural distribution patterns or constriction of the population due to heavy fishing pressure), or poor sampling (including landings). This issue needs to be further explored as it has bearing on the geographical validity and usefulness of the assessment for regional management.

There was some concern by the RP about the method the Assessment Team used for combining the GGGC and the REEF survey as there is a potential for bias (e.g. potential for targeting sites with known high abundance of Goliath Grouper in the GGGC survey). How influential the inclusion of the GGGC data was to the outcome of the model should be explored.

Many of the research recommendations provided in the Assessment Report include research that would not necessarily improve future assessments for this species. The SEDAR 23 RW concluded that "The next benchmark assessment cannot be successfully completed without data from the research recommended by the Data, Assessment, and Review Panels." The outcome of the SEDAR 47 benchmark assessment process indicates that much of this information is still needed in order to successfully complete an assessment for Goliath Grouper.

Specifically, research and monitoring efforts that could improve future assessments for Goliath Grouper include:

<u>Life history information</u>

Basic reproductive data is lacking throughout the species distribution. This includes size and age at maturity for each sex, sexual sequence with size and age for each sex, and fecundity. In the SEDAR 47 assessment, the reproduction functions used in the models made some strong assumptions about the maturity schedule and fecundity rates that were based on insufficient data. Greater resolution of data, especially maturity at size or age, would alleviate the impact of these assumptions for future assessments.

A limited research harvest should be considered to fill the remaining gaps in life history information for Goliath Grouper. Such a harvest should incorporate individuals from across the size spectrum, but should focus on larger individuals as they may be beneficial to ground truth the fin-ray aging techniques used for the offshore age composition, and to develop fecundity schedules.

Additional research on the age structure of the catch, especially in the offshore recreational fishery, is needed. The SEDAR 47 assessment used age composition of only 22 adult individuals that were caught by a research fishery and aged with fin rays (Koenig et al. 2013). This age composition was used for multiple parts of the assessment and may provide a large source of the assessment uncertainty. Cooperative research efforts with the recreational charter and headboat fisheries could be informative towards generating better information on the offshore recreational age composition.

Discard mortality estimates are needed across the species distribution. For the SEDAR 47 assessment, a fixed discard mortality estimate was applied to the post-moratorium harvest. However, the uncertainty around this estimate is unknown and may be substantial.

<u>Stock definition</u>

SEDAR 23 recommended that Goliath Grouper should be genetically sampled from areas across the stock range in the South Atlantic and Gulf of Mexico to allow for a more thorough examination of the current single stock definition. The SEDAR 47 RW was presented with a brief summary of these efforts,

which seem to support that single stock definition. Like many other sources of information informing the SEDAR 47 assessment, this information remains in progress or is incomplete and has not yet been vetted by peer review.
Examination of spawning aggregations over the entire distribution range should include seasonality, sex ratios, and individual fidelity.

<u>Fishery independent sources of information are lacking or uncertain</u>
The SEDAR 47 AT indicated that a specifically designed pre-fishery recruit survey (e.g. mangrove habitat) would help guide recruitment in the assessment model.

<u>Develop and/or explore methods to take into account episodic mortality events.</u>
One issue with the SEDAR 47 assessment was the use of a fixed value for natural mortality at age, despite evidence that episodic mortality events (i.e. cold-kills) have affected the Goliath Grouper population. Options to account for this mortality should be explored for future assessments. Methods used in other assessments (e.g. to address red tide events affecting red and gag grouper in the GOM) include incorporating episodic mortality events as a separate removal fleet. These methods may be appropriate for Goliath Grouper and could reduce some of the uncertainty in the estimates of natural mortality.

<u>Reexamine methods of constructing historical removals</u>
The use of length data from MRFSS/MRIP recreational Goliath Grouper removals need to be further examined. In SEDAR 47, the methods used to apply mean length of catch was inconsistent between years when there was missing and/or suspect data, and years with an estimate from the MRFSS/MRIP database. This introduced a significant amount of uncertainty to the harvest estimates.

