Estimating Management Uncertainty for Marine Fisheries in the South Atlantic United States

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ABSTRACT

With the latest reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act (MSA) and the precarious state of many of the nation's fisheries, it has become essential to incorporate uncertainty in the process of setting annual catch limits (ACLs) and annual catch targets (ACTs). The accuracy with which we predict landings can be thought of as management uncertainty, and it can be estimated by comparing the predicted landings intended by a regulation to the fisheries' actual landings estimates. The National Standard 1 Guidelines for the MSA state that management regulations should take into account management uncertainty when establishing ACLs or ACTs, prescribing more precaution when management uncertainty is high. This study compared pre-season landings predictions of managed fish species in the South Atlantic to post-season estimates and investigated the existence of management uncertainty, and evaluated its magnitude and direction. Results indicate that the magnitude of management uncertainty for some stocks in the region may be significant. It appears that recreational fisheries have significantly greater management uncertainty than commercial fisheries, and that commercial fisheries are often producing landings smaller than intended or predicted. No relationship was found between regulatory mechanism or the magnitude of a fishery and management uncertainty. The study also revealed that documentation of the methodology used to determine preseason catch estimates is often not sufficient to repeat estimation procedures. The results of this study will have immediate and direct utility in the setting of future management regulations, ACLs, and ACTs in the South Atlantic region, and perhaps beyond.

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Chapter 1: General Introduction to Management Uncertainty

Introduction

Over the past few decades, many of the world's fish stocks have been heavily exploited and many have become vulnerable to collapse (Worm et al. 2009). In the United States alone, the National Marine Fisheries Service (NMFS) 2011 Report To Congress, conducted on the most important recreational and commercial fish stocks, listed that out of 222 stocks or stock complexes for which an overfishing (fishing pressure too high) determination could be made, 36 (14%) were subject to overfishing. Of the 174 stocks or stock complexes for which an overfished (biomass too low) determination could be made, 45 (25%) were overfished (NMFS 2011). In order to address this critical problem, the most recent reauthorization of the Magnuson-Stevens Fisheries Conservation and Management Act (MSA, Magnuson-Stevens Act) attempts to ensure that overfishing does not occur through new requirements for annual catch limits (ACLs) and through the creation of accountability measures (AMs). ACLs and AMs were required to be developed by fishing year 2010 if overfishing was occurring in a fishery, and for all other fisheries by fishing year 2011. The National Standard 1 (NS1) guidelines for the Magnuson-Stevens Act were revised to incorporate these new requirements.

With these new regulations in place, measures have become stricter to ensure overfishing does not occur. Stock assessments provide an overfishing limit (OFL), a catch level above which a stock is considered to be experiencing overfishing. An acceptable biological catch (ABC), which accounts for scientific uncertainty, is set equal to or below the OFL. ACLs can be equal to or below the ABC and can be adjusted for management uncertainty. The AMs, triggered if harvest meets or exceeds the ACL during a fishing year, may include severe actions such as immediate season closures, adjustments of the ACLs, or dramatically shortened future fishing seasons, all of which have implications for resource users. AMs may also be used as a planned aspect of management to ensure that regulations can quickly be altered or adjusted when appropriate. The intent of AMs is to prevent the ACL from being exceeded, or to compensate for an overage if landings are above the ACL. ACTs, which are optional, can be set below the ACL to account for management uncertainty. The intent of this system of OFLs, ABC, ACLs, AMs, and ACTs is to ensure overfishing does not occur. An understanding of management uncertainty is an important component of this system.

Unfortunately, fisheries management remains an uncertain business, with complexity arising in nearly every element of its assessment and regulatory processes. In general, stock assessment and management fall under the categorization of “wicked problems” – problems that are extremely challenging to solve not only because of the complex interdependent relationships between variables but also because each instance of a wicked problem is usually a novel occurrence (Rittel and Webber 1973). Fisheries management is an example of a living laboratory, where each situation can only be tested once and there are no guarantees and no do-overs. However, more fortunately, problems in the fisheries field tend to fall at the level of *partially reducible* uncertainty, where the collection of data and continued analysis can somewhat, although not completely, reduce the amount of uncertainty faced in trying to solve these “wicked” problems (Lo and Mueller 2010).

For example, scientific uncertainty can be ascertained and estimated during the assessment process, where information necessary to assess stocks is gathered to determine the stock’s current level of biomass, historic biomass, the current fishing pressure, and the level of harvest that is considered sustainable, among other factors. The collection of more and better information, combined with increasingly sophisticated mathematical models that can better use this new information to understand and predict population dynamics, allows scientists to decrease the amount of scientific uncertainty in assessments. Alternatively stated, it decreases the degree to which uncertainty about the data or relationships between natural phenomena and fish stock behavior exist. In fact, many workshops, meetings, and conferences exist to help scientists share ideas about how to minimize the impact that scientific uncertainty could have on stock assessments.

Yet the assessment phase of fisheries management is one step in the process of measuring uncertainty. Once a determination has been made as to the optimal fishing level for a stock, managers must decide how much confidence they have in that value, and then decide how to optimally translate that numeric amount into a real-world regulatory action. This difference, between the *intended* impact of a regulation and its *actual* impact can be considered the *management uncertainty* associated with a particular fishery. Little effort has historically been spent on working to understand this uncertainty, even though the need for such an evaluation has been clearly expressed (Peterman 2004, Prager and Rosenberg 2008, Fisheries Leadership & Sustainability Forum 2010). In order to clarify the concept of management uncertainty, two, *very* oversimplified, theoretical examples of extremely low and extremely high management uncertainty are described below.

First, picture a fishery that is only harvested commercially. Part of the permitting process requires that each boat report its daily catch and discards. The fishery can be shut down on the exact day that the reports indicate that the quota has been caught. Such a fishery should have extremely low management uncertainty, since managers are able to guarantee that fishing will end precisely when the desired catch has been taken.

In contrast, imagine a fishery that is utilized by thousands of individuals both in boats and on the shore. The fishery is managed using a minimum size limit. Gathering data on harvest requires a survey, because it is impossible to obtain catch information from each fisher at every fishing location. Due to the complex survey procedures, an estimate of total catch is only available at the end of the season. Such a fishery could have extremely high management uncertainty, since managers would be unable to tell exactly when the desired catch had been taken and there could be a great deal of uncertainty in the post-season catch estimate. If this high uncertainty resulted in a catch that was greater than the intended harvest, the stock could become overfished, or regulations might have to be changed to reduce the intended catch in the next season to prevent overfishing from occurring. Again, keep in mind that these two examples represent oversimplified extremes of management uncertainty but both extremes do exist.

Of the types of uncertainty generally shown to be involved in fisheries assessment and management, scientific uncertainty tends to address issues in resource dynamics, reporting, monitoring, and assessment, while the evaluation of management uncertainty can address issues in management decisions, implementation, enforcement, and human fishing activity behavior (Fulton et al. 2010). Furthermore, the NS1 Guidelines recommend that scientific and management uncertainty be incorporated into a system of targets and limits to ensure overfishing does not occur. Without information about management uncertainty, managers can be limited in their ability to sustainably manage a stock because the direct effects (and magnitude of those effects) of a regulation on harvest are not completely known (Prager and Rosenberg 2008). Yet even with the clear need for increased understanding of management uncertainty, little information has been collected on historic management uncertainty. Having at least a basic understanding of the degree to which management uncertainty exists and any factors that might correlate with its direction or magnitude would greatly enhance managers' ability to predict the impact of their regulatory actions.

The goal of this project, therefore, is to provide clarity on the magnitude and direction (positive or negative) of management uncertainty for a variety of stocks. This information will help managers clarify to what degree the precautionary approach to management should be applied to a particular fishery, the need for which has been established in the literature (Charles 1998, Hilborn 2011). Methodologies for determining management uncertainty will be useful to managers in setting appropriate management measures, ACLs, and ACT to help ensure overfishing of fish stocks does not occur.

Management Uncertainty

The concept of management uncertainty can be thought of broadly as the degree to which management goals are realized. The complexity of fisheries management results in regulatory objectives that vary widely – from providing year round fishing for user groups to the creation of highly productive marine protected areas (MPAs). Each of these regulatory objectives corresponds with different criteria for success, or rather, a different metric by which management uncertainty could be evaluated. Management regulations designed to accommodate resource users could be evaluated through surveys of user satisfaction and compliance while MPAs could be evaluated through a comparison of past and present productivity levels. In the context of a retrospective evaluation of management uncertainty, however, many of these metrics are difficult or impossible to estimate. Decades after the fact, it is impossible to survey resource users to determine their satisfaction with particular management actions. Furthermore, it is difficult to discuss specific management objectives with policymakers in order to understand precisely what was intended by a particular regulation.

Fortunately, one way in which management uncertainty can be evaluated retrospectively relates to the degree to which managers were able to successfully make landings predictions. In cases when managers explicitly described the intent behind their actions in terms of the effects it may have on harvest, management uncertainty could be evaluated through a comparison of the landings intended by regulations and the actual landings resulting from those regulations. Knowledge of how accurate landings predictions are would allow managers to consider the potential uncertainty associated with particular regulations, even in contexts when an overall management scheme is selected based primarily on other management goals. The National Marine Fisheries Service (NMFS) NS1 Guidelines for the Magnuson-Stevens Act support this approach:

> Councils can derive some idea of their overall extent of management uncertainty by comparing past actual catches to target catches to evaluate the magnitude and frequency of differences between actual catch and target catch, and how often actual catch exceeded the overfishing limit for a stock (NMFS 2009).

This management uncertainty potentially could be caused by a large number of factors, including changes in fishing pressure due to abnormal weather, fuel prices, and the general state of the economy (NMFS 2009). Further, changes in year class strength, where episodic increases or decreases in biomass could occur, or changes in predator-prey dynamics could confound the intended result of certain management measures. Management uncertainty in this context differs from scientific uncertainty in that the former relates to the ability to estimate the effect of regulations on catch, while the latter evaluates the ability to accurately estimate stock life history parameters and predict stock levels.

Fisheries Management

Understanding the critical nature of management uncertainty requires a brief overview of fisheries management and terminology.

The Magnuson-Stevens Act was enacted in 1976 and formally established the exclusive economic zone (EEZ) of the United States, giving the federal government control of coastal waters from three miles from shore out to a distance of 200 miles and removing much of the foreign fishing competition from the area. Additionally, the Magnuson-Stevens Act created the modern system of regional fisheries management councils (Councils), and charged the Councils with managing the fishery resources within the EEZ (MSA 2006).

In 1996, the Magnuson-Stevens Act was amended (becoming known as the *Sustainable Fisheries Act*) to provide a set of national standards which mandated that policymakers work to prevent overfishing, use the best scientific information available, minimize bycatch and release mortality, take community needs into account, and promote human safety (MSA 1996).

To further the goal of sustainable fisheries and to ensure that fishery resources are managed for the greatest overall benefit to the nation, the Magnuson-Stevens Act was reauthorized in 2006 to ensure overfishing does not continue to occur through the use of ACLs and AMs. This system further includes the use of: Fishery Management Plans (FMP), which outline how management of a fishery or fisheries should occur; an OFL, which is an estimate of the catch level above which overfishing is occurring; an ABC, which is a level of a stock or stock complex's annual catch that accounts for the scientific uncertainty in the estimate of OFL; an ACL, which is the level of annual catch of a stock or stock complex that serves as the basis for invoking AMs; and AMs, which are management controls to prevent ACLs, including sector-specific including sector-specific ACLs, from being exceeded; and annual catch targets (ACTs), which are optional and can be set below an ACL.

The reauthorized Magnuson-Stevens Act requires a Council's Scientific and Statistical Committee (SSC) to assess the level of exploitation a particular stock can sustain and specify an

OFL, if possible, to ensure that overfishing will not occur. Then, the SSC uses an ABC control rule, set at a level equal to or below the OFL, to account for scientific uncertainty that exists in the data and models. The higher the level of scientific uncertainty, the lower the ABC is set in comparison to the original OFL. Conversely, a very low degree of scientific uncertainty would lead to an ABC set very close to the original OFL. The SSC employs an ABC control rule to specify the ABC. After the ABC is set, the Council then selects a specific harvest target (called an annual catch limit or ACL). The ACL is required to be equal to or lower than the established ABC. The Council also has the option to establish an annual catch target (ACT) that can be set at a lower level than the ACL to account for management uncertainty and provide greater assurance overfishing does not occur:

> ACT control rule means a specified approach to setting the ACT for a stock or stock complex such that the *risk of exceeding the ACL due to management uncertainty is at an acceptably low level* (NMFS 2009, emphasis added).

To clarify further, the NS1 Guidelines state ACTs can be used to help ensure that the ACL is not exceeded. Setting an ACT below an ACL (with consideration of management uncertainty) is one way to achieve this, but may not be needed in all cases. In fisheries with reliable catch monitoring and effective in-season management measures, managers may be able to prevent ACLs from being exceeded through direct monitoring and regulation of the fishery. Therefore, the final NS1 Guidelines make ACTs optional, but, to prevent ACLs from being exceeded, Councils should adequately address the management uncertainty in their fisheries in order to prevent overfishing.

Exceeding the ACL during a fishing year triggers an AM. AMs can include a reduction in the ACL or ACT, a shortened fishing season, or the immediate closure of a fishery, among other possibilities, but will almost certainly result in a reduction of allowable catch. The NS1 guidelines proposed a performance standard such that if catch of a stock exceeds its ACL more often than once in the last four years (i.e., more often than 25 percent of the time), then the system of ACLs, ACTs, and AMs should be re-evaluated to improve its performance and effectiveness (NMFS 2009).

Fisheries in the United States South Atlantic

Although most fisheries experience management uncertainty, this project focuses on evaluating the management uncertainty for stocks found in the South Atlantic region of the United States' EEZ. The U.S. South Atlantic region includes any stocks contained in FMPs within the U.S. controlled waters off the coasts of North Carolina, South Carolina, Georgia, and east Florida to Key West. The decision to focus on the South Atlantic is appropriate for a review of management uncertainty because the region contains some stocks which are overfished and/or undergoing overfishing, and contains economically important fisheries (NMFS 2011). The South Atlantic, unlike many regions of the U.S, supports both recreational and commercial fisheries for many species. A valuation study of fishing in the combined South Atlantic and Gulf of Mexico regions has indicated that recreational fishing expenditures alone totaled $12.5 billion (in 2001 currency) in a single year, and direct expenditures only constitute a portion of the total economic value of the fisheries (Gentner et al. 2001).

The South Atlantic Fisheries Management Council (SAFMC) manages 98 species in five FMPs, 60 of which are contained in the snapper-grouper fishery. The 60 species contained in the snapper-grouper complex includes snappers, groupers, triggerfish, jacks, tilefishes, grunts, wrasses, sea basses, and spadefish (SAFMC 2011).

Commercial Sector

The South Atlantic commercial fishing sector is a highly diversified, multi-species, year-round industry. It is composed primarily of high-value, but small-scale, ventures, many of which are closely associated with specific fishing communities and tied into local cultural heritage (Heinz Center 2000). In 2009, the industry collectively landed an estimated 112,907,000 pounds of fish (NMFS 2010). This value includes species subject to state and federal management, with state managed fisheries comprising the bulk of the landings.

Commercial regulations for stocks contained in the snapper-grouper complex vary considerably, but often a combination of size and trip limits are utilized. Many stocks also have closed seasons, and in-season commercial closures, which occur when an annual quota or ACL is met or is projected to be met. However, the requirement of ACLs has only recently been put into place as a result of the reauthorized Magnuson-Stevens Act. Amendments 17A and 17B to the FMP for the Snapper-Grouper Fishery of the South Atlantic Region was developed in 2010 to establish ACLs and AMs for snapper-grouper species undergoing overfishing. The Comprehensive ACL Amendment was developed in 2011 and established ACLs and AMs for all remaining species in the snapper-grouper fishery management unit as required by the Magnuson-Stevens Act. The AMs established in these amendments include specification of an ACT for the recreational sectors, in-season and post-season regulation changes, and specification of other management actions (e.g., size or bag limits). This Comprehensive ACL Amendment additionally removed 13 species from the snapper-grouper fishery management unit (reducing the number from 73 to 60) and designated six species as ecosystem component species (which are not required to have ACLs, AMs, or management measures).

Two types of snapper-grouper federal commercial permits are in use in the region: a transferable unlimited permit, and a 225-lb trip limit non-transferable permit, which limits the permit holder to harvesting no more than 225 lbs of snapper-grouper species on a given trip. Individuals with an unlimited transferable permit are not restricted in the amount of fish they can catch on a trip unless a trip limit has been established for a species. Currently, no new permits of either type are being issued for the region, and direct transfers are only allowed to occur between immediate family members. Acquiring an unlimited permit requires purchasing two previously held permits and exchanging them for one new one, a program designed to slowly reduce the number of participants in the fishery (SAFMC 2011). Allowable gear for the complex includes vertical hook-and-line arrangements, spearfishing (without re-breathers), powerheads, bottom longlines (in specific locations and at specific depths), and black sea bass pots. Only 32 individuals with snapper-grouper unlimited permits have endorsements to fish with black sea bass pots, and endorsements are being established through Amendment 18B to the FMP for the Snapper-Grouper Fishery of the South Atlantic Region to limit the number of individuals with snapper grouper unlimited permits who can target golden tilefish with longline gear.

Some of the other species in the region, such as those in the Coastal Migratory Pelagics fishery management unit (king mackerel, Spanish mackerel, and cobia), are managed through quotas and size limits. ACLs were established for these species in Amendment 18 to the FMP for the Coastal Migratory Pelagics Fishery of the Atlantic. ACLs were also established for the Dolphin and Wahoo Fishery of the Atlantic, the Golden Crab Fishery, and the *Sargassum* Fishery in the Comprehensive ACL Amendment

Recreational Sector

The recreational sector in the South Atlantic is utilized by a higher number of participants than the commercial sector, including individuals engaged in fishing privately, with headboat operations, or with charter operations (Heinz Center 2000, NMFS 2010). Roughly half of the individuals who fish in the region are classified as out-of-state anglers (NMFS 2010).

Recreational regulations for the snapper-grouper complex vary among species, but, in general, harvest is controlled by minimum size limits and a daily bag limits, and only specific types of gear are allowed. Allowable gear includes vertical hook-and-line arrangements, spearfishing (without rebreathers), and powerheads (in specific locations). All snapper-grouper species are required to be landed whole, with the tail, fins, and head intact. ACLs have been established for snapper-grouper species, dolphin, and wahoo in the Comprehensive ACL Amendment. Recreational ACLs were also established for king mackerel, Spanish mackerel, and cobia in Amendment 18 to the FMP for the Coastal Migratory Pelagics fishery of the Atlantic.

