Effects of a simulated fishing moratorium on the stock assessment of red porgy (*Pagrus pagrus*)

Michelle L. Davis (contact author)
Department of Fisheries and Wildlife Sciences
Virginia Polytechnic Institute and State University
100 Cheatham Hall
Blacksburg, Virginia 24061-0321
Email address: midavis1@vt.edu

Jim Berkson
National Marine Fisheries Service RTR Unit
Virginia Polytechnic Institute and State University
100 Cheatham Hall
Blacksburg, Virginia 24061-0321

Abstract—Much of the information available on the population status of a harvested fish species is obtained from landings data. When fishing restrictions are in place, fishery-dependent data are reduced and assessments rely more heavily on fishery-independent data. Stock assessments of red porgy (*Pagrus pagrus)* have shown a declining population and have led to a number of management measures, including a moratorium on fishing this species. To investigate how a lack of fishery-dependent data during a moratorium would affect stock assessment results for red porgy, we conducted simulations representing a range of periods of moratorium. As data were removed from the model, stock status indicators and projections became increasingly variable. Projections estimated that a 12-year moratorium would be needed for stock rebuilding, but simulations showed that uncertainty surrounding stock assessment estimates would increase after three years without fishery-dependent data. Unless additional data are collected during periods of strict fishing regulations, it may be difficult to accurately assess the length of time needed for the stock to rebuild and to assess the population status.

Manuscript submitted 28 March 2005 to the Scientific Editor's Office.

Manuscript approved for publication 19 January 2006 by the Scientific Editor.

Fish. Bull. 104:585–592 (2006).

For commercial or recreational fisheries, a large portion of the information available for assessment of the population status of a species is obtained during harvesting operations. When harvest restrictions are in place, fishery-dependent data are reduced and assessments become more reliant on fishery-independent data. During a moratorium, harvest ceases completely and new methods may be required to assess the status of the stock. It is assumed that stock assessment results accurately portray the current population and that these results are used in policy decisions affecting future stock status. However, stock assessment results are not solely a product of the population being assessed, but are also a function of stock status, data sources, and sample size. Although most stock assessments include close evaluation of data sources, few assessments include the quantification of potential effects of changes in fishery-dependent data as a byproduct of changing harvest restrictions. We therefore investigated the effects of the reduced availability of fishery-dependent data on stock assessment results and management decisions.

To accomplish this goal, we conducted model simulations for red porgy (*Pagrus pagrus*) that is found off the coast of the southeastern United States from North Carolina to Florida. This reef-associated fish is an important resource for commercial and recreational fisheries (Huntsman et al., 1978; Low et al., 1985). Red porgy have an extensive native range and inhabit coastal waters on both sides of the Atlantic Ocean in both hemispheres (Pajeulo and Lorenzo, 1996; Labropoulou et al., 1999; Hood and Johnson, 2000). They are associated with live-bottom reef habitats on rocky outcroppings and therefore have a patchy distribution off the southeastern United States (Grimes et al., 1982). Red porgy are protogynous hermaphrodites; females dominate the smaller size classes, and males occur at all ages (Manooch, 1976). Females generally reach maturity from age-1 to age-2 at approximately 300 mm total length, and the majority of red porgy age-5 and older are mature males (Hood and Johnson, 2000).

Red porgy have been harvested extensively by three major fisheries (Fig. 1): commercial, recreational, and a fishery comprising large-scale charter boats called "headboats" (Huntsman et al., 1978). All three fisheries use mainly hook-and-line gear and target a wide variety of temperate reef fishes (Chester et al., 1984), not exclusively red porgy. In the early 1980s, the red porgy stock began showing signs of decline (Collins and Sedberry, 1991; Vaughan et al., 1992). As the stock decline became more evident, the minimum size limit was raised (Table 1) by the South Atlantic Fishery Management Council (SAFMC), the group mandated with managing red porgy and other fish off the coast of North