<u>Incorporate Data from Low Abundance Years into Indices</u>
The Assessment Team discarded some of the data from index development due to very low catch rates in years adjacent to the moratorium. As a result, low abundance indices are removed from the assessment. Methods for incorporating these data into appropriate statistical models for standardization and development of indices should be explored.

2.1.7. Consider whether the stock assessment constitutes the best available scientific information available using the following criteria as appropriate: relevance, inclusiveness, objectivity, transparency, timeliness, verification, validation, and peer review of fishery management information.

The model was appropriately configured, but the nature of the data, data choices, and model choices not provide results that can be considered BSIA. Details are provided under various TORs above.

2.1.8. Provide guidance on key improvements in data or modeling approaches that should be considered when scheduling the next assessment.

Inclusion of a complete and comprehensive data report, as well as a complete assessment report would have been helpful to the RP in evaluating this assessment, specifically how the data were handled. The analysts indicated other modeling approaches were investigated, but uninformative results led to their exclusion from the discussion. The RP indicated that information associated with those runs would have helped evaluate model uncertainty.

- Given the nature of the (limited) data and resulting modeling approaches, a Data Workshop, and possibly an Assessment Workshop (or webinars) should be considered when scheduling a next assessment.
- Consideration of other (data poor) model approaches. It will be useful for the RP if explored models and outcomes of those explorations are included in the assessment report.
- Explore methods that allow for a varying M (e.g. as result of cold kills).
- Considerably more age data is required to inform the model.
- Explore other stock/recruit relationships.
- More complete sampling of the catch to provide lengths and weights of all individual fish.
- The REEF “abundance” was a ranked abundance scale, not a true abundance scale. Other ways of estimating abundance, and the effect of the choice on the model configuration and outcome should be explored.
- Spatial analyses of the REEF data may be informative in terms of the spatial extent of population trends.
- Improved estimate of bycatch mortality, e.g. by using experiment studies. Also, commercial bycatch mortality was not included in the model. Acknowledging the paucity of data, estimates of this source of mortality may improve the model outcome.

2.2. Summary of Results of Analytical Requests

The analytical team provided several additional analyses and clarification of model structure and results. All are summarized and discussed in the previous sections of this report.

2.3. Additional Comments.

The RP had no additional comments.

3. Submitted Comment.

There were no additional submitted comments.

SEDAR

Southeast Data, Assessment, and Review

SEDAR 47

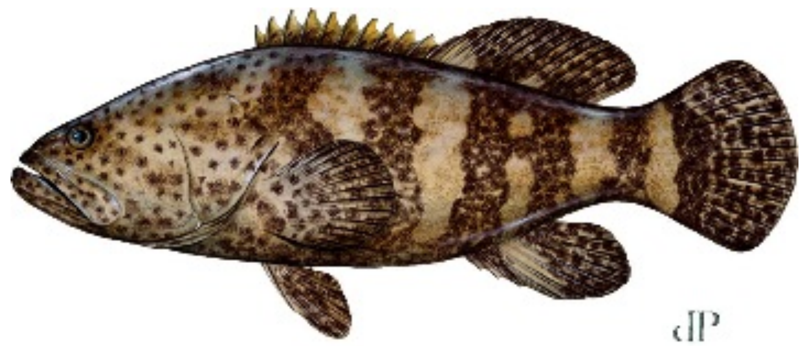
Southeastern U.S. Goliath Grouper

SECTION V: Addenda and Post-Review Workshop Updates

May 2016

SEDAR
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

Addendum to SEDAR 47 Stock Assessment Report for Goliath Grouper of the South Atlantic and Gulf of Mexico, 2016.



Joe O’Hop and Joseph Munyandorero

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100 8th Avenue SE
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FWC Report IHR2016-001 Addendum 2, May 25, 2015

Executive Summary

- The review panel at the SEDAR 47 Review Workshop (RW), during May 17-19, requested some additional information regarding the stock reduction analysis (SRA) and catch-free models or the data compiled as inputs to these models. The addendum for the SRA analyses was sent previously (May 19) to the RW. This addendum provides the information presented about data inputs and about an analysis of the catches predicted from the catch-free model.