Intended Landings

In order to identify appropriate management measures for a stock, fishery managers and scientists collect as much information as possible on a fishery and then develop predictions about how the stock will respond to a given level of fishing pressure. Estimating the likely, or *intended*, effects of regulations on landings is the responsibility of a group that includes individuals from the NMFS Southeast Regional Office (SERO) and the NMFS Southeast Fisheries Science Center (SEFSC), the SAFMC, its scientific and statistical committee (SSC), and SAFMC staff.

Management measures are often put into place following a stock assessment with the intent of reducing harvest of a particular stock in order to end overfishing, prevent overfishing from occurring, or allow a stock to recover from an overfished condition. Stock assessments may also indicate an improved condition of a stock and management measures are put into place with allowing harvest to increase to sustainable levels. It is important to note that some management measures (i.e., spawning season closures, marine protected areas) often have conservation goals rather than target harvest levels.

Stock assessments often provide information on the level of fishing or amount of harvest reduction or increase would be desirable in a given year. The SAFMC identifies a variety of methods to control fishing, such as a bag limit, size limit, a change in the season length, trip limit, a gear change, or another method. Because regulations must ensure that overfishing does not occur while also taking into account possible negative social and economic effects, the evaluation process for each alternative management option involves an interdisciplinary team of individuals who examine the biological, ecosystem, sociological, administrative, enforcement, and economic concerns for the fishery in question. Public input and information from the SAFMC's advisory panels is also used to identify an adequate range of management alternatives.

However, within this complex process, the methods for determining the effects of management measures on harvest reductions are fairly simple. If, for example, the SAFMC is interested in using a shortened season as a management technique, the individuals on the interdisciplinary team will look at a set number of years of past catch (determined by the SAFMC, and normally about five years). Using estimates for average daily catch, the team calculates how many days would need to be removed from the season in order for the total catch to be lowered to the desired level. Similar calculations, for example, are done in order to determine the impact of a change in size limit, bag limit, or trip limit. If the SAFMC wanted to consider raising a size limit, members of the interdisciplinary team would look at the number of fish caught at the larger size and remove them from the previous catch estimates to predict how it would affect harvest.

Post-season Estimates

Unfortunately, pre-season estimates of landings resulting from a particular management measure will usually not exactly match post-season estimates. The degree of uncertainty in how well actual landings match the pre-season estimate will likely vary between the type of management measure used, species, and environmental effects, as well as the methods to collect landings data. Furthermore, with the exception of data reporting systems associated individual fishing quotas, it is usually not possible to accurately count or examine every fish that is actually caught. In some situations, commercial landings are very closely monitored so that scientists have a very good estimate of what is being landed. However, reporting frequency and rate of landings can greatly affect the uncertainty in how close commercial landings are to a commercial ACL.

Estimating recreational landings is more problematic and there can be great uncertainty in how close landings are to a recreational ACL. Scientists avoid these limitations for some recreational fisheries by estimating the actual total catch based on random sampling, (i.e., quantifying a portion of what it brought to shore and then multiplying it by the estimated total effort). In order to do this estimation, however, basic information must be collected on the fishery through a variety of data collection techniques.

Data Collection

Data on actual landings are collected in the South Atlantic through a few main mechanisms, with different programs established for the commercial and recreational sectors, in order to provide information on total catch in any particular season.

Recreational catch and effort data are collected through the NMFS Fisheries Headboat Program and the Marine Recreational Information Program (MRIP) (NOAA 2011). Headboat operators are required to participate in the program and must complete logbooks, which include information on the composition and size of the catch, the number of passengers or anglers on board, and the location fished (NOAA 2011). The MRIP program was introduced in 2011, to replace the Marine Recreational Fishing Statistical Survey (MRFSS) (which had been in place since 1981), and to quantify the catch and effort of the recreational sector (NOAA 2011) through survey methods. Catch is estimated through in-person intercepts, i.e., through field samplers located at marinas, boat ramps, and shore fishing locations. Fishers are asked about the catch composition of their trip and their catch is weighed and measured. Effort is estimated by conducting telephone interviews with anglers (NOAA 2011). The primary difference between the new MRIP program and its predecessor is that MRIP includes telephone interviews conducted only with anglers listed in the National Saltwater Angler Registry (established in 2011). In contrast, the MRFSS program was based on a random sample of all U.S. phone numbers and was thought to produce data with very large error margins. It will take some time before a comprehensive study of MRIP effectiveness is done, but efforts have been made to calibrate the new program with historic MRFSS data.

The SEFSC quota monitoring system tracks the landings of species managed with quotas by obtaining landings information from all dealers. Currently, dealers are required to report either every month or every two weeks to the SEFSC through either paper or electronic reporting. However, the SAFMC and the Gulf of Mexico Fishery Management Council have approved a Dealer Reporting Amendment that would require, if approved by the Secretary of Commerce, that all dealers report landings each week through electronic means. This new methodology is expected to greatly improve monitoring of commercial landings and reduce the chance that commercial ACLs are exceeded. Dealers additionally report all landings of federally caught species to the SEFSC, which are incorporated in the Accumulative Landings System. Landings for the commercial sector are also tracked through the use of trip interview and logbook programs. The SEFSC runs the Trip Interview Program (TIP) which involves sampling targeted to gather more specific data on catch composition, including the collection of otoliths and/or spines, genetic information, and samples for contaminants testing and has been ongoing since 1984 (Cody and Turner 2011). Additionally, participation in the SEFSC Logbook program, started in the South Atlantic in 1992, is a requirement for individuals with federal permits, and vessels must report catch type and composition, gear type, and trip specifics, as well as dealer information and catch sold (Cody and Turner 2011).

The data gathered through these programs are used to develop estimates of the actual catch or landings of stocks managed by the SAFMC. Much of the information is publically available, although privacy concerns prevent the release of some forms of non-aggregated data.

Estimating Management Uncertainty

By comparing the established estimate of a fishery's actual landings to the intended pre-season landings, an estimate of management error can be made. The magnitude of management error is determined using a relative error estimator, which allows fisheries of varying magnitude to be directly compared (Singh 2001) (Equation 1.1):

$$(1.1) \qquad \frac{\textbf{(Actual Landings - Intended Landings)}}{\textbf{Intended Landings}}$$

Potential Impact

Although the current magnitude of management uncertainty for various species and management measures in the South Atlantic is unknown, there is reason to believe that it may, at times, exceed the uncertainty found in scientific models and stock assessments (Prager and Rosenberg 2008). The fisheries in the South Atlantic are vitally important to many resource users and their communities, and it is critical that management of those fisheries is done using every available tool to determine the best course of action.

Without an understanding of historic management uncertainty in the South Atlantic, managers may set regulations and ACLs without fully understanding their potential impacts. If there is a high level of unknown management uncertainty, ACLs could be set at too high a level and might not be sufficient to ensure overfishing does not occur, and the OFL is not exceeded. However, an understanding of historic management uncertainty doesn't just mean more precautionary harvest needed. Fisheries with historically low management uncertainty might require less restrictive management measures and higher ACLs than are currently in place. Although vulnerable fisheries with high historic management uncertainty may require caution, healthy fisheries found to have very low levels of management uncertainty may be managed with a large emphasis on social or ecosystem factors and with less emphasis on variability in catch.

Once the overall magnitude and direction of management uncertainty is established, specific sectors can be evaluated to determine trends or patterns. Due to a number of variables, such as large participant pools and varied fishing locations (and the difficulty in accurately surveying all of the participants), recreational fisheries may show management uncertainty that varies significantly from that of commercial fisheries. The uncertainty associated with recreational fisheries may be higher, both absolutely and on average, than that associated with commercial fisheries. However, the commercial and recreational fisheries of a particular stock may display similar trends as a result of the stock's overall status at any particular point in time. This would mean that managers may potentially need to be more precautionary when dealing with recreational fisheries than with commercial fisheries, and that regulations for commercial fisheries may be set with a greater emphasis on resource user preference. It is possible that the size of a fishery may trend with management uncertainty, as perhaps larger fisheries result in more uncertainty in the data collection process. If a clear association was evident between size and uncertainty, managers may be able to extrapolate this information to stocks without management uncertainty history based on their size.

The type of management regulation used on a particular fishery may also trend with management uncertainty, as fisheries that are managed with inseason data reporting systems or limited access programs (management regimes that limit participation in the fishery) may allow managers to better ensure that landings targets are achieved. The NMFS NS1 Guidelines for the Magnuson-Stevens Act state that:

> Management uncertainty may include late catch reporting, misreporting, and underreporting of catches and is *affected by a fishery's ability to control actual catch*. For example, a fishery that has inseason catch data available and inseason closure authority has better management control and precision than a fishery that does not have these features (NMFS 2009, *emphasis added*).

If true, managers may be able set less precautionary catch limits for stocks managed with these programs because of the lower potential for uncertainty. Increasingly sophisticated data reporting systems and new management types (such as limited access programs) may result in an overall decreasing trend in management uncertainty over time, which would indicate an improvement in our predictive abilities. However, the reauthorized Magnuson-Stevens Act is the first piece of federal fisheries legislation that specifically calls for management uncertainty to be addressed, so there may be no improvement in the overall trend.

This information is particularly important due to the recent reauthorization of the Magnuson-Stevens Act. The intent of the reauthorized Magnuson-Stevens Act is to use the system of OFL, ABC, ACLs, ACTs, and AMs to ensure overfishing does not occur. Knowing the degree of management uncertainty historically associated with a species and management measure would allow managers to specify appropriate management measures, ACLs, AMs, and/or an ACTs that ensure overfishing does not occur and an OFL would not be exceeded. Knowing the magnitude of management uncertainty associated with different management measures would allow managers to choose a measure that is most appropriate for the stock, and allow managers to set the ACL or ACT to a level that accounts for the management uncertainty. Without knowing this information, managers have to guess how effective a regulation will be in ensuring overfishing does not occur, resulting in a greater probability of exceeding the ACL or OFL. For example, recreational fisheries may have higher levels of management uncertainty than commercial fisheries and therefore ACTs might significantly lower than the established ACLs. In contrast, while a commercial fishery that historically has had very low levels of management uncertainty may have an ACT set (appropriately) very close to the ACL, since there is low risk of that ACT being exceeded.

The better managers understand management uncertainty, the more effective they will be in preventing overfishing from occurring by setting appropriate management measures and catch levels. The large number of people who depend on fisheries necessitates that managers ensure that stocks are managed optimally. An understanding of historic management uncertainty may allow managers to better understand the effects of new types of regulations, determine what regulations may be best for each stock, and to consider to what degree uncertainty needs to be considered when setting regulations and catch levels. The results of this study will have immediate and direct utility in the setting of future management regulations, ACLs, AMs, and ACTs in the South Atlantic region, and perhaps beyond.

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Chapter 2: An Estimation of Management Uncertainty for Marine Fisheries in the South Atlantic United States

Introduction

Fisheries management is an uncertain affair. Difficulties in assessing existing stock status, determining the life history characteristics of species, and predicting the likely impacts of particular management actions all contribute to the challenge of regulating fisheries. In the past few decades, a greater appreciation of the potential consequences of ignoring this uncertainty has emerged and has led to increasingly advanced assessment models and precautionary management choices. Although thousands of man-hours have been spent to increase understanding uncertainty inherent in scientific work, little has been done to assess the direct impact of uncertainty in management choices (Prager and Rosenberg 2008). While it is imperative that we have precise estimates of the maximum sustainable yields of our fisheries, such estimates are much less useful *unless* intended effects of management actions are reflected in actual landings.

Management uncertainty, therefore, can be thought of broadly as the extent to which the harvest intended by a regulation matches the actual harvest of a fishery, during a given season. Specifically, a review of the regulatory history of a species should reveal the intent behind each management action. This intent, often expressed as a reduction or increase of historic landings, can be compared to actual landings in a given season and indicate how closely actual landings compare to management predictions. The uncertainty associated with the effectiveness of management measures has not always been explicitly addressed by managers when setting new regulations, although the need for such inclusion has often been expressed (Peterman 2004, Prager and Rosenberg 2008, Fisheries Leadership & Sustainability Forum 2010). However, there are some management measures such as marine protected areas, spawning season closures, and spawning area closures that have conservation purposes to protect a species when they may be particularly vulnerable to fishing pressure rather than provide a target reduction in landings. In these cases, managers may be more concerned with the biological benefits of the regulations, rather than focusing on target reductions in harvest.

The uncertainty in the effectiveness of management regulations can be a result of a wide variety of factors, including those both human and non-human (NMFS 2009). Changes in targeting, fishing gear, regulations affecting co-occurring species, or data reporting could man-made causes of the discrepancy between predicted and actual landings, while factors such as fuel costs, ecosystem interactions, stock condition, or severe weather could be other drivers of this uncertainty (Fulton et al. 2010). As fisheries are inherently complicated systems, it is very difficult to determine the degree to which these particular factors may contribute to management uncertainty in a particular year. However, it is possible (and useful) to estimate the overall magnitude of the uncertainty, as well as its direction (positive or negative).

With the most recent reauthorization of the Magnuson-Stevens Fisheries Conservation and Management Act (MSA, Magnuson-Stevens Act), increased attention has been placed towards the inclusion of management uncertainty when establishing annual catch limits (ACLs) and annual catch targets (ACTs) to prevent overfishing from occurring. As part of this process, accountability measures (AM) are triggered for a fishery when an ACL is met or projected to be met (MSA 2006). An AM may include measures such as an inseason closure, adjustments to the ACLs, or shortening the length of a following fishing season. Precautionary management, based on an awareness of this uncertainty, could help to ensure that overfishing does not occur and that AMs are triggered only when appropriate (Hilborn 2011, Charles 1998). An understanding of the management uncertainty associated with a given stock is crucial to help ensure that management targets are achieved and overfishing does not occur. Furthermore, different fishing sectors or management types may demonstrate differing levels of management uncertainty.

Objectives

The overall objectives of this study, therefore, included analyzing the magnitude of management uncertainty, learning the frequency with which actual landings exceeded predicted landings, and evaluating whether any clear trends or factors existed. The specific hypotheses evaluated were:

H_1: The overall magnitude of management uncertainty declines over the time series.

Over time, the predictive capabilities of managers have improved, as more sophisticated simulations are put into place and longer time series are available. This change, combined with the increasing direct control that managers have over some fisheries, may have resulted in an overall trend of declining management uncertainty over the time series.

H_2: The recreational sector, overall, displays higher magnitude management uncertainty than the commercial sector.

As discussed in Chapter 1, the data collection procedures for recreational and commercial stocks vary considerably. In fact, sufficient problems have been identified with the historic Marine Recreational Fisheries Statistics Survey (MRFSS) that it was recently replaced with the Marine Recreational Information Program (MRIP). Landings data collected through the MRFSS program was inherently more uncertain than landings data collected through commercial mechanisms, which may contribute to greater management uncertainty associated with the recreational sector. If true, this may indicate that recreational fisheries need to be managed in a more precautionary manner, while commercial fisheries could be managed with less need for precaution and more on the management style preference of user groups.

H_3: Commercial and recreational sectors, within a particular stock, display the same management uncertainty.

Within a stock, changes in the overall population health may result in changes to landings for both the commercial and recreational sectors. A high recruitment year for a species could result in landings increasing for all sectors, and therefore in a higher management uncertainty. Comparing the management uncertainty associated with both the recreational and commercial sectors of particular stocks should reveal whether these trends hold true.

H_4: Larger fisheries have a greater management uncertainty than smaller fisheries.

The magnitude of landings may also correlate with management uncertainty, indicating that the size of a fishery could be a predictive factor about the degree of uncertainty associated with the stock. Because larger fisheries generally have a high number of participants and a high number of discrete fishing locations, the uncertainty associated with these stocks may be higher than those of a smaller size. If the size of a fishery correlates with management uncertainty, then managers may be able to generalize these results to other fisheries based on similar characteristics.

H_5: Mean management uncertainty differs between the regulatory mechanisms of quotas, permits, and limits.

Management uncertainty may vary depending on the type of regulation used to manage a fishery. Size limits, for example, may be more imprecise than quotas. If the type of management regulation implemented results in differing management uncertainties then managers would be able to evaluate the amount of uncertainty a particular regulation is likely to generate before it is implemented. Further, managers could specify an ACL or ACT that captures the magnitude of management uncertainty for the management measure selected to better ensure overfishing does not occur. Vulnerable species could be managed with techniques known to be linked to low levels of management uncertainty, while managers could consider a more broad range of options for stocks with which management uncertainty is less of a concern.

Overall, if management uncertainty proves to be low or nonexistent, managers could choose to set regulations based also on user preference or ease, rather than on just the needs of the stock. In addition, ACLs and ACT would need to incorporate less management uncertainty into their estimates and could be set closer to the acceptable biological catch (ABC) specified by a Fishery Management Council's Scientific and Statistical Committee (SSC). However, if management uncertainty does exist, managers may need to take it into account when setting regulations, ACLs, and ACTs in order to ensure that overfishing does not occur.

The aim of this study, therefore, was to provide an initial estimate of management uncertainty for stocks in the U.S. South Atlantic region, which includes federal waters from the northern border of North Carolina to the southernmost tip of Florida. Identifying the overall magnitude and direction of management uncertainty, or possible trends between different fishery sectors (such as commercial vs. recreational), may prove highly valuable when estimating the future management uncertainty in U.S. South Atlantic fisheries.

Methods

In order to investigate the direction and magnitude of historic management uncertainty in the U.S. South Atlantic region, the estimate of a fishery's actual landings were compared to the landings intended by its governing regulation. These estimates were found in a variety of formats, from numbers caught to whole weights, and the time-series available depended upon the stock in question. Data about intended landings were gathered from a thorough review of historic management documents including: The Fishery Management Plan for the Snapper-Grouper Fishery of the South Atlantic Region (FMP); amendments to the FMP, regulatory amendments, *Federal Register* notices, and scientific documents (e.g., Southeast Data, Assessment and Review (SEDAR) assessments, peer reviewed publications, technical reports), and in consultation with fisheries professionals. The predicted impact of a regulatory action on the magnitude of landings was then compared to actual landings in a given year using a relative error estimator

This study focused on stocks found in the South Atlantic region of the United States, which was a region of interest due to the presence of highly valuable fisheries in both the commercial and recreational sectors. Fisheries in the region are overseen by the South Atlantic Fisheries Management Council (SAFMC), which is aided by the SAFMC's SSC. The criteria required for a stock's inclusion in this study were a clear regulatory history, explicit intended landings from those regulations, and updated actual landings data. The eight stocks which had enough historical information for analysis were black grouper (*Mycteroperca bonaci*), black sea bass (*Centropristis striata*), gag (*Mycteroperca microlepis*), golden tilefish (*Lopholatilus chamaeleonticeps*), greater amberjack (*Seriola dumerili*), hogfish (*Lachnolaimus maximus*), red porgy (*Pagrus pagrus*), and vermilion snapper (*Rhomboplites aurorubens*).

