CONSEQUENCES OF THE PRECAUTIONARY APPROACH IN THE MADISON SWANSON MARINE PROTECTED AREA

by

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Abstract

The Madison Swanson Marine Protected Area was established to protect gag grouper, *Mycteroperca microlepis,* spawning aggregations on high relief, deepwater habitat in the Gulf of Mexico. Fishery biologists observed a decline in the proportion of male individuals in the population. The decline led fishery managers to question the reproductive health of the gag grouper population. However, competing theories on gag grouper ecology led to divergent views on the best management policy for gag grouper protection. In the end, fishery managers chose to use the precautionary approach to implement an MPA to protect gag grouper spawning aggregations. In this case, the precautionary approach had consequences that should be considered when managing fisheries in the future. I investigated the pertinent literature and participated in NOAA research within the MPA in the summer of 2006.

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Acronyms

CCA	Coastal Conservation Association
EEZ	Economic Exclusive Zone
FMP	Fishery Management Plan
GMFMC	Gulf of Mexico Fishery Management Council
MPA	Marine Protected Area
MSY	Maximum Sustainable Yield
NMFS	National Marine Fisheries Service
NOAA	NOAA Fisheries Service
RFSAP	Reef Fish Stock Assessment Panel
SEDAR	Southeast Data, Assessment and Review
SHU	Standard Habitat Unit
SPR	Spawning Potential Ratio
SSB	Spawning Stock Biomass
TOC	The Ocean Conservancy
USCG	United States Coast Guard

Introduction

The gag grouper, *Mycteroperca microlepis*, is found in the waters from Brazil to New England with a center of distribution in the eastern Gulf of Mexico. Gag grouper is a large, long-lived reef fish; some males live greater than 30 years and reach 80 pounds. The species is a protogynous hermaphrodite, beginning its life as a female and later transforming into a male. The long-lived life cycle and protogynous reproductive habits make it difficult for the gag grouper population to recover from the effects of overfishing and difficult to formulate the most effective management strategies for gag grouper in the Gulf of Mexico.

The Gulf of Mexico Fishery Management Council (Council) is charged with implementing fishery management plans to ensure that species in the Gulf of Mexico do not become overfished. In 1999, the gag grouper stock was approaching an overfished condition [1]. Scientists observed a drastic decline in the percentage of males in the total population, which led them to question the reproductive potential of the population. In an effort to reduce overfishing and protect spawning aggregations, the Council established the Madison Swanson Marine Protected Area (MPA) in the northeastern Gulf of Mexico.

In this report, I will discuss the precautionary approach, the history of the Madison Swanson MPA, the scientific support for the MPA, and the current status of gag grouper. Since the gag grouper has complex life-history and reproductive patterns, I will discuss three opposing theories on gag grouper ecology and the management implications of each theory. This critical analysis will determine what scientific justification is reflected in the MPA. Based on the competing theories and the overfished condition of gag grouper, I will discuss the role of the precautionary approach in fisheries management in the Gulf of Mexico. I will highlight the policy process and the costs involved when making a policy decision in the face of scientific uncertainty.

The Precautionary Approach

One way to deal with scientific uncertainty is the use of the precautionary approach. Most commonly, the precautionary approach urges managers to “exercise additional caution in favor of conservation in any case in which information is absent, uncertain, unreliable, or inadequate as to the effects of any existing or proposed action on fish, essential fish habitat, other marine species, and the marine ecosystem in which a fishery occurs;" and "selecting and implementing any action that will be significantly more likely than not to satisfy the conservation objectives" [2].

In an ideal world, fishery managers would be able to completely understand every aspect of a marine ecosystem and would be able to precisely control catches in a fishery to prevent overexploitation [3]. However, scientists find that it is increasingly difficult to understand the complexities of marine ecosystems. Thus, we are left with the best available science. Clark [3] believes that large scale marine protected areas may provide adequate protection for marine species when there is scientific uncertainty surrounding the overexploited stock.