Contents

I. Introduction

1. SEDAR 47 Review Workshop

The Review Workshop was held on May 17-19, 2016 in St. Petersburg, FL at the Hampton Suites & Inn. The review panel was comprised of three members from the Center for Independent Experts, two members representing the South Atlantic Fishery Management Council Scientific and Statistical Committee (SSC), and two members representing the Gulf of Mexico Fishery Management Council SSC. Over the course of the three days, the review panel received presentations on the origins of data used in the stock assessment, the assumptions made regarding the treatment of the data and how these were translated into model inputs, the reasoning behind the choices made for model inputs and the types of models explored, and the analyses of the model runs. The review panel posed many questions to the analysts and asked for additional information and analyses. This addendum summarizes some of those requests for additional information and additional analyses using the catch-free model which were provided in spreadsheet form to the panel on Wednesday, May 18.

II. Additional Analyses from the Catch-free Model

Even though the catch-free model has no information on the estimated total harvests (landings and dead discards) of Goliath Grouper by fisheries, it calculates population abundance and removals (harvests) on a relative scale using a growth curve, natural mortality rates, indices of abundance, and index selectivities supplied as fixed inputs or with priors as starting values if some or all of them are being estimated during the model run. Estimated annual harvests by weight (on a relative scale) can be calculated from the model outputs using the annual population relative abundance by age ($N_{a,y}$), annual fishing mortality rates by age ($F_{a,y}$), age-specific natural mortality rates (M_a), and weight-at-age (w_a) values using Baranov's catch equation (e.g., Haddon 2011):

$$predicted\ catch\ (in\ weight) = \sum_a \frac{F_{a,y}}{F_{a,y} + M_a} \cdot N_{a,y} \cdot w_a \cdot \left(1 - e^{-(M_a + F_{a,y})}\right)$$

Estimates for ages 1 to 35 were included in the model outputs, with the last age representing a plus group (estimated for ages 35-37). The review panel requested a comparison of the predicted catches from the catch-free model with the estimated harvests of Goliaths over 1950-2014 (to correspond to the removals used in the stock reduction analysis). The panel also requested a sensitivity run of the catch-free model "base" modified to run with index selectivities fixed at their initial input values.

1. Predicted harvests with estimated index selectivities

The "base" model run was configured as shown in Table 7.2.1 in the stock assessment report, with the ENP index selectivities fixed at the input values by turning off the phase control (a "-" sign in front of the phase number) and the selectivity parameters for the other three indices (REEF FL, MRFSS/MRIP Estuarine, MRFSS/MRIP Offshore) with the phase number positive and the model allowed to estimate (Fig. A-II.1, c-f). The predicted annual harvest (Fig. A-II, g) shows a declining trend from 1950, a brief spike around 1980 which represents the joining of two periods of F-estimation internally in the model, and a decline after 1980 to a low point in 1990 and increasing thereafter to 2012. There is an indication of a slight decline after 2012 which also appears in the REEF FL index (Fig. 7.5.2 in the stock assessment report). The trends in the predicted harvest from the model run compared to the estimated harvest are remarkable in that the catch-free model does not use any of the externally estimated harvests, though it does use trends in catch from the catch-rate indices (ENP, MRFSS/MRIP Estuarine, MRFSS/MRIP Offshore).

2. Predicted harvests with fixed index selectivities

When all of the index selectivity patterns were fixed at their input values (Fig. A-II.2, c-f), the patterns of predicted harvests were similar in trend (Fig. A-II.2, g), though the magnitude differed, to those of the "base" run. The AIC (Akaike Information Criterion) for this model run was higher than for the "base" run (Table A-II.1), indicating that the fit to the indices was degraded. Other differences in the model estimates for these runs are in Table A-II.2).

3. Lengths and weights measured from the NMFS MRFSS.

Panel members inquired about the quantity of actual measurements from the NMFS' Marine Recreational Fishery Statistics Survey (MRFSS) for 1981-1989. Data were extracted from the recreational interviews, and records representing fish observed by the field samplers were retained. There were 26 records representing Goliath Grouper that were identified by the field samplers, of which there were 18 length measurements and 21 weights (Table A-II.3).