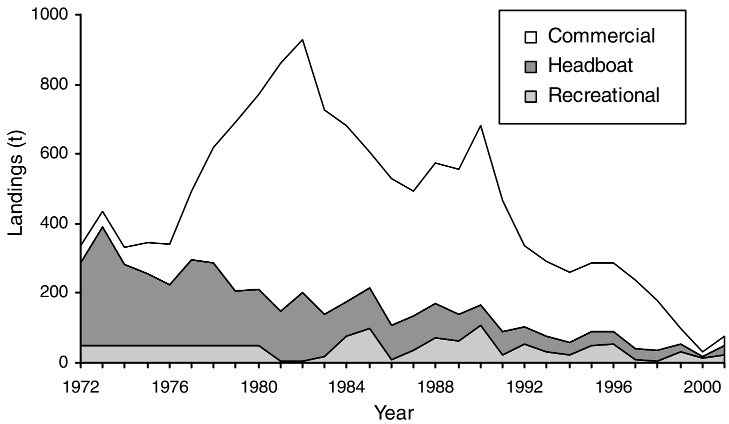

Figure 1

Landings (in metric tons) of red porgy (*Pagrus pagrus*) off the coast of the southeastern United States for the commercial, recreational, and headboat fishery sectors from 1972 through 2001.

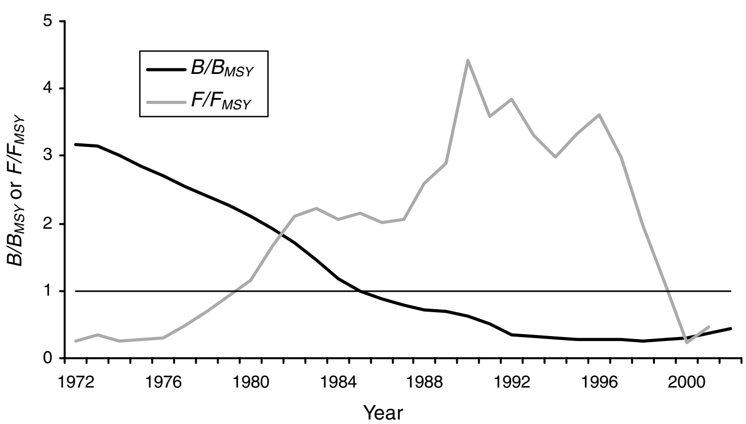

Figure 2

Relative biomass (B/B_{MSY}) and relative fishing mortality (F/F_{MSY}) for red porgy (*Pagrus pagrus*), as estimated in SAFMC (see Footnote 3 in the general text). The horizontal line represents $B=B_{MSY}$ and $F=F_{MSY}$.

Carolina, South Carolina, Georgia, and eastern Florida (SAFMC[1]). However, red porgy abundance continued to decrease (Vaughan and Prager, 2002), such that an emergency moratorium was put into place (Table 1) prohibiting the harvesting of red porgy by all fishery sectors. Following debate on the actual severity of the population decline and uncertainty surrounding the stock assessment, the moratorium was relaxed a year later to a seasonal closure, a recreational bag limit, and a commercial bycatch allowance (Table 1; SAFMC[2]). A recent stock assessment (Fig. 2; SAFMC[3]) identified this red porgy stock as having low biomass, but not as being currently overharvested. The strict harvest regulations applied to red porgy led to SAFMC concerns regarding the ability of scientists to accurately assess a population under a moratorium when fishery-dependent data are unavailable.

[1] SAFMC (South Atlantic Fishery Management Council). 1991. Final, amendment number 4, regulatory impact review, initial regulatory flexibility analysis and environmental assessment for the fishery management plan for the snapper grouper fishery of the South Atlantic region, 99 p. + appendices. South Atlantic Fisheries Management Council, One Southpark Circle, Suite 306, Charleston, SC 29407.

[2] SAFMC (South Atlantic Fishery Management Council). 2000. Final, amendment number 12 to the fishery management plan for the snapper grouper fishery of the South Atlantic region, 159 p. + appendices. South Atlantic Fishery Management Council, One Southpark Circle, Suite 306, Charleston, SC 29407.

[3] SAFMC (South Atlantic Fishery Management Council). 2002. Southeast Data, Assessment, and Review (SEDAR) stock assessment for red porgy, 39 p. South Atlantic Fishery Management Council, One Southpark Circle, Suite 306, Charleston, SC 29407.

Table 1

History of fishing regulations for red porgy (*Pagrus pagrus*) applied to both commercial and recreational fisheries, unless otherwise specified.