Data Collection

Data on intended landings from the U.S. South Atlantic region were obtained primarily through a review of documents published by the SAFMC and/or peer review panels, such as the SAFMC's SSC. Due to variability in record keeping, documentation of intended predicted landings varied widely and even the landings predictions themselves often were absent from management documents (Chapter 3). Often, the intended impact of a regulation was only calculated for a single year, despite the intention of keeping the regulation in place for multiple years. In these cases, when only a single year was estimated, two methods were developed: First, the intended landings were kept constant until a new regulation was passed; second, the intended landings were only evaluated for the year immediately following the implementation of the regulation. When only a single year estimate is available, there is uncertainty about whether the intention of the management measure was to control catch directly, control fishing effort, or provide some biological protection for a stock without any need for a specified harvest reduction, which would result in variable catch over time. Method one assumes that catch was meant to remain constant; while method two assumes that a fishing rate was meant to remain constant. The methods were evaluated to compare the resulting management uncertainty estimates.

Occasionally, the assessment of the impact of a regulation would use simulations to predict the likely impact of that regulation for years beyond just the immediate time period. In these cases, such as when a size limit impact was estimated for the next five years, the simulated values were used in the analysis. This led to intended landings that were variable between regulatory periods. Years in which there was not a clearly estimated harvest associated with a management measure, or for which the landings prediction simply could not be found, were excluded from analysis.

Estimates of official post-season landings (actual landings) for the selected stocks were gathered with help from fisheries scientists in the southeast region (Dr. Nick Farmer, Dr. Jack McGovern, Refik Orhun, Vivian Matter, NMFS, personal communication). Landings for the South Atlantic were generally obtained from the Southeast Fisheries Science Center's datasets. Additional landings information was taken from the official landings tables that appear in SEDAR documents. Landings data were primarily divided into recreational and commercial sectors, as the data resolution did not allow for further subdivision (e.g., for-hire, private, handline, trawl sectors).

Since fisheries data are gathered in a variety of metrics (whole weights, gutted weights, numbers, etc.), conversion factors were pulled from a variety of official documents (e.g., FMP amendments, SEDAR working papers, fisheries studies by state agencies, and university projects) so that pre- and post-estimates could be directly compared. The management uncertainty estimated for most stocks used whole weight or gutted weight comparisons, while the estimates for the remaining stocks used numbers landed values.

Metrics Used

In order to be able to evenly compare fisheries of different magnitudes, management uncertainty was calculated as relative error (Singh 2001) (Equation 2.1):

$$(2.1) \qquad \frac{(\textbf{Actual Landings - Intended Landings})}{\textbf{Intended Landings}}$$

When using the relative error, 0.0 represents a stock whose actual landings exactly matched its intended landings. Any positive number represents a percent increase over the intended landings, and any negative number equated to a percent lower than intended landings. The lowest possible number on this scale is -1.00, which would represent actual landings of 0.0.

Additionally, management uncertainty was often displayed for reader ease as adjusted relative error (Equation 2.2):

$$(2.2) \qquad \frac{(\textbf{Actual Landings - Intended Landings})}{\textbf{Intended Landings}} + 1$$

With the adjusted relative error, 1.0 represents a stock whose landings exactly match intended landings, any number exceeding one equates to a stock that landed more than intended, and any number below one equates to a stock that landed less than intended. The lowest possible number on this scale is 0.00, which would represent actual landings of 0.0.

In order to determine the magnitude and direction of the management uncertainty associated with stocks in the South Atlantic region, the relative error estimates of stocks were compared over the time-series.

Analysis

Two methods were developed to estimate management uncertainty – (1) assuming constant-catch based management and (2) assuming fishing-pressure based management. Under the constant-catch based management method, regulations put in place for multiple years, when not specified otherwise, were assumed to be designed to maintain constant catch. In these cases when a pre-season (intended) catch estimate was available for one year only, pre-season catch estimates were assumed to stay constant in subsequent years, until new pre-season estimates were available.

Under the fishing-pressure based management method, regulations put in place for multiple years, when not specified otherwise, were assumed to be designed to control effort and/or fishing pressure. In these cases, when a pre-season catch estimate was available for one year only, pre-season catch estimates could not be calculated for missing values in subsequent years in the absence of the projection models used at the time. As a result, fewer data points were available for the analysis.

The magnitude of management uncertainty was evaluated by examining the mean and range of the data over the time series, as well as by determining the frequency by which actual landings exceeded predicted landings. A qualitative assessment was used to determine if a trend was present over the course of the time series (H_1). A two-tailed t-test was used to test the null hypothesis that there was no difference between the management uncertainty of the commercial and recreational sectors overall (H_2). The error level to judge significance was set at $\alpha=0.05$.

Within a particular stock, differences between the commercial and recreational sectors (H_3) were evaluated using a matched pairs t-test. The test was performed on the 6 stocks that had sufficient data for analysis – meaning that they had greater than 3 data points in each sector in consecutive, matched, years.

The relationship between the size of a fishery (magnitude of landings) and management uncertainty (H_4) was tested through linear regression. The stocks that utilized whole weights were compared (commercial: vermilion snapper, golden tilefish, hogfish, greater amberjack, gag, black sea bass; recreational: greater amberjack, gag, black sea bass), while those using gutted weight or numbers were excluded from the test in order to maintain consistency within the data.

The primary regulatory action associated with a fishery was compared to its management uncertainty (H_5) using a one-way analysis of variance test. The test evaluated the null hypothesis that no significant difference existed between the three categories of management action: quota, permits, and limits.

Additionally, four case studies were also developed and explored based on the management uncertainty trends discovered in the study (Appendix A). Two species were selected due to their high management uncertainty, and two were selected due to the clear changes they displayed in management uncertainty as a result of the implementation of new management actions.

Results

Method One – Assuming Constant Catch

Overall, this method produced 142 estimates of management uncertainty, averaging about 9 per stock. The largest set (commercial hogfish) had 17 available estimates while the smallest sets had only 4 (Table 1). Using Method 1, actual landings ranged from 18% to 605% of predicted landings, meaning that actual landings at times exceeded predicted landings by several times over (Figure 1, Figure 2, Figure 3, Figure 4). Fifty-two of the 142 estimates of management uncertainty exceeded 0.0, and thus exceeded the predicted landings. The average management uncertainty for all of the estimates combined was 106%, indicating that the landings that were positive were, in general, of larger magnitude than the stocks that fell below 0.0. Seventy percent of the estimates displayed management uncertainty of at least 20%, meaning that they ranged from greater than 0.20 to less than -0.20, in terms of relative error (Figure 5).

The range of commercial management uncertainty was smaller than that of recreational management uncertainty, with the former being -0.82 to 0.79 (relative error, mean of -0.14) and the latter being -0.79 to 5.05 (relative error, mean of 0.51). Variation among the estimates of management uncertainty was also smaller for commercial (standard deviation of 0.32) than for recreational (standard deviation of 1.18) (Figure 6). In the commercial data set, only 1 estimate was more than 3 standard deviations away from the commercial mean, while 2 recreational estimates were more than 3 standard deviations away from the recreational mean.

Management uncertainty for the recreational fisheries overall was significantly higher than in commercial fisheries overall (H_2, P=0.00013). Within individual species, differences in management uncertainty between the commercial and recreational sectors were significant 50% of the time, indicating no consistent relationship between management uncertainty and sector within a stock (H_3, Table 2).

Furthermore, management uncertainty showed no significant relationship with the magnitude of a fishery (H_4, r^2=0.036, P=0.078, Figure 7) or with particular regulatory mechanism (H_5, P=0.451, Table 3). This indicates that larger magnitude fisheries do not generally have a larger management uncertainty than smaller magnitude fisheries, meaning that a large number of participants may not be a factor in predicting management uncertainty for a stock.

Method Two – Assuming Constant Fishing Pressure

Under this method, there were 66 estimates of management uncertainty, fewer than with method one. The largest set (commercial vermilion snapper) had 16 available estimates while the smallest sets had only 1 estimate (Table 4). The overall range of management uncertainty was similar between the methods. With method two, actual landings ranged from 21% to 500% of predicted landings (Figure 8, Figure 9, Figure 10). Only 11 of the estimates of management uncertainty exceeded 0.0, and thus the predicted landings. The overall average management uncertain was 96%, indicating that actual landings, on average, did not exceed predicted landings. Similar to method 1, 65% of the estimates had a management uncertainty of at least 20%, meaning that their corresponding management uncertainty was greater than 0.20 or less than -0.20, in terms of relative error (Figure 11).

However, the differences between the recreational and the commercial fisheries were less distinct under this method. The range of commercial management uncertainty was still smaller than that of recreational management uncertainty, with the former being -0.60 to 0.79 and the latter being -0.79 to 4.00, but the average for commercial data was 0.005 while the average for recreational data was -0.09.

Under method 2, overall recreational management uncertainty was not significantly different from overall commercial management uncertainty (H_2, P=0.584). Variation among the data sets was still smaller for commercial sector (standard deviation of 0.29) than for recreational (0.89). However, unlike method 1, when 6 of the recreational estimates exceeded a management uncertainty of 2.0 (relative error), under method 2 only one recreational estimate exceeded a value of 2.0 (relative error). Under method 2, low sample sizes made it not possible to conduct a matched-pairs t-test on any of the stocks (H_3).

Also, as with method one, the correlation between magnitude of landings and uncertainty was not significant (H_4, r^2=0.027, P=0.271, Figure 12), nor was the analysis of variance comparing the primary management mechanism (H_5, P=0.398, Table 5). This again shows that larger fisheries do not generally have a larger management uncertainty than smaller magnitude fisheries, indicating that the magnitude of a fishery may not be a good predictor of potential management uncertainty for a stock.

Overall, regardless of the method used, no clear trend seems to exist indicating that the range of management uncertainty has narrowed over the past twenty years, although the spotty nature of the data set in the earliest regulatory years makes it impossible to conclude that management uncertainty has increased. Individual stocks have trended in both directions during the past two decades of management, producing no clear overall change.

Discussion

These results indicated that management uncertainty is a factor worthy of serious consideration in the setting of future regulations including management measures, ACLs, AMs, and ACTs. No matter how exact estimates of stock population status or health may be, an inability to ensure that regulations have their desired effect is a matter of serious concern in ensuring overfishing does not occur. In general, although the *average* management uncertainty hovered around 0, the fact that 65%-70% of predicted landings are off by at *least* 20%, regardless of estimation method used, indicates the difficulty in predicting the effect of a regulation, the chosen regulatory methodology, and regulatory enforcement. While a management uncertainty of 20% or less may not be cause for great concern in some natural systems, a management uncertainty that is regularly exceeding 20% may indicate a problem for managers to address. In addition, it seems to demonstrate the underlying uncertainty of fisheries and the effect on landings – from economic issues to weather events, there are simply some factors that can ever be predicted with confidence. An awareness of these issues, compiled with the clear evidence that this study presents, may demonstrate the need to be increasingly precautionary in managing some fisheries.

In general, both the magnitude (amount) and direction (positive or negative) of the management uncertainty for a stock are potential causes for concern. Management uncertainty that is large represents a real problem in that regulations are not having their intended effect. However, the directionality of the management uncertainty also comes into play because positive or negative uncertainty may pose different difficulties, as discussed below.

In particular, recreational fisheries may be of interest because they produced the highest overall values of management uncertainty. Although only half of the recreational data points developed using method one were positive, the ones that were outpaced the positive commercial points (method two actually produced higher numbers of positive commercial values in comparison to the recreational data, but the recreational values still displayed the highest magnitude). Landings that are 400% or 500% above a landings target could push a stock into overfished territory if it continued for multiple years. Depending on the management uncertainty in these cases, large adjustments to reduce ACLs or ACTs may be needed to ensure overfishing does not occur. However, it is important to keep in mind that the high recreational values may, to some degree, be a result of the historic difficulties found in collecting accurate data through the MRFSS.

In contrast, the commercial fisheries displayed, on average, lower management uncertainty than the recreational stocks. This indicates, perhaps, that commercial management measures are more effective at preventing overfishing, but economic concerns also come into play. With the reauthorized Magnuson-Stevens Act, many fisheries are having their catch allowances reduced to ensure overfishing does not occur. ACLs are now in place for multiple species and AMs are being triggered each year, putting additional economic and social pressure on resource users. Stocks that consistently have negative management uncertainty may represent an unused potential in the fishery, or rather an opportunity for resource users to increase harvest. If a species had consistently low and negative management uncertainty, it may be possible for managers to be less precautionary in their regulation setting, and specification of an ACL or ACT because they know it is highly likely that the fishery will not catch as much as predicted by the regulation.

Surprisingly, the type of management action associated with a stock did not act as a reliable indicator of the degree or direction of management uncertainty, which was inconsistent with the original hypothesis that management uncertainty varies between regulatory mechanisms.
This result may be due to the widespread use of management methods such as size and bag limits that are less able to constrain catch than quotas and ACLs. The primary differences in management uncertainty associated with recreational and commercial sectors are likely related to data collection methods, and are so great that they mask any underlying effects from the different management types. There are too few data points to estimate management uncertainty for a species within each sector in a significant fashion, but the addition of future data points will allow for this type of analysis. It is important is to know what the magnitude of management uncertainty of a particular management measure is for a species in the commercial or recreational sector to specify appropriate management measures and set ACLs and ACTs at levels which

ensure overfishing does not occur. If management uncertainty is very large, then a manager might not use that measure. If there is some management uncertainty then a manager might use that management measure but adjust the ACL or ACT to account for the management uncertainty associated with the management measure in question.

The magnitude of landings also was not a significant predictor of the management uncertainty. However, golden tilefish consistently had the highest magnitude of uncertainty out of the recreational stocks. This may be due to extremely small and variable landings, and associated difficulty with estimating landing with a survey-based system. In contrast, black sea bass, which is an extremely productive species with very high recreational landings, exhibited low management uncertainty in the recreational sector.

The fact that the magnitude of management uncertainty did not decrease over time, regardless of selected method, is surprising, considering the fact that enforcement, reporting, and estimation and documentation of predicted catch seem to have improved over the past few decades. Furthermore, overfishing has been ended for many snapper grouper species in the last 10 years, suggesting management measures have been effective and have had their intended effect (in some cases, management uncertainty varied between highs and lows, but averaged out close to 0). The results presented in this study suggest that although management measures have become more numerous and restrictive, the uncertainty of the effectiveness of those measures in achieving a target level of landings has not changed. This may be an artifact of the data set itself as many stocks have only a few years of available information, and no species' data consistently runs from its original fisheries management plan to present day. The species that display the highest degrees of management uncertainty today may have had similar levels historically, but the data are simply not available for comparison. The fact that no trend is clear perhaps indicates the necessity of treating each species independently according to its historic trend when assessing potential future management uncertainty for a particular management measure.

Method Comparison

Unfortunately, the lack of clarity provided in the management documents makes it difficult to determine which strategy (catch-based management or fishing-pressure based management) was intended when some regulations were put into place, especially throughout the 1990s. Both methods have been used historically, and the selection of the appropriate strategy by managers may have depended, at least in part, on the potential effects of the method on the fishery.

Catch-based strategies (method one) are intended to hold catch constant over time, producing the same amount of landings season to season. Assuming that a stock is currently overfished and requires rebuilding, constant catch-based management allows for higher initial catch than constant harvest rate management. This high immediate catch tends to be beneficial for resource users who need or want higher levels of catch right away. Over time, the percentage of uncaught stock quickly rises as the population rebounds. However, even as the stock abundance does increase, resource users are limited to the initial catch level and cannot take direct advantage of the increasing population size.

In contrast, management strategies based on maintaining a constant fishing pressure (method two) have the opposite effect. In order to use this kind of strategy, stock assessment scientists have to simulate what catch would be in successive years, to ensure that the correct fishing pressure level was ultimately chosen. This is often provided in rebuilding projections from a stock assessment. Under that given fishing pressure, catch is directly proportional to the population size, meaning that early on, when the stock size is low, catch is correspondingly small. This can create difficulty for resource users who may see an immediate and substantial decrease to their income. However, this low initial catch allows the population to begin recovering at a faster rate and, as the stock size grows, the proportional catch also increases. This allows resource users to harvest more of the stock over time and to take immediate advantage of stock recovery. At the end of, say, a ten-year rebuilding period, resource users operating under a constant fishing pressure strategy should have larger harvests than resource users operating under a constant catch strategy (assuming those resource users survived the initial drop in harvest).

Both methods have advantages, so the selection of the strategy to be used is left up to the resource managers, depending on what options are available to them concerning types of regulations allowed, their ability to monitor catch, the existing status of the stock itself, and the overall rebuilding requirements (if overfished). Additionally, managers are able to consult with resource users to determine what strategy is most acceptable for them or which strategy they think will be the most beneficial economically over time. Managers may even be able to move from one strategy to another as the health of the stock and the needs of resource users evolve.

However, not all management measures have the intended effect of constraining harvest to certain target levels. The SAFMC has implemented management measures that had conservation goals rather than intending to rebuild overfished stocks. Some of the early minimum size limits implemented through the original Snapper Grouper FMP had the intended effect of ensuring snapper-grouper species had the opportunity to spawn rather than limit harvest to some target level. Spawning season closures have been put into place for shallow water grouper species with the intent of protecting species that may be particularly vulnerable to fishing pressure during a time of the year when they form spawning aggregation. The SAFMC prohibited the use of trawling gear and traps, and indicated this would have biological benefits to fish stocks; but the primary intent of these measures was to protect habitat from damaging fishing gear. The SAFMC implemented marine protected areas to provide a refuge for deepwater snapper-grouper species and to prohibit harvest in areas in where snapper-grouper species were known to spawn. The SAFMC acknowledged that the action could reduce harvest of snapper-grouper species but the amount could not be quantified. The action was taken to provide a biological benefit for snapper-grouper species rather than provide a target reduction in harvest.