4. Commercial landings of Goliath Grouper from the Southeastern United States.

Panel members inquired about the distribution of Goliath Grouper in other states southeastern U.S. There were reported commercial landings of Goliaths (Table A-II.4) over the last 100+ years, and appreciable landings in states other than Florida in some of those years. But, commercial fishing vessels may range quite broadly and fish in areas not necessarily adjacent to the state where they landed product, so there is no guarantee that the commercial landings are an absolute indicator of a species distribution. Over the time period covered by these landings data, about 76% of the weight of Goliath Grouper was reported in Florida.

III. References

Haddon, M. 2011. Modelling and Quantitative Methods in Fisheries. Second Edition. Chapman & Hall / CRC Press. Boca Raton, FL.

IV. Tables

Table A-II.2 A selection of model estimates from the "base" run and from a run with all of the parameters for index selectivities fixed at their input values.

Estimate	"base" run	all index selectivity parameters fixed at input values
AIC (Akaike Information Criterion)	35.5	46.36
M (constant, y^{-1}) input	0.18	0.18
M (constant, y^{-1}) estimate	0.16	0.12
$F_{current}$ (y^{-1}, relative)	0.09	0.03
$F_{50\%SPR}$ (relative)	0.06	0.04
$F_{current}$ / $F_{50\%SPR}$ (relative)	1.50	0.57
$SSB_{current}$ (relative)	0.66	0.61
$SSB_{50\%SPR}$ (relative)	0.49	0.46
$SSB_{current}$ / $SSB_{50\%SPR}$ (relative)	1.35	1.31
Steepness (*h*)	0.91	0.77
Reduction in F (%)	87	88
Growth (L-inf, cm)	2255	2305
Growth (k, y^{-1})	0.095	0.095

Table A-II.3. Lengths and weights for Goliath Grouper from the NMFS MRFSS, 1981-1989. Fish seen and that were not measured for length and/or weight are shown as blanks. The MRFSS length measurement is measured from the tip of the snout to the center of the tail, which corresponds to a total length for Goliaths.

ID_CODE	YEAR	subregion	state	county	AREA_X	Area	Fish Inspected	Length (mm)	Weight (kg)
1000719811017010	1981	South Atlantic	Florida	Brevard	5	Estuarine	1	350	0.5
1051219840728000	1984	South Atlantic	Florida	Brevard	1	Offshore-State waters	1	470	1.8
1100719870614000	1987	South Atlantic	Florida	Brevard	1	Offshore-State waters	1	750	11.5
1134819881001000	1988	South Atlantic	Florida	Broward	1	Offshore-State waters	1	458	2.2
1121419890325000	1989	South Atlantic	Florida	Miami-Dade	1	Offshore-State waters	1		
1000119820821000	1982	Gulf of Mexico	Florida	Monroe	3	Offshore-State waters	1	1305	23
1000919820421010	1982	Gulf of Mexico	Florida	Sarasota	3	Offshore-State waters	2		56.8
1000919820421010	1982	Gulf of Mexico	Florida	Sarasota	3	Offshore-State waters	2		110
1000919820711010	1982	Gulf of Mexico	Florida	Pinellas	3	Offshore-State waters	2	1500	28
1000919820711010	1982	Gulf of Mexico	Florida	Pinellas	3	Offshore-State waters	2	1525	26
1030719820523000	1982	Gulf of Mexico	Louisiana	Cameron	1	Offshore-State waters	1	425	5.2
1030719820829000	1982	Gulf of Mexico	Louisiana	Cameron	2	Offshore-Federal waters	1	520	9.5
1030519840331010	1984	Gulf of Mexico	Louisiana	Plaquemines	2	Offshore-Federal waters	1	1580	41.8
1051019850817010	1985	Gulf of Mexico	Florida	Lee	4	Offshore-Federal waters	1	940	11.8
1093219861211000	1986	Gulf of Mexico	Florida	Monroe	4	Offshore-Federal waters	1		10
1085719860614000	1986	Gulf of Mexico	Louisiana	Cameron	2	Offshore-Federal waters	1		1.9
1085719860615000	1986	Gulf of Mexico	Louisiana	Cameron	2	Offshore-Federal waters	1	254	0.5
1085719860615010	1986	Gulf of Mexico	Louisiana	Cameron	2	Offshore-Federal waters	13		
1085719860716000	1986	Gulf of Mexico	Louisiana	Cameron	2	Offshore-Federal waters	1	410	1.4
1071319870620010	1987	Gulf of Mexico	Florida	Pinellas	4	Offshore-Federal waters	1	1350	50
1093219870114000	1987	Gulf of Mexico	Florida (add-on)	Monroe	4	Offshore-Federal waters	1		2
1075919870501000	1987	Gulf of Mexico	Louisiana	Lafourche	2	Offshore-Federal waters	1	810	9.8
1075919870510000	1987	Gulf of Mexico	Louisiana	Lafourche	2	Offshore-Federal waters	2	650	5.6
1075919870510000	1987	Gulf of Mexico	Louisiana	Lafourche	2	Offshore-Federal waters	2	810	10.6
1026319880625010	1988	Gulf of Mexico	Florida	Bay	4	Offshore-Federal waters	4	325	0.7
1136519890312000	1989	Gulf of Mexico	Florida	Collier	4	Offshore-Federal waters	1		

