An Interactive Combined Effects (ICE) Model for South Atlantic Red Snapper

NOAA Fisheries Service
Southeast Regional Office
263 13th Avenue South
Saint Petersburg, Florida 33701

Introduction

The SEDAR-24 (2010) benchmark stock assessment of U.S. South Atlantic red snapper indicates the stock is undergoing overfishing and is severely overfished (SEDAR 24 2010). The South Atlantic Fishery Management Council (SAFMC) is currently developing Regulatory Amendment 10 (Reg10) to the Snapper-Grouper Fishery Management Plan (FMP) to address overfishing of red snapper and rebuild this stock (SAFMC 2010). Three ‘plausible’ stock assessment model outcomes were identified by the SAFMC’s Scientific and Statistical Committee (SSC) as being the most useful for red snapper management purposes. These runs improved model fits to the headboat catch-per-unit-effort index, and were presented to the SEDAR-24 (2010) Review Workshop as ‘hb=0.2’, ‘hb=0.25’, and ‘hb=0.3’. Given $F_{rebuild}$ = 98%$F_{30\%SPR}$, a 70-75% percent reduction in total removals of red snapper from 2007-2009 baseline levels is projected to end overfishing and rebuild the red snapper stock under these various scenarios.

Amendment 16 to the Snapper-Grouper FMP was implemented in July 2009, closing the vermilion snapper (VS) recreational fishery in the U.S. South Atlantic during November through March of each year. Amendment 16 also closed shallow-water grouper (SWG) to commercial and recreational harvest during January through April of each year. Amendment 17B, if implemented, would include a prohibition on harvest of several deepwater snapper-grouper species beyond 240 feet (73 m). These regulatory actions may indirectly affect red snapper removals (e.g. landings and dead discards) if trips targeting other regulated species no longer occur due to closed seasons or areas. Additionally, red snapper removals will be directly impacted by the implementation of Amendment 17A, which includes a year-round prohibition on red snapper harvest, possession, and retention in the U.S. South Atlantic exclusive economic zone (EEZ).

Five reports were completed by Southeast Regional Office personnel analyzing the effects of SAFMC FMP amendments on red snapper removals (SERO 2009a-e). Input assumptions and data for these previous reports were based upon an earlier red snapper stock assessment (SEDAR-15 2009). This report uses input assumptions and data from the new 2010 benchmark assessment (SEDAR-24 2010) to project reductions in red snapper removals across all three fishing sectors (i.e., commercial, recreational private, and for-hire charter and headboat) based upon an interactive combined effects (ICE) model. The ICE model was developed to project red snapper removal rates under a variety of spatial closure sizes, configurations, and input assumptions.

Methods

Trip Elimination: Overview

Trip elimination models were developed for the commercial, headboat, and recreational private and charter sectors to simulate the impacts of previously approved amendments to the Snapper-Grouper FMP. The impacts of Amendments 16, 17A, and 17B were not captured by 2007-2009 baseline data, as regulations associated with these amendments became effective either in late 2009 or later. Impacts were expressed as changes in total catch (landings and discards, in lbs) by month and statistical area, by sector.

Trip elimination methods for the commercial sector were performed by the Southeast Fisheries Science Center (SEFSC) and followed procedures described in SERO (2009a), as updated for SEDAR-24 (2010) assumptions and input years. Fishermen with permits to fish in federal waters for species in the snapper-grouper fishery have been required since 1993 to submit logbook reports of their landings by species. These logbook trip reports from 2007-2009 constitute the source of data used in this analysis. Amendment 13C was not modeled, as it was implemented in 2006 and its effects should have been captured by the 2007-2009 baseline.

The simulation model uses logbook trip reports to predict the short-term economic effects of proposed management alternatives (Waters 2008). The general method of analysis is to hypothetically impose proposed regulations on individual fishing trips as reported to the logbook database, and then calculate their effects on trip catches, revenues and costs. Trips were eliminated and landings re-estimated according to the scenarios described in Table 1.

Table 1. Trip elimination scenarios explored by the commercial trip elimination model. An 'X' denotes elimination of trips. Amendments 16 ('A16') closes shallow-water grouper during January through April, Amendment 17B ('A17B') includes a deepwater closure (240 feet seaward) to protect Warsaw grouper and speckled hind, Amendment 17A ('A17A') closes red snapper throughout the EEZ, and Regulatory Amendment 10 ('Reg10') closes fishing for managed Snapper-Grouper throughout the EEZ with a specified depth range.

Scenario	A16	A17B	A17A	Reg10
Baseline	n/a	n/a	n/a	n/a
1			X	No Closure
2	X	X	X	No Closure
3			X	All Depths
4	X	X	X	All Depths
5			X	66-240 ft
6	X	X	X	66-240 ft
7			X	98-240 ft
8	X	X	X	98-240 ft

The simulation model examines the effects of proposed management alternatives on trip revenues and trip costs. If trip revenues remain greater than trip costs plus the opportunity cost of labor after accounting for the likely effects of proposed restrictions, then the trip is recorded as taken in the simulation model, and reported catches of species that would be prohibited or restricted by law are considered to be caught anyway and released. If the proposed management alternatives would cause trip revenues to fall below the sum of trip costs and the opportunity cost for labor after accounting for the likely effects of proposed restrictions on trip-level harvests, then the trip is recorded as not taken in the simulation model, and reported catches are assumed to no longer occur given the new regulatory restrictions. As a result, red snapper would not be caught, would not be released, and would not incur release mortality.

This method of analysis has advantages and disadvantages. The advantages are that logbook data are reported by fishermen, and are available in sufficient detail to analyze and compare the proposed scenarios. The disadvantage is that logbook data reflect fishing patterns and strategies given regulations that will no longer apply. Fishermen will modify their fishing patterns and strategies to minimize the effects of new regulations, but the simulation model does not account for these changes. Therefore, it can only approximate the true, but unknown, outcomes of proposed regulations. Nevertheless, the approach provides useful insights about the relative magnitudes of change due to proposed management scenarios and the distribution of effects among commercial gear sectors .

Because the commercial logbook does not account for all commercial landings (e.g. sales made on state permits), landings and new management discard (e.g., post-Amendment 17A) estimates generated by the trip elimination model were scaled up to account for this missing data. Expansion factors for under-reporting were computed by year based upon differences between the baseline logbook data and commercial landings inputs to the Beaufort Assessment Model used in SEDAR-24. Expansion factors for under-reporting were 8.9%, 7.3%, and 3.1% for 2007-2009, respectively. Additionally, the commercial logbook dataset does not contain information on discards, which are estimated for the commercial fishery from a supplemental discard logbook and are presented in SEDAR-24 (2010) as discards in numbers. Discard logbook estimated dead discards were converted from numbers to pounds assuming an average weight of 2.88 lbs from SEDAR-24 (2010). For the baseline commercial scenario, red snapper removals were expressed as landings plus dead discards. Dead discards accounted for 18.2%, 8.7%, and 8.1% of the total removals during 2007-2009, respectively.

All non-baseline trip elimination scenarios contained an Amendment 17A moratorium on the harvest of red snapper. Output from Scenarios 1-8 (Table 1) was expressed as new management dead discards. Catch that would have been landed on trips not eliminated by A16, A17A, and A17B regulations were converted to dead discards using the discard mortality rate (*D*) in Equation 1 (SEDAR -24 2010):

$$D = \frac{1}{\left(1 + e^{-(-2.3915 + 0.0592 * 0.304801 * d)}\right)} \tag{1}$$

where *d* represents water depth (in feet) of fishing for red snapper as reported in the SEFSC commercial logbook database. This equation applies to red snapper that would be landed by all commercial gear types except dive gear. Fishermen with dive gear are assumed to not take red snapper if prohibited or restricted. Hence, there would be no release mortality associated with dive gear.

Moratorium simulated dead discards were then expanded to account for discard logbook estimated dead discards. To create expansion factors, baseline landings were converted to dead discards using the average commercial release mortality rate (48%; SEDAR-24 2010), and the ratio of these converted landings to discard logbook estimated dead discards (in lbs) was computed by year (37.8%, 18.1%, and 16.8% for 2007-2009, respectively). Expanded outputs for all commercial trip elimination scenarios were expressed as total removals (in lbs) by statistical area and month.

Trip Elimination: Recreational Headboat

Trip elimination methods for the headboat sector followed procedures described in SERO (2009b) and SERO (2009d), as updated for SEDAR-24 (2010) assumptions, data, and input years. The recreational headboat sector of the snapper-grouper fishery was evaluated using headboat survey (HBS) logbook data (Southeast Region Headboat Survey data, accessed 19 April 2010) reported by headboat operators. Headboats are large, for-hire vessels that typically accommodate 20 or more anglers on half- or full-day trips. The three-year average of trips and landings (in pounds whole weight) derived from HBS catch-effort data files from 2007-2009 was assumed to be representative of future behavior and effort in the fishery. Impacts of Amendment 17B were not modeled for the headboat sector as SEDAR-24 (2010) suggested minimal headboat catch beyond 240 ft depth.

Directed trips were eliminated from catch-effort data files (2007-2009) using criterion determined from catch-frequency distributions derived from the catch-effort data files (see SERO 2009b). Similar to the approaches used for the commercial trip elimination model, headboat trip records with catches exceeding a pre-determined criterion for vermilion snapper (November-March), shallow-water grouper (January-April), or red snapper (all months) were eliminated under various management scenarios and landings were subsequently re-estimated from the modified catch-effort files. The time periods evaluated correspond to proposed closed seasons for vermilion snapper and shallow-water grouper in Amendment 16, and red snapper in Amendment 17A. All trips landing at least 25 vermilion snapper, SWG, or vermilion snapper/SWG combined during closed months with the aggregate catch of these species exceeding 25% of the Snapper-Grouper FMP (all 73 regulated species) landings on the trip were defined as 'directed' trips that would be impacted by Amendment 16. Similarly, all trips landing at least 25 red snapper with red snapper landings exceeding 25% of the Snapper-Grouper FMP landings on the trip were defined as 'directed' trips that would be impacted by Amendment 17A. By defining 'directed' trips in terms of both quantity and percentage of landings, trips landing small quantities but high percentages of fish or trips landing large quantities representing a small percentage of the trip's landings were excluded from elimination.

Modified catch-effort headboat files were used to calculate headboat catch by month and statistical area based on SEFSC methods for management scenarios described in Table 2.

Table 2. Trip elimination scenarios explored by headboat sector trip elimination models, considering the effects ('X' denotes elimination of trips) of Amendments 16 ('A16') and Amendment 17A ('A17A') closing red snapper throughout the EEZ.

Scenario	**A16**	**A17A**
Baseline	n/a	n/a
1	X	
2		X
3	X	X

Headboat landings computed from the modified catch-effort files for the scenarios listed in Table 2 were subsequently expanded to include dead discards from SEDAR-24 (2010). Dead discards were converted from numbers to weight using the average SEDAR-24 dead discard weights of 1.77, 1.87, and 2.17 for 2007-2009, respectively. Headboat dead discards were computed for trip elimination scenarios using the ratio of trip elimination landings (later converted to dead discards) to baseline landings times the baseline mean dead discards (17.2 TP). Removals were assigned spatially using headboat four-digit statistical grids, with blanks filled in following methods described in SERO (2009d). Headboat reporting of statistical areas for 2007-2009 was significantly improved over 2005-2007.

Trip Elimination: Recreational Private and Charter

Trip elimination methods for the recreational private and charter sectors followed procedures described in SERO (2009c), as updated for SEDAR-24 (2010) assumptions, data, and input years. The private, rental, and for-hire charter sectors were evaluated using data from the Marine Recreational Fisheries Statistics Survey (MRFSS) dockside intercept records. MRFSS intercepts collect data on port agent observed landings ('A' catch), angler reported landings that were not observed ('B1' catch) and discards ('B2' catch). Data are reported in numbers by species, two-month wave (e.g., Wave 1 = Jan/Feb, … Wave 6 = Nov/Dec), area fished (inland, state, and federal waters), mode of fishing (charter, private/rental, shore), and state (east Florida, Georgia, South Carolina, and North Carolina).

MRFSS data were post-stratified for the state of Florida into two regions: Southeast Florida and Northeast Florida. Landings and discard data were additionally post-stratified by mode of fishing (e.g. 'Charter' and 'Private/Rental'). Mean annual landings and discards in numbers and weight were computed for 2007-2009. Landings and discards reported as occurring in inshore waters were eliminated following rationale of the SEDAR-24 Data Workshop (DW). Discard estimates in numbers were converted to discard estimates in weight following the previously described protocol for the headboat discards. Discard estimates in weight for each year (2007-2009) were converted to dead discards by multiplying by the recreational release mortality for red snapper, estimated at 38.9% for the 'Private/Rental' mode and 41.3% for the 'Charter' mode (SEDAR-24 2010). Total baseline removals were computed by adding landings and dead discards.

Similar to the approaches used for the headboat trip elimination model, MRFSS intercept records with catches exceeding a pre-determined criterion (see SERO 2009c) for vermilion snapper (November-March), shallow-water grouper (January-April), or red snapper (all months) were eliminated under various management alternatives scenarios and landings were subsequently re-estimated from the modified intercept files. These time periods evaluated correspond to proposed closed seasons for vermilion snapper and shallow-water grouper in Amendment 16, and red snapper in Amendment 17A. Impacts of Amendment 17B were not modeled for the private or charter recreational sectors as SEDAR-24 (2010) suggested minimal private or charter red snapper catch beyond 240 ft depth. All trips landing at least 5 vermilion snapper per angler or 1 SWG per angler during closed months with the 'closed season species' landings per angler exceeding 50% of the Snapper-Grouper FMP (all 73 regulated species) landings per angler were defined as 'directed' trips that would be impacted by Amendment 16. Similarly, all trips landing at least 1 red snapper per angler with red snapper landings per angler exceeding 50% of the Snapper-Grouper FMP landings per angler were defined as 'directed' trips that would be impacted by Amendment 17A. Similarly, primary and secondary target species identified in the MRFSS intercept records were also used to identify 'targeted' trips. If anglers reported targeting red snapper, vermilion snapper, or SWG, then the trip was identified as a 'target' trip for these species during the closure months.

Table 3. Trip elimination scenarios explored by recreational sector trip elimination models, considering the effects ('T' denotes elimination of 'targeted' trips; 'DT' denotes elimination of 'directed' and 'targeted' trips) of Amendments 16 ('A16') and Amendment 17A ('A17A').

Scenario	A16	A17A
Baseline	n/a	n/a
1	n/a	T
2	DT	T
3	n/a	DT
4	DT	DT

Once 'targeted' and 'directed' trips were defined, these trips were removed from the MRFSS intercept records dependent upon the model scenario (Table 3) and assumed to no longer occur. Landings and discards were then re-estimated using the MRFSS post-stratification program and modified intercept records. Re-estimated catch (in lbs) was apportioned by wave using the sector and scenario-specific 2007-2009 distribution of catch by wave, and then apportioned by month within waves using the ratios of days per month, assuming a uniform distribution of catch across days.

To evaluate the impacts of Amendment 17A spatial area closures, MRFSS landings had to be partitioned into statistical grids. MRFSS red snapper landings in the south Atlantic are reported primarily by state (FL, GA, SC, and NC), mode (charter, private), and area fished (federal waters, state waters, and inland waters), providing little spatial resolution to where red snapper landings occur. In order to partition MRFSS removals (landings + discards) into logbook grids, headboat removals by logbook grid were used as a proxy (see SERO 2009b-d). MRFSS removals were assigned to logbook grids using equation 2:

$$R_a = \frac{\%L_a}{\sum_{a=1}^{\Omega} \%L_a} * R_{\Omega} \qquad (2)$$

where, *R* is MRFSS removals, *a* is logbook grid, *%L* is the percentage of headboat landings, and *Ω* is MRFSS post-stratified region. In some instances, logbook grids overlapped state boundaries. If the majority of a logbook grid occurred in the MRFSS post-stratified region, then MRFSS post-stratified landings were assigned to that logbook grid.

Changes to Post-Release Mortality

Mortality of discarded red snapper has been estimated at 38.9% for the private recreational sector, 41.3% for the recreational for-hire (i.e., headboat and charter) sector, and 48% for the commercial sector (SEDAR-24 2010). Release mortality rates were based upon barometric mortality curves from a meta-analysis of laboratory and field studies combined with the average depth of fishing from observer data (see Equation 1). Differences in discard mortality rates between sectors result from differences in average depth fished, although it should be noted that longer handling time (longer surface interval) in the commercial fishery and hook trauma (all sectors) are also important sources of post-release mortality (SEDAR-24 2010).

Some closure alternatives may result in commercial and recreational fishermen moving into shallower water to fish, potentially decreasing barometric trauma and associated post-release mortality rates. The ICE Model allows the user to input post-Reg10 changes in release mortality by sector across all statistical areas. In addition, statistical areas 3379, 2981, 3081, and 3181 do not contain any depths greater than 66 ft. If effort shifts into shallower water due to annual spatial closures then a decrease in 'inshore' release mortality could be specified to account for this effort shift. The release mortality rate at 66 feet is estimated to be 20% (SEDAR-24 2010). The removals associated with changes in release mortality were computed by multiplying the sector-specific, statistical area-specific catch (in lbs) by the sector-specific, statistical area-specific release mortality rate.