Regulation period	Regulation details	Regulation period	Regulation details
To 1992	No size, bag, or trip limits or closures	Sept 1999 to Aug. 2000 (moratorium)	No landings permitted
Jan 1989 to present	Trawl gear banned	Aug 2000 to present (Amendment 12)	356-mm minimum size limit; 1-fish recreational bag limit; Jan–Apr commercial closure; 22.7-kg commercial trip limit
1992 to Jan 1999	305-mm minimum size limit		
Feb 1999 to Aug 1999 (Amendment 9)	356-mm minimum size limit; 5-fish recreational bag limit; Mar–Apr commercial closure		

Red porgy is a relatively well-studied species; more than 30 years of information are available. However, the majority of the data for this species is a direct result of fishing operations. Fishery-dependent data for red porgy include landings (number of fish) from commercial, recreational, and headboat fisheries, as well as large sample sizes of lengths from these fisheries (Table 2; Huntsman et al., 1978; Low et al., 1985; NMFS[4]). The headboat fishery also provides an abundance index based on catch-per-unit-of-effort data. Although fishery-dependent data provide large sample sizes and a relatively long time series, there are a number of problems associated with this information source. Fishery-dependent statistics have been affected by frequent changes in regulations, economics, technology, and gear (Collins, 1990) that may cause difficulties for comparisons of landings, abundance indices, or lengths among years. Moreover, harvest data have inherent biases due to the nature of the fishery, which attempts to maximize catch, selects fishing areas nonrandomly, and targets larger size classes of fish.

In an attempt to compensate for some of the biases potentially present in harvest data, the National Marine Fisheries Service (NMFS) instituted the Marine Resources Monitoring, Assessment, and Prediction (MARMAP) program in 1979. During this annual survey, fishery-independent data are collected on a variety of reef fishes in waters from North Carolina to Florida (Collins, 1990; Harris and McGovern, 1997). In the MARMAP survey standardized gear types are used and known amounts of effort are applied to sample randomly selected sites between May and August (Collins, 1990), during which information on length, weight, age, sex, fecundity, and level of maturation are collected. An abundance index is also calculated for each gear type.

[4] NMFS (National Marine Fisheries Service). Fisheries Statistics Division. 2005. Website: http:www.st.nmfs.gov/st1 [accessed on 31 January 2005].

The MARMAP survey and other well-designed fishery-independent surveys are extremely useful for stock assessments because standardized gears are used with known efforts in documented locations, which constitute a statistically valid experimental design that facilitates comparisons among years, areas, and gear types (Collins and Sedberry, 1991). However, the MARMAP survey does not provide information on harvesting, and the survey's sampling methods are inherently different from fishery-dependent sources. Therefore, MARMAP data cannot serve as an absolute substitute for fishery-dependent information in existing stock assessment strategies. In addition, MARMAP sample sizes are much smaller than those from fishery-dependent sources, particularly for length-frequency data; 92% of samples for length-frequency estimates were obtained from fishery-dependent sources (Table 2).

In a highly restricted or closed fishery where fishery-dependent data are limited, information from fishery-independent sources may be the only data available to managers. This decreased amount of data could affect stock assessment results, including the estimation of stock status indicators and benchmarks used in management. It is therefore important to understand how to best use both fishery-independent and fishery-dependent data in assessments of red porgy and other species, both in unrestricted and heavily restricted fisheries.

During a moratorium or other period of strict regulation, the reduction in fishery-dependent data may increase variability surrounding status indicators and management benchmarks. We quantified the increase in variability for red porgy by using stock assessment model simulations and projections, and we identified how the uncertainty surrounding estimates could affect management decisions. By evaluating the effects of a lack of data before harvest restrictions are put in place, managers will be able to identify future data needs, improving their ability to assess and manage species of concern.

Table 2

Sample sizes for estimation of lengths and ages of red porgy (*Pagrus pagrus*) from fishery-independent (Marine Resources Monitoring, Assessment, and Prediction, [MARMAP] survey) and fishery-dependent (commercial and headboat fisheries) sources. The stock assessment model covered 1972–2001; therefore "model years" is equal to a span of 30 years.