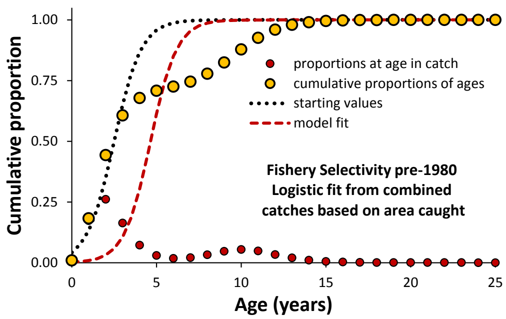
Table A-II.4 Reported commercial landings of Goliath Grouper from the Southeastern United States. Sources: U.S. Bureau of Commercial Fisheries, NOAA Fisheries, and State of Florida [Fish and Wildlife Conservation Commission (1986-present) and State Board of Conservation (1939-1949)].

Year	Texas	Louisiana	Mississippi	Alabama	Florida West Coast	Florida East Coast	Georgia	South Carolina	North Carolina	Grand Total	Florida (statewide)	FL statewide (FL SBC)
1890	9,500	na	na	na	na	na	na	na	na	na	na	
1897	33,281	0	0	0	0	0	0	0	0	33,281	0	
1902	65,722	0	0	2,000	0	0	0	79,500	0	147,222	0	
1918	39,965	0	8,800	2,000	69,844	12,487	0	0	0	133,096	82,331	
1923	13,450	0	5,200	0	109,188	250	2,767	0	0	130,855	109,438	
1927	11,175	0	7,500	200	295,159	15,100	2,388	0	0	331,522	310,259	
1928	75,746	2,000	5,700	3,400	49,477	13,500	3,200	0	0	153,023	62,977	
1929	43,859	10,000	1,353	150	74,003	13,500	1,473	0	0	144,338	87,503	
1930	1,430	6,000	1,274	5,021	18,050	8,000	4,629	0	0	44,404	26,050	
1931	275	7,050	690	0	7,314	2,250	0	0	0	17,579	9,564	
1932	5,750	2,400	0	0	na	na	0	0	0	38,440	0	
1934	28,300	5,000	0	0	na	na	0	0	0	46,700	0	
1936	2,900	21,000	0	0	10,000	28,800	0	0	0	62,700	38,800	
1939	6,900	5,800	0	14,700	99,200	15,300	0	0	0	141,900	114,500	183,111
1940	10,000	14,200	0	0	96,100	18,000	0	0	0	138,300	114,100	189,506
1941												
1942												
1943												424,141
1944												218,219
1945	12,500	2,500	0	2,700	206,500	216,300	0	0	0	440,500	422,800	475,859
1946												251,243
1947												202,961
1948	7,600	0	0	5100	na	na	na	na	na	na	0	221,547
1949	5,300	0	0	3,600	177,900	na	na	na	na	na	177,900	196,048
1950	20,800	0	0	7,400	74,200	23,300	0	0	0	125,700	97,500	
1951	73,900	500	500	0	65,200	54,400	0	0	0	194,500	119,600	120,563
1952	31,500	400	200	53,600	44,200	40,000	0	0	0	169,900	84,200	84,419
1953	24,600	3,400	0	123,000	97,500	35,700	0	0	0	284,200	133,200	132,744
1954	22,600	5,700	0	0	55,600	31,500	0	0	0	115,400	87,100	86,356
1955	3,500	0	0	2,000	53,200	24,100	0	0	0	82,800	77,300	77,187
1956	2,200	1,100	0	1,000	36,500	17,300	0	0	0	58,100	53,800	
1957	1,000	0	0	5,600	27,200	24,300	0	0		61,500	51,500	