Generally speaking, it appears that fishing pressure based methods (method two) may have been historically used for many of the stocks in this study, mainly because they were governed primarily by bag, size, and trip limit regulations, which will produce landings that vary along with the population size. However, little information was recorded directly specifying the utilized strategy. Although using fishing pressure based methods requires stock assessment scientists to simulate seasonal catch estimates, these estimates were not recorded into the management documents. Instead, only the next season's expected reduction or increase was generally described.

The absence of this information prevents the calculation of historic management uncertainty for stocks in the region, making it difficult to determine how accurate predictions ultimately were. Potentially, this is because understanding management uncertainty has only recently been recognized as an essential part of the management process. If the importance of validating the predicted impacts of regulations had been recognized earlier, the trend in overall management uncertainty throughout the last few decades may have been very different.

With this in mind, it is likely that the second methodology used in this study is the more accurate one, as the types of regulations used historically were more commonly matched with fishing pressure based management strategies. Fortunately, the results generally agree well enough between the two estimation methods that knowing which strategy was intended at a particular point in time is not essential to produce meaningful information. Method 1 may indicate that the historical management uncertainty associated with recreational fisheries is worse than it actually was, due to the fact that rising landings are interpreted differently between the two management strategies. A fishing pressure-based strategy would consider rising landings under a stable regulation as a sign of success, while rising landings under a constant catch strategy would be cause for concern. Overall, however, the results are generally consistent between both methods used in the study.

Additionally, the data gathering process for this study revealed that, historically, the predicted landings of specific regulations are not always explicitly estimated and have also sporadically been recorded clearly into management documents. Although improvements have been large in recent years, it appears that opportunities remain to improve the methods used to report preseason predictions of harvest so that estimates are reviewable and repeatable in the future. This will be discussed further in Chapter 3.

This study not only provided the direct results presented above, but, perhaps even more importantly, an accessible database of the historic information. With future work, this database can be quickly and easily updated to facilitate comparisons over time-series, regions, or to examine the impact of new regulatory mechanisms. As fisheries shift to the use of the system of ACLs, AMs, and ACTs that is used in concert with traditional management measures to limit harvest, managers will be able to more quickly quantify management uncertainty. Looking forward, one benefit of the most recent reauthorization of the Magnuson-Stevens Act is newly required ACLs essentially function as pre-season intended landings for stocks. To determine the current management uncertainty associated with a stock, one can simply compare the actual landings with the stock's established ACL or ACT. Although future iterations of the Magnuson-Stevens Act could change to this requirement, as long as ACLs are in place, managers should be able to quickly and easily estimate management uncertainty for a stock.

Overall, the key limitation of this study was sample size. Out of the 60 snapper-grouper species managed by the SAFMC, only a limited number had sufficient data to determine meaningful historic management uncertainty, due primarily to limitations in the number of assessments that can be conducted each year and the length of time between management actions. There is little evidence to indicate that these data can be extrapolated to the entire South Atlantic region or the greater United States, especially due to the lack of a clear trend between uncertainty and fishery size or regulatory mechanism. However, the selected species include those with a variety of life history characteristics, so in cases where no evaluation of management uncertainty can be made for a species, the study does at least provide a starting point for managers to consider. It also clearly establishes methods that can be used in any region for assessing management uncertainty should the necessary information be available.

Management Implications

The goals of fisheries management are multifaceted. In addition to ensuring that stocks are not overfished, managers also have to balance the often complex and conflicting priorities of ensuring the existence of healthy ocean ecosystems, the economic well being of resource users, and competing interests of different sectors. Sometimes management is designed to address broader "conservation" goals, while other times it is designed to create specific changes in harvest.

With the most recent reauthorization of the Magnuson-Stevens Act, increased focus has been placed on ensuring that overfishing does not occur and that overfished stocks are recovered to healthy levels. To accomplish this, harvest limits have been brought to the forefront of the management picture. When managers seek to select appropriate regulations, they have to not only balance the wide variety of management goals, but they also have to ensure that overfishing does not occur through use of a system of ACLs, AMs, and sometimes ACTs. The SSC considers scientific uncertainty when setting an acceptable biological catch (ABC) at some level below the overfishing limit (OFL). Based on the ABC, managers will specify an ACL equal to or below the ABC. The manager also specifies the AMs to ensure the ACL is not exceeded. If an ACL is met or expected to be met, an AM will be triggered to ensure an overfishing limit is not exceeded and overfishing does not occur. Managers also have the option of implementing an ACT below the ACL to account for management uncertainty. With the results of this study in hand, managers should be better equipped to make decisions about the degree to which management uncertainty should be considered when identifying management measures and specifying ACLs and ACTs.

If such a system of ACLs and AMs had been in place historically, under method 1, 52 of the 142 years (11 of 66 under method 2) evaluated would have resulted in overages, as actual landings exceeded intended landings. This may indicate to managers the difficulty surrounding accurate predictions, and highlight the need to evaluate the past history of the stock (or of similar stocks) when selecting appropriate targets. It may also suggest to managers that a system with a high ACL and appropriately designed AMs, chosen to allow rapid response to greater than predicted catch, may be preferable to a system with a lower ACL, but more severe AMs.

Based on this research, managers may need to assume that recreational fisheries with traditionally low harvest levels (such as golden tilefish) have a high risk of large, and potentially variable, management uncertainty. This is likely due the small recreational landings being infrequently encountered by the sampling methodology, which results in variable and uncertain estimates of recreational landings. Furthermore, a situation where actual landings slightly exceed predicted landings may not always indicate a poorly regulated system. Rather, an appropriately set target with good management may cause management uncertainty to fluctuate slightly above and below 100%. Instead of indicating a problematic regulation, it may instead indicate a regulation that is effectively causing harvest to be as accurate as is possible in a complicated natural system, such as in the case of recreational gag.

As for the commercial sector, although some stocks did occasionally exceed 100% of intended landings, the general trend indicated that management uncertainty was not much of an issue. This suggests that for measures with low management uncertainty, the ACL can be set close to the ABC specified by a SSC. However, it is also important for managers to keep in mind that large commercial fisheries are often based on populations with high – but variable – fecundity, and that landings appropriate in one season may not always be reflected in the next season, causing management uncertainty to vary.

Additionally, further investigation into management uncertainty, centered around identifying trends between uncertainty and the life history characteristics of a species or between uncertainty and the regulatory mechanism used, could provide managers with key information to use in the decision making process. The sheer number of stocks present in the region (and nationally), combined with the difficulty of retrospective analysis, makes it unlikely that an evaluation of management uncertainty could be done for every, individual stock. More likely, an assessment of many of the stocks, and a comparison of their life history characteristics, regulatory mechanisms, and/or magnitude, could allow managers to develop a database with "possible" levels of management uncertainty associated with different management techniques. Managers would then be able to select the management technique that not only fit the needs of the stock and of their constituents, but also minimized the likelihood of high magnitude management uncertainty.

Conclusions

Overall, it appears that management uncertainty can vary widely between stocks and sectors, and can result in landings several times larger or smaller than desired. Differences appearing between recreational and commercial sectors warrant further study, to address whether or not these categorizations may be useful to managers, along with differences possibly connected to magnitude of landings, regulatory measures, or the life history characterizes of the species under consideration. Acknowledgement of this uncertainty and inclusion of it in the management process may be key to ensuring that stocks are not subjected to overfishing in the future and can be fully utilized for their economic potential.

Management uncertainty of a high magnitude can present a problem for stocks either positively or negatively. Stocks that have a large management uncertainty, such as some of the recreational fisheries described above, may be at serious risk of overfishing depending on how close the predicted landings were set to the OFL. Any instance where actual landings exceed ACLs will trigger AMs. In some cases, AMs drastically reduce the amount of landings allowed in a season following an ACL overage. AMs ensure ACLs are not exceeded or that an overage of an ACL is not detrimental to the stock. However, individuals who depend on the resource could experience negative economic impacts from AMs being triggered or ACLs/ACTs that are adjusted to account for management uncertainty.

Furthermore, instances of negative management uncertainty, such as in many of the commercial fisheries described above, may also be problematic because they represent potential lost economic gain for resource users. However, it will be quickly recognized by managers if landings are well below an ACL each year, and adjustments can be made through a regulatory amendment to the fishery management plan so that fisheries can be utilized to their full potential and optimal yield can be attained. Further, negative management uncertainty would indicate little or no adjustment is needed when ACLs or ACTs are specified, and they can be set close to the ABC identified by a Fishery Management Council's SSC. As more stocks are regulated, and as those regulations are tightened, it becomes more imperative for resource users to be able to catch their full allocation.

However, many management measures were initially set with conservation goals rather than harvest targets. For the first time, the reauthorized Magnuson-Stevens Act promotes increased awareness of management uncertainty through recommendations that it be considered within the system of ACLs, ACTs, AMs to ensure overfishing does not occur. The lack of historic awareness of management uncertainty limited managers' ability to learn from past management actions and to improve their predictive capabilities. Now, with the results of this study in hand, managers should be more able to effectively estimate the potential management uncertainty associated with a particular stock and choose regulations that can minimize that uncertainty, and specify ACLs and ACTs, which will help ensure overfishing does not occur.

Although it will not be possible to retrospectively evaluate the management uncertainty associated with every stock in the region, an assessment of some of the stocks, and a comparison of their life history characteristics, regulatory mechanisms, and/or magnitude, may allow managers to develop a database of the "possible" levels of management uncertainty associated with different management techniques. In the future, as additional regulations are set and evaluated, managers and stock assessment scientists can look back upon this database and select regulations that not only address the needs of the stock and of resource users, but that also minimize management uncertainty. Furthermore, managers can use this analysis to compare current rates of management uncertainty with historic rates, and ensure the future trend for management uncertainty is downward. Given the magnitude of management uncertainty identified in this study and its implications, it is imperative that policymakers incorporate management uncertainty into their management regimes.

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Table 1. Comparison of management uncertainty for select species in the U.S. South Atlantic, assuming a constant-catch based management strategy if unspecified in management documents. Indicating fishery, sector, range and average of management uncertainty, number of data points and the years in which an estimation of management uncertainty is possible.

		Management Uncertainty				
Fishery	**Sector**	**Min**	**Max**	**Average**	**N**	**Years Available**
Vermilion Snapper	Commercial	-0.37	0.42	-0.03	18	1992-2005, 2007-2008, 2010-2011
	Recreational	-0.37	1.23	0.25	14	1992-2005
Golden Tilefish	Commercial	-0.05	0.24	0.09	5	2007-2011
	Recreational	0.03	4.00	2.00	4	2007, 2009-2011
Greater Amberjack	Commercial	-0.51	-0.20	-0.32	7	2000-2006
	Recreational	-0.30	0.53	0.08	7	2000-2006
Gag	Commercial	-0.22	0.09	-0.09	10	1999-2008
	Recreational	-0.79	0.18	-0.29	16	1993-2008
Red Porgy	Commercial	0.20	0.30	0.24	4	2007-2010
	Recreational	-0.70	-0.15	-0.45	7	1992-1998
Black Grouper	Commercial	-0.82	-0.53	-0.64	12	2000-2011
	Recreational	-0.20	5.05	1.40	13	1999-2011
Black Sea Bass	Commercial	-0.28	0.79	0.16	4	2007-2010
	Recreational	-0.25	0.69	0.08	4	2007-2010
Hogfish	Commercial	-0.52	0.16	-0.29	17	1995-2011

Table 2. Within-stock comparison of sector specific management uncertainty through a matched-pairs t-test. Results compare the management uncertainty between the recreational and commercial sectors of a particular stock to evaluate correlation. Null hypothesis: no significant difference exists between the means of the recreational and commercial sectors for given stock.

Species	**DF**	**Correlation**	**Prob > t**
Vermilion Snapper	13	0.46875	0.0184
Golden Tilefish	3	-0.3893	0.0633
Greater Amberjack	6	-0.0892	0.011
Gag	9	0.07989	0.6585
Black Grouper	11	0.49177	0.0004
Black Sea Bass	3	0.21694	0.6047

Table 3. Management uncertainty (measured as relative error and assuming a constant-catch based strategy) prepared for one-way analysis of variance (ANOVA) comparing management uncertainty and primary regulatory mechanism (quota, permit, or limit).

	Quota	**Permits**	**Limits**
n	20	11	111
Mean	-0.03	-0.20	0.10
Standard Deviation	0.32	0.39	0.93

Table 4. Comparison of management uncertainty for select species in the U.S. South Atlantic, assuming a fishing pressure based management strategy if unspecified in management documents. Indicating fishery, sector, range and average of management uncertainty, and the years in which an estimation of management uncertainty is possible.

		Management Uncertainty				
Fishery	**Sector**	**Min**	**Max**	**Average**	**n**	**Years Available**
Vermilion Snapper	Commercial	-0.37	0.42	-0.04	16	1992-2005, 2007, 2010
	Recreational	-0.37	0.52	-0.17	8	1992-1999
Golden Tilefish	Commercial	-0.05	0.24	0.09	5	2007-2011
	Recreational	0.03	4.00	2.02	2	2007, 2011
Greater Amberjack	Commercial	-0.51	-0.20	-0.32	7	2000-2006
	Recreational	0.15	0.15	0.15	1	2000
Gag	Commercial	-0.12	-0.12	-0.12	1	1999
	Recreational	-0.79	0.06	-0.56	7	1993-1999
Red Porgy	Commercial	0.30	0.30	0.30	1	2007
	Recreational	-0.70	-0.15	-0.45	7	1992-1998
Black Grouper	Commercial	-0.60	-0.60	-0.60	1	1999
	Recreational	1.24	1.24	1.24	1	1999
Black Sea Bass	Commercial	-0.28	0.79	0.16	4	2007-2010
	Recreational	-0.25	0.69	0.08	4	2007-2010
Hogfish	Commercial	0.16	0.16	0.16	1	1995

Table 5. Management uncertainty (measured as relative error and assuming a fishing pressure based strategy) prepared for one-way analysis of variance (ANOVA) comparing management uncertainty and primary regulatory mechanism (quota, permit, or limit).

	Quota	**Permits**	**Limits**
n	18	8	40
Mean	-0.05	-0.36	-0.03
Standard Deviation	0.33	0.33	0.76

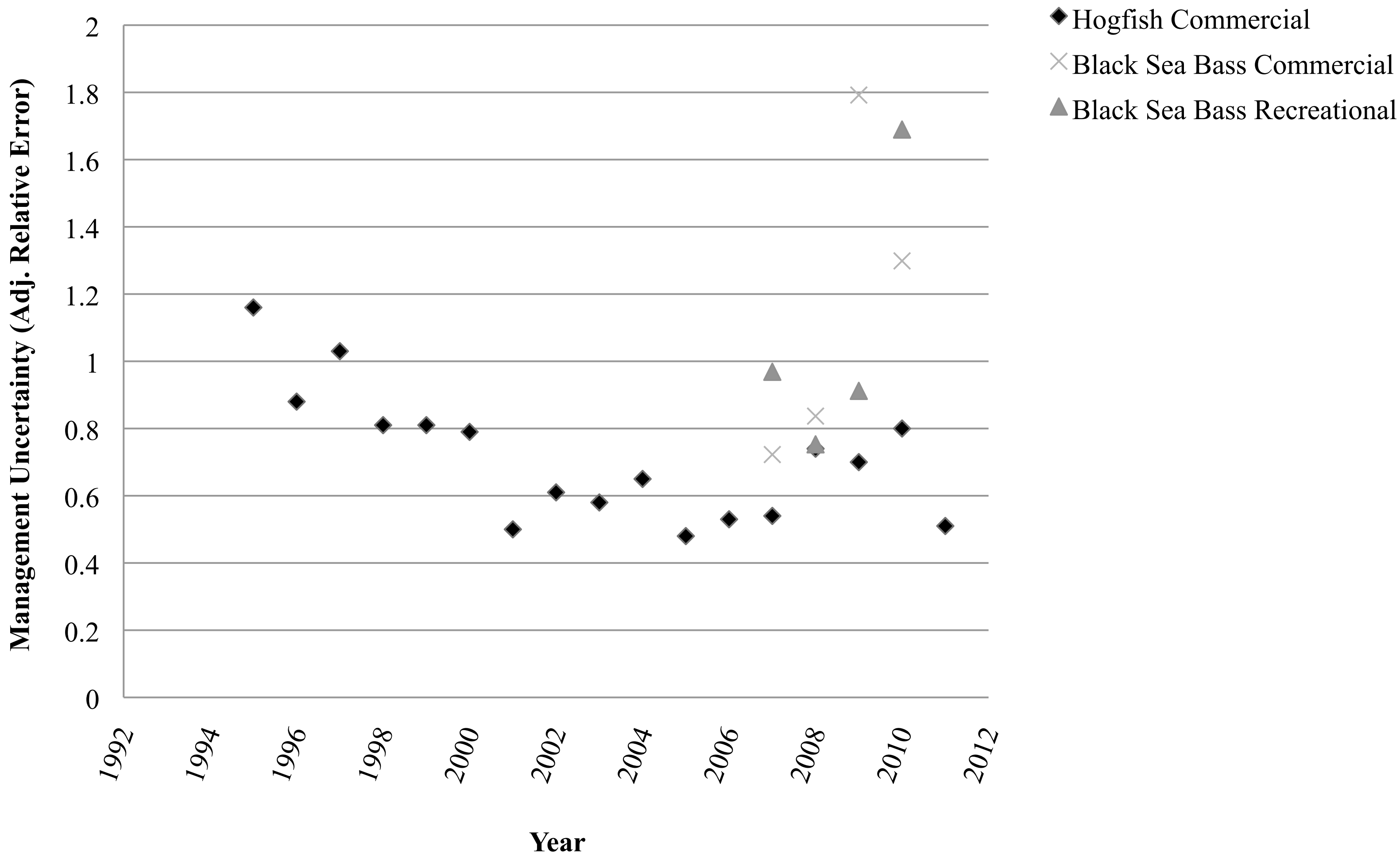

Figure 1. Historic management uncertainty, as an adjusted relative error, for commercial hogfish, commercial black sea bass, and recreational black sea bass in the U.S. South Atlantic region (assuming a constant catch based strategy).