Hilborn et al [4] believe that the precautionary approach could benefit fishery management if implemented and evaluated properly. They suggest that the precautionary approach could be useful, but its scope must extend beyond harvest controls. Specifically, Hilborn et al [4] recommend that the precautionary approach focus on "data collection, evaluation of the results of past management, response mechanisms to adjust management action as appropriate, effective enforcement of regulations, and a process that facilitates communication and fosters cooperation among the different sectors involved with and affected by management."

Lauck et al [5] studied various ways to implement the precautionary approach in fisheries management. The authors concede that the design and implementation of marine protected areas will depend on what is known about the biological and ecological characteristics of each species or species complex. In order to properly implement marine protected areas and the precautionary approach, the authors recommend [5]:

1. The area included in the reserve should be large enough to protect the resource in the event of overfishing in the unprotected area. Mathematical models suggest that reserves need to include up to 50% of the original population in order to hedge successfully against overfishing.
2. The reserve area should serve as a source capable of replenishing the exploited stock in the event of its depletion. In particular, the reserves should protect spawning grounds and other areas critical to the viability of the population.
3. The reserve area should be rigorously and completely protected. Typically, reserve areas will contain greater concentrations of fish than exploited areas, making them prime targets for poaching.

Fishery managers responsible for managing fish populations in the Gulf of Mexico observed a decrease in the proportion of males in the gag grouper population. In an effort to rebuild the population, the fishery managers chose to implement a marine protected area because scientific uncertainty surrounded certain aspects of gag grouper reproductive habits. I will analyze the consequences of the precautionary approach in this report specific to the Madison Swanson Marine Protected Area in the Gulf of Mexico. It is important to realize the breadth of the competing scientific information and the costs incurred as a result of the precautionary approach.

History of Madison Swanson Marine Protected Area

In July 1999, the Gulf Council established the Madison Swanson Marine Protected Area (MPA) in the northeastern Gulf of Mexico (Figure 1). The purpose of the MPA is protection of gag grouper spawning aggregations on high relief habitat that lies 200 to 400 feet below the water's surface. The area is approximately 50 miles south southeast of Panama City Beach, Florida and encompasses 100 square miles.

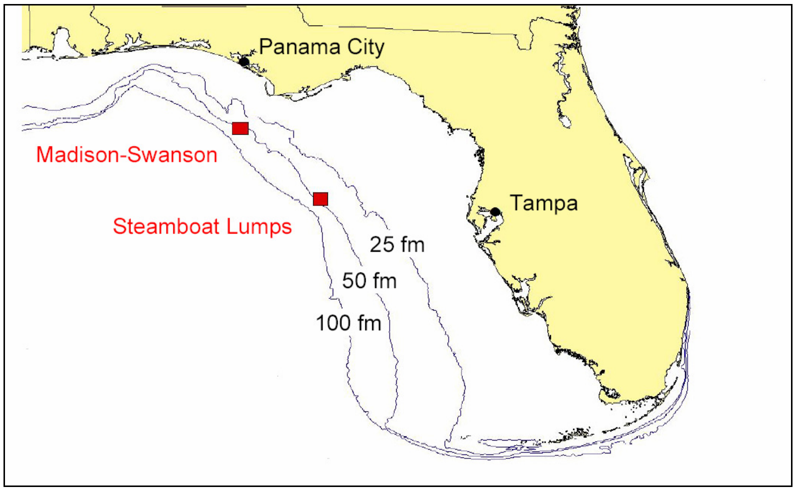

Figure 1: Madison Swanson and Steamboat Lumps Marine Protected Areas Map[1]

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[1] Source: http://www.nmfs.noaa.gov/habitat/ead/ecosysdocs/MadSwanPoster.pdf

Biologists were concerned about a substantial reduction in the proportion of males that had occurred in the Gulf population of gag grouper since the late 1970's. Archival data showed that historically the gag grouper population was 21% male while the 1999 population was only 2% male [6]. Historically, males comprised 17 percent of the commercial harvest, but in recent stock assessments they comprise from 2-10% of the harvest [7]. Although there has been no indication of declining recruitment, it is possible the current recruitment levels were lower than in years prior to the period covered by the stock assessment [8]. The scientists were particularly concerned that the proportion of males had been reduced to the point that females in the population might be unable to find a mate [9].