1958	30,400	600	0	7,000	51,800	34,400	0	0		132,600	86,200	76,130
1959	20,200	18,300	0	18,500	65,100	9,000	0	0	600	131,700	74,100	62,076
1960	0	20,000	0	4,400	66,800	11,000	0	0	0	115,500	77,800	
1961	0	9,500	0	24,900	50,600	16,200	0	0	700	101,900	66,800	
1962	300	4,100	0	15,500	48,500	21,400	0	0	0	89,800	69,900	
1963	7,800	8,300	0	41,400	65,500	16,700	0	0	0	139,700	82,200	
1964	2,700	2,200	0	118,400	86,200	31,700	0	0	0	241,200	117,900	
1965	0	1,300	0	134,200	61,400	40,100	0	0	0	237,000	101,500	
1966	0	1,700	0	100,300	41,900	38,700	0	0	0	182,600	80,600	
1967	200	200	0	76,500	67,400	55,800	0	0	0	200,100	123,200	
1968	0	200	0	115,600	99,200	50,800	0	0	0	265,800	150,000	
1969	0	2,900	0	49,900	101,900	46,100	0	0	0	200,800	148,000	
1970	0	6,500	0	73,300	130,400	21,200	0	0	0	231,400	151,600	
1971	0	2,400	0	41,500	148,900	3,300	0	0	0	196,100	152,200	
1972	0	0	0	80,000	150,700	7,600	0	0	0	238,300	158,300	
1973	0	5,500	0	59,400	161,500	15,800	0	0	0	242,200	177,300	
1974	0	300	0	29,200	160,700	46,400	0	0	0	236,600	207,100	
1975	0	0	0	22,900	185,500	40,500	0	0	0	248,900	226,000	
1976	0	0	0	15,900	184,900	53,200	0	0	0	254,000	238,100	
1977	0	0	0	22,500	199,800	50,800	0	0	0	273,100	250,600	
1978	0	32	0	4,551	192,249	17,185	0	0	0	214,017	209,434	
1979	0	0	0	2,690	160,071	18,064	0	0	0	180,825	178,135	
1980	0	0	0	2,887	201,875	19,423	0	0	0	224,185	221,298	
1981	0	0	0	6,062	183,414	12,397	1,154	0	0	203,027	195,811	
1982	0	0	0	12,827	156,836	6,131	0	0	0	175,794	162,967	
1983	0	0	0	13,536	174,541	12,293	0	0	0	200,370	186,834	
1984	0	0	0	7,240	89,377	11,440	0	0	0	108,057	100,817	
1985	0	0	0	0	101,539	9,367	0	0	0	110,906	110,906	
1986	0	0	0	0	108,952	10,492	0	0	0	119,444	119,444	
1987	24	1,146	0	0	99,540	17,911	0	0	0	118,621	117,451	
1988	491	0	0	0	135,715	12,931	0	0	0	149,137	148,646	
1989	0	0	0	0	93,066	8,669	0	0	0	101,735	101,735	
1990	0	2,272	0	0	7,488	1,814	0	0	0	11,574	9,302	
1991	0	798	0	0	0	0	0	0	0	798	0	
1992-2015	0	0	0	0	0	0	0	0	0	0	0	

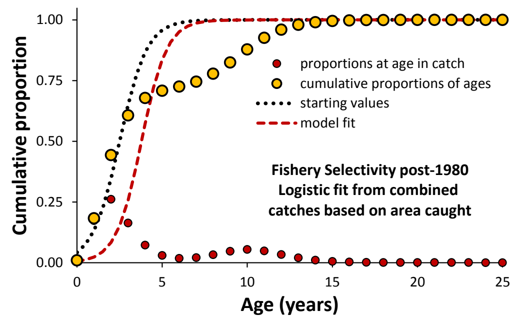
V. Figures

Fig. A-II.1 a-g. Starting values and model-estimated (unless fixed) selectivities for fishery and indices, and predicted relative harvests from the catch-free model.