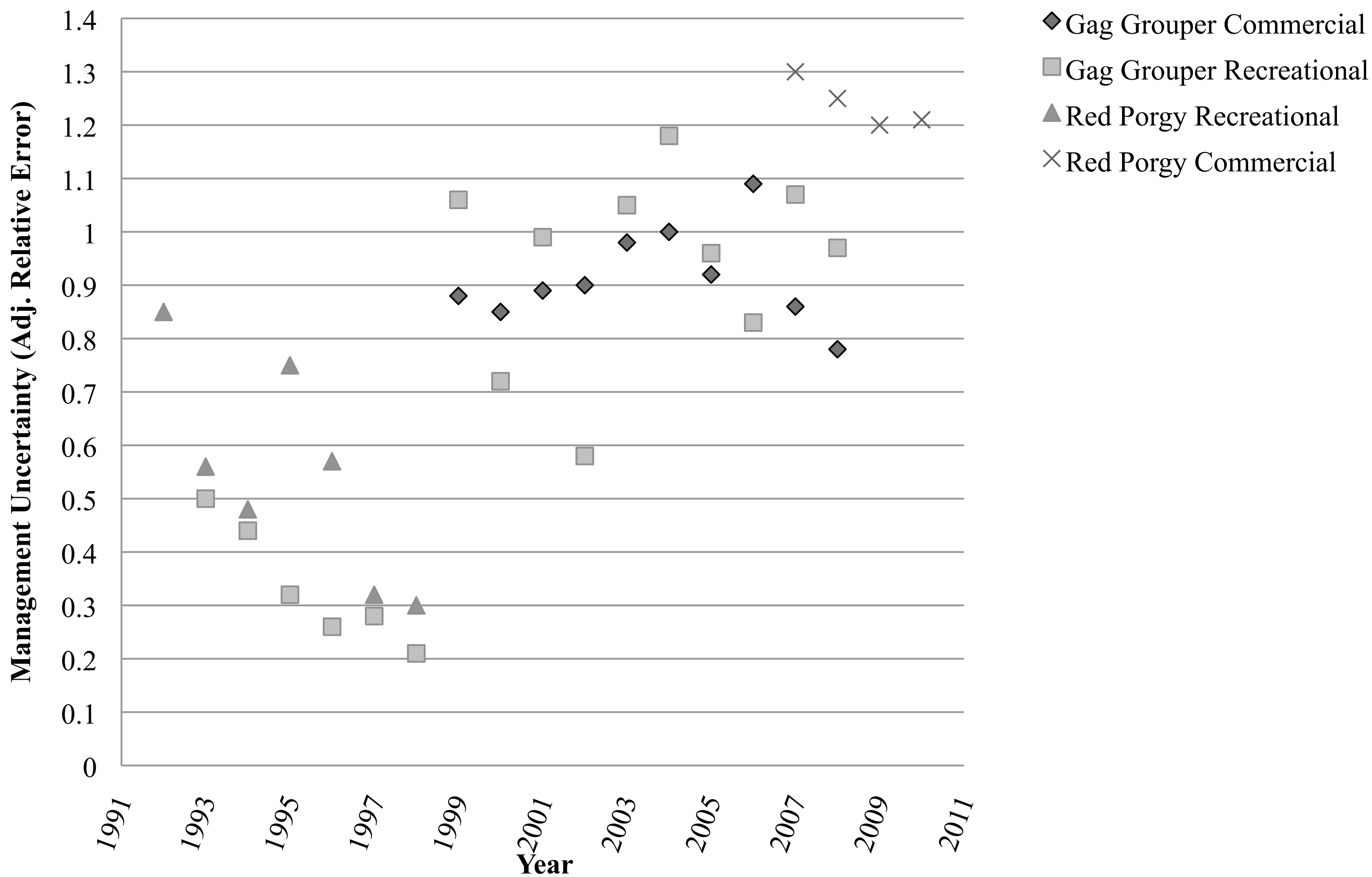

Figure 2. Historic management uncertainty, as an adjusted relative error, for commercial and recreational gag and commercial and recreational red porgy in the U.S. South Atlantic region (assuming a constant catch based strategy).

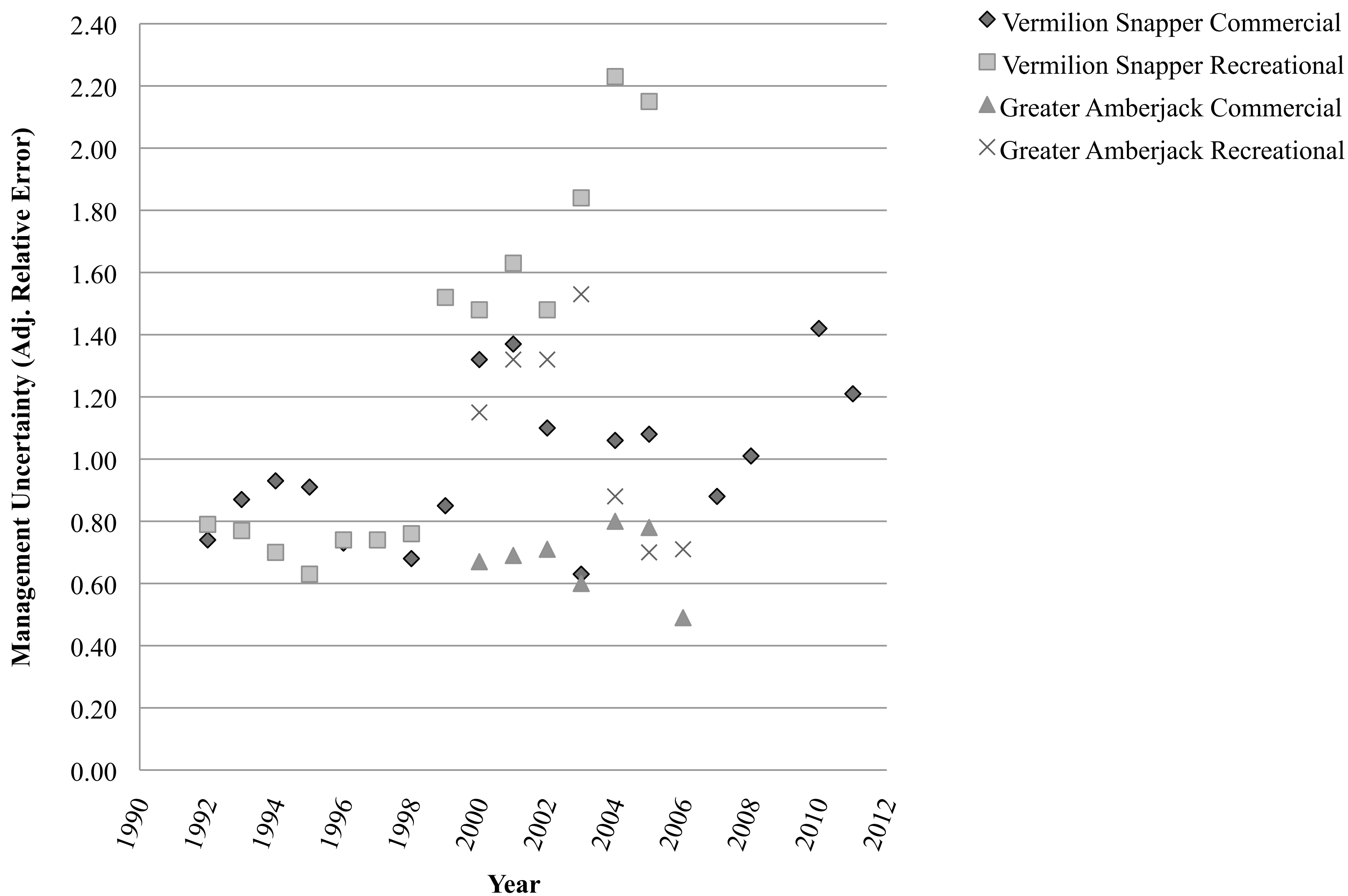

Figure 3. Historic management uncertainty, as an adjusted relative error, for commercial and recreational vermilion snapper and commercial and recreational greater amberjack in the U.S. South Atlantic region (assuming a constant catch based strategy).

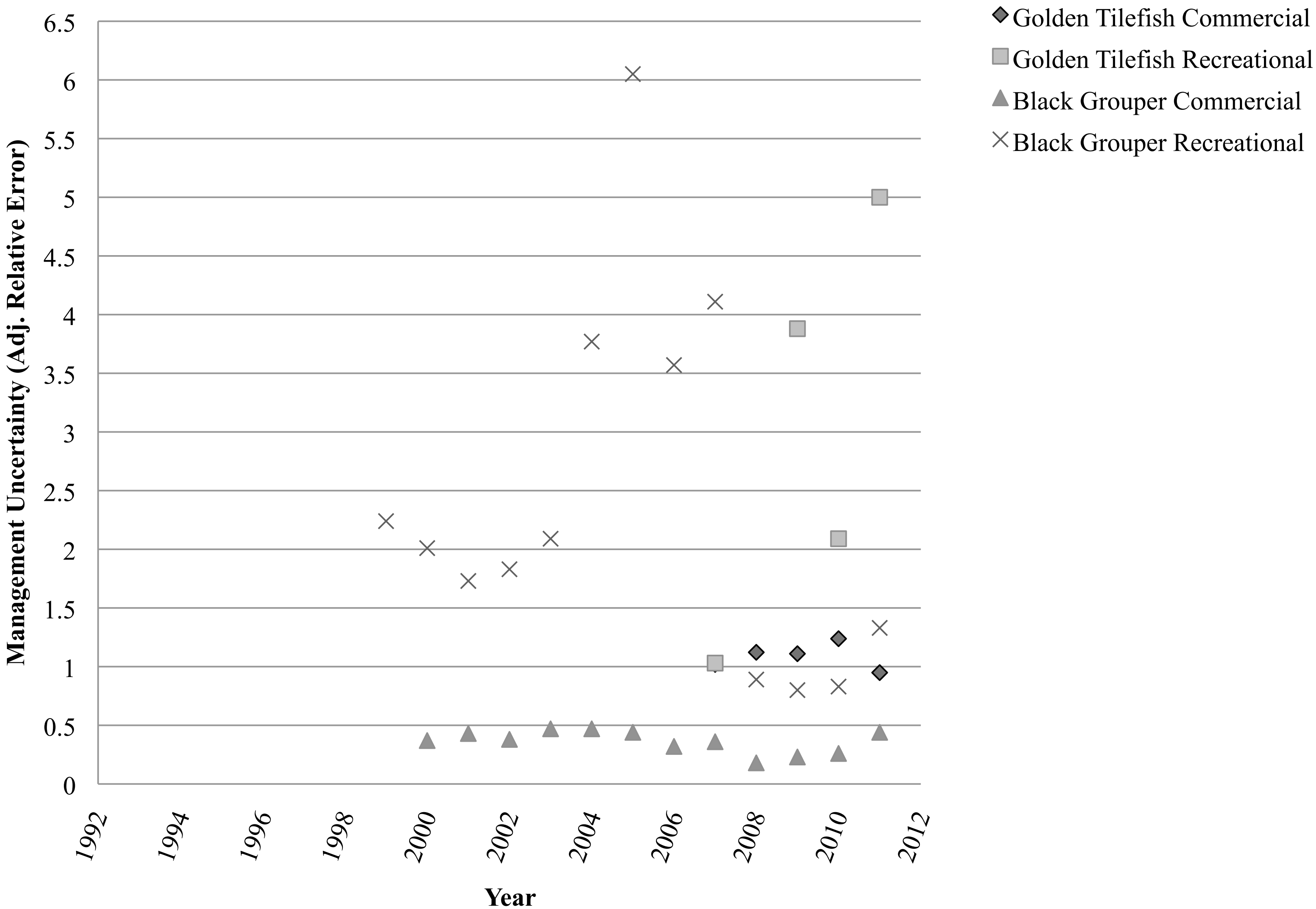

Figure 4. Historic management uncertainty, as an adjusted relative error, for commercial and recreational golden tilefish and commercial and recreational black grouper in the U.S. South Atlantic region (assuming a constant catch based strategy).

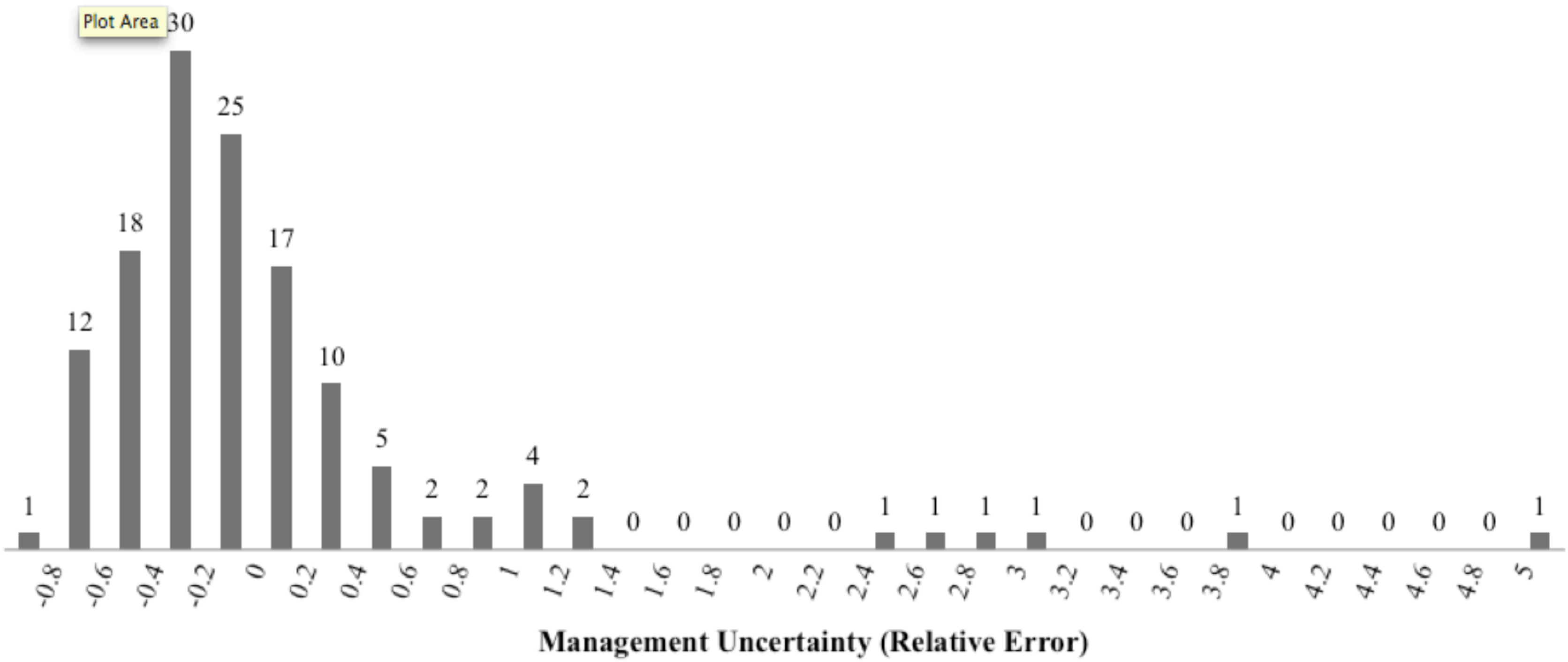

Figure 5. Distribution of management uncertainty, expressed as relative error, for all combined sectors of South Atlantic stocks, assuming a constant-catch based management strategy. Each bar represents the number of data points that fell between the presented levels of management uncertainty (e.g. 25 data points fell between -0.2 and 0). The minimum value is -1.0 while 5.2 is the maximum value.

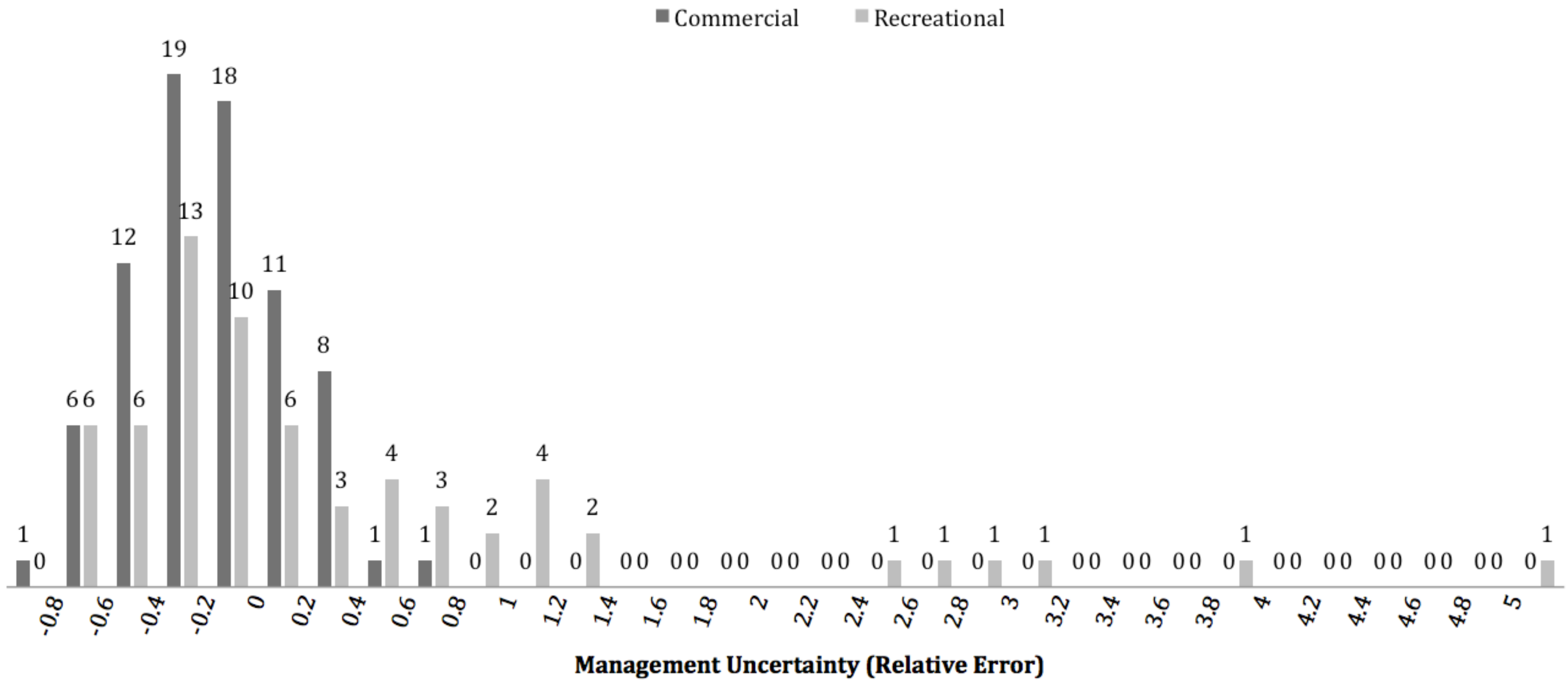

Figure 6. Distribution of management uncertainty, expressed as relative error, between commercial and recreational sectors of South Atlantic stocks, assuming a constant-catch based management strategy. Each bar represents the number of data points that fell between the presented levels of management uncertainty (e.g. 19 commercial and 13 recreational data points fell between -0.2 and 0). The minimum value is -1.0 while 5.2 is the maximum value.

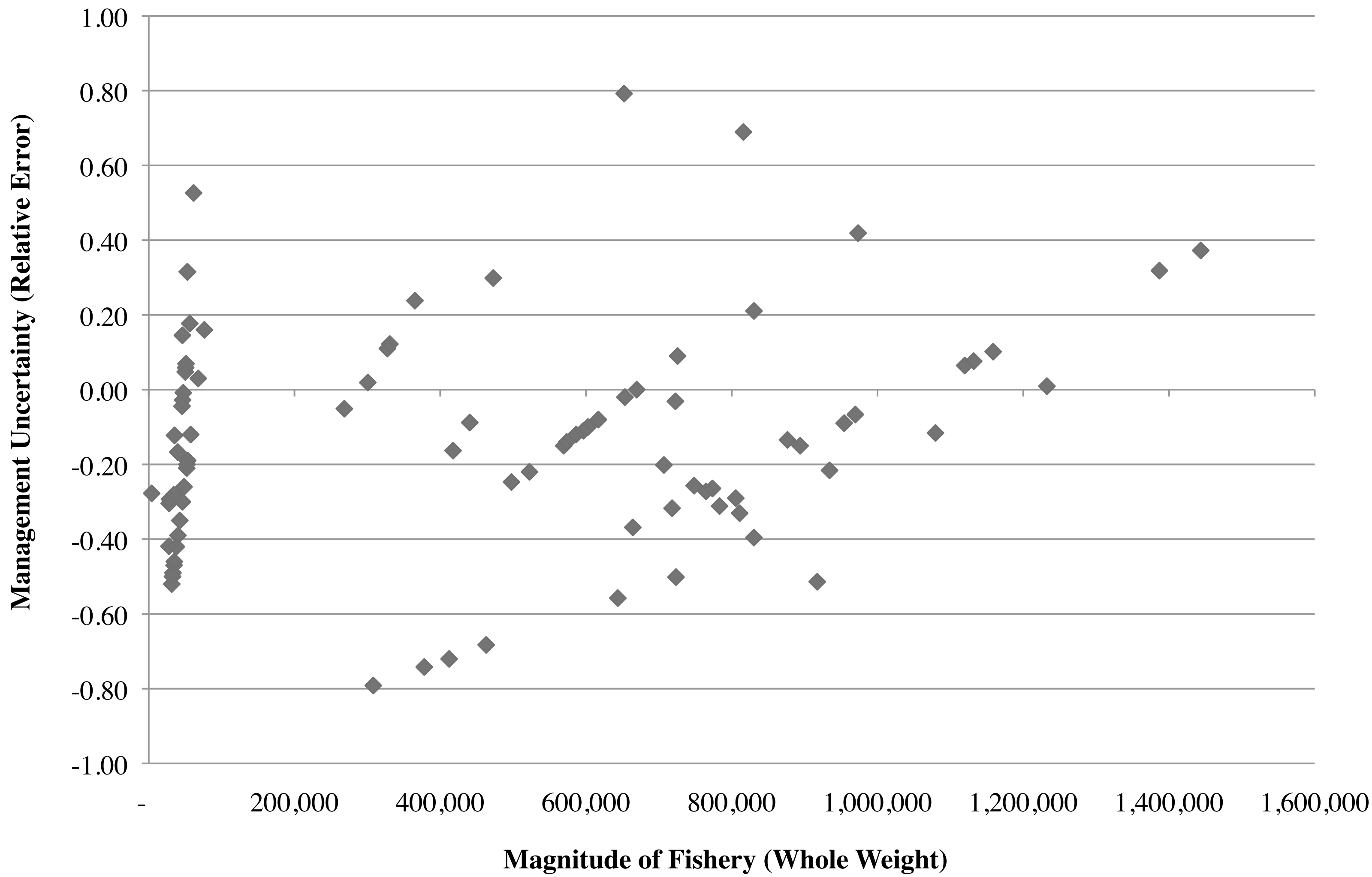

Figure 7. Relationship between magnitude of fishery (given in whole weight of landings) and management uncertainty (as a relative error), assuming a constant catch based management strategy. Relationship between the variables was not significant (r^2=0.036, P=0.078, α=0.05).

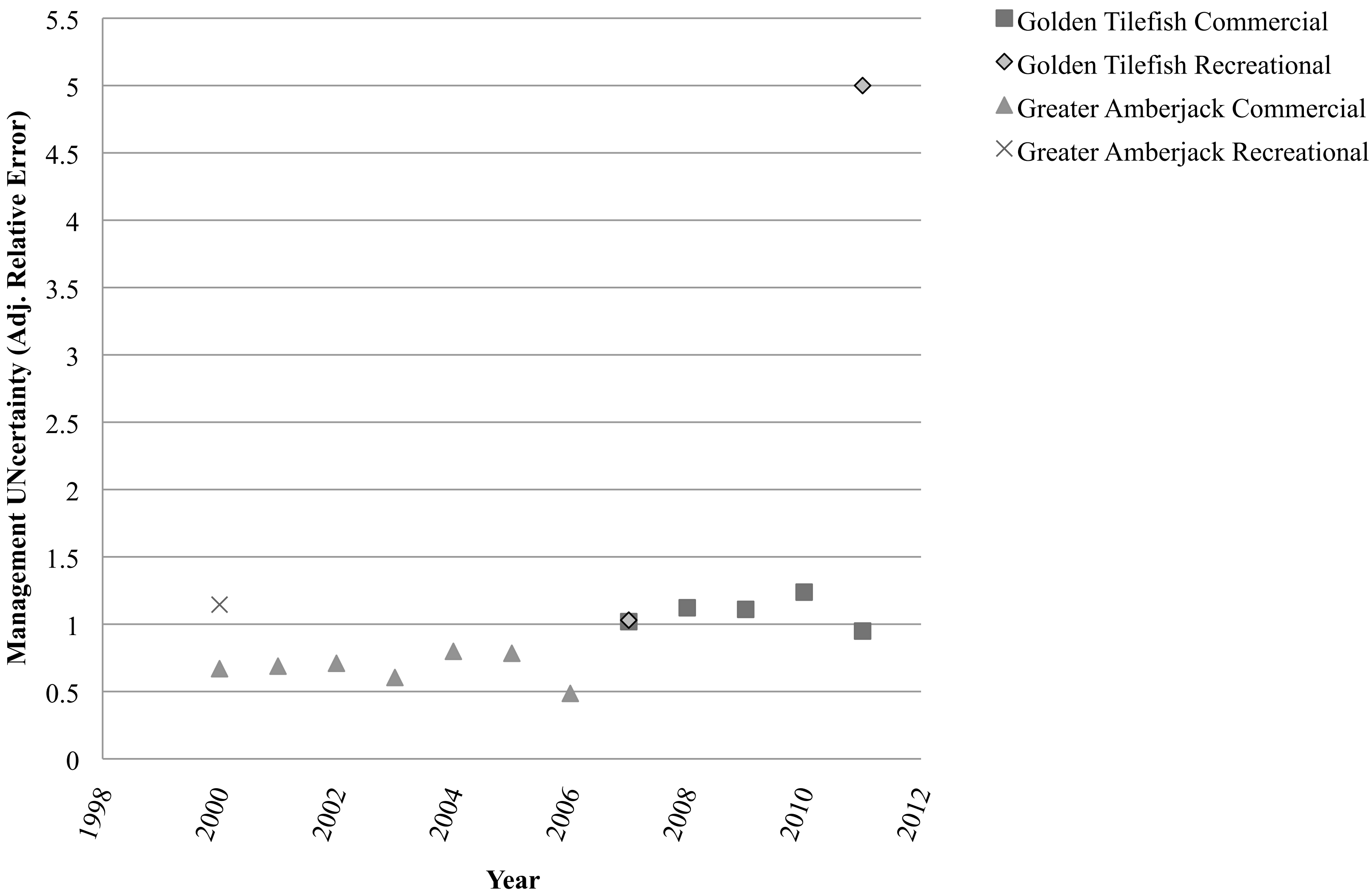

Figure 8. Historic management uncertainty, as an adjusted relative error, for commercial and recreational golden tilefish and commercial and recreational greater amberjack in the U.S. South Atlantic region (assuming a fishing pressure based strategy).

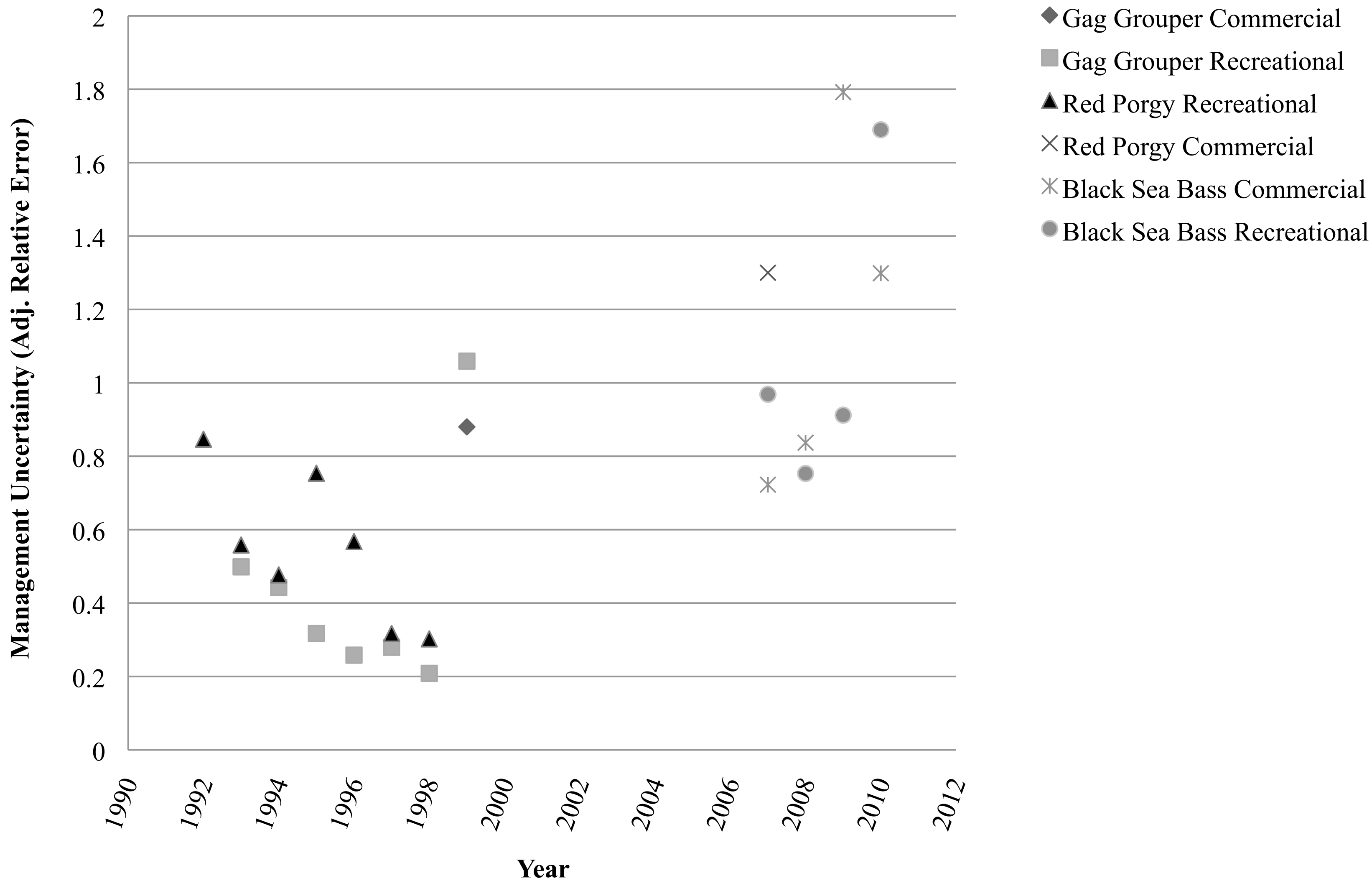

Figure 9. Historic management uncertainty, as an adjusted relative error, for commercial and recreational gag, commercial and recreational red porgy, and commercial and recreational black sea bass in the U.S. South Atlantic region (assuming a fishing pressure based strategy).

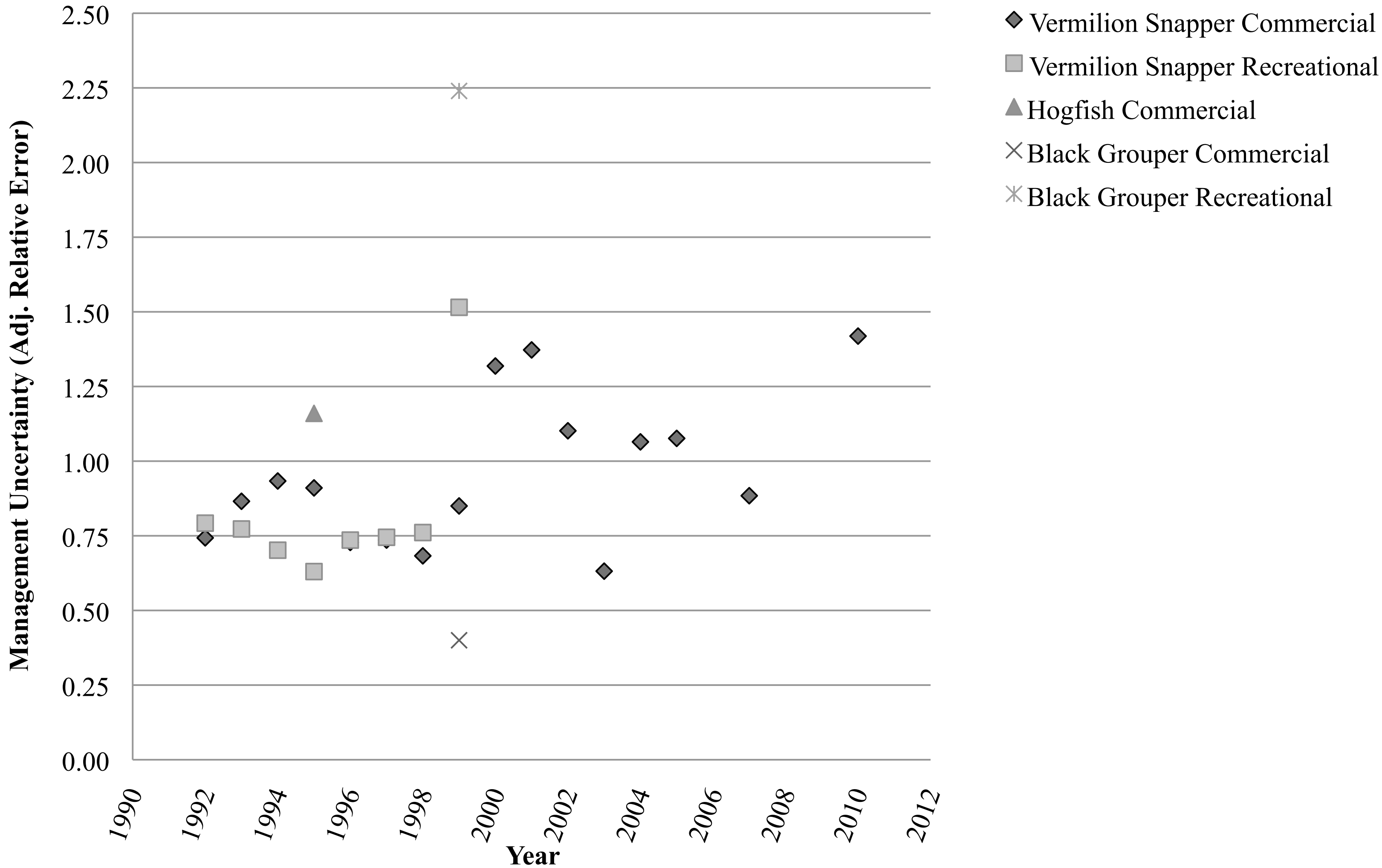

Figure 10. Historic management uncertainty, as an adjusted relative error, for commercial and recreational vermilion snapper, commercial and recreational black grouper, and commercial hogfish in the U.S. South Atlantic region (assuming a fishing pressure based strategy).

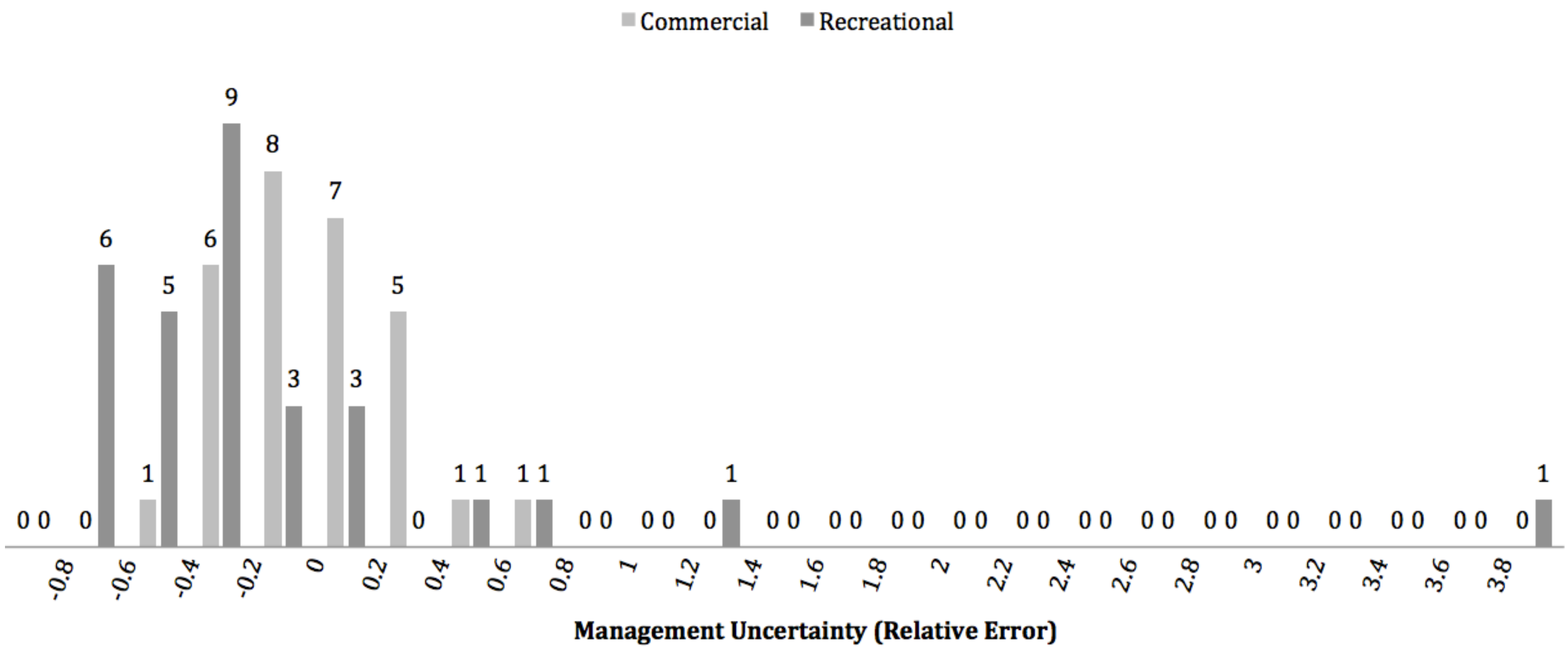

Figure 11. Distribution of management uncertainty, expressed as relative error, between commercial and recreational sectors of South Atlantic stocks, assuming a fishing-pressure based management strategy. Each bar represents the number of data points that fell between the presented levels of management uncertainty (e.g. 6 commercial and 9 recreational data points fell between -0.2 and 0). The minimum value is -1.0 while 4.2 is the maximum value.

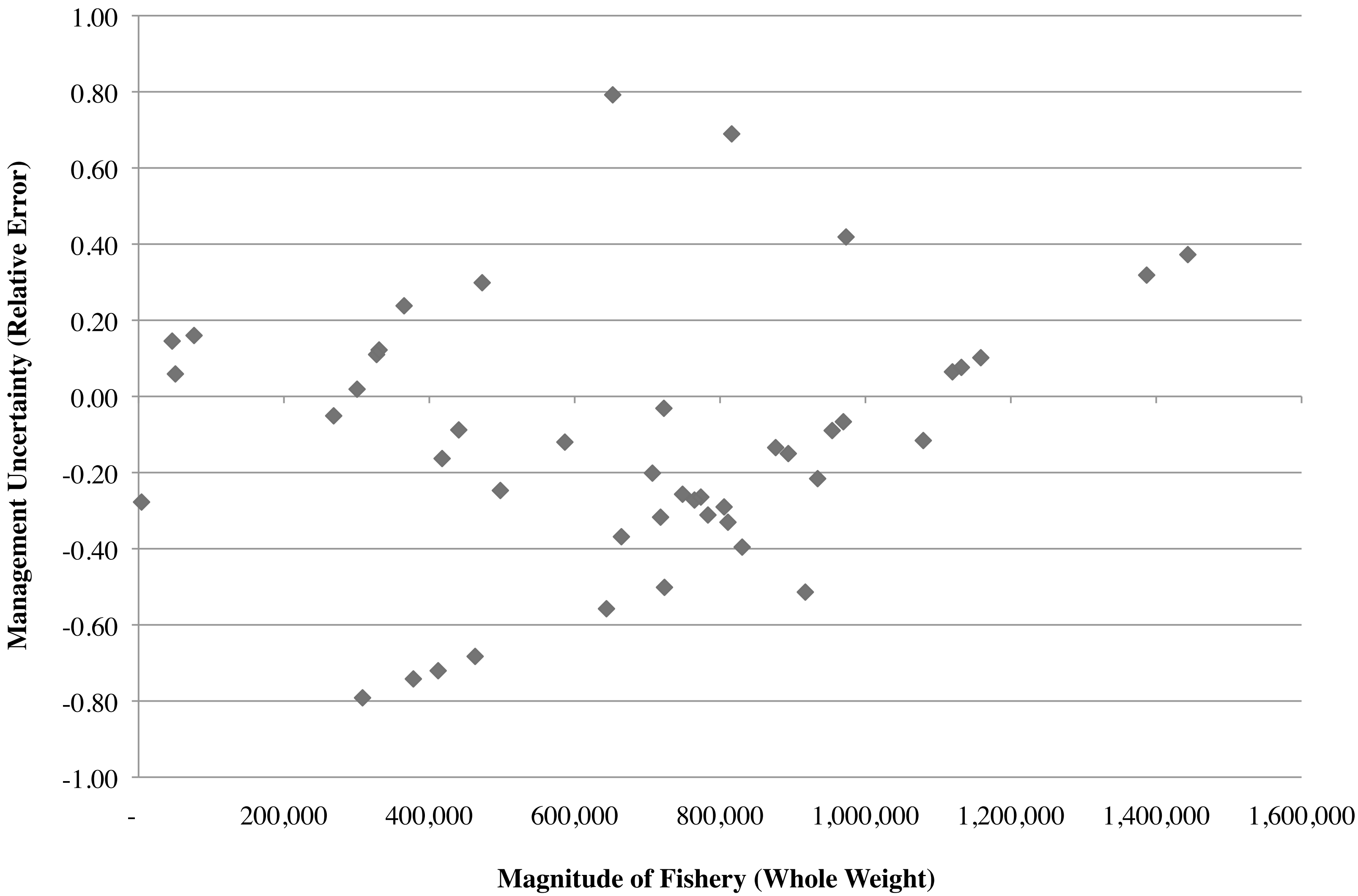

Figure 12. Relationship between magnitude of fishery (given in whole weight of landings) and management uncertainty (as a relative error), assuming a fishing pressure based management strategy. The relationship between the variables was not significant (r^2=0.027, P=0.271, α=0.05).

Chapter 3: Content Analysis of Management Documents in the South Atlantic United States

Introduction

The inherent complexity of the fisheries management process requires the coordination of a large number of individuals – from resource users to appointed managers, from stock assessment scientists to regulatory enforcers – to identify, implement, and enforce effective regulatory measures that ensure overfishing does not occur. Throughout the process, information must be transferred between these groups in a manner that is both clear and transparent. One part of this information flow, however, seems to have historically been lacking: describing the *intent* behind these regulations. That is, while managers have been clear about listing the regulatory mechanism suggested for a particular fishery and biological benefits a proposed regulation might provide, little information has been recorded detailing what the specific regulatory goal was in terms of impact on harvest (the degree to which it was expected to increase, maintain, or decrease landings).

The aim of this study was to evaluate the degree to which information content inclusion in fisheries data sources has varied over time. Specifically of interest was the degree to which information was recorded about the regulations intended impact on landings. This information is critically important when attempting to estimate the management uncertainty associated with a stock in order to determine the degree to which the goal of a management action is met in the real world (Prager and Rosenberg 2008). Unless the methods, data sources, and harvest estimations related to the intent of regulations are clearly listed and described in management documents, it is impossible to review and verify the accuracy of the predictions or discover opportunities for improved estimation methodology.

Through recent work on estimating the management uncertainty associated with stocks in the South Atlantic region of the United States (Chapter 2), an evaluation was made of the information contained in historical management documents. In order to determine regulatory intent, a prediction must be made to figure out what impact the regulation is expected to have on landings. This estimation should draw on an existing data source, such as the landings data recorded in a previous year. The management documents associated with each regulation that was put into place were analyzed for evidence of this estimation procedure, clearly described data, and, of course, for the output of the estimation procedure (i.e., the regulatory intent). This evaluation was further developed by categorizing the repeatability of the information, to determine where gaps may have existed in the past and to see if there has been an improvement in content inclusion over time.

Methods

Data for this study were gathered from a review of historic management documents relating to fisheries in the U.S. South Atlantic region, which includes federally controlled waters from the northern border of North Carolina to the southernmost tip of Florida (SAFMC 2011). The stocks evaluated here were chosen based on their suitability for the management uncertainty study, addressed in Chapter 2. The criteria for inclusion included a clear regulatory history, evidence of regulatory intent, and updated post-season landings data. Eight stocks were analyzed: black grouper (*Mycteroperca bonaci*), black sea bass (*Centropristis striata*), gag (*Mycteroperca microlepis*), golden tilefish (*Lopholatilus chamaeleonticeps*), greater amberjack (*Seriola dumerili*), hogfish (*Lachnolaimus maximus*), red porgy (*Pagrus pagrus*), and vermilion snapper (*Rhomboplites aurorubens*).

The primary data sources for this study were the original Fisheries Management Plan (FMP), which was established by the South Atlantic Fisheries Management Council (SAFMC) in 1983, and the subsequent updates (amendments) to the original FMP (SAFMC 1983). The FMP established regulations for 60 snapper-grouper species found in South Atlantic waters and addressed the status of many of the stocks. The amendments passed since the FMP have generally updated the status of a stock and changed or modified the regulatory mechanism in place for that stock. Due to resource constraints (e.g., data, human resources, time, budgets), assessments of stock status and amendments to regulatory mechanisms are generally not done on an annual basis, but rather several years apart, depending on the stock's importance to the region. In addition to the FMP and the FMP amendments, technical papers and stock assessment documents were also reviewed to determine whether they contained additional information about the harvest intent behind regulatory actions.

Once the documents had been reviewed, the regulatory history of each selected stock was broken down into discrete management actions. Each regulation that had been put into place for a particular stock was considered a regulatory data point. Each of the regulatory data points was then evaluated on the presence or absence of three discrete items: a regulatory intent expressed as a change or maintenance of catch or landings; an estimation procedure detailing how that intended catch was calculated; and the source of the data used in the estimation procedure (Table 1). While the presence of the intended catch was of the highest interest, evaluating the process used to develop the intent is not possible without a clearly described estimation procedure and a clearly listed source of the data used in that estimation procedure.

Additionally, each of the three categories (estimation procedure, data sources, or intent) could be further characterized as repeatable or unrepeatable. For example, a data source that listed the specific year and database from which the data were gathered (such as 1995 commercial landings data) would be considered repeatable, because it would be possible to gather the same data today that were used in the original assessment. In contrast, a description of the data stated solely as "historic landings" would be considered unrepeatable, because there is no clear information about precisely what information was used. In terms of the estimation procedure, a detailed methodology outlining each step used in the process would be considered repeatable. The presence of a sole graph demonstrating size class distribution (cited as the estimation procedure) would be considered unrepeatable because it would not be possible to re-do the estimation with just this information. The *overall* assessment of the intent behind a regulation is only repeatable if both the estimation procedure and the data sources are repeatable, and the intended catch is provided for comparison.

Once each data point was evaluated for the presence of the three items of interest, we cataloged each according to the following rubric:

0: No information on estimation procedure, data sources, or intent

1: Intent provided, no information on estimation procedure or data sources

2: Intent and estimation procedure provided, or intent and data sources provided

3: Estimation procedure, data sources, and intent all provided

This rubric allows for a comparison of the quality of the data points over time. Higher numbers correspond to better information, while lower numbers reveal a lack of data.

Results

In general, the trend over time of information content available in management documents was positive. Overall, 47 data points were categorized over three decades of available regulatory data and revealed a clear trend of increasing information content (Figure 1).

When the original FMP was passed in 1983, the majority of the stocks analyzed had no clearly described regulatory intent behind their management actions in terms of harvest reductions, and there was no description of estimation procedure or data sources for any of the stocks. By 2011, 50% of the data points analyzed had clear regulatory intent and either evidence of an estimation procedure *or* a data source, while the other half displayed all three of the evaluated categories. The trend over time is clearly evident when the frequency of the information content in each data point is compared between the historic (1983-1998) and current (1999-2011) time series (Figure 2). A statistical test, such as a chi-squared test, was not possible due to the presence of zero count categories.

Both the commercial and the recreational sectors of the fisheries evaluated displayed the same overall trend (Figure 3). As the commercial and recreational fisheries of a single stock tend to be assessed at the same time, there appears to be a close association between the information provided about each sector for each time period.

Discussion

It is clear from the data analyzed that reporting methods in intended fisheries calculations have improved. Although estimates of impacts of regulations were generally provided in earlier management documents, there was essentially no description of the methods used to get to those estimates or of the data that were input into the estimators. When information was provided on estimation techniques, it was generally extremely vague and the lack of data made it impossible to repeat. Over time, the inclusion of data sources was the first part of the process to show clear improvement. Although methodology was still seriously lacking, management documents began to show evidence of data sources (such as a particular year in which a data set was used or the name of the individual who conducted the estimation).

In terms of the repeatability associated with the data points, there was a wide range of detail provided (described below). For example, in the original FMP, the stock status of black sea bass was evaluated and an attempt was made to determine the effect of an 8-inch size limit on the fishery (SAFMC 1983). The methodology used was an "internal rate of return analysis" which is no longer in use today. In fact, there is so little information provided on this rate of return analysis that it is impossible to replicate the estimation today and calculate the intended landings (personal communication, NMFS, Jack McGovern).

Another example of the lack of detail found in the data concerns golden tilefish (SAFMC 1993). In 1993, Amendment 6 to the FMP aggregated all tilefish species in with the existing grouper bag limit of 5 fish. Although this was expected to produce a reduction in harvest, and although the text indicates that a bag limit analysis could be done to estimate the degree of reduction, such an analysis was either never performed, or performed but never recorded.

A similar difficulty was identified in the 1994 hogfish data – although estimations were performed based on the data collected by the Marine Recreational Fishing Statistical Survey (MRFSS) and on the data collected from headboats (private charter fishing) individually, no comprehensive assessment was ever done for the overall recreational fishery (SAFMC 1994).

Since the 12-inch minimum size limit was implemented for the entire recreational fishery, it is not possible to directly compare the predictions made.

These examples demonstrate instances where the information content recorded in management documents has been lacking. Although they may seem insignificant individually, collectively they represent a problem now shown to be chronic in historic regulatory documents. A fundamental component of fisheries management is the prediction of the effects that regulations will have on particular stocks as well as individuals dependent upon those stocks. In all cases, the biological, economic, social, and economic impacts of regulations are always analyzed, as this is a requirement of the National Environmental Policy Act. However, predictions on changes in the harvest associated with those regulations are not always provided. In some cases, it may not have been possible to estimate the effect of a management measure as the intent might have been oriented more towards conservation goals rather than a target reduction in harvest (i.e., a prohibition on anchoring in the Oculina Habitat of Particular Concern). Since fisheries management is such a complicated and difficult process, ensuring that the success of past management predictions can be evaluated is critical to improving the ability to make estimates of management uncertainty in the future. Unless detailed and meticulous records concerning the procedures used to estimate harvest changes associated with proposed management measures, it is impossible to verify the accuracy of harvest predictions.

One key benefit of the recent reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act (MSA; Magnuson-Steven Act) is the inclusion of annual catch limits (ACLs) in future management actions (MSA 2006). These ACLs represent the greatest amount of catch that can be taken in a particular year, and essentially function now as pre-season estimates of our intended catch. The intent of the Magnuson-Stevens Act is to adjust ACLs or annual catch targets for management uncertainty to help ensure overfishing does not occur. As long as ACLs are in place we will be able to use them to directly and efficiently estimate the management uncertainty associated with a particular stock. However, as there is no guarantee that the next wave of changes to the Magnuson-Stevens Act will continue to require the inclusion of ACLs, it is critical that we continue to include our estimation procedure, data sources, and the intended consequences of our management actions in a manner that is both transparent and repeatable.

Conclusions

The degree to which information on the intended impacts of regulations has been included in management documents has varied greatly over time. Since fisheries management began in the U.S. South Atlantic region there has been continuous improvement in the degree to which management documents have listed the estimation procedures, data sources, and regulatory intents of regulations. The presence of this information is critical to the estimation of management uncertainty and to ensure that the estimation techniques used in predictions are accurate and precise. Without these data, it is difficult for managers to assess the historical success rate of regulatory actions and ensure that targets will be met in the future. Although recent legislative actions have made it more likely that this information will be reported, uncertainty about future changes to federal law make it imperative that stock assessment scientists and managers are aware of the need to include these data in future management documents.

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Table 1. Regulatory history tables for recreational and commercial vermilion snapper used to evaluate information content found in South Atlantic Fisheries Management Council documents, including evidence of regulatory intent, estimation methodologies, data sources, and references.

Vermillion Snapper – Recreational

Year	Regulation	Estimate	Methodology	Data/Method Source	Reference
1983	12 inch size limit	Not explicit	Not explicit	Not explicit	FMP; Final Rule FR: 48 FR 39463
1991	10 inch total length + 10 fish bag limit	Not explicit	Not explicit	Not explicit	Amendment 4. Final rule published October 31, 1991. 56 FR 56016
1998	11 inch total length	Combined recreational catch would be reduced by 34% in numbers of fish in the first year.	Not explicit	Bob Dixon, NMFS Beaufort Lab; 1995 Commercial, Headboat and MRFSS Data	Amendment 9, pg 130, table 42. Final rule published January 25, 1999. FR: 64 FR 3624
2006	12 inch total length	20.5% reduction based on data from 1999-2003 and a 19.6% reduction based on data from 1999-2001	"Method of Modeling Management Alternatives", A-13C, pg 10-29	See Appendix of A-13C, pg 10-17, table C-3 through C-6	Amendment 13C. Final rule published September 21, 2006. FR: 71 FR 55096

Vermillion Snapper – Commercial

Year	Regulation	Estimate	Methodology	Data/Method Source	Reference
1983	12 inch size limit (accomplished with a 4 inch mesh size trawl)	projected landings = 27617 pounds	Not explicit	Not explicit	FMP; Final Rule FR: 48 FR 39463
1991	Prohibit fish traps, entanglement nets, & longlines within 50 fathoms; 12" minimum size limit; vessel permit	Expected commercial landings with 12" minimum size limit is 1,007,100 lbs relative to the total landings 1,007,900 lbs (0.3%); pdf page 226.	Not explicit	Not explicit	Amendment 4. Final rule published October 31, 1991. 56 FR 56016
2006	Establish an annual commercial quota of 1,100,000 lbs gw (1,221,000 lbs ww)	20.5% reduction based on data from 1999-2003 and a 19.6% reduction based on data from 1999-2001 (1,100,000 lbs gw)	See "Method of Modeling Management Alternatives", A-13C, pg 10-29	See Appendix of A-13C, pg 10-17, table C-3 through C-6	Amendment 13C. Final rule published September 21, 2006. FR: 71 FR 55096

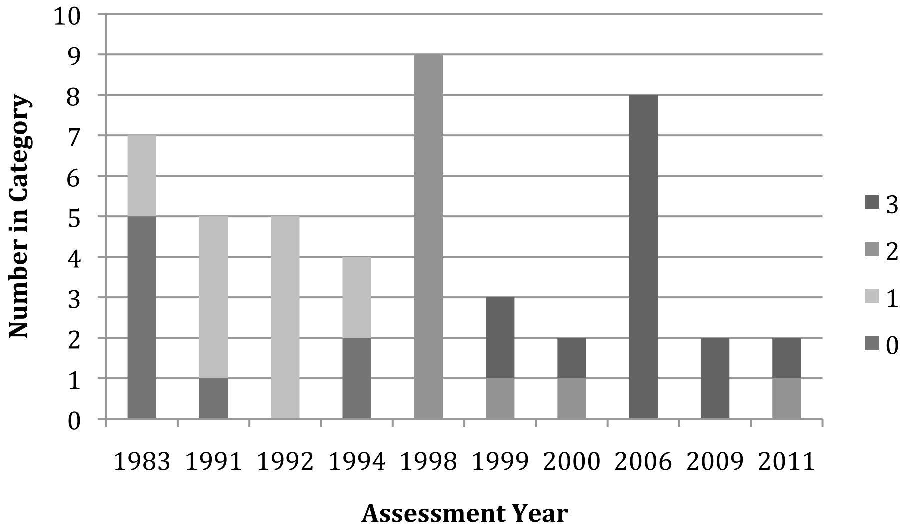

Figure 1. South Atlantic Fisheries Management Council snapper-grouper amendments by year, categorized by information content. A 0 indicates no information provided on regulatory intent, estimation procedure, or data source, a 1 indicates that information was available on regulatory intent, but not on estimation procedure or data source, a 2 indicates that information was available on regulatory intent and on estimation or data, and a 3 indicates information was provided in all categories to a repeatable degree.

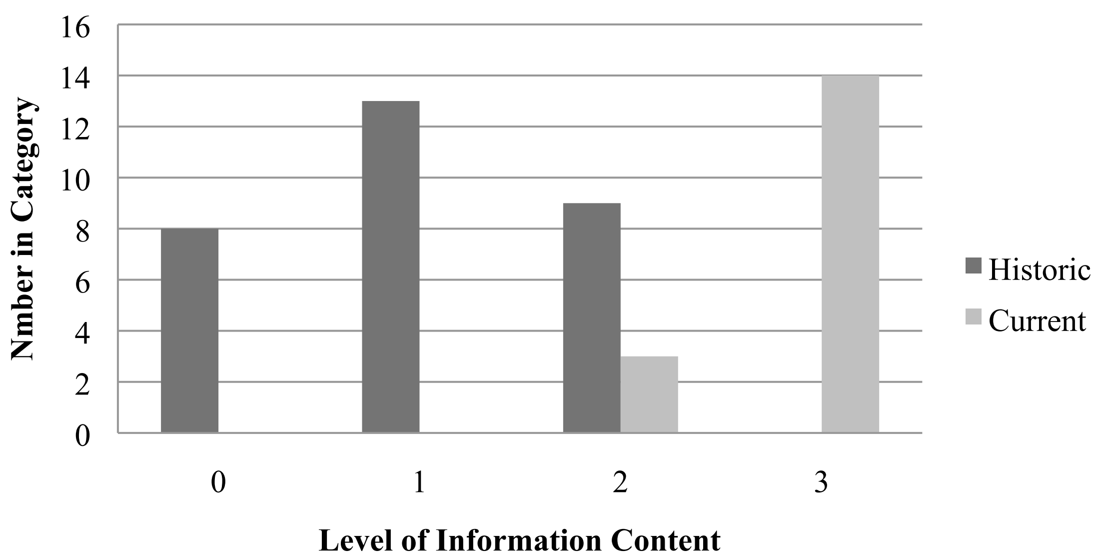

Figure 2. Frequency of information content level in South Atlantic Fisheries Management Council snapper-grouper amendments in historic (<1998) and current (>1999) categories. A 0 indicates no information provided on regulatory intent, estimation procedure, or data source, a 1 indicates that information was available on regulatory intent, but not on estimation procedure or data source, a 2 indicates that information was available on regulatory intent and on estimation or data, and a 3 indicates information was provided in all categories to a repeatable degree.

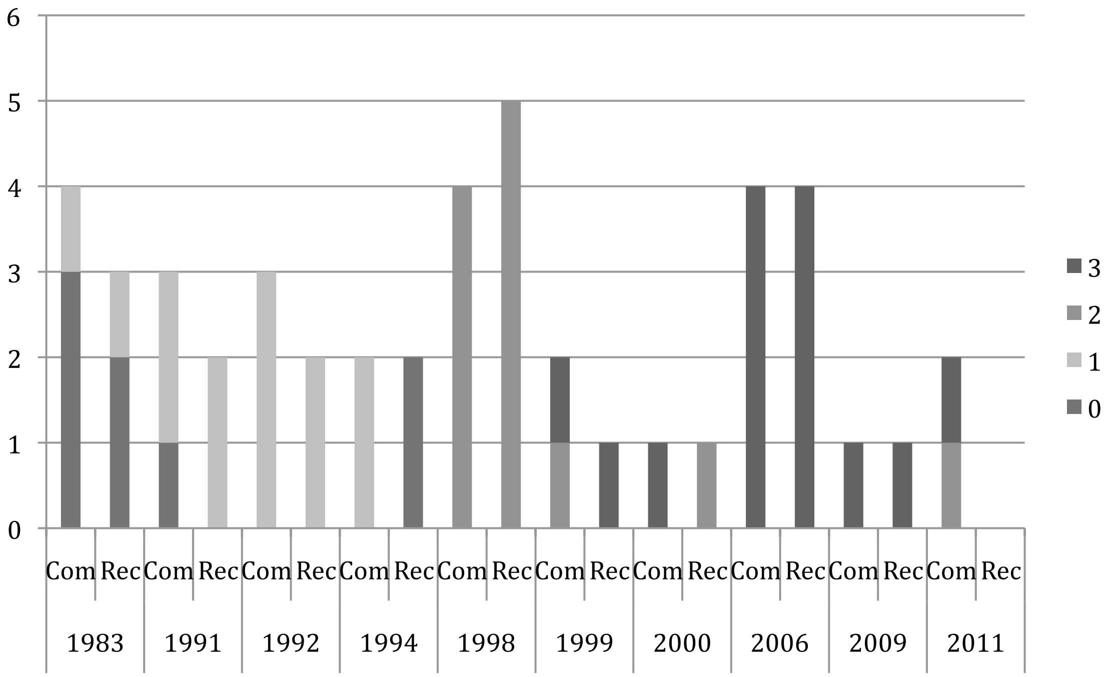

Figure 3. South Atlantic Fisheries Management Council snapper-grouper amendments by year and by sector, categorized by information content. A 0 indicates no information provided on regulatory intent, estimation procedure, or data source, a 1 indicates that information was available on regulatory intent, but not on estimation procedure or data source, a 2 indicates that information was available on regulatory intent and on estimation or data, and a 3 indicates information was provided in all categories to a repeatable degree.

Appendix A: Case Studies

Golden Tilefish

Golden tilefish (*Lopholatilus chamaeleonticeps*) are found along the western coast of the Atlantic, ranging primarily from Massachusetts to the Gulf of Mexico. Preferring deeper waters, the species is generally found at depths of 250 feet or greater, generally on sandy or muddy seafloors. The species is quite long lived, with individuals thought to occasionally reach 50 years in age, and they can grow up to almost 4 feet in length. Studies conducted by Harris et al. (2001), and Lombardi et al. (2011) concluded golden tilefish were likely gonochorists (separate sexes). However, in a Gulf of Mexico study, Lombardi et al. (2011) found evidence of possible sex change in golden tilefish with males and females possessing reproductive tissue of the opposite sex. Considering the larger size at age in males and the increasing proportion of males with increasing age, protogynous hermaphroditism is possible (Fishwatch 2012a).

Management of golden tilefish in the South Atlantic began in earnest in 1994, when Amendment 6 to the Fishery Management Plan for the Snapper-Grouper Fishery of the South Atlantic Region (FMP) included the species in the recreational aggregate bag limit, created a commercial quota, established a commercial trip limit, and established a trip bycatch limit. The commercial sector was further regulated in 1998, when the final rule for Amendment 8 to the FMP instituted a limited entry program involving transferable and non-transferable permits. The next major management changes occurred in 2006, when a stock assessment determined that the species was subject to overfishing (SEDAR 4 2004). To end overfishing, the commercial quota and trip limit were both reduced, and the recreational bag limit was reduced to 1 per person per day through Amendment 13C to the FMP. In 2011, Amendment 17B to the FMP slightly increased the allocation to the recreational sector by 2% and, correspondingly, slightly reduced the quota set for the commercial sector, and established a recreational ACL. A new stock assessment conducted in 2012 indicated the stock was no longer undergoing overfishing (SEDAR 25 2011). In 2012, Regulatory Amendment 12 to the FMP increased the commercial quota by 258,476 lbs. and the recreational ACL by 1,513 fish. Management measures are being considered to establish an endorsement program for the commercial longline sector and adjust commercial trip limits through Amendment 18B to the FMP.

The management uncertainty for recreational golden tilefish, under method 1, includes the second highest outliers of the data set, with the uncertainty for the stock ranging from 103% to 500% (Figure 4). Under method 2, the data point that produces a management uncertainty of 500% is still included (Figure 8). The most likely reason for this high level of management uncertainty is the inherent variability in recreational data from the MRFSS program, and the very small magnitude of the recreational landings. MRFSS, which was replaced by the Marine Recreational Information Program (MRIP) in 2012, is a random survey approach that collects data through dockside interviews and telephone calls. In 2011, the recreational ACL for golden tilefish was only 1,578 fish – just a fraction (3%) of the overall allowable catch for the species. Such a small fishery is particularly vulnerable to the sampling issues in the MRFSS program. As MRFSS/MRIP is a survey that does not capture all the recreational landings, rare or infrequent encounters with a species will provide very imprecise estimates of landings. Therefore, large or small over-predictions of actual catch would not be unexpected. These data indicate it is difficult to estimated management uncertainty for small, recreational fisheries because the issues with sampling methodology may lead to imprecise estimations of actual landings. Additionally, a difference of only a few fish results in a greater change in management uncertainty with a small fishery than it would with a large fishery.

Vermilion Snapper

Vermilion snapper (*Rhomboplites aurorubens*) are distributed along the western coast of the Atlantic, ranging from Cape Hatteras, North Carolina to Brazil. The species is generally found in reef-like bottom habitats at depths of 80-350 feet. Adults can grow to lengths of up to 24 inches and weigh up to 7 pounds, but reach sexual maturity at just 8 inches. Vermilion snapper can live as long as 15 years. (Cuellar et al. 1996, Zhao et al. 1997, Fishwatch 2012b, SAFMC 2012a)

Management of vermilion snapper in the South Atlantic began with the original FMP in 1983, when a 4-inch mesh size trawl limit was put into place (designed to create a 12-inch size limit for the stock). In 1991, a 10-inch total length minimum size limit (commercial and recreational) and a 10 fish per person per day recreational bag limit were put into place to regulate catch through

Amendment 4 to the FMP. The amendment additionally prohibited commercial fish traps to preserve habitat integrity and prevent ghost fishing. The recreational size limit was changed in 1998, when Amendment 9 to the FMP increased the vermilion snapper recreational minimum size limit to 11-inches total length. The next major change came with Amendment 13C to FMP, which increased the recreational minimum size limit to 12-inches total length and established an annual commercial quota. These actions were done in response to a 2003 stock assessment, which indicated the stock was experiencing overfishing (SEDAR 2 2003). In response to new stock assessments (SEDAR 2 Update 2007 and SEDAR 17 2008), which indicated overfishing had not been ended, Amendment 16 to the FMP in 2009 further reduced the commercial quota, and divided it into two seasons (January-June and July-December). For the recreational sector, Amendment 16 to the FMP established a seasonal closure (November through March), reduced the 10 fish bag limit to 5 fish per person per day, and prohibited captain and crew from retaining vermilion snapper on for-hire trips. In 2011, Amendment 17B to the FMP established recreational ACLs and AMs for vermilion snapper, and recognized the commercial quota and inseason closure as an ACL and AM, respectively. Also in 2011, Regulatory Amendment 9 to the FMP established a commercial trip limit for vermilion snapper. A new stock assessment completed in 2012, indicated vermilion snapper was not experiencing overfishing and was not overfished (SEDAR 17 Update 2012).

The recreational sector of vermilion snapper is especially interesting due to the clear demonstration of the impact of regulatory action on management uncertainty. After the management measures specified in Amendment 4 of the FMP were implemented, management uncertainty for the stock hovered around 80% throughout the 1990s (Figure 3, Figure 10). When the recreational minimum size limit was increased through Amendment 9 to the FMP, the next season's management uncertainty jumped to approximately 150% (regardless of the assumptions of method 1 or method 2). Landings themselves did not rise considerably, but relative to the desired landings, actual landings were considerably higher than in all past cases. The increase in the management uncertainty after implementation of the recreational minimum size limit in Amendment 9 to the FMP suggests the management measures was unable to constrain catch to desired levels. With minimum size limits, the expected effect would be a decrease in harvest in the year following the management measure (as fish below that size limit could no longer be legally retained). However, if biomass increases in response to the management measure, landings may increase in subsequent years despite the presence of the minimum size limit. The lack of a decrease in landings in the year following the implementation of a minimum size limit could be the result of many factors including enhanced recruitment, increased fishing pressure, and non-compliance with the management measure.

Gag

Gag (*Mycteroperca microlepis*) are found in the western Atlantic from North Carolina to Brazil. The species prefers the rocky bottom habitat (up to 500 feet), and use inshore estuarine areas as a nursery during the first year of their life. Adult gag can reach a length of 4.75 feet and weigh approximately 37 kilograms. They are protogynous hermaphrodites, beginning life as females, and undergo transition to males at around 8 years. The maximum-recorded lifespan for gag is 26 years (McGovern et al. 1998, Bester 2012, SAFMC 2012b).

A 20-inch minimum size limit was first instituted for gag in 1991, under Amendment 4 to the FMP, along with an aggregate grouper bag limit of 5 fish per person, per day. In 1998, under Amendment 8 to the FMP, a limited entry program was put in place for the commercial sector, creating both transferable and non-transferable permits. The same year, under Amendment 9 to the FMP, the minimum size limit was increased to 24 inches total length, a March-April spawning season closure was established, and the recreational bag limit was reduced to 2 gag within the 5 grouper aggregate bag limit. In response to SEDAR 10 (2006), which indicated gag was experiencing overfishing and approaching an overfished condition, Amendment 16 to the FMP created a commercial quota, closed the commercial and recreational sectors during the January-April spawning season, lowered the bag limit to 1 gag or 1 black grouper per day within a 3 grouper aggregate bag limit, and prohibited the captain and crew of a for-hire recreational vessel from possessing gag and other species within the grouper aggregate. In 2011, Amendment 17B to the FMP established recreational ACLs and AMs for gag for the first time, and recognized the commercial quota and inseason closure as an ACL and AM, respectively. Also in 2011, the final rule for Regulatory Amendment 9 to the FMP implemented a commercial trip limit for gag.

Similar to recreational vermilion snapper, recreational gag also demonstrated a clear change in management uncertainty after the implementation of a new regulation. In the years after Amendment 4 to the FMP was put into place, the management uncertainty of recreational gag ranged from 50% to 20%, some of the lowest values found in the study (Figure 2, Figure 9). When the minimum size and bag limits in Amendment 9 to the FMP were implemented, the management uncertainty associated with gag rose to 106%. Although, the magnitude of management uncertainty was small, it was the first time the uncertainty associated with gag had exceeded 100%. One likely explanation is new management measures were not constraining catch, and the desired landings under Amendment 4 to the FMP were much larger than the desired landings under Amendment 9 to the FMP. Since the overall landings target had been reduced, exceeding that threshold was more likely.

Black Grouper

Black grouper (*Mycteroperca bonaci*) are found in the western Atlantic from Massachusetts to southern Brazil. Juveniles occur off the coast of Florida in seagrass beds, but adults prefer rocky or coral environments in depths ranging from 19-108 feet. Maximum age for the species is thought to be greater than 30 years, at a size of 52 inches and a weight of up to 80 kilograms. Like gag, black grouper are protogynous (Crabtree and Bullock 1998, Ford 2012).

The management history of black grouper is similar to gag, beginning with the implementation of a 20-inch size limit under Amendment 4 to the FMP, in 1991, which was changed to a 24-inch size limit under Amendment 9 to the FMP, in 1998. The bag limits and spawning season closures for black grouper have also mirrored those for gag. Amendment 16 to the FMP closed the commercial and recreational sectors for black grouper and other shallow water grouper during the January-April spawning season, lowered the bag limit to 1 gag or 1 black grouper per day within a 3 grouper aggregate bag limit, and prohibited the captain and crew of a for-hire recreational vessel from possessing gag and other species within the grouper aggregate. In 2011, Amendment 17B to the FMP established aggregate black grouper, red grouper, and gag recreational and commercial ACLs and AMs. In 2012, the Comprehensive ACL Amendment established individual ACLs and AMs for black grouper in the recreational and commercial sectors. SEDAR 19 (2010) indicated black grouper was no longer experiencing overfishing and the stock was not overfished.

Recreational black grouper displayed some of the highest levels of management uncertainty of any stock, regardless of whether method 1 or method 2 was used for the estimation (Figure 4, Figure 10). This may primarily be a result of the fact that the management uncertainty estimation focused solely on the headboat sector, rather than the entire recreational sector, because the estimation of intended catch under Amendment 9 to the FMP only addressed the impact to headboat operators. As headboats make up a small portion of the overall recreational fishery, even small overages or underages are reflected by large changes in management uncertainty. If pre-season landing estimates had been available for the entire black grouper recreational sector, it is possibly the magnitude of management uncertainty would have been much lower.

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