Data source	Samples	Years	Samples per model year	Percentage
Lengths				
MARMAP	11,649	17	388	8.2
Commercial	81,625	26	2721	57.4
Headboat	49,012	30	1634	34.4
Total	142,286		4743	
Ages				
MARMAP	5274	13	176	57.5
Commercial	1250	4	42	13.7
Headboat	2645	4	88	28.8
Total	9169		306	

Materials and methods

Stock assessment model

The simulations to determine impacts of a lack of fishery-dependent data involved the use of a recent stock assessment model for red porgy, a forward-projecting age-structured model developed during the Southeast Data, Assessment, and Review (SEDAR) stock assessment workshop. The model was an expansion of the Methot (1989) stock-synthesis model and is similar in structure to models used in assessment of cobia (Williams, 2001). With the red porgy model, we simulated a population through time, applying annual fishing mortality, natural mortality, recruitment, and growth (SAFMC[3]) while attempting to statistically match the simulated population with observed data sources. The stock assessment model incorporated data from 1972 through 2001. These data included information from fishery-dependent sources (commercial hook-and-line, trawl, and trap fisheries, and recreational headboats, charter boats, and private boats) and the fishery-independent MARMAP survey. Data included annual values for total landings by fishery, length and age frequencies by gear, and indices of abundance for the headboat fishery and MARMAP survey. Additional parameters incorporated in the model included natural mortality rate (assumed to be constant over time), gear selectivity for both MARMAP and fishery data, growth (based on the von Bertalanffy growth equation), recruitment (based on a Beverton-Holt recruitment model), and fishing mortality (SAFMC[3]). This model was specified and programed by SEDAR workshop participants using AD Model Builder software (vers. 6.0.3, Otter Research, Sidney, B.C., Canada).

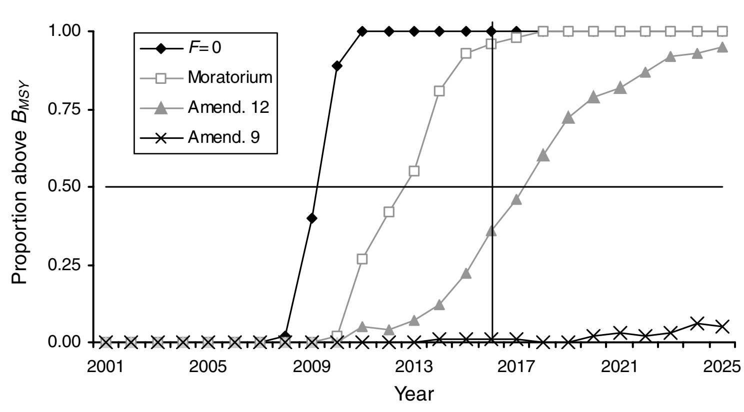

Figure 3

SEDAR population projections for red porgy (*Pagrus pagrus*) under four potential management scenarios. For a management option to be recommended, there must be at least a 50% likelihood (horizontal line) of the population biomass being greater than B_{MSY} before the year 2016 (vertical line).

Data modification

To simulate the lack of fishery-dependent information resulting from a moratorium, we omitted length- and age-frequency data used as input for the stock assessment model from commercial and headboat fisheries for the most recent 0, 1, 2, 3, 4, 5, or 6 years (Table 2). Landings, catch per unit of effort, life history parameters, and the model code were not altered. We did not remove landings from the stock assessment model because omitting landings would have changed the estimates of both fishing mortality and biomass, making comparisons of results among models impossible. Therefore, these simulations represent how the lack of fishery-dependent length and age information due to a moratorium would affect assessment results, rather than show the direct effects of reduced fishing mortality on the population. To incorporate stochasticity, we randomly sampled (with replacement) MARMAP length and age frequencies from observed frequencies. For each duration of moratorium (0, 1, 2, 3, 4, 5, and 6 years), we conducted 50 model runs. Results from the stock assessment models, including the status indicators relative biomass (B/B_{MSY}) and relative fishing mortality (F/F_{MSY}), were compared among simulations. In order to identify differences in variability, we calculated the standard deviation of status indicators among the 50 simulations for each simulated moratorium duration.

Population projections

Output from each of the stock assessment model runs was used as input for population projections to evaluate potential management options according to the method developed during the SEDAR process (SAFMC[3]). Starting with the biomass estimate from the most recent year (as estimated by each stock assessment model), stock projections were run under four potential management scenarios: 1) no fishing mortality or bycatch mortality, as if all fisheries in the region were closed (F=0); 2) fishing mortality under a red porgy moratorium (i.e. where there is only bycatch mortality [F=0.054]); 3) fishing mortality representative of Amendment 9 (F=0.173); and 4) fishing mortality representative of Amendment 12 (F=0.107; Table 1). SEDAR workshop attendees determined fishing mortality rate (F) for each option, and SEDAR projection results are shown in Figure 3 (SAFMC[3]).

The 25-year projections were based on a simulated age-structured population with stochastic stock-recruit relationship and fishing mortality. Initial (2001) stock size-at-age, weight-at-age, annual biomass and recruitment, B_{MSY}, and steepness estimated by the stock assessment model for each model run were used as input for population projections. Other projection input that remained constant among model runs included natural mortality, maturity at age, and selectivity. Projections for each model run were repeated 100 times for each simulation. The resulting projections allowed us to investigate how data reduction would affect management decisions. For each moratorium length, we estimated the probability of rebuilding success as the proportion of the stochastic runs in which the biomass reached B_{MSY} before the rebuilding deadline of year 2016. For a management option to be recommended, the SAFMC wanted at least a 50% likelihood of the population biomass exceeding B_{MSY} before 2016.

Results

Variability among the simulations increased when multiple years of fishery-dependent length and age data were removed (Fig. 4, and Fig. 5, A and B). When only one or two years of fishery-dependent length and age data were removed, variability and status indicator estimates (such as B/B_{MSY} and F/F_{MSY}) did not differ substantially from simulations where no data were removed. However, when three to six years of fishery-dependent data were omitted, variability increased, especially for F/F_{MSY} (Figs. 4 and 5B). These trends in variability were also evident in population projections, where the range and confidence interval width of projected outcomes increased as data were removed (Fig. 6).

Additionally, removal of data led to higher estimates of population productivity (i.e., higher biomass and faster population rebuilding). When greater than three years of data were removed, projections tended to predict a slightly faster recovery (Figs. 6 and 7). Data availability would have affected management decisions for Amendment 12 because many data-poor models would have incorrectly identified Amendment 12 as a suitable management option (Figs. 6 and 7).

Discussion

Removing data from fishery-dependent sources for multiple years increased the variability of stock status indicators and projections. This variability was amplified during population projections, when the likelihood of rebuilding became increasingly variable as data were removed. Projections are, by nature, uncertain, but this uncertainty increased with even small reductions in information. Similar increases in variance were found by Chen et al. (2003) when information was removed from a New Zealand abalone (*Haliotic iris*) stock assessment model. When Chen et al. (2003) removed fishery-independent length data, standard deviation of parameter estimates increased 33%.

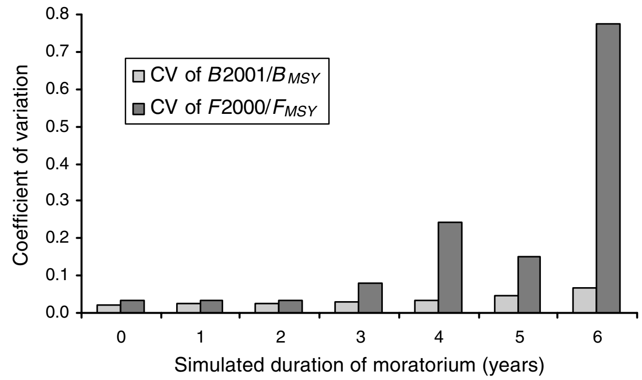

Figure 4

Coefficient of variation (standard deviation among 50 simulations for each moratorium duration divided by the mean) for red porgy (*Pagrus pagrus*) for B_{2001}/B_{MSY} and F_{2000}/F_{MSY}. Fishery-dependent length and age data were removed from the stock assessment model runs for the number of years specified.

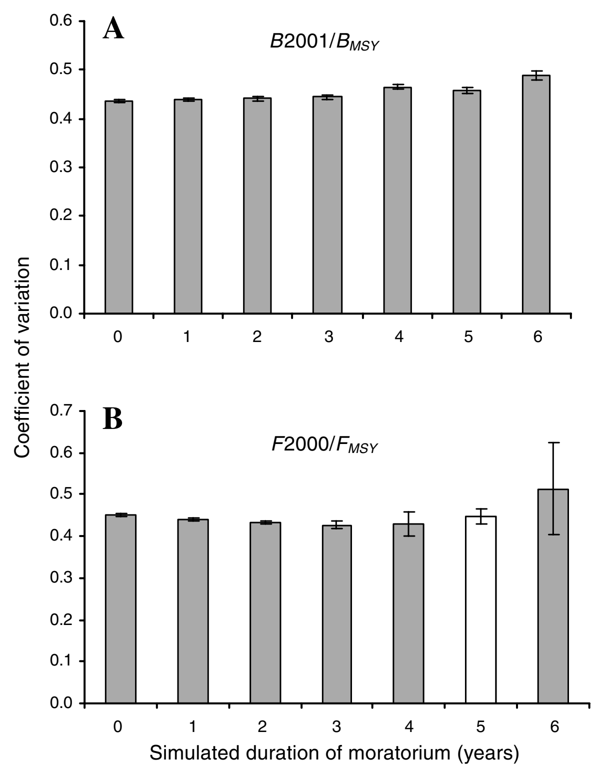

Figure 5

Mean estimates and 95% confidence intervals of (**A**) B_{2001}/B_{MSY} and (**B**) F_{2000}/F_{MSY} for 50 model runs for each moratorium duration for red porgy (*Pagrus pagrus*). Fishery-dependent length and age data were removed from stock assessment model runs for the number of years specified.

In addition to the expected outcome of higher variance as data were removed, we also found a slight tendency toward overestimating stock productivity that resulted from eliminating multiple years of data. When fishery-dependent length and age information were removed, the model tended to predict slightly higher biomass, lower fishing mortality, and faster population recovery. This finding was also supported by Chen et al. (2003), for whom data removal led to a more optimistic estimation of the current fishery status and stock productivity. This bias would increase the potential for overharvesting because the population may not be as productive as the model results suggest. The results of our study are specific to the South Atlantic red porgy stock and may not be applicable to other stocks or species. Stock status indicators and productivity estimates are affected by life history parameters, population size, historical and current fishing pressure, and data availability and these will differ among species. Additionally, use of an alternative stock assessment model could also affect results. However, if this bias is present for other species and stock assessment models, it could have serious implications for managers because it implies that the less information we have on a population, the more productive we would estimate (incorrectly) the population to be.

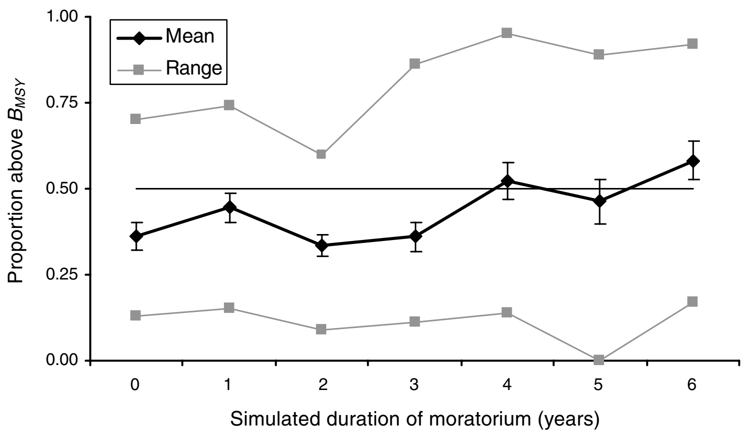

Figure 6

Proportion of projected red porgy *Pagrus pagrus* biomass estimates for the year 2016 under Amendment 12 for which the biomass was greater than B_{MSY}. The mean likelihood for 50 model runs for each moratorium duration is shown (with 95% confidence intervals) and the range of the 50 model runs is shown in gray. For a management option to be recommended, there must be at least a 50% likelihood (horizontal line) of the biomass being above B_{MSY}. Fishery-dependent length and age data were removed from stock assessment model runs for the number of years specified.

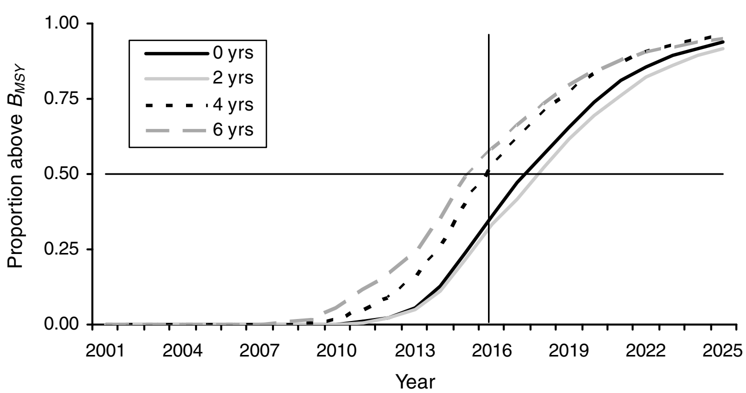

Figure 7

Stock projections (50 model runs for each moratorium duration) under Amendment 12 fishing mortality levels. Fishery-dependent length and age data were removed from stock assessment model runs for the number of years specified. For a management option to be recommended, there must be at least a 50% likelihood (horizontal line) of the population biomass being greater than B_{MSY} before the year 2016 (vertical line).

In general, removing red porgy length and age data had only minor effects on status indicator estimates, projections, or management decisions. The signal of a declining red porgy population was so strong and relatively consistent among data sources that removing a portion of this information did not greatly affect results. All model runs showed an overfished population but one that is not currently undergoing overfishing, and management decisions were also relatively consistent. In all cases, projections showed that rebuilding to B_{MSY} by the year 2016 would occur with no fishing mortality or a moratorium, and fishing mortality representative of Amendment 9 would be insufficient to rebuild the stock. Differences in management decisions did exist for model runs conducted under Amendment 12 fishing mortality levels; some data-poor models incorrectly identified Amendment 12 as a suitable option for rebuilding the stock. For a fish population closer to an overfished status or to a condition where overfishing is in progress, or where data sources were contradictory, data removal could affect stock assessment results and management decisions to a greater extent.

Because red porgy is a well-studied species for which there are 30 years of information from multiple sources, we removed a relatively small proportion of the data used in the stock assessment for our model runs. Conducting these types of simulations on a lesser-studied species would most likely result in larger changes in status indicator estimates, projections, and management decisions because a larger proportion of information would be removed. The results of our study on red porgy identified the importance of investigating the potential effects of reducing fishery-dependent information on stock assessment results. If used before implementing management actions, this kind of data simulation study could estimate the potential impact of a lack of data before harvest restrictions are put in place that would cause data loss.

Management implications

These types of simulation studies aid in understanding the impacts of data quantity on stock assessments, particularly with respect to uncertainty and variance. By incorporating uncertainty due to data loss into management decisions, managers will be better able to assess and manage these populations. For example, SEDAR population projections estimated that red porgy required a 12-year moratorium for the population to rebuild to B_{MSY} (Fig. 3). However, our data simulations showed that variability surrounding status indicators increased when as few as three years of fishery-dependent data were removed (Fig. 4) and that a tendency toward overestimating productivity also increased with duration of the moratorium (Fig. 7). Therefore, if managers implemented a 12-year moratorium for red porgy (with no additional sampling), it is possible that a stock assessment conducted at the end of the moratorium would be unable to accurately estimate stock status and identify whether or not the population biomass had reached B_{MSY}.

This study highlights the importance of additional sampling during periods of strict regulations to compensate for the fishery-dependent data that are lost (Olney and Hoenig, 2001). Because many reef fish species are caught in the same fisheries, analysis of bycatch through a fisheries observer program would yield valuable data for a number of species. Another option for data collection would be to initiate a "test fishery" after a moratorium in order to collect fishery-dependent data in a relatively short time and then use these data to estimate stock status. A third option would be to use additional sampling during a moratorium from fishery-independent sources. Although MARMAP data are currently insufficient for assessments of many reef fishes, an expanded survey (i.e., into deeper water, more gear types, etc.) could prove to be valuable in future assessments. Even without a moratorium in place, assessments of many species would undoubtedly benefit from information collected by a fisheries observer program or an expanded fishery-independent survey. Data collected from these sources before a period of strict regulation would improve the ability of scientists to detect trends because a longer time series would make population recovery more apparent than that seen without such data.

The data quantity simulations conducted in our study could also be used for other species. This method allows managers to simulate the effects of a lack of data before enacting regulations or sampling changes that cause data loss. If a loss of information is shown to affect stock assessment results, simulations can be conducted to identify whether additional data will be needed and to test the effectiveness of additional sampling before implementing a sampling program. Stock assessments frequently use population projections to predict the effects of a policy on the stock. Our methodology is an expansion of this idea, using simulations to predict how a policy affects our ability to identify changes in the stock. By incorporating uncertainty due to data loss into management decisions, managers will be better able to assess and manage these populations and improve sampling to better fulfill future research needs.

Acknowledgments

This research was funded by the South Atlantic Fishery Management Council. We thank E. Williams, M. Prager, D. Vaughan, and K. Shertzer for providing modeling advice, J. Potts and P. Harris for information, J. Ney and R. Neves for guidance, and the many state and federal biologists and SAFMC staff members that assisted us in this project. This manuscript was improved by the comments and suggestions of M. Prager and two anonymous reviewers. We greatly appreciate the time and effort of all involved.

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