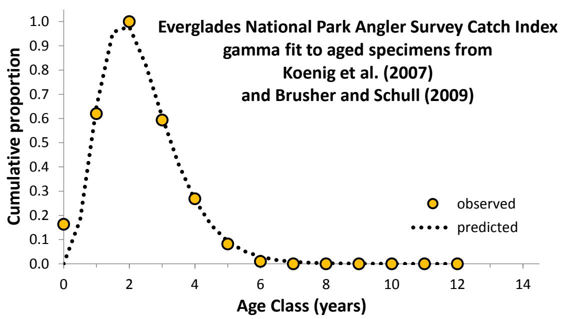
a. Pre-1980 fishery selectivity



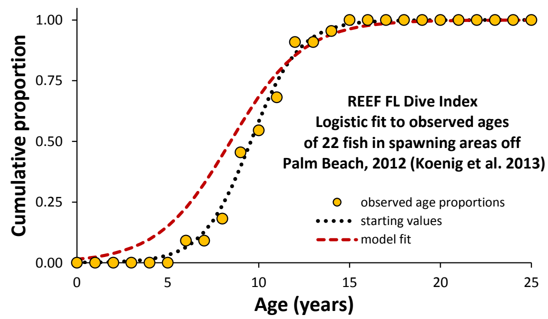
b. Post-1980 fishery selectivity



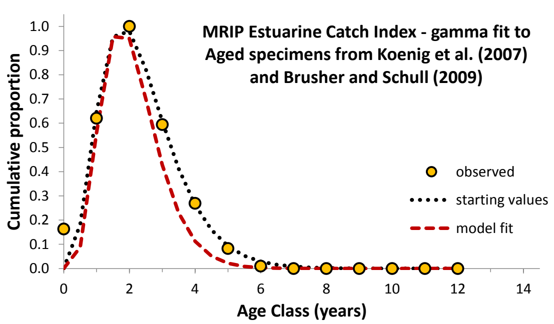
c. ENP index selectivity (fixed)



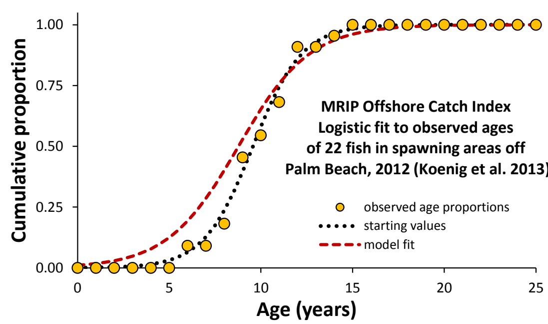
d. REEF FL index selectivity (estimated)



e. MRIP Estuarine index selectivity (estimated)



f. MRIP Offshore index selectivity (estimated)



g. Predicted relative harvest (catch-free model; in blue) compared with observed harvests (in black) using three estimated index selectivities (ENP index was fixed)

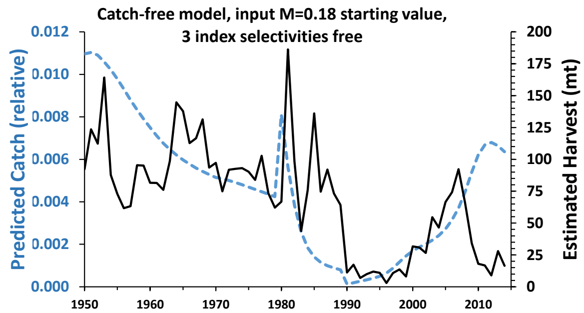
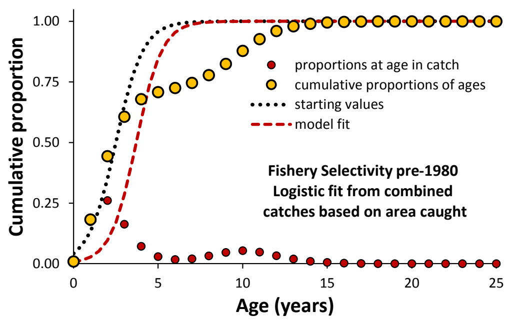
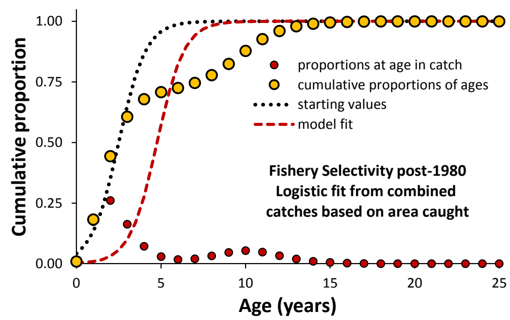


Fig. A-II.2 a-g. Starting values and model-estimated (unless fixed) selectivities for fishery and indices, and predicted relative harvests from the catch-free model.

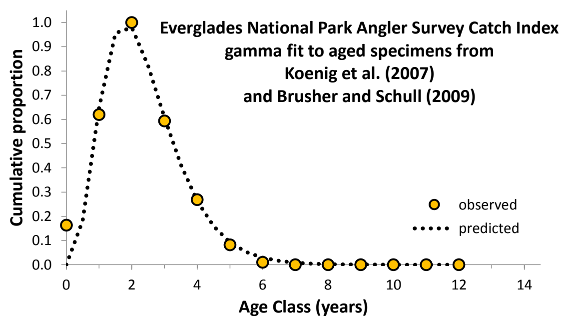
a. Pre-1980 fishery selectivity



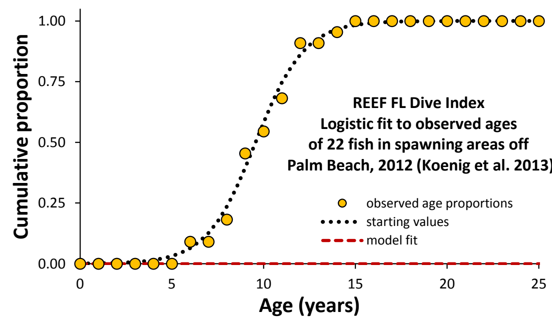
b. Post-1980 fishery selectivity



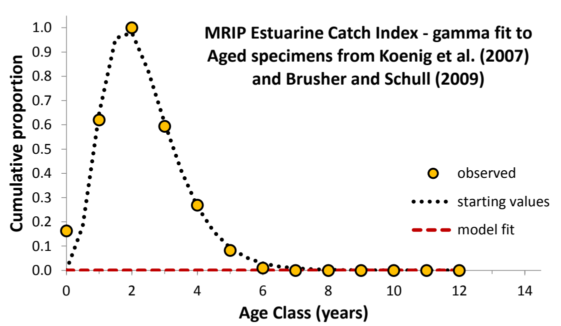
c. ENP index selectivity (fixed)



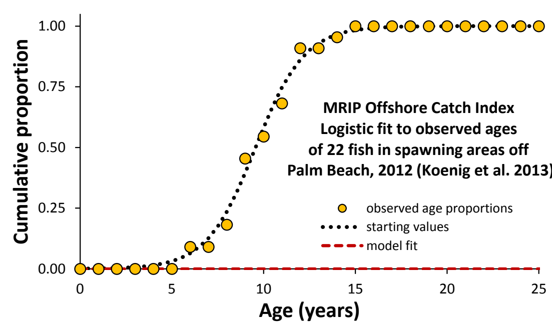
d. REEF FL index selectivity (fixed)



e. MRIP Estuarine index selectivity (fixed)



f. MRIP Offshore index selectivity (fixed)



g. Predicted relative harvest (catch-free model; in blue) compared with observed harvests (in black) using fixed index selectivities