FishSmart: A stakeholder-centered approach to improve fisheries conservation and management

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Abstract: Fisheries management often limits an effective and meaningful exchange of information and ideas between stakeholders and managers. Our objective was to develop a process that allows stakeholders to develop recommendations to improve the fishery through voluntary measures and provide management recommendations that they supported. We developed a "stakeholder-centered" process that facilitated explicit goal setting and iterative evaluation of options acceptable to stakeholders. An initial application involved angler, tournament, commercial, management, recreational industry, and conservation stakeholders for the southeastern U.S. king mackerel (*Scomberomorus cavalla*) fishery. The stakeholder workgroup developed objectives for the fishery, options that could be used to achieve the objectives, and performance measures to gauge whether objectives were reached. Objectives included traditional and non-traditional goals such as maintaining high and stable catches and retaining the opportunity to catch large fish, and options included voluntary changes in fishing practices and mandatory regulations. Stakeholders were an integral component in developing a model to allow them to compare how well their options met their objectives. Based on the results of the decision analysis, stakeholders developed a consensus suite of recommendations, including more conservative length and bag limits than those initially recommended by management. The immersion of stakeholders in reviewing the available science and developing the model led to recognition that more conservative management was necessary to achieve their objectives. This project demonstrated that stakeholders can be included in a meaningful participatory process that can improve fisheries management, but inclusion requires increased time and an effort to provide science without jargon or condescension.

Keywords: decision analysis, *Scomberomorus cavalla*, recreational fisheries management, stakeholder participation

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Introduction

Fishery stakeholders are becoming increasingly involved in management throughout many of the world's fisheries. These activities can range from complete control of the resource by stakeholders (Hilborn 2007) to advisory panels composed of stakeholders, such as those used by several of the U.S. regional fishery management councils, to less formal use of public meetings to obtain stakeholder input. Despite these efforts, some stakeholders, such as environmental non-governmental organizations (ENGOs) and recreational anglers, have been historically left out of the process because fisheries management often limits an effective and meaningful exchange of information and ideas between stakeholders and managers, which can lead to distrust among stakeholder groups and between stakeholder groups and the management agency.

Marine recreational fisheries are increasing in importance for many U.S. stocks (Coleman et al. 2004). However, management of these fisheries is still largely dominated by goals and objectives of maximum or optimum sustainable yield, which may be more appropriate for commercial fisheries. This dissatisfaction has lead to numerous law suits against national and regional management agencies in attempts to block a range of management decisions including allocations, rebuilding plans, and access. Paralleling the increase in prominence of marine recreational fisheries has been an increasing focus on marine issues by a diverse array of conservation oriented ENGOs such as the Nature Conservancy, the Blue Ocean Institute, and the Cousteau Society. Sometimes the interests of fisheries organizations and ENGOs make them effective partners; in other instances their interests diverge. Clearly, disputes over management goals and actions will be reduced if all potential stakeholders are included in the management process from the very beginning before contentious policies are adopted. However, the current regional management Council process under which fisheries are managed in U.S. federal waters does not fully provide such an opportunity.

Multiple user groups usually have a suite of objectives they would like the fishery to meet. Commonly applied approaches to fisheries management are not well suited to deal with these multiple factors because most harvest policy analyses only consider total yield and variability in yield (Deroba and Bence 2008). In particular, the fishery management process has yet to fully integrate the views of diverse stakeholder groups into management decisions. In particular, input from stakeholders is often sought only once management options have been formulated. This has led to the perception among some stakeholders that their interests are not fully valued, and that managers are seeking only a "rubber stamp" of approval. Stakeholders do not have the responsibility of direct decisions, which may influence compliance and effectiveness of management. Co-management may be an alternative option to traditional fisheries management (Hilborn 2007). Under this framework, stakeholders play a significant role in developing and implementing policy. There is also a large middle ground between full co-management and traditional fisheries management. This area includes efforts to involve stakeholders in the science and development of policy, although they may not implement or enforce policy (e.g., Cox and Kronland 2008).

Our objective was to evaluate alternative management and conservation options through a collaborative modeling process to improve the level of stakeholder input into the management process and thus improve the relationship between stakeholders and managers. The process involved the development of recommendations for management and angling practices to improve fishery sustainability by a focused workgroup of stakeholders. We conducted a collaborative simulation model analysis of the effects of alternative fishing practices and management choices, which we have termed FishSmart. The collaboration involved anglers, commercial fishermen, ENGOs, tackle shop owners, managers, and scientists, and sought to identify changes in angling practice and management that could lead to increased sustainability and to improve relations among stakeholder groups. The process centered on developing a simulation model to explore how changes in the fishery affect the ability to achieve stakeholder objectives over a series of several workshops. At the heart of the process are the central assumptions that fisheries management will more likely achieve its goal of sustainable fisheries if all stakeholders contribute and are fully empowered at all stages of the management process.

Methods

Stock selection

We chose a species that could serve as a case study for the development and testing of a stakeholder driven process designed to explore and recommend options for improving the quality of marine recreational fisheries for the target species. Following extensive review of candidate fisheries, we chose the king mackerel (*Scomberomorus cavalla*) fishery in the southeast Atlantic as the first system in which the FishSmart process would be implemented. The most important features of candidate fisheries were that: 1) the recreational fishery comprises the majority of the landings, 2) there was some conservation concern for this fishery, but not so much so that management response was mandated by law, 3) the stock had sufficient data available such that a stock assessment was possible, 4) management action was likely in the near future, and 5) management and stakeholders were welcoming of our involvement. Following this review, the steering committee endorsed the selection of the fishery for the Atlantic migratory group of king mackerel. This stock was primarily chosen as the first case study for FishSmart both because it is an important marine recreational fishery and because it was believed that stakeholder recommendations could be made to managers before management recommendations were formally adopted.

King mackerel is a migratory coastal pelagic with a range extending from the northeastern U.S. to Brazil (Collette and Russo 1984; Godcharles and Murphy 1986), and is the target of recreational and commercial fisheries. The U.S. king mackerel fishery is managed as two stocks: one centered in the Gulf of Mexico managed by the Gulf of Mexico Fishery Management Council, and a second distributed along the southeastern U.S. Atlantic coast from Florida to North Carolina, which is managed by the South Atlantic Fishery Management Council (Fig. 1). For our work we only considered the south Atlantic migratory group. The Atlantic migratory group of king mackerel was considered to be overfished in the late 1980s (SAFMC 1989). As a result, substantial changes in regulations were enacted to reduce fishing mortality rates, such as gear restrictions for commercial fisheries and increased size and reduced bag limits for recreational fisheries. Harvests are currently managed by quotas, with approximately 70% of total landings allocated to the recreational sector. During the last decade, the fishery landings have been relatively steady with total landings of approximately 400 metric tons (MT – Fig. 2). The recreational fisheries have not achieved their portion of the quota; thus, recreational landings are only approximately 60% of the total landings. In addition to traditional commercial and recreational fisheries, this is an important species for tournaments throughout the southeastern U.S. Many of these tournaments are organized by the Southern Kingfish Association (http://www.fishska.com/) and provide substantial prize money for the largest fish brought to the weighing station. However, catches due to tournaments are poorly represented in current data collection programs and stock assessments.

Workgroup

The application of the FishSmart process to king mackerel involved establishing a workgroup of representatives of the principal stakeholders in the king mackerel fisheries. The workgroup worked closely over a period of eight months to develop a suite of recommendations for management approaches that they believed would lead to an improved king mackerel fishery and would also satisfy requirements under U.S. law. Workgroup members were selected to represent classes of stakeholders (see Ihde et al. in review for details on workgroup member selection). Potential members were identified following extensive consultation with steering committee members, South Atlantic Fishery Management Council (SAFMC) staff, Gulf of Mexico Fishery Management Council (GMFMC) staff, recreational angling organizations and with individual anglers. Because the workgroup had to be limited in size to less than 25 to ensure its effectiveness, and because constituent groups of stakeholders had to be represented effectively, members were chosen from recognized leaders among their constituents. Members also had to be willing to work constructively with stakeholders of different interest groups. An additional and important requirement for members was that they had to commit to attending all of the workshops. This was an important criterion for workgroup membership because the workshops build upon one another and educating new members partway through the process would have severely diminished the rate of progress we could expect to achieve. Further, continuity was viewed as important to maximize the development of positive working relationships between stakeholder groups. Participation of individuals in the process was voluntary, so members had to be satisfied that the process would be a valuable use of their time.

The final workgroup consisted of 13 members. Stakeholder groups included independent recreational anglers, angling organizations, charter captains, the tournament sector, commercial fishers, tackle shop owners, environmental NGOs, and state biologists and managers. Group members included the sitting chairperson, the past chairperson and two members of the SAFMC Mackerel Advisory Panel and the managing partner of the Southern Kingfish Association, the largest U.S. tournament circuit for the Atlantic migratory group of king mackerel.

The workgroup conducted its work using consensus-building techniques with the assistance of professional facilitators. Facilitators were from the Florida Conflict Resolution Consortium, a division of Florida State University. The facilitation team ensured that each workshop was a smooth and efficient process, that the goals of each of the workshops were met, and that all stakeholders in the workgroup were able to express their views and fully contribute to the process. General consensus was a participatory process in which the workgroup members strived for agreements in which all of the members can accept, support, live with or agree not to oppose. In instances where, after vigorously exploring possible ways to enhance the members' support for the final package of recommendations, and the workgroup found that 100% acceptance or support was not achievable, final consensus recommendations required at least

75% favorable vote of all members present and voting. This super majority decision rule underscored the importance of actively developing consensus throughout the process on substantive issues with the participation of all members. While all workgroup members, staff, and facilitators were present at discussions, only workgroup members voted on proposals and recommendations.

Workshops

Stakeholders developed recommendations for improving management of the king mackerel fishery over the course of four workshops during 2008 (Ihde et al. in review). The workshops centered around developing objectives for the fishery, performance measures to gage whether objectives were reached, and options that could be used to reach the objectives. Through an iterative process, stakeholders assisted in developing a stochastic simulation model of the fishery for and dynamics of Atlantic migratory group of the U.S. king mackerel fishery to allow them to compare how well the options they wanted to consider met their vision for a quality fishery. The purpose of model development in the process is to ensure that all stakeholders are aware of the information and assumptions that go into predicting expected benefits.

The workshop process enabled stakeholders to evaluate the effectiveness of different management and voluntary options for achieving their objectives for the king mackerel fishery (Table 1). Stakeholders developed a stochastic simulation model with us over the course of a series of four workshops. The workshops sought to first develop a vision for the future fishery that is shared among all stakeholders by defining objectives as a group. Subsequent workshops then focused on identifying options and performance measures that stakeholders believed to be important (Table 2). Within the process, we defined options as voluntary behaviors or management actions that could be used to achieve the objectives of the group, while performance measures were defined as metrics that could be used to gauge whether options achieved the shared objectives. The simulation model described the dynamics of the fishery over a 50-year period for each of the chosen options that the stakeholders wanted to evaluate, and summaries were based on 5-, 15-, and 50-year summaries. The performance measures also provided a basis for ranking the outcome of different options. Upon completion of the option evaluation process, the workgroup recommended a package of preferred options to the SAFMC.

Model Description

In collaboration with the workgroup, we developed a stochastic simulation model that was age-, size-, sex-, and spatially-structured. This level of detail was required to include the options and performance measures selected by the workgroup. The model included ages 1 through 19+, where 19+ was an aggregate age class of all fish age 19 and older, and 131 1-cm length bins from 30 cm to 160 cm, which includes most of the range of potential king mackerel sizes. Two areas (northern, NC-GA, and southern FL) and a 3-month time step were included to allow for seasonal north-south migration of king mackerel along the Atlantic coast. Uncertainty is included in the model through parameter uncertainty, within simulation uncertainty, and uncertainty in how the fishery will respond to changes in the population and regulations. Inclusion of uncertainty is a critical part of the modeling process, but explicit inclusion of some factors was very difficult. For example, workgroup members had long discussions about future trends in recreational fishing effort and effects of increasing fuel prices, changes in management of other fisheries, and overall declining participation rates in U.S. recreational fisheries. We were unable to include these considerations in the model explicitly. However, we conducted sensitivity analyses to evaluate how future effort patters could affect the efficacy of different options. The workgroup identified other major uncertainties that were not explicitly factored into the model such as effects of global warming, economic impacts of changes in the fishery, and uncertainty about migration patterns and timing of migration. Model variables and parameters are described in Table 3 and equations are in Tables 4 and 5.

Recruitment (number of age-1 individuals) followed a Beverton-Holt stock recruitment function (Eq. 4.1; Fig. 2; Mace and Doonan 1988), where recruitment was a function of spawning stock biomass, the biomass of mature females during summer (SSB; Eq. 4.2), and a lognormal error (Eq. 5.1). In U.S. waters spawning occurs from April to October (Finucane et al. 1986), and we used the midpoint of this distribution as a spawning date in the model. The steepness parameter of the Beverton-Holt model and its coefficient of variation (CV) were estimated using a meta-analysis (Myers 1996) of seven other mackerel stocks and was drawn from a lognormal distribution for each simulation, h = 0.36, σ_h=0.255 (Eq. 5.2). The distribution was truncated at a steepness of 0.2, although this happens for a small proportion of the distribution (1%). SSB_0 was determined by dividing mean SSB from the stock assessment (Eq. 4.3; Anonymous 2008) by a uniformly distributed random number that assumed the current status of the stock was between 0.3 and 0.7 of virgin SSB (Eq. 5.3). After h and SSB_0 were determined for a simulation, R_0 was calculated by solving Eq. 4.1 for R_0 given the other parameters and median recruitment and mean SSB from the stock assessment (Eq. 4.4). This procedure forces the median stock-recruitment curve through the median recruitment and mean SSB. The sex ratio at recruitment was 1:1. The CV of interannual recruitment variation was estimated from the variability of the assessment model estimates of recruitment and was random among simulations (Eq. 5.4). There is believed to be only limited exchange between the Gulf of Mexico and south Atlantic migratory groups (Gold et al. 1997, 2002). However, a study using DNA microsatellites suggests that gene exchange between areas may be more substantial (Broughton et al. 2002). To simplify the model, we assumed that the net spawning contribution to the Atlantic migratory group from the Gulf of Mexico was zero.

Abundance in the first year of the model began at the estimated abundance at age in 2007 from the assessment modified with a lognormal error (Eq. 5.5). After the first year and first age, abundance of a cohort in an area changed because of mortality and migration (Eq. 4.5). Fish migrated from north to south in the fall and from south to north in the spring (Fig. 2). The fall migration was assumed to occur instantaneously on October 1 and the spring migration on April 1. Mortality was a function of natural mortality, mortality from harvest, and mortality of releases (Eq. 4.6). Age-specific migration rates were multiplied by a lognormally distributed scalar with a coefficient of variation of approximately 20% (Eq. 5.6).

Natural mortality was a decreasing function of size (Lorenzen 1996), and the same pattern of natural mortality was used in the model as in the stock assessment (Fig. 4; Anonymous 2008). This was converted to age-based mortality by taking the weighted average of the length-specific mortality rates weighted by abundance. The natural mortality curve was scaled so that the average was the same as the value calculated using Hoenig’s (1983) method and a maximum observed age of 26 for king mackerel (Anonymous 2008). These functions were sex-specific because females and males have different growth patterns and the Lorenzen (1996) method models natural mortality as a function of mass (Anonymous 2008). Median natural mortality-at-age and length was multiplied by a lognormal random scalar with a CV of 20% for each simulation to include uncertainty about the natural mortality rate (Eq. 5.7).

The fishery included three sectors: recreational (private, charter, and headboats), commercial, and tournament. For the recreational sector, median fishing mortality followed three general patterns with annual lognormal errors: constant over time, increasing at 0.5% per year for the first 25 years, then constant for the remaining 25 years, and decreasing at 0.5% per year for the first 25 years, then constant for the remaining 25 years. For the commercial and tournament sectors, fishing mortality varied about a constant median (Eq. 5.8). Mean initial fishing mortality rates were chosen such that the spawning potential ratio (SPR) in the first year of the model was the same as the average SPR in the most recent years of the stock assessment. We also conducted sensitivity analyses where the recreational fishing mortality was reduced by 50%, but the results of these simulations are not shown. The patterns of seasonal and spatial fishing mortality for each sector were based on the seasonal pattern of landings in the fishery during different months for the recreational and commercial fisheries. Age-based fishing mortality rates from harvest and releases were calculated from the overall fishing mortality, the selectivity and retention functions, the proportion of dead discards, and released fish mortality rates (Eqs. 4.7 and 4.8). Age-based selectivity and retention were the weighted average of length-based selectivity and retention (Figs. 5 and 6) weighted by the proportion at age of a given length (Eqs. 4.9 and 4.10). The proportion of catch released dead and the release mortality were both randomly drawn for each simulation (Eqs. 5.9 and 5.10). Values for selectivity at length were taken from a previous version of the stock assessment model (Ortiz et al. 2008) that estimated the length-based selectivity (Fig. 4). Retention in the commercial and recreational sectors was based on past practices and regulations, and selectivity and retention of the tournament sector were based on expert judgment of the workgroup panel members. Because most king mackerel tournaments do not allow fish less than 4.5 kg to be entered, the retention function was zero for sizes where the average weight was less than 4.5 kg and increased such that an 11.3 kg fish was always retained. Size limits were implemented by modifying the retention functions so that only legal sized fish were retained. The proportion of dead discards used in most of the model runs was 0% for the commercial fishery and 15.5% for recreational and tournament fisheries (see Table 1) because this was the average proportion of dead releases during the most recent five years (B1 classification in MRFFS). We used expert judgment of the workgroup to estimate the mortality rate of fish released alive, and the average estimate from the workgroup was 12.5%. This value is somewhat less than estimates from a telemetry study that estimated release mortality of 20%. The proportion of dead discards and the release mortality rate were randomly drawn for each simulation from a lognormal distribution with CVs of 10% and 20% respectively to represent uncertainty in these quantities.

Bag limits and quotas required a different modeling approach than size limits. Overall fishing mortality in an area, season and fishery were modified to simulate the effects of these regulations (Eq. 4.11). Bag limits were implemented by decreasing F by the proportional decrease in catch caused by the bag limit (Eq. 4.12; Porch and Fox 1991). A truncated negative binomial distribution was used to model the distribution of catch-per-trip under a bag limit (Wilberg 2009; Eq. 4.13), and a negative binomial distribution was used in the absence of a bag limit (Eq. 4.14). The distribution of catch-per-trip was similar among trips of different sizes and therefore, only a party size of two was used in the model (NOAA MRFFS, unpublished data). This assumption was reasonable because bag limits for king mackerel have a similar effect across party sizes (Wilberg 2009). The parameters of the distribution of catch-per-trip were randomly chosen for each simulation (Eq. 5.11) and were independent of population size because an analysis of the MRFFS catch-per trip data showed no relationship with estimated population size from the stock assessment (NOAA MRFFS, unpublished data). Combinations of size and bag limits were implemented by first determining proportionally how much catch should be reduced by the bag limit. The mean parameter of the catch per angler distribution was decreased by this proportion, thus causing catch per angler to decrease. Additionally, the median mortality of fish released because of higher size limits was increased to 20% to simulate the effects of potentially increased handling caused by effects of more fish being measured.

Catch, harvest (retained catch in numbers), and deaths due to catch and release were calculated with the Baranov catch equation (Eqs. 4.15, 4.16, 4.17). Alternative catch and release practices were simulated by adjusting median of the proportion of fish that are released dead, the median mortality rate of fish that are released alive, and by changing the proportion of fish that are released alive (sometimes by size class). Quotas were implemented to constrain the catch so it could not be more than the quota. The catch equation was solved numerically to find the fishing mortality rate that would achieve the quota if catch was higher than the quota given the level of effort. The overall quota was constant throughout a simulation. The quota was divided between commercial (37.1%) and recreational and tournament sectors (62.9%). The approximate day the quota was reached was estimated by calculating the fraction of the harvest in the season that was necessary to achieve the quota and multiplying the number of days in the season by this fraction.

Mean length at age was constant over time and followed a von Bertalanffy growth model (Eq. 4.18; Fig. 7). Parameters of the model were separate for males and females because females grow faster and to larger size than males and were randomly drawn for each simulation (Eq. 5.12 and 5.13). Parameters of the growth model were taken from the stock assessment (Ortiz and Palmer, 2008). Length-at-age was normally distributed about the mean and had a constant sex specific CV (Eq. 4.19). The coefficient of variation for the first age was reduced to 5% because fish were predicted to be too large with higher levels of CV. Numbers-at-length were calculated by summing the product of numbers-at-age and sex and the proportion for each age of a given length (Eq. 4.20).

Maturity of females was described by a logistic function of length (Eq. 4.21; Fig. 8), which was estimated from data in Finucane et al. (1986). Using this relationship, female king mackerel reach 50% maturity at about 1.5 years of age. Mean mass-at-length followed a power function of length that was constant over time (Eq. 4.22; Fig. 9). For a given length bin, mass was normally distributed (4.23). The CV of this distribution (Fig. 10) changed with length (D. DeVries, unpublished data). Numbers-at-weight were calculated by summing the product of numbers-at-length and the proportion for each length of a given weight (Eq. 4.24).

Performance measures

Options were compared by evaluating how well they achieved the objectives through the use of performance measures from the simulation model. 750 50-year simulations were run for each option (2500 for each trend of recreational fishing mortality). This number allowed reasonably precise estimates of the median, mean, and interquartile range of performance measures. Performance measures were summarized as the average over 5, 15, or 50 years or as the proportion of years over 5, 15, or 50 years that an event occurred (e.g., proportion of years recreational quota was reached).

The workgroup based their recommendations on the following three minimum criteria: 1) the option should maintain the Atlantic king mackerel stock above the overfished and below overfishing thresholds over a period of 15 years or more, 2) The option should result in the least impact to both recreational and commercial, and 3) the option should prevent seasonal closures and avoid area closures. Although the workgroup originally suggested 22 performance measures (Table 2), three were primarily used to craft recommendations: proportion of years SSB was less than estimated equilibrium biomass at $F_{30\%}$ ($SSB_{F30\%}$; proxy for SSB at maximum sustainable yield), proportion of years F was greater than $F_{30\%}$, and the proportion of the year closed to recreational fishing. The values for $SSB_{F30\%}$ was taken from the base model for the south Atlantic migratory group stock assessment (Anonymous 2008). $F_{30\%}$ was recalculated each year because the overall pattern of fishing mortality at age changed each year due to trends in the recreational fishery and random deviations in effort from year to year, and differed among options because selectivity and retention patterns were changed by some options.

Results

The status quo management and fishing practices predicted a long-term decrease in SSB of king mackerel (Fig. 11). This decline in abundance had a negative effect on most of the performance measures, although the mean size in the catch was relatively unaffected by changes in population size. All of the options remained above the SSB threshold (not overfished) during the first five years on average in at least 50% of the simulations. However, most of the options were below the SSB threshold in more than 50% of the simulations over 50 years.

No single type of option was best in all cases. None of the options exceeded the fishing mortality threshold in more than 50% of the runs for any of the periods (Fig. 12). The status quo produced the highest fishing mortality rate and the other options were somewhat lower. This is not surprising because of the way the model is parameterized using relatively constant average fishing mortality rates. All of the options tested had a low proportion of years the recreational fishery was closed early because the quota was reached, except for the 5 million and 6 million lb quota options (Fig. 13), and most of the options allowed the fishery to remain open during the whole year (Fig. 14). In general, voluntary measures could be just as effective as management options if they were effectively implemented.

The workgroup developed concrete, constructive recommendations to improve the king mackerel fishery. The workgroup decided to base their recommendations on the performance of options over 15 years, with the goal of having greater than 50% of the simulations remain above the SSB threshold, below the F threshold, and have a low probability of recreational closures because the quota was reached. The workgroup chose three options that met their criteria for management recommendations: a 2 fish per angler bag limit, a 81 cm minimum size limit, and a combination of a 2 fish per angler bag limit with a 71cm minimum size limit. Of the recommended options, the 81 cm minimum size limit was farthest from the overfishing threshold and the combination of a 2 fish per angler bag limit and a 28 in minimum size limit was most protective of SSB.

Discussion

Stakeholders were able to develop and evaluate alternative management options and make useful recommendations for management of the king mackerel fishery. We were impressed by the stakeholders' understanding of the results of the modeling. Stakeholders were willing and able to use a complicated simulation model to guide their choice of management options at the end of the process. We believe this came about because of trust built during the workshops. When stakeholders are truly involved in the process, they take ownership of the results, which lends credibility to the results and momentum for the process (Walters 1986; Lee 1993).

The workgroup proposed three consensus Atlantic king mackerel management options that each meet and exceed the minimum criteria defined above. The workgroup did not establish a priority order for the following three options: 3.6 million kg annual total allowable catch, and a 2 fish per angler daily bag limit for the recreational fishery, 3.6 million kg annual total allowable catch, 2 fish per angler daily bag limit, and a 71 cm minimum size limit for the recreational fishery, and 3.6 million kg annual total allowable catch, and a 81 cm minimum size limit for the recreational fishery. The modeling results and analysis suggest that each option may perform differently relative to their overall effects on the recreational and commercial fishery, on increasing spawning stock biomass, and on fishing mortality. As a result, the workgroup decided to recommend these management combination options be considered and evaluated by the SAFMC. The SAFMC added the workgroup's recommendations to the list of potential options for the public scoping process.

This study resulted in more conservative management recommendations than the SAFMC assessment and review process, which recommended maintaining the status quo management. Our results suggest that $F_{30\%}$ exceeded F_{MSY} and thus was not a conservative reference point for the stock. Status quo expected to drive down SSB because of the relationship between steepness and sustainable SPR reference points (Punt et al. 2008). Results from Punt et al. (2008) suggest that fishing mortality targets of $F_{80\%}$ may be more appropriate if the true value of steepness is near the median (0.32). The results from this analysis were different than the stock assessment because a different steepness was assumed. We used a meta-analysis of other mackerel stocks, whereas the stock assessment chose a value based on the observation of relatively flat recruitment over a range of stock sizes.

Including stakeholders in the model development and evaluation increases their acceptance of the model results because they had a good understanding of the model by the end of the process and did not see it as a "black box." Others have also found this effect of collaborative model development (Walters 1986). Thus, effective communication and setting of expectations is extremely important to the success of this kind of project. Establishing trust and respect among the workgroup participants is important. The modeling team must avoid jargon and use language that is understandable, but not pandering. One simple way we did this was to use English units of length and weight during the workshops and to display model output instead of metric units. It is also likely that having an independent modeling team makes it easier to build trust more quickly because the analysts do not have any direct interest in previous management decisions or in pursuing specific management recommendations.

The collaboration with stakeholders had a significant effect on the final model that was developed. In addition, collaborative modeling with a group of stakeholders adds an additional component of difficulty to the modeling endeavor, but also substantial benefits. Stakeholders generally tend to prefer realism over abstraction in the model, which complicates model development. These complications arise both from the use of abstract models as well as from a tendency toward a desire for a reductionist approach to model development. For example, stakeholders wanted the model to include the distribution of mass at a given length, when the original version of the model only included average mass at length, yet this distinction had little effect on model results. In contrast, the stakeholders provided estimates of tournament catches and size distributions of landed fish to scope out this previously unmeasured portion of the king mackerel fishery. Inclusion of this component of the fishery had an effect on the sustainability of different options and allowed the workgroup to explore how changing tournament regulations may affect sustainability of the fishery.

The major criteria the workgroup used to evaluated policies were the goal of access to the fishery during the whole year and compliance with U.S. federal fisheries law. Most analyses of harvest policies focus on maximizing catch as the primary goal of the fishery (Deroba and Bence, 2008). The de facto utility function defined by the stakeholder workgroup generally did not include the total amount of catch. In contrast, the workgroup concluded that maximizing access, i.e., the amount of time available to fish, was most important. This may be because this study focused on the recreational fishery, and much of the recreational fishery values the opportunity to fish over catching fish. Similar results have been found in human dimensions research of recreational angler motivations (Reference). Ability to fish during the entire year means that recreational anglers are able to fish whenever they want, charter boat captains can book trips throughout the year, and tournaments can be scheduled throughout the year without concern over whether the fishery will be open. The workgroup found season closures to be the most undesirable form of management.

It was challenging to make the simulation and the assessment models match because the assessment model was age based while the simulation model was age and length based. We chose to include length and fishing mortality as a function of length because the workgroup was interested in considering options that changed the legal length limits. To a certain degree, differences between the assessment model and simulation model were mitigated by starting the model fishing mortality at a level that achieved the same SPR on average as the assessment estimated in the last year. It is important for the modeling team to have a close collaboration with the stock assessment team because the stock assessment will form much of the base of information for the simulation model, including starting conditions, parameter values, and estimates of uncertainty in parameters.

We believe that widespread adoption of collaborative policy evaluations will improve management and decrease conflicts among user groups and stakeholders that have characterized management of many fisheries. Processes that include stakeholders in a meaningful way, such as FishSmart, provide substantially more education of stakeholders about the science on which decisions are made and develop a deeper understanding of the available data, potential problems with the data, and assumptions used to make decisions. Inclusion of the views of a wider range of stakeholders and their views should produce better decisions and reduce conflict, which has been seen in systems that have adopted co-management of resources (Hilborn 2007). Optimally, collaborative policy evaluations can be used to guide management before problems becomes too contentious and views of some groups become irrevocably entrenched. While this kind of procedure may not always lead to as good of results as demonstrated here (e.g., Kolody et al. 2008; Butterworth 2008), other exercises have indicated that they can be successful (e.g., Cox and Kronland 2008).

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Table 1. Stakeholder-identified options for the south Atlantic king mackerel fishery.

Options	Status quo (2007 SAFMC)	Values Compared to status quo
Management		
Size limits	61 cm (24 in)	71 cm (28 in), 81 cm (32 in), slot limit
Bag/creel limits	2 fish (FL), 3 fish (NC-GA)	2 fish, 1 fish (all areas)
Season limits	Closed when quota reached	Closed when quota reached
Constant quota control rule	4.5 M (million kg)	2.3 M, 2.7 M, 3.2, M, 3.6 M
Voluntary		
Increased minimum size for tournaments	4.5 kg (~86 cm)	6.8 kg (~97 cm)
Increased catch and release fishing (CR)	26%	30%, 50%, 80% (over all sizes) release all fish > 9.1 kg
Reduction of catch and release mortality (RM) (by half)	12.5%	6.25%
Combinations		
Increase CR + reduce RM + increase min. size	As above for status quo	50% CR, 6.25% RM, 71 cm min. size

Table 2. Stakeholder-identified performance measures for the south Atlantic king mackerel fishery.

Performance measures
Population
Abundance (numbers)
Spawning stock biomass relative to $SSB_{F30\%}$ (SSB; biomass of mature females)
Average weight of spawners
Proportion of the population ≥ than 15 years old
Fishing mortality and SSB relative to threshold reference points
Fishery
Fishing mortality relative to $F_{30\%}$
Recreational harvest (numbers)
Recreational catch – all fish caught (numbers)
Tournament harvest (numbers)
Commercial harvest (weight, numbers)
Recreational harvest of fish larger than 20 lbs (recreational target)
Tournament harvest of fish larger than 50 lbs (tournament target)
Commercial harvest of fish between 10 and 12 lbs (commercial target)
Average weight in recreational harvest
Average weight in tournament harvest
Average weight in commercial harvest
Number of days in the recreational fishing season (before quota is reached)
Number of days in the commercial fishing season (before quota is reached)
Proportion of years that recreational quota is reached or exceeded
Proportion of years that commercial quota is reached or exceeded
Number of dead fish due to release mortality

Table 3. Symbols and descriptions of variables used in description of stochastic forecasting model. Indicators are used to denote structural parameters and error terms that were constant over simulations and time ("constant"), or were randomly drawn for a given simulation ("sim") or for each year ("year"). See Table 5 for additional details on distributions.

Symbol	Description
	Index variables
t	Time in seasons (1/4 of a year)
o	Area (NC-GA, FL)
x	Sex (male = 1, female = 2)
a	Age in years (1-19+)
l	Length bin (≤30, 30-31, …,159-160, ≥160 cm)
n	Season
f	Fishery
	Constants, state variables, and control variables
N	Actual abundance
R	Recruitment (age-1 abundance)
SSB	Spawning stock biomass (lbs, females)
L	Mean length (in)
CVL_a	Coefficient of variation of length-at-age
W	Mass-at-length (lbs)
CVW_l	Coefficient of variation in length-at-age
Ω	Maturity-at-length
F	Instantaneous fishing mortality rate from retained catch
E	Instantaneous fishing mortality rate from released catch
Z	Instantaneous total mortality rate
C	Catch in numbers (harvest)
$\dot{p}$	Proportions at length for each age
$\ddot{p}$	Proportions at weight for each length
s	Fishery selectivity (constant)
r	Fishery retention (constant)
v	Proportion released alive (constant)
p_q	Proportion of fishing mortality necessary to achieve quota
p_b	Proportion of fishing mortality achieved due to bag limit
$\tilde{C}$	Catch achieved under bag limit
$\hat{C}$	Catch achieved with status quo bag limit
b,k	Parameters describing negative binomial distribution of catch per trip (sim)
g	Bag limit
$\bar{\lambda}$	Mean fishing mortality
	Structural parameters
h	Beverton-Holt stock-recruitment steepness parameter (sim)
SSB_0	Virgin SSB (sim)

R_0	Virgin average recruitment (sim)
λ	Fishing mortality rate (for fully selected individuals) (year)
P	Proportion of recruits allocated to an area (sim)
$\dot{a}$	Mass-at-length parameter (constant)
B	Mass-at-length parameter (constant)
m_1	Maturity-at-length parameter, slope (constant)
m_2	Maturity-at-length parameter, half-saturation (constant)
L_∞	Asymptotic mean length (sim)
K	Growth coefficient (sim)
t_0	Age at length zero (sim)
M	Instantaneous natural mortality rate at age or length (sim)
d	Proportion released dead (sim)
ω	Proportion released alive that die (sim)
η	Depletion from SSB_0 (sim)

<u>Error terms</u>

ε	Recruitment error (year)
δ	Error for δ fishing mortality (year)

<u>Functions</u>

Φ	Normal cumulative distribution function
Γ	Gamma function

<u>Mean parameters</u>

$\bar{\sigma}_R$	Median log-scale recruitment standard deviation (constant)
μ_{VB}	Vector of mean L_∞ and K (constant)
$\bar{t}_0$	Median t_0 parameter (constant)
$\bar{P}$	Median migration rate vectors (constant)
μ_h	Median steepness of the stock-recruitment function (constant)
$\bar{M}$	Median natural mortality vectors (constant)
$\bar{N}$	Median initial population size vectors (constant)
$\bar{d}$	Median proportion of dead discards (constant)
$\bar{\omega}$	Median release mortality (constant)
$\bar{b}$	Median b parameter for distribution of catch per trip (constant)
$\bar{k}$	Median k parameter for distribution of catch per trip (constant)

<u>Standard deviation parameters</u>

σ_R^2	Standard deviation for ε (sim)
σ_h^2	Log-scale variance for steepness (constant)
$\sigma_{\sigma_R}^2$	Log-scale variance for log-scale recruitment errors (constant)
σ_N^2	Log-scale variance for initial abundance (constant)
σ_P^2	Log-scale variance for migration rates (constant)

σ_M^2	Log-scale variance for natural mortality (constant)
σ_δ^2	Log-scale variance for annual error in fishing mortality (constant)
σ_d^2	Log-scale variance for the proportion of fish released dead (constant)
σ_ω^2	Log-scale variance for release mortality (constant)
σ_b^2	Log-scale variance for bag limit *b* parameter (constant)
σ_k^2	Log-scale variance for bag limit *k* parameter (constant)
Σ_{VB}	Variance-covariance matrix for L_∞ and *K* (constant)
$\sigma_{t_0}^2$	Log-scale variance for t_0 (constant)

Table 4. Description of equations used in the model.

Equation Number	Equation	Description
4.1	$R_{y,x,o} = 0.5 P_o \dfrac{4hR_0 SSB}{(SSB_0(1-h) + SSB(5(h-1))} e^{\varepsilon_y}$	Beverton-Holt stock recruitment
4.2	$SSB_t = \sum_o \sum_l N_{t,x=2,l,o} W_l \Omega_l$	Spawning stock biomass
4.3	$SSB_0 = \dfrac{\mu_{SSB}}{\eta}$	Virgin SSB
4.4	$R_0 = \dfrac{\mu_R \left(SSB_0(1-h) + \mu_{SSB}(5h-1)\right)}{4hSSB_0 \eta}$	Virgin recruitment
4.5	$N_{t+1,a+\frac{1}{4},x,o} = \sum_o p_{a,n} N_{t,a,x,o} e^{-Z_{t,a,x,o}}$	Abundance
4.6	$Z_{t,a,x,o} = M_{a,x} + \sum_f F_{t,a,x,o,f} + \sum_f E_{t,a,x,o,f}$	Total mortality
4.7	$F_{t,a,x,o,f} = (1-d)\lambda_{t,f,o} s_{a,x,f} r_{a,x,f} (1-v)$	Fishing mortality of retained fish
4.8	$E_{t,a,x,o,f} = d\lambda_{t,f,o} s_{a,x,f} + (1-d)\lambda_{t,f,o} s_{a,x,f} \left(1 - r_{a,x,f}(1-v)\right)\omega$	Fishing mortality of released fish
4.9	$s_{t,a,x,f} = \sum_l s_{l,f} \dot{p}_{a,x,l}$	Age-based selectivity
4.10	$r_{t,a,x,f} = \sum_l r_{l,f} \dot{p}_{a,x,l}$	Age-based retention
4.11	$\lambda_{t,f} = \begin{cases} \bar{\lambda}_{t,f,o} e^{\delta_t} & \text{No bag limit or quota effects} \\ p_q p_b \bar{\lambda}_{t,f,o} e^{\delta_t} & \text{Recreational fishery} \\ p_q \bar{\lambda}_{t,f,o} e^{\delta_t} & \text{Commercial and tournament} \end{cases}$	Effects of bag limits and quota on fishing mortality (recreational only)
4.12	$p_b = \dfrac{\tilde{C}_{t,f,o}}{\hat{C}_{t,f,o}}$	Effects of quota on fishing mortality
4.13	$\tilde{C}_{t,f,o} = \sum_{i=0}^{g} i \dfrac{\Gamma(i+k)}{\Gamma(k) i!} \left(\dfrac{b}{b+k}\right)^i \left(1 + \dfrac{b}{k}\right)^{-k} + \sum_{i=g+1}^{\infty} g \dfrac{\Gamma(i+k)}{\Gamma(k) i!} \left(\dfrac{b}{b+k}\right)^i \left(1 + \dfrac{b}{k}\right)^{-k}$	Relative catch under the bag limit
4.14	$\tilde{C}_{t,f,o} = \sum_{i=0}^{\infty} i \dfrac{\Gamma(i+k)}{\Gamma(k) i!} \left(\dfrac{b}{b+k}\right)^i \left(1 + \dfrac{b}{k}\right)^{-k}$	Relative catch in absence of the bag limit
4.15	$C_{t,a,x,o,f} = \dfrac{f_{t,x,o} s_{a,x,f}}{Z_{t,a,x,o}} \left(1 - e^{-Z_{t,a,x,o}}\right) N_{t,a,x,o}$	Catch
4.16	$C_{t,a,x,o,f} = \dfrac{F_{t,a,x,o}}{Z_{t,a,x,o}} \left(1 - e^{-Z_{t,a,x,o}}\right) N_{t,a,x,o}$	Retained catch

4.17	$C_{t,a,x,o,f} = \frac{E_{t,a,x,o}}{Z_{t,a,x,o}}\left(1-e^{-Z_{t,a,x,o}}\right)N_{t,a,x,o}$	Numbers of dead releases
4.18	$L_{x,a} = L_{\infty_x}\left(1-e^{-K_x(a-t_{0_x}}\right)$	Mean length at age
4.19	$\dot{p}_{a,x,l} = \Phi\left(\frac{l+1-L_{a,x}}{L_{a,x}CVL_{a,x}}\right) - \Phi\left(\frac{l-L_{a,x}}{L_{a,x}CVL_{a,x}}\right)$	Proportion at length
4.20	$N_{t,x,l,o} = \sum_a N_{t,a,x,o}\dot{p}_{a,x,l}$	Abundance at length
4.21	$\Omega_l = \frac{1}{1+e^{-m_1(l-m_2)}}$	Maturity
4.22	$W_{x,l} = \dot{a}l^B$	Weight at length
4.23	$\ddot{p}_{l,w} = \Phi\left(\frac{w+1-W_l}{W_lCVW_l}\right) - \Phi\left(\frac{w-W_l}{W_lCVW_l}\right)$	Proportion at weight
4.24	$N_{t,w,o} = \sum_l N_{t,l,o}\ddot{p}_{l,w}$	Abundance at weight

Table 5. Stochastic parameters and their distributions. LN indicates a lognormal distribution, N a normal distribution, MVN a multivariate normal distribution, and U a uniform distribution.

Equation number	**Distribution**	**Description**
5.1	$\varepsilon \sim N(0,\sigma_R^2)$	Stock recruitment deviations
5.2	$h \sim LN\left(\mu_h,\sigma_h^2\right)$	Steepness of the stock-recruitment relationship
5.3	$\eta \sim U(0.3,0.7)$	Mean depletion
5.4	$\sigma_R \sim LN(\overline{\sigma}_R,\sigma_{\sigma_R}^2)$	Interannaul recruitment variation standard deviation
5.5	$N \sim LN(\overline{N},\sigma_N^2)$	Initial abundance variation
5.6	$P_{a,n} \sim LN(\overline{P},\sigma_P^2)$	Migration rates
5.7	$M \sim LN(\overline{M},\sigma_M^2)$	Natural mortality variation
5.8	$\delta \sim N(0,\sigma_\delta^2)$	Fishing mortality deviations
5.9	$d \sim LN(\overline{d},\sigma_d^2)$	Proportion released dead
5.10	$\omega \sim LN(\overline{\omega},\sigma_\omega^2)$	Release mortality
5.11	$b \sim LN(\overline{b},\sigma_b^2)$	Bag limit parameters
	$k \sim LN(\overline{k},\sigma_k^2)$	
5.12	$L_{\infty_x},K_x \sim MVN(\mu_{VB},\Sigma_{VB})$	von Bertalnaffy parameters
5.13	$t_0 \sim LN(\bar{t}_0,\sigma_{t_0}^2)$	Age at length zero

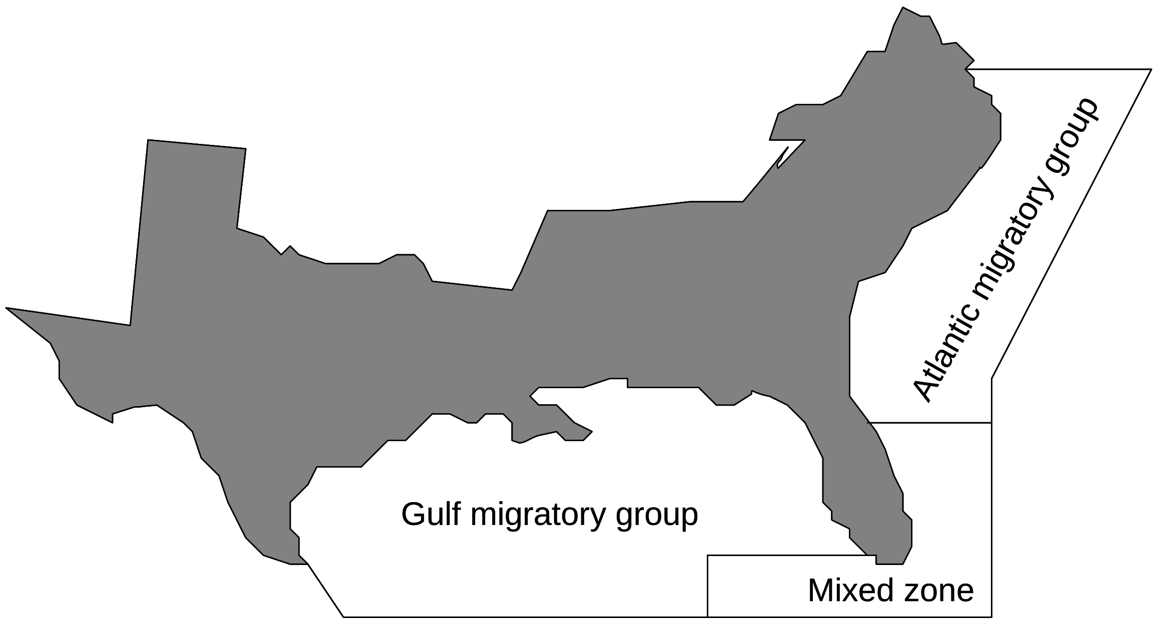

Fig. 1. U.S. definitions of king mackerel migratory groups.

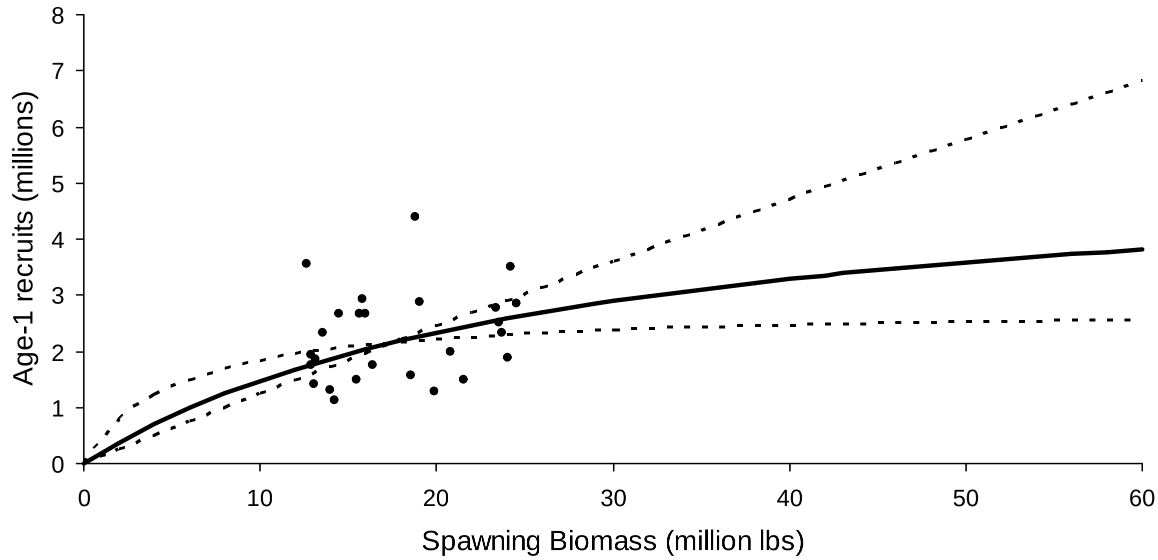

Fig. 2. Estimated stock and recruitment from the assessment model (filled circles), and the Beverton-Holt stock recruitment function used in the decision analysis model. The solid line is the median predicted relationship, and the dashed lines indicate curves generated using the upper and lower 95% confidence intervals of the parameters.

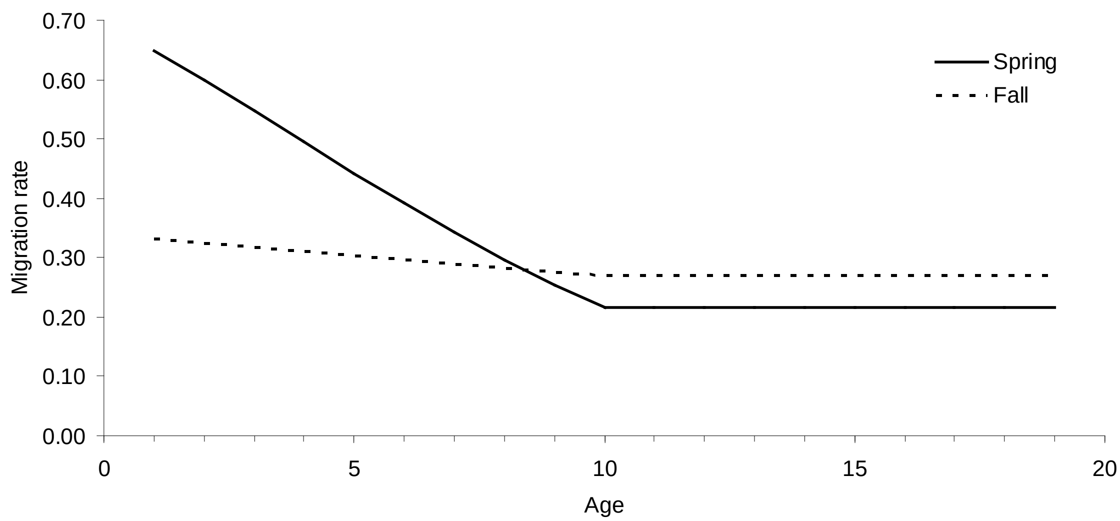

Fig. 3. Average migration rates by season and age. The dashed line indicates proportion of individuals that migrate south in winter, and the solid line indicates the proportion of individuals that migrates north in the spring as a function of age.

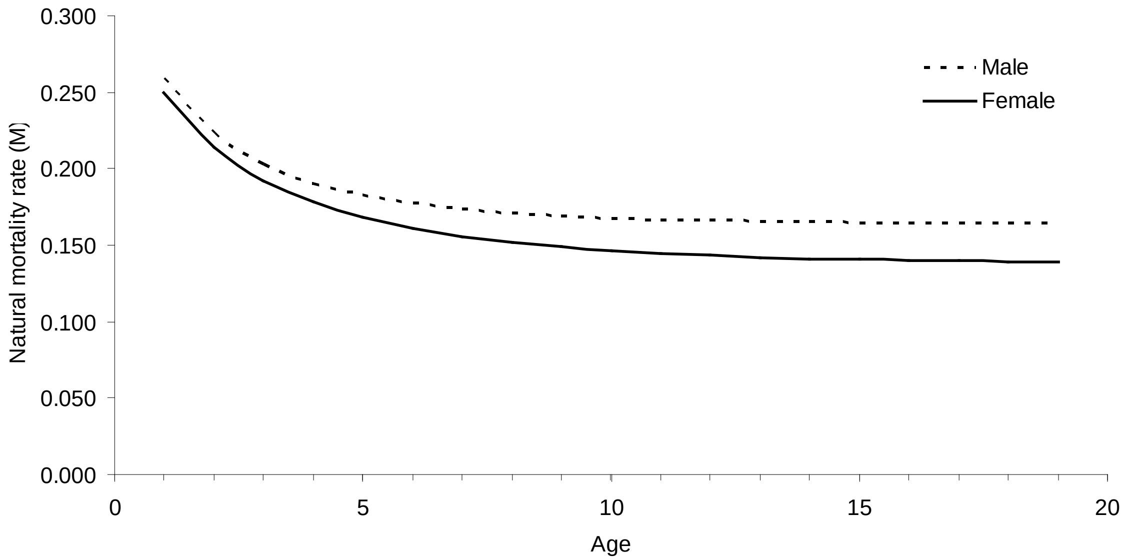

Fig. 4. Median instantaneous natural mortality as a function of age. The dashed line indicates natural mortality of males and the solid line indicates the natural mortality of females.

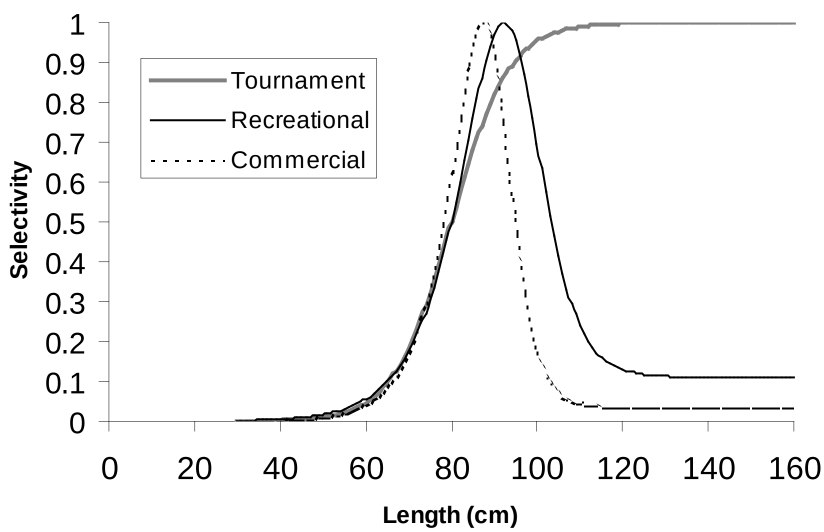

Fig. 5. Selectivity patterns as a function of length for commercial, recreational, and tournament fisheries.

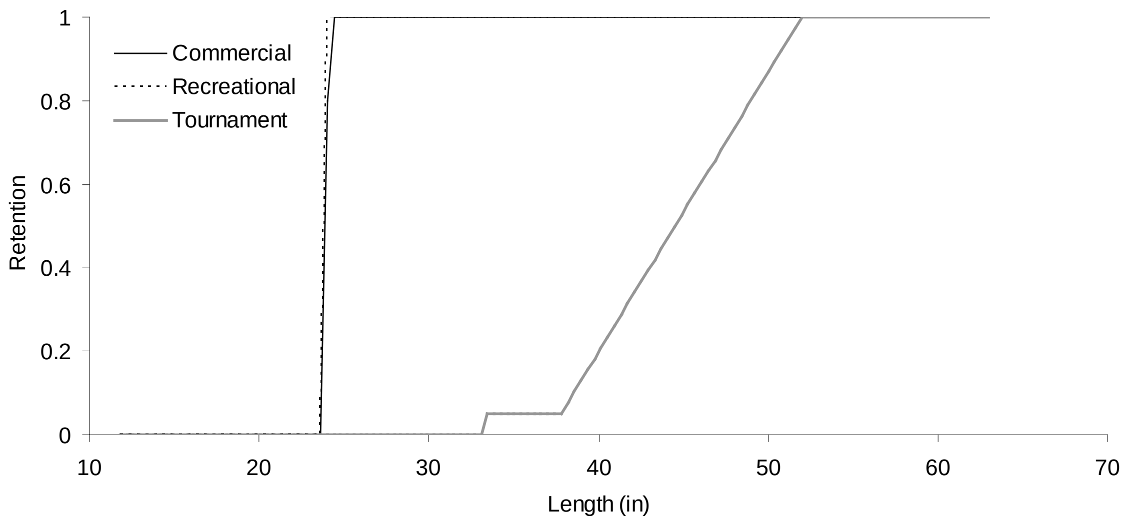

Fig. 6. Retention patterns as a function of length for commercial, recreational, and tournament fisheries.

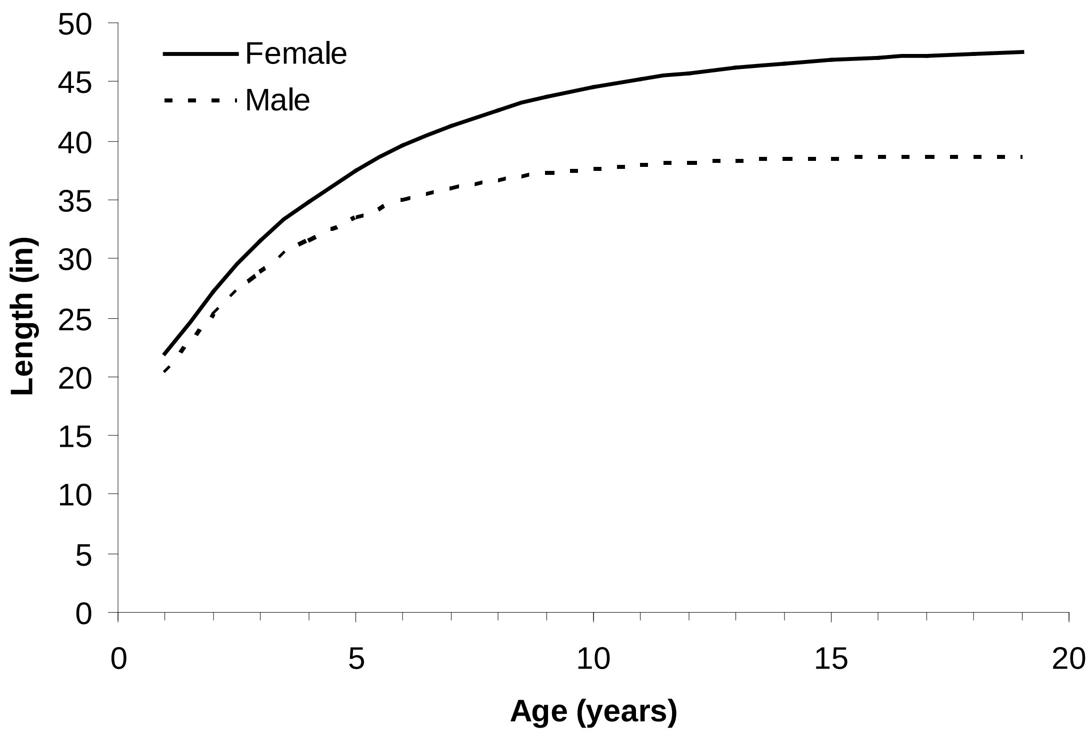

Fig. 7. Median pattern of mean length-at-age for male and female king mackerel.

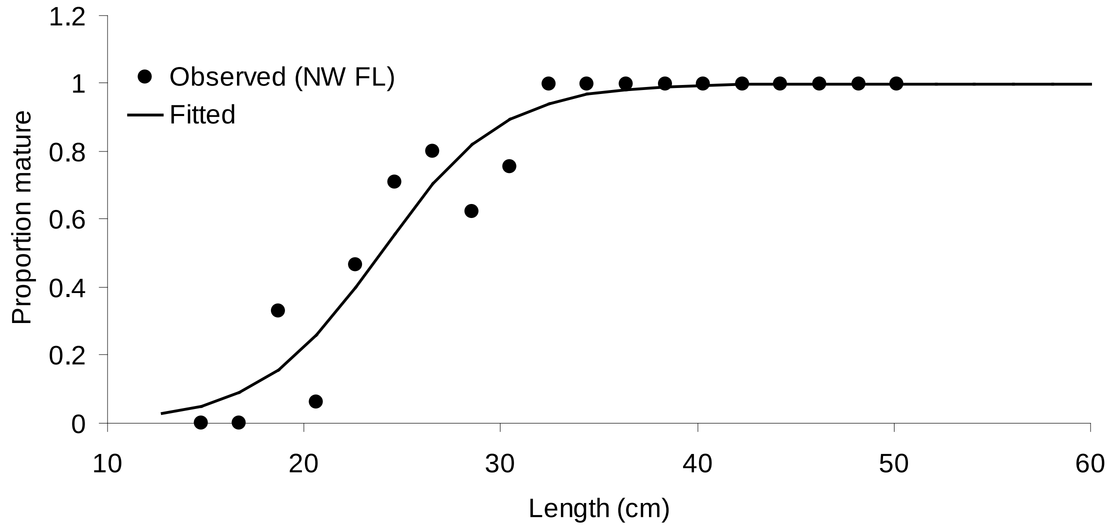

Fig. 8. Observed and estimated maturity as a function of length for female king mackerel.

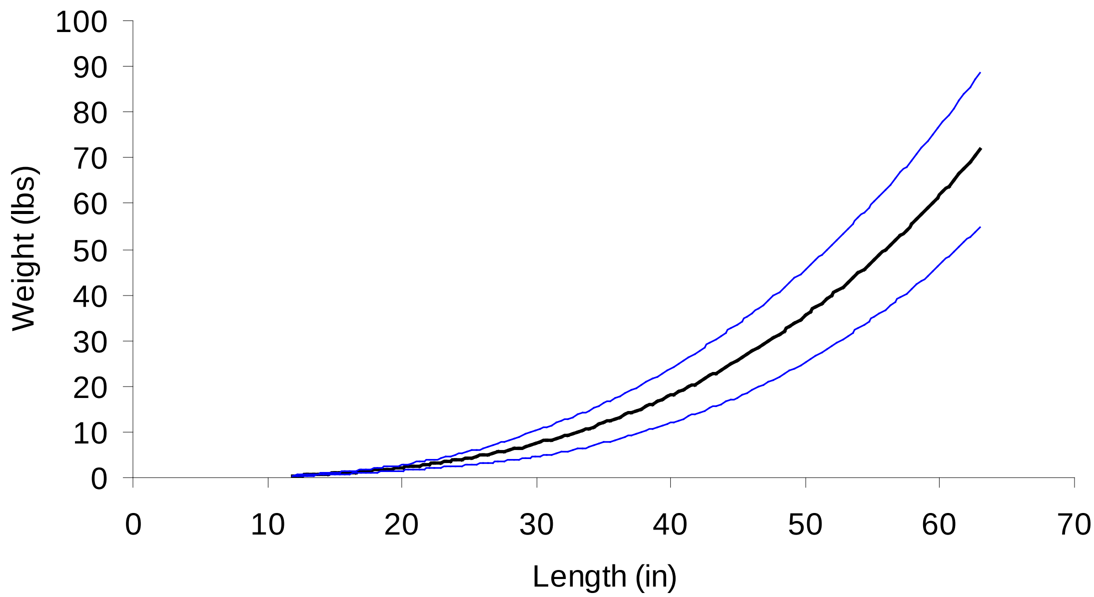

Fig. 9. Mean weight-at-length for king mackerel in the south Atlantic migratory group. The black line indicates the mean and the blue lines indicate the interval that includes 95% of the distribution of weight-at-length.

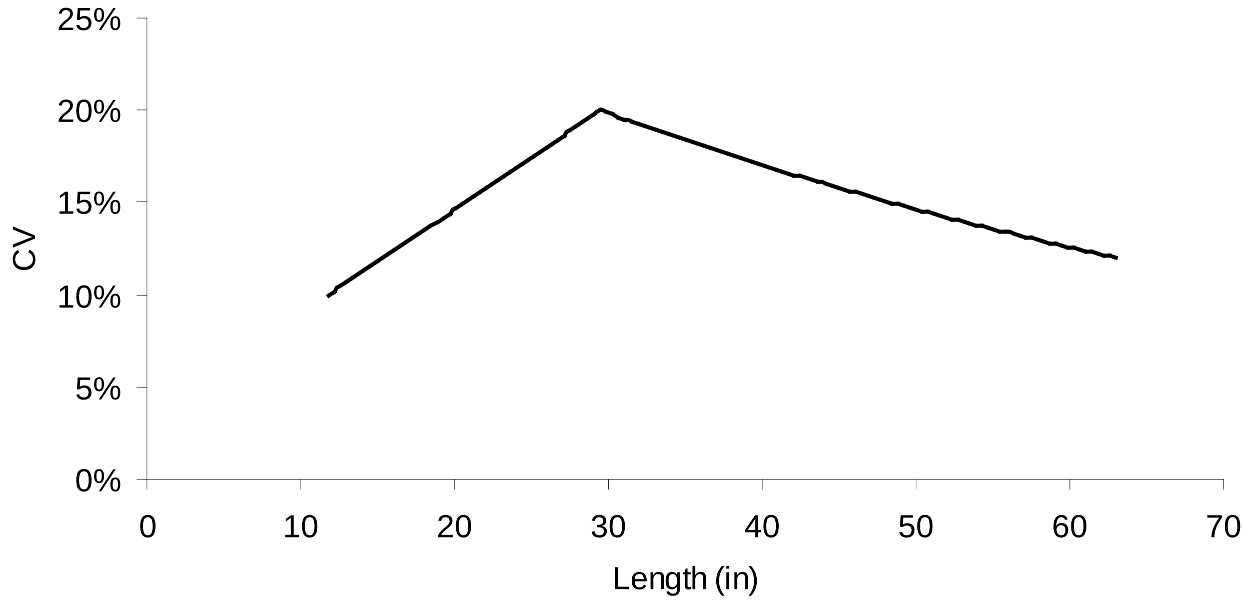

Fig. 10. Coefficient of variation (CV) in weight-at-length for south Atlantic migratory group king mackerel.

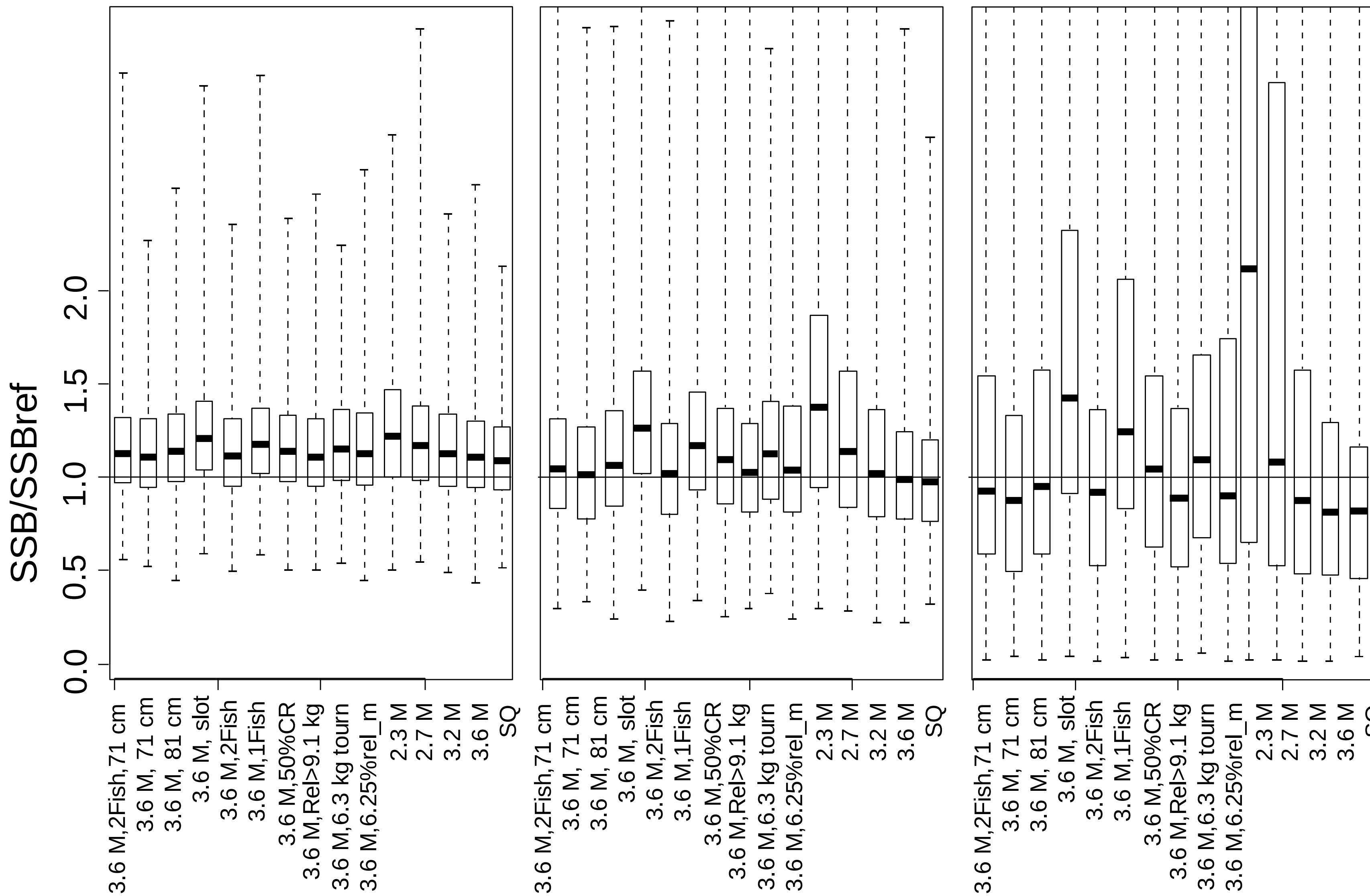

Fig. 11. Average spawning stock biomass (SSB) divided by SSB at $F_{30\%}$ for 5-, 15-, and 50-year summaries. Dark lines indicate the median, boxes indicate the interquartile range, and dashes beyond the boxes indicate the minimum and maximum. Options indicated by abbreviations: SQ indicates status quo of 4.6 million kg quota, 3 fish per angler bag limit in the north, 2 fish per angler bag limit in the south, 24 in minimum size limit for commercial and recreational, 34 in minimum size limit for tournaments, 15.5% of recreationally caught fish are released dead, 12.5% release mortality of fish released alive, and 26% catch and release fishing. Other

options are the same except as described in the label: XM indicates the quota where X is millions of kg, X fish indicates the bag limit in both areas, X cm indicates the minimum size limit, slot indicates 24-36 in slot limit, 50% rel. mortality indicates 50% percentage reduction in dead discards and release mortality, 50% catch_rel indicates 50% catch and release fishing, and 15lbs tourn indicates 15 lb minimum size for tournaments.

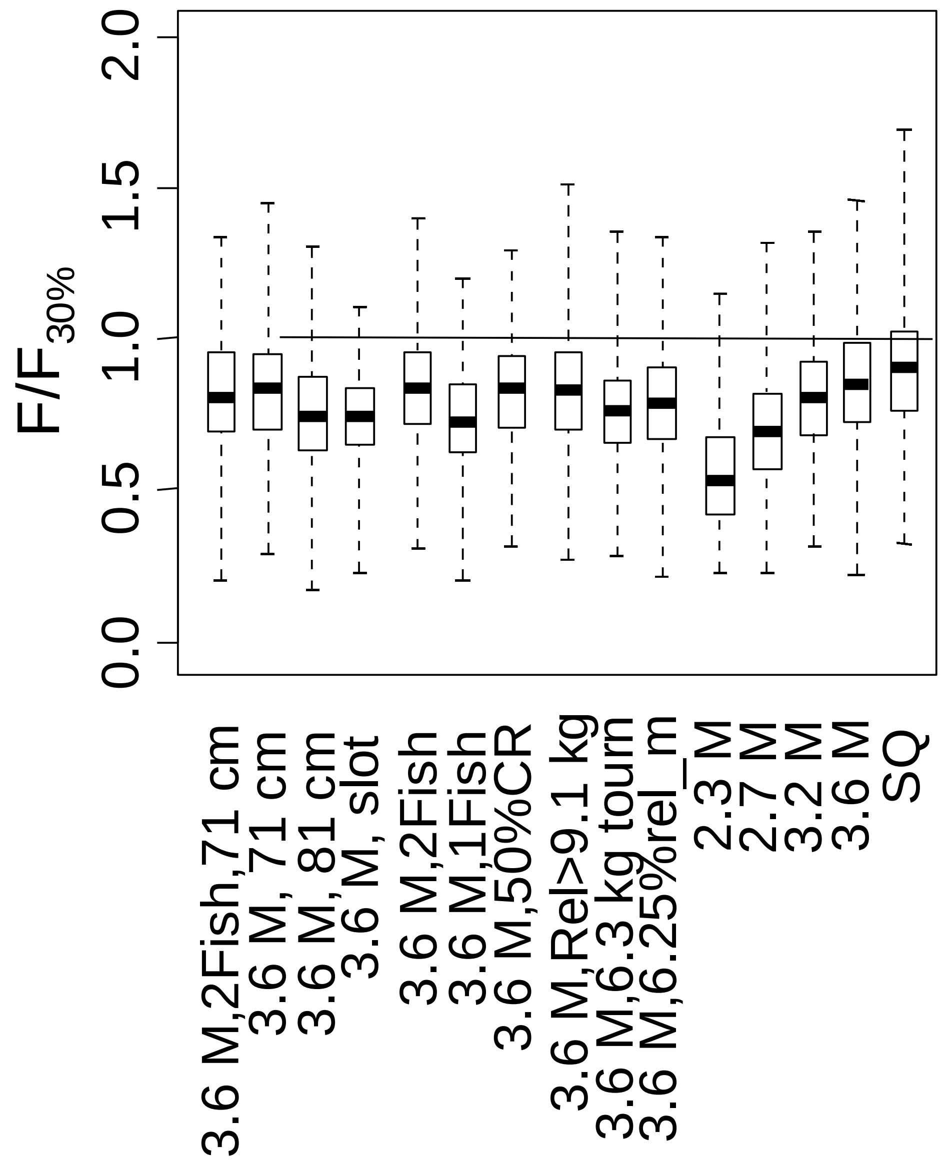

Fig. 12. Box plots of the proportion of years the recreational quota is reached for 5-, 15-, and 50-year summaries. Options and box plot definitions as in Fig. 10.

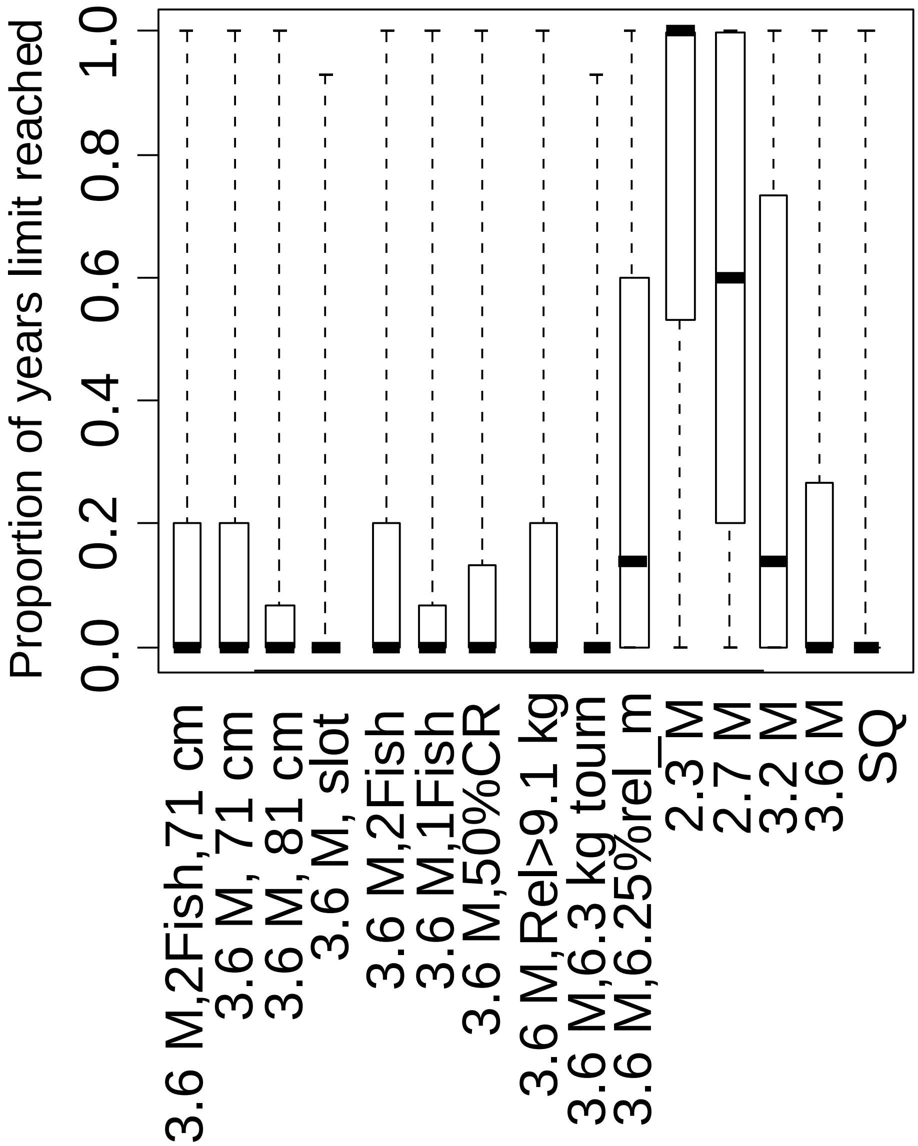

Fig. 13. Box plots of the proportion of years the quota was reached summarized over 15 years. Box plot definitions as in Fig. 10.

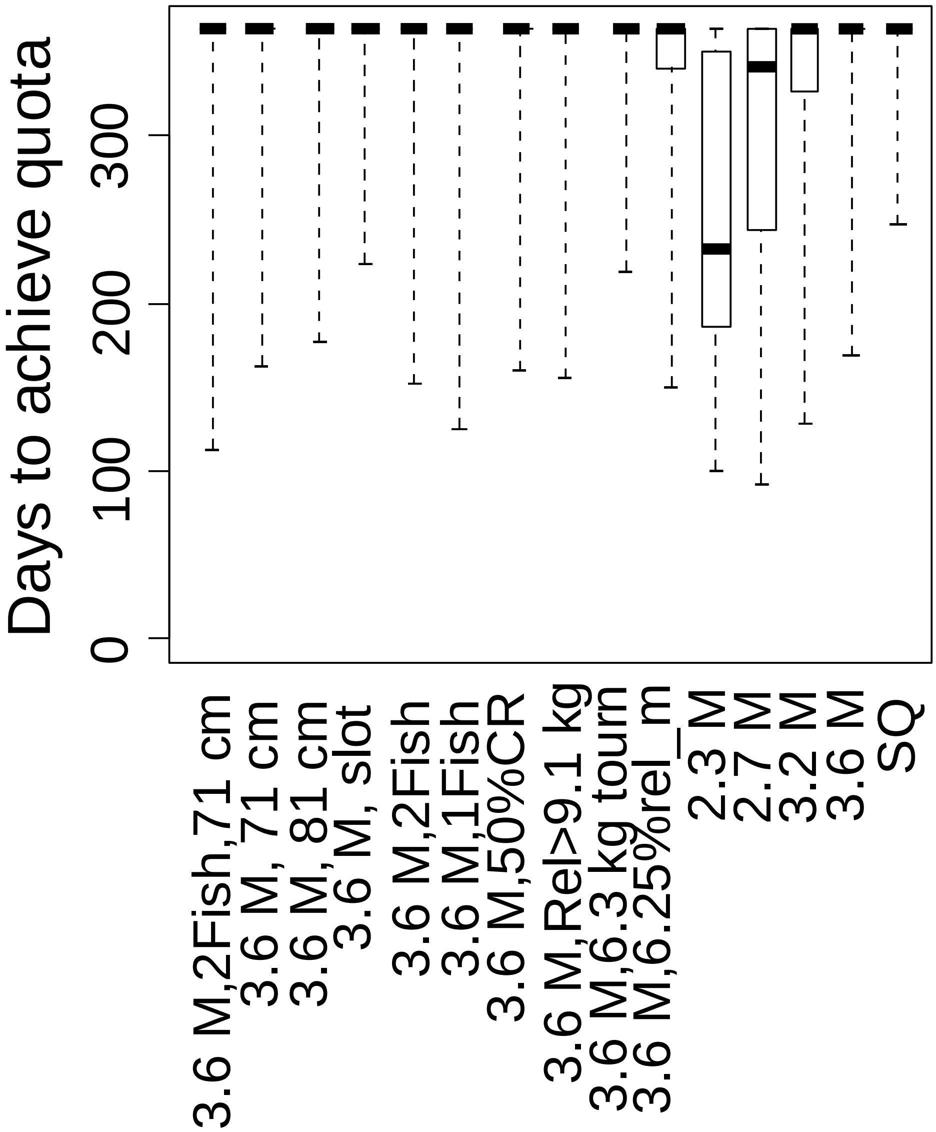

Fig. 14. Box plots of the length of the fishing season necessary to reach the annual quota summarized over 15 years. Box plot definitions as in Fig. 10.