Impacts of Bathymetric Closures

Reg10 contains alternatives for two bathymetric closures: (1) 66-240 ft and (2) 98-240 ft. The SEDAR-24 (2010) Data Workshop generated an Excel workbook entitled 'Rec-Discard-Mort-Dept-Analysis.xlsx.' The depth distributions of red snapper targeted by the recreational charter, headboat, and private fleets were computed in this workbook based upon available observer and port sampler data. To compute the impacts of the bathymetric closure, the red snapper stock was assumed to be heterogeneously distributed. Coastal relief mapping was used to determine if any depths between the specified depths (66-240 ft or 98-240 ft) were present within a closed statistical area. The percentage of the red snapper stock protected was estimated using the SEDAR-24 (2010) proportions of red snapper caught by depth. At 100% compliance, the percentage of the red snapper protected within various depth closures is presented in Table 4. Red snapper caught in statistical areas without these depths present would receive no protection from a bathymetric closure. The impacts of the bathymetric closure for the commercial sector were computed explicitly within the commercial trip elimination model as described previously.

Table 4. Proportion of red snapper removals originating within bathymetric contours, by sector.

Sector	66-240	98-240
Headboat	88.5%	40.6%
Charter	92.2%	74.2%
Private	81.0%	62.1%

Note: Computed from 'Rec-Discard-Mort-Dept-Analysis.xlsx' (SEDAR-24-DW 2010).

Compliance Rate

Most of the fisheries benefits of spatial closures are dependent on compliance with no-take regulations (Fogarty et al. 2000). Although published data exists to estimate rates of non-compliance (Ward et al. 2001), numerous modeling efforts and case studies have shown that even relatively low levels of poaching can rapidly erode the fisheries benefits of spatial closures (Tegner 1993, Attwood et al. 1997, Gribble & Robertson 1998, Guzman & Jacome 1998, Murray et al. 1999, Rogers-Bennett et al. 2000; however, see Jennings et al. 1996). As such, the projection model was designed to account for reduced compliance rates. Compliance rate was treated as a scalar multiplier, uniformly distributed across closed cells. For example, if a cell with 1,000 lbs of removals in June were 100% closed during the month of June with 90% compliance, 100 lbs of removals would still occur in that cell (see Equations 3 and 4).

Temporal Closures

All baseline and trip elimination scenarios expressed catch (in lbs) by month and by sector. The ICE Model allows the user to specify the statistical areas that will be closed, the months during which they will be closed, and the percentage of the month that will be closed. For example, a scenario might be modeled in which cell 3080 were 100% closed during the months of June – August, and open for the remainder of the year. The associated removals would be computed using the month- and sector-specific catch within that cell (see Equations 3 and 4).

Effort Intensification

Partial monthly openings of closed areas may lead to an intensification of effort relative to historical levels. The ICE Model allows the user to enter a scalar multiplier for effort intensification for partial openings of closed cells. This adjusts the 'baseline' removal rate to account for increased effort that may occur (see Equations 3 and 4).

Effort Shifting

Effort may shift from closed statistical areas to nearby adjacent statistical areas, or shift from closed months to open months within a statistical area. The ICE Model allows the user to specify where effort might shift, what sectors might shift effort, and the percent scalar of effort shifting that may occur. Effort shifting within a cell with a time-area closure was modeled as occurring in the month prior to the closure and the month following the closure. For example, if cell 3080 were closed in June-August and the effort shifting scalar were 50%, removals in May and September would be 125% (e.g., 100% + 50%/2 months = 125%) of the modified baseline output from Equations 3 and 4. Effort shifting to adjacent statistical areas during time-area closures was assumed to occur during the time-area closure, and the percent effort shifting scalar was apportioned equally amongst the specified effort shifting cells. For example, if cell 2980 were closed in June and effort shifting was specified into cells 3081, 3080, 2981, and 2880 at 50%, then removals in each of these adjacent cells would be 112.5% (e.g., 100% + 50%/4 cells = 112.5%) of the modified baseline output by Equations 3 and 4.

Combined Effects

The approach taken for computing combined effects was somewhat different between the commercial and recreational sectors. The projected impacts of Reg10 upon removals (*R*) during a given month (*m*) in a cell (*c*) were computed for the commercial sector as follows:

$$R_{m,c}^{new} = R_{m,c}^{adj} + \left(\delta_{m,c} * \left(1 - \Phi_{m,c}\right) * \left(R_{m,c}^{old} - R_{m,c}^{adj}\right) + \left(\Phi_{m,c} * (1 - \xi) * \left(R_{m,c}^{old} - R_{m,c}^{adj}\right)\right)\right) \quad (3)$$

where R^{adj} denotes removals derived from the pertinent trip elimination scenario inclusive of explicitly-computed impacts of spatial closure and changes in release mortality (Table 1), R^{old} denotes baseline removals, δ denotes effort shifting or effort intensification (for partial closure) scalar, Φ denotes percent of month cell is subject to time-area closure, and ξ denotes percent compliance. This equation takes the adjusted commercial removals expected under the given management scenario by statistical area and by sector and scales it accordingly for effort shifting, effort intensification, closures, and non-compliance.

The projected impacts of Reg10 upon removals in the recreational sector were computed as follows:

$$R_{m,c}^{new} = \begin{cases} \Phi \neq (0{,}100),\ \rho_c * \left[C_{m,c}^{adj} * \delta_{m,c} * \left(1 - \Phi_{m,c}\right) - \left(\Phi_{m,c} * \gamma * C_{m,c}^{adj}\right)\right] \\ \Phi = 100,\ \rho_c * \left[C_{m,c}^{adj} - \left(\Phi_{m,c} * \gamma * C_{m,c}^{adj}\right)\right] \\ \Phi = 0,\ \rho_c * \left[C_{m,c}^{adj} * \delta_{m,c}\right] \end{cases} \qquad (4)$$

where C^{adj} denotes catch derived from the pertinent trip elimination scenario exclusive of impacts of spatial closure and changes in release mortality (Table 1), C^{old} denotes baseline catch, ρ denotes post-Reg10 release mortality rate for the recreational sector for the given statistical area, and γ denotes percent of stock protected (computed as percent of stock within bathymetric closure times compliance rate). This equation takes the adjusted catch expected under the given management scenario by statistical area and by sector and scales it accordingly for spatial closures, bathymetric closures, effort shifting, effort intensification, and non-compliance; then converts this adjusted catch to removals using the statistical area- and sector-specific post-Reg10 release mortality rate.

To compute the percent reduction achieved by a given set of combined management measures and input assumptions, the ICE Model sums across months, statistical areas, and sectors, then compares the total removals under the new management regime to the baseline (2007-2009) removals. Reduction targets were handled as percentages to compensate for deviations between SEDAR-24 (2010) input data and Beaufort Assessment Model (BAM) output estimates of removals. BAM outputs deviate from SEDAR-24 DW data because BAM accepts input for the recreational sector in numbers of fish landed, rather than pounds. BAM then estimates the weights of the catch using a von Bertalanffy growth curve coupled with the sector-specific selectivity curves. The proportional differences between mean BAM output removals (2007-2009) and projected total allowable removals under three model runs (i.e., 'hb=0.2', 'hb=0.25', and 'hb=0.3') at F = $F_{rebuild}$ = 98%$F_{30\%SPR}$ were used to compute the reduction targets for 2011, which ranged between 70-75%.

Results

Mean (2007-2009) baseline removals for the commercial sector were 259 thousand pounds (TP). Baseline headboat removals (landings + dead discards, in lbs) were computed as 105 TP. Baseline 'Private/Rental' removals were computed as 690 TP; 'Charter' removals were computed as 196 TP. Total baseline removals across sectors were 1,253 TP. These totals are consistent with SEDAR-24 (2010). Total removals varied by statistical area (Figure 1), with statistical areas 2980 (Ponce and St. Augustine Inlets), 2880 (Port Canaveral Inlet), and 3080 (St. Augustine and St. John's River Inlets) comprising the top three sources of removals.

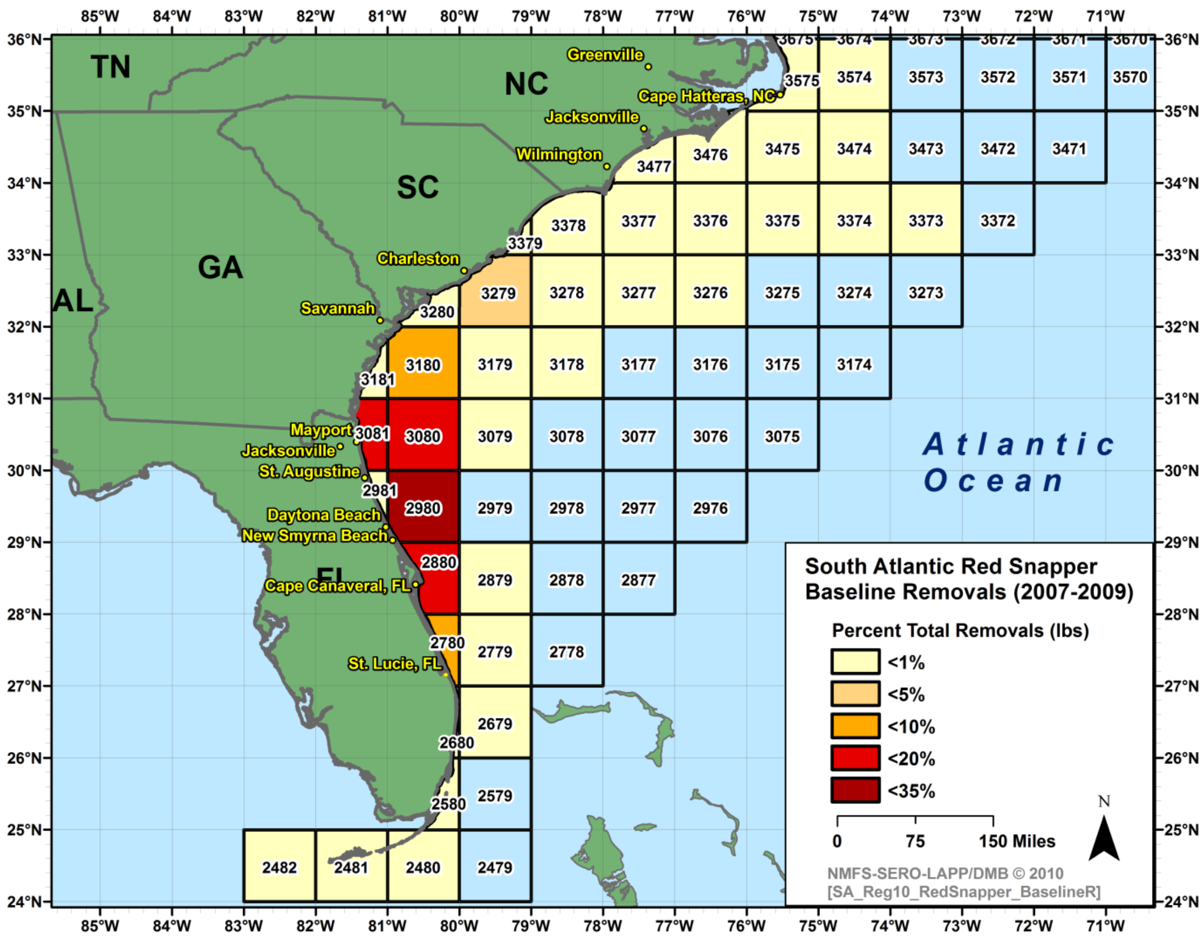

Figure 1. Percent of U.S. South Atlantic red snapper baseline removals (2007-2009), by statistical area.

The ICE Model suggests a moratorium on red snapper with no spatial closures to snapper-grouper fishing might provide a 45-66% reduction in removals (Table 5). Elimination of targeted trips for red snapper by Amendment 17A has a substantial effect (19%) upon projected reductions, with minimal additional reductions associated with the projected effects of other amendments (2-3%).

To achieve a 70-75% reduction in removals, a spatial area closure during at least part of the year would be needed in 2011. The ICE model indicates that the Amendment 17A closure might provide a 79-81% reduction. The ICE Model also indicates reductions in removals associated with short-term (one- or two-month) closures may be partially or completely offset by effort-shifting and effort intensification (Table 6).

A variety of input parameter assumptions and scenarios were investigated to explore the sensitivity of the model to the combined effects of the broad suite of potential input parameters. Table 6 presents the projected reductions associated with management alternatives under consideration in Reg10. The input parameter stream has been reduced in this presentation to reflect input parameters selected by the SAFMC and their SSC during the development of Amendment 17A (e.g., elimination of directed and targeted trips for all sectors, reduction of inshore release mortality rate to 20% all sectors for annual closures, 90% compliance rate).

Table 5. Projected reductions across sectors associated with trip elimination scenarios under a red snapper harvest moratorium. A 'T' denotes elimination of 'targeted' trips; 'DT' denotes elimination of 'targeted' and 'directed' trips.

A16	A17B	A17A	Reduction
			45%
		T	64%
		DT	64%
DT	DT	T	66%
DT	DT	DT	66%

Note: Amendments 16 ('A16') closes shallow-water grouper during January through April, Amendment 17B ('A17B') includes a deepwater closure (240 feet seaward) to protect Warsaw grouper and speckled hind, Amendment 17A ('A17A') closes red snapper throughout the EEZ, and Regulatory Amendment 10 ('Reg10') closes fishing for managed Snapper-Grouper throughout the EEZ with a specified depth range.

Table 6. Projected reductions in red snapper removals associated with different levels of effort shifting and various spatial and bathymetric closures.

			Reductions by Pct. Effort Shift		
Closed Statistical Areas	**Depth (ft)**	**Closed Months**	**0%**	**50%**	**100%**
No Closure	n/a	n/a	66%	n/a	n/a
2980	98-240	Annual[1]	72	70	69
2980	98-240	June-July	67	67	66
2880, 2980	98-240	Annual[1]	75	74	72
2880, 2980	98-240	May-Oct	70	69	68
2880, 2980	98-240	July	67	66	66
2880, 2980	98-240	Jan-Apr	71	69	68
2880, 2980, 3080	98-240	Annual[1]	81	80	79
2880, 2980, 3080	98-240	May-Aug	71	70	68
2880, 2980, 3080	98-240	July-Dec	71	69	67
2880, 2980, 3080	98-240	May-Dec	73	71	70
2880, 2980, 3080	66-240	May-Dec	75	73	71
2880, 2980, 3080	98-240	July-Dec	72	70	69

Note: Assumes elimination of directed and targeted trips for all sectors and 90% compliance rate for all scenarios (SAFMC Amendment 17A 2009).
[1]Inshore release mortality rate reduced to 20%.

Discussion

SEDAR-24 projections indicate between a 70-75% reduction in red snapper removals (based on a $F_{rebuild} = 98\%*F_{30\%SPR}$) is needed to end overfishing and rebuild the red snapper stock in the south Atlantic region (SEDAR-24 2010). Amendment 17A implements a closure of the red snapper fishery in the south Atlantic. Our analyses suggest that without additional regulations, this closure will be inadequate to achieve the reductions in red snapper removals necessary to end overfishing of red snapper. This is due to the high rate of encounter with red snapper during other snapper-grouper fishing operations as well as the moderately-high release mortality of red snapper. To achieve a 70-75% reduction, the interaction rate with red snapper must be reduced through the closure of specific areas to harvest of all members of the snapper/grouper fishery management unit (FMU), in addition to a general closure of the red snapper fishery. A variety of scenarios were identified that would provide reductions in the 70-75% range while allowing for a reasonable rate of effort shifting. To achieve the higher end of this range of targeted reductions, longer (>6 months) and larger (three statistical areas, 66-240 ft) closures may be required. However; the time-area closures necessary to achieve the targeted reductions from SEDAR-24 (2010) are significantly smaller than the three statistical area annual closure selected as the preferred alternative in Amendment 17A.

As with most statistical analyses, assumptions can limit the applicability of results and conclusions. Assumptions in this analysis included: 1) discards occur in the same proportion as landings, 2) headboat landings are reasonable spatial proxies for private and charter boat landings, 3) no movement of fish across closed area boundaries, and 4) historical trends are reasonable proxies for future trends.

If discards do not occur proportionally to landings, the overall reductions generated by spatial closures would be different than presented herein. If fishermen relocate their effort to open areas rather than eliminating trips, reductions would be less than presented herein. If fishermen go out of business due to the stringency of proposed regulations, overall reductions might be greater than those presented herein.

If historical trends are not reasonable proxies for future trends, then the predictive utility of the ICE Model, which is based upon 2007-2009 trends in red snapper catch, is reduced. The ability of the 2007-2009 baseline data to predict fishery trends in 2011 is adversely impacted by fluctuations in the environment, rebuilding of the red snapper stock, and changes in the economy that effect fishing effort. If economic hardship creates a disincentive to fish, especially for the recreational sector, effort and associated removals in 2011 may be lower than projected.

The ability of the ICE Model to predict reductions beyond 2011 is further constrained as the trends in the fishery move further from the 2007-2009 baseline. A major concern in predicting future trends is that the ICE Model is predicated upon an equilibrium (average 2007-2009) stock; whereas the red snapper stock is in a rebuilding plan. As the stock rebuilds, the proportional representation of various age classes will shift, as will their absolute abundance.

The various sector-specific selectivities may then generate different levels of removals that would not be captured by historical data.

Most of the positive benefits of spatial area closures, including projected reductions in red snapper, are dependent on compliance with no-take regulations (Fogarty *et al.* 2000). Numerous modeling efforts and case studies have shown that even relatively low levels of poaching can rapidly erode the fisheries benefits of spatial area closures (Tegner 1993, Attwood et al. 1997, Gribble & Robertson 1998, Guzman & Jacome 1998, Murray et al. 1999, Rogers-Bennett et al. 2000; however, see Jennings et al. 1996). Little published data exists to estimate rates of non-compliance (Ward et al. 2001), but a multi-year study in the Great Barrier Reef reported high levels of intrusion into a no-take zone of the Great Barrier Reef Marine Park (Gribble & Robertson 1998). For results summarized in Table 6, compliance was fixed at 90% based on Council recommended compliance rates during A17A deliberations. If compliance is less than 90%, reductions in red snapper removals might be substantially less than those estimated in this report. Reg10 differs from A17A in that the time-area closures are smaller and of limited duration. A smaller closure is more easily enforced when enforcement resources are limited, and may also receive more public support or buy-in. Both of these factors may increase compliance rate. If compliance is greater than 90%, reductions in red snapper removals might be higher than those estimated in this report.

The use of headboat landings locations as spatial proxies for private and charter boat landings is discussed in SERO (2009c). A comparison of post-stratified aggregated landings showed similar patterns in red snapper removals, although MRFSS reports higher relative landings off Northeast Florida and lower relative landings off South Carolina (SERO 2009c). Given the large size of the statistical areas involved in the spatial portioning of landings and the locations of major population centers, it seems reasonable to assume that broad-scale landings patterns between these sectors might be similar. If charter boat and private recreational landings patterns are not reasonably approximated by the headboat fishery, then overall reductions might be greater or lower than those projected by these analyses.

Movements of exploited fish species across closed area boundaries can help maintain fisheries yields but also reduce the ability of the closed area to protect spawning stock biomass (Farmer 2009). Fishermen may take advantage of these movements by redistributing fishing effort along closed area boundaries (review in Gell & Roberts 2003), further reducing the closed area's ability to control fishing pressure on the stock. Modeling efforts suggest larger closed areas provide a buffer, reducing the impacts of 'fishing-the-line' upon the core population (Fogarty 1999, Bohnsack 2000, Crowder et al. 2000, Walters 2000, Farmer 2009). Regardless, a combination of fish movement across closed area boundaries and a redistribution of fishing effort along boundaries might substantially reduce the protections afforded by the closures proposed in Reg10 for the red snapper stock.

In summary, model results suggest a moratorium on red snapper with no spatial closures to snapper-grouper fishing will not be sufficient to achieve the necessary SEDAR-24 (2010) reductions. Similarly, model results indicate the A17A closure achieves a greater reduction in removals (79-81%) than may be needed. To achieve the SEDAR-24 (2010) necessary reductions in removals, a spatial area closure during at least part of the year would be needed in 2011 to achieve a 70-75% reduction in removals. Larger spatial area closures effective for longer durations are more likely to achieve necessary reductions in removals, as removals associated with short-term (one- or two-month) closures may be offset by effort-shifting and effort intensification (Table 6). Similarly, closure of 66-240 ft would greatly increase protection of red snapper spawning grounds, especially in statistical areas 2980 and 3080, as compared to a 98-240 ft closure (Figure 2), but would result in a significantly larger area closed to fishing.

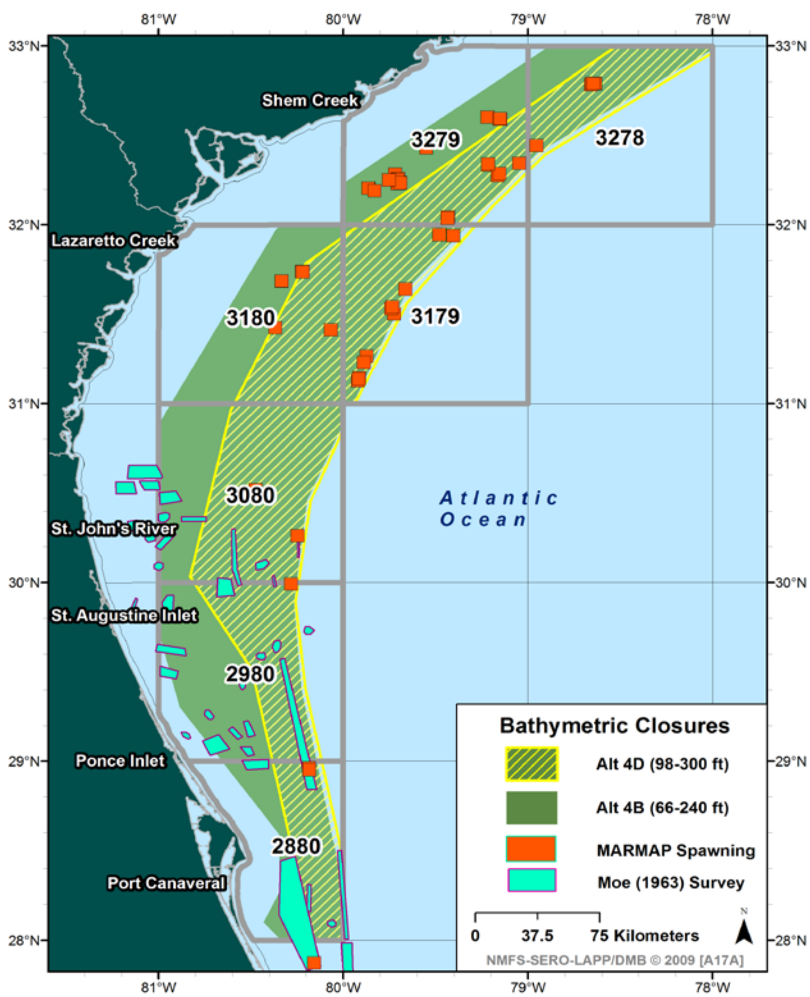

Figure 2. Generalized bathymetric closure areas from SAFMC Snapper-Grouper Amendment 17A, illustrating 66-240 ft and 98-300 ft closures relative to Moe (1963) survey-reported spawning grounds for red snapper and MARMAP sampling locations (1977-2009) where red snapper were captured in spawning condition.

Literature Cited

Attwood, C.G., J.M. Harris and A.J. Williams. 1997. International experience of marine protected areas and their relevance to South Africa. *South African Journal of Marine Science* 18: 311–332.

Bohnsack, J.A. 2000. A comparison of the short-term impacts of no-take marine reserves and minimum size limits. Bulletin of Marine Science, 66(3): 635-650.

Crowder, L.B., Lyman, S.J., Figueira, W.F., and J. Priddy. 2000. Source-sink population dynamics and the problem of siting marine reserves. Bulletin of Marine Science, 66(3): 799-820.

Farmer, N.A. 2009. Reef fish movements and marine reserve designs. Ph.D. Dissertation, University of Miami, Miami, FL. 216 pp.

Fogarty, M.J. 1999. Essential habitat, marine reserves and fishery management. Trends in Ecology & Evolution, 14(4): 133-134.

Fogarty, M.J., J.A. Bohnsack and P.K. Dayton. 2000. Marine reserves and resource management. In: *Seas at the Millenium: An Environmental Evaluation. Volume III Global Issues and Processes*. C.R.C. Sheppard (Editor). Pergamon, Elsevier Science, New York. p. 375–392.

Gell, F. R. and C.M. Roberts. 2003. The fishery effects of marine reserves and fishery closures Washington, DC: WWF-US.

Gribble, N.A. and J.W.A. Robertson. 1998. Fishing effort in the far northern section cross shelf closure area of the Great Barrier Reef Marine Park: the effectiveness of area-closures. *Journal of Environmental Management* 52: 53–67.

Guzman, H.M. and G. Jacome. 1998. Artisan fishery of Cayos Cochinos Biological Reserve, Honduras. *Revista de Biologia Tropical* 46: 151–163.

Jennings, S., S.S. Marshall and N.V.C. Polunin. 1996. Seychelles' marine protected areas: comparative structure and status of reef fish communities. *Biological Conservation* 75: 201–209.

Murray, S.N., T. Gibson Denis, J.S. Kido and J.R. Smith. 1999. Human visitation and the frequency and potential effects of collecting on rocky intertidal populations in Southern California marine reserves. *California Cooperative Oceanic Fisheries Investigation Report* 40: 100–106.

Rogers-Bennett, L., Bennett, W. A., Fastenau, H. C. and C. M. Dewees. 1995. Spatial variation in red sea urchin reproduction and morphology: implications for harvest refugia. *Ecological Applications* 5: 1171–1180.

SAFMC 2010. Amendment 17A to the Snapper-Grouper Fishery Management Plan. SAFMC, Charleston, SC. 417 pp.

SEDAR 15. 2009. Stock Assessment Report 1 (SAR 1) South Atlantic red snapper. Southeast Data, Assessment, and Review, Charleston, SC. 511 pp.

SEDAR 24. 2010. Stock Assessment Report: South Atlantic red snapper. Southeast Data, Assessment, and Review, Charleston, SC. 524 pp.

SERO. 2009a. Evaluating the Effects of Amendment 13C, Amendment 16, and Amendment 17A Regulations on Red Snapper Removals by South Atlantic Commercial Fisheries. SERO-LAPP-2009-03, NMFS, SERO, St. Petersburg, FL. 41 pp.

SERO. 2009b. Evaluating the Effects of Amendment 16 Regulations on 2005-2007 South Atlantic Red Snapper Headboat Removals. SERO-LAPP-2009-04, NMFS, SERO, St. Petersburg, FL. 10 pp.

SERO. 2009c. Evaluating the Effects of Amendment 16 Regulations on 2005-2007 South Atlantic Red Snapper Private and Charterboat Removals. SERO-LAPP-2009-05, NMFS, SERO, St. Petersburg, FL. 22 pp.

SERO. 2009d. Evaluating the Effects of Amendment 17A Regulations on 2005-2007 South Atlantic Red Snapper Headboat Removals. SERO-LAPP-2009-06, NMFS, SERO, St. Petersburg, FL. 13 pp.

SERO. 2009e. Projected Combined Effects of Amendments 13C, 16, and 17A Regulations on south Atlantic Red Snapper Removals. SERO-LAPP-2009-07, NMFS, SERO, St. Petersburg, FL. 17 pp.

Tegner, M.J. 1993. Southern California abalones: can stocks be rebuilt using marine harvest refugia? Canadian Journal of Fisheries and Aquatic Sciences, 50: 2010–2018.

Walters, C.J. 2000. Impacts of dispersal, ecological interactions, and fishing effort dynamics on efficacy of marine protected areas: How large should protected areas be? *Bulletin of Marine Science*, 66(3): 745-757.

Ward, T.J., Heinemann, D., and N. Evans. 2001. The role of marine reserves as fisheries management tools: A review of concepts, evidence, and international experience. *Australia Bureau of Rural Sciences: Agriculture, Fisheries, and Forestry*, 105 pp.

Waters, J.R. 2008. An Economic Model to Analyze Management Alternatives Proposed for the Commercial Fishery in Amendment 16 to the Snapper-Grouper Fishery Management Plan. NOAA National Marine Fisheries Service, Southeast Fisheries Science Center, 14p.