The establishment of the Madison Swanson MPA was also (in part) a response to the condition of the gag grouper stock's nearing an overfished condition. In August, 1998, the Reef Fish Stock Assessment Panel (RFSAP) reviewed a gag stock assessment prepared by NMFS in October 1997 [8, 9]. Based on this assessment and an overfishing and overfished threshold of 20% Spawning Potential Ratio (SPR)[2], the RFSAP concluded that gag stock was not considered to be overfished. However, the RFSAP warned that based on the SPR estimate, which is an estimate for fishing mortality rate, the fishery may be undergoing overfishing, The estimates of SPR for gag grouper ranged from 18 percent (overfishing occurring) to 23 percent (overfishing not occurring).

Box 1 describes the Gulf Council's definition and explanation of Spawning Potential Ratio. It is important to note the methods used to calculate SPR

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[2] See Box 1 for explanation of Spawning Potential Ratio

because it is used to determine the status of the stock.

Box 1: The Definitions and Implications of Spawning Potential Ratio (SPR)

Spawning potential ratio is an index of a population's health as measured by the biological ability of the adult fish to produce spawn or eggs. A particular level of SPR is directly dependent on the estimated number of living adult fish (or females) and their longevity, or number at age, which is controlled by the prevailing fishing mortality exerted on the population. Spawning potential can be measured as the average number of female fish alive times the average number of eggs spawned (or proxy such as gonad weight or total female fish biomass). The spawning potential thus measured, when divided by the spawning potential of a population in the absence of fishing mortality, produces the SPR estimate. An alternative way of measuring SPR is on a per-recruit basis, where a recruit is defined as a young of-the-year fish that has grown large enough to be sampled by juvenile sampling devices. The life expectancy of that recruit is determined by a combination of natural mortality, fishing mortality, and bycatch mortality. The average lifetime egg production is calculated based on that life expectancy and fecundity (or weight) at age, and is divided by the average lifetime egg production of a recruit that is subject only to natural mortality to determine the SPR.

Various measures of optimal fishing have been defined whereby fishing greater than the optimal level results in overfishing. For reasons set forth in Amendment 1, the measure of optimal fishing for reef fish was chosen to be a fishing mortality rate corresponding to 20 percent SPR, which was deemed to be the minimum SPR level at which stocks could safely maintain themselves under equilibrium conditions. Under the Sustainable Fisheries Act of 1996, future overfishing thresholds and optimum yield targets must be determined on the more conservative basis of maintaining stocks at levels capable of producing maximum sustainable yield (MSY). This does not mean that the MSY yield levels must actually be harvested, but that the stocks be at levels capable of producing that yield on a continuing basis. For most stocks, these levels are to occur when stocks are fished at fishing mortality rates corresponding to SPR levels of 30 to 40 percent.

Before discussing the different theories of reproductive behavior specific to gag grouper, it is important to consider the life history characteristics and community dynamics of long-lived reef fish such as gag grouper.

Life History Characteristics of Long-lived Reef Fish

Long-lived reef fish exhibit complex life history strategies, consisting of a planktonic larvae stage, a benthic juvenile stage and an adult stage. Larval dispersal, recruitment, and distribution play a collective role in the success or failure of the population viability. The life history of long-lived reef fish makes them particularly susceptible to overfishing because they are slow-growing and late-maturing. The effects of overfishing can cause changes in the life history and community dynamics of long-lived reef fish that result in a negative feedback response that hinders future exploitation. In the case of gag grouper, fishery scientists observed a decrease in the proportion of males, which led them question the reproductive success of the entire stock.

Generally, reef fish begin a development stage as planktonic larvae. This stage can last a week or as long as several months, depending on the species. During the planktonic larval stage, larvae generally are dispersed passively by wind, waves, and currents in the open ocean. Fish larvae experience high mortality in the larval stage due to unfavorable environmental conditions, lack of food resources, and predation [10]. Fisheries ecologists are unsure as to how and when the transition occurs between the planktonic larval stage and the benthic juvenile stage. Previously, many scientists contended that larvae arrive in the nursery grounds by chance [11]. However, Leis [12] recently discovered that larvae actively navigate to nursery areas in Lizard Island near Cairns, Australia. He found that larvae as small as few centimeters can propel themselves to specific benthic juvenile habitats, but it was unclear what cues larvae use to locate in a certain nursery area. Leis [12] speculated that at a local level, chemical and sound cues or differences in wave and wind direction might facilitate settlement of larvae in nursery habitats. On a larger scale, planktonic larvae may respond to changes in environmental conditions such as a rapid shift in water temperature.

During the benthic juvenile stage, reef fish inhabit inshore nursery habitats such as seagrass beds and oyster beds in shallow, high salinity water for approximately 5-6 months until they reach about 14-16 inches in size. Recruitment to inshore nursery habitats is linked to high levels of primary productivity on seagrass beds in the spring months of the year [13].

Most reef fish species grow slowly and are slow to reach reproductive maturity. Once juvenile reef fish have reached reproductive maturity, they migrate to offshore reefs and aggregate in large numbers at specific locations used as habitat and protection. As adults, reef fish focus less on growth and the majority of available energy is preferentially allocated towards reproduction. Reproductive habits are influenced by the seasons and changes in moon phases [11]. Long-lived reef fish are especially susceptible to overfishing because of the slow growth and length of time it takes to reach reproductive maturity (5 years for the gag grouper). The protection of specific areas of habitat and spawning grounds may help offset the effects of overfishing.

Community Dynamics of Long-lived Reef Fish

Long-lived reef fish, such as gag grouper, live in highly diverse communities. All species in the community have functional roles and symbiotic relationships that maintain the high level of diversity [14]. Niche partitioning among reef fish has led to habitat specialization, which creates and maintains diversity by increasing specificity toward a food resource and by reducing competition [15]. Most reef fish use the 'lottery' approach for reproduction; in that reef colonization occurs randomly as drifting larvae become juveniles and then progress to the adult stage. As noted by Fox and Connell [16] in their intermediate disturbance hypothesis, disturbances such as red tide, storms, and algal blooms help maintain diversity by not allowing any particular species to dominate.

Predation also helps maintain diversity. An intense level of piscivory limits competition among reef fish by limiting the abundance of each individual species. The removal of top-predator reef fish can have strong impacts on the delicate reef ecosystem. For example, Hughes [17] found that the removal of top predator reef fish in Jamaica allowed herbivorous fish to increase in number and ultimately allowed the herbivorous fish to dominate the ecosystem.

Each piece of the reef ecosystem must be in balance to avoid shifts that can cause ecological damage. When a species in the reef fish community is overfished, it may lead to decreased reproductive output in all species within the community due to changes in the functional relationships among community members. More importantly, overfishing can create trophic cascades in reef fish communities. As top-level predators, gag grouper are important components of the shelf-edge reef that they inhabit. Thus, their biotic interactions are likely to influence the structure and function of the reef fish community. Since the gag grouper likely has multiple ecological roles, its loss would have implications that affect the entire reef ecosystem.

Gag Grouper Ecology in the Gulf of Mexico

The gag grouper is a protogynous hermaphrodite, beginning its life as a female with some individuals later transforming males. The species uses annual spawning aggregations to ensure reproductive success. Intense fishing on spawning aggregations and an observed decrease in the proportion of males in the populations led scientists to question the reproductive potential of the gag grouper. While the decrease in the proportion of males was used to establish the Madison Swanson MPA, fishery scientists have differing opinions on gag grouper ecology and each theory has strong management implications. In this section, I will discuss the three opposing theories and the implications of each theory.

Spawning aggregation sites occur on drowned Plesitocene coral reefs on the continental shelf west of Florida in depths of 120-400ft, with preferred depths at 200-300ft [18, 19]. The reproductive season begins in November and lasts until mid-May, but most spawning activity occurs in February and March [20]. During the spawning season, gag form aggregations of tens to hundreds of individuals. After fertilization, larval gag spend 30-70 days suspended in the upper portions of the water column. When the larvae develop tails, they settle on shallow seagrass habitats in estuarine systems [19]. Settlement occurs in April and May and is followed by a period of rapid growth. Once the juveniles reach approximately 300mm, they leave the nursery habitat and migrate to shelf reef habitats [21]. Although exact movements of gag are unclear, evidence suggests that juveniles first inhabit shallow water, near-shore areas and gradually move offshore to deeper habitats with increased age and size [20].

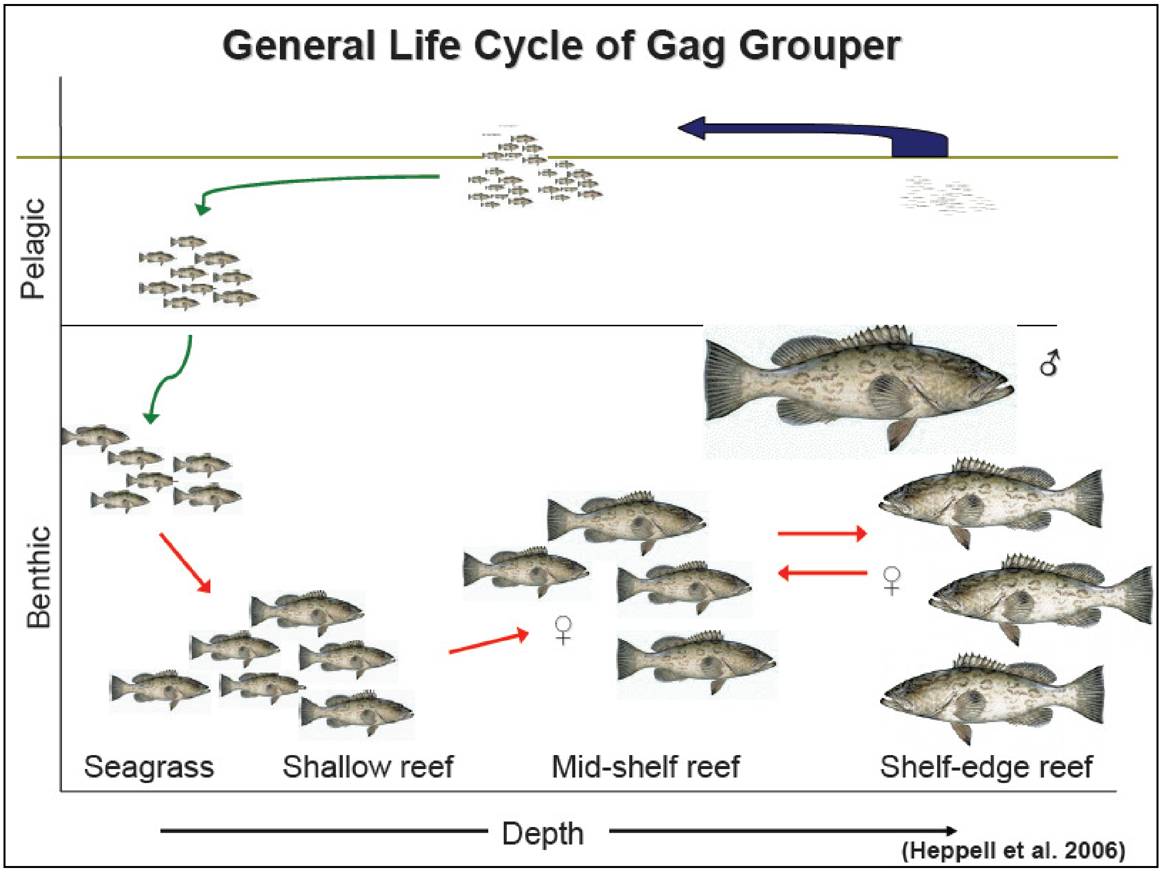

Figure 2: Gag Grouper General Life Cycle.

The most unique characteristic of gag grouper life history is their protogynous hermaphroditism. Early in life, all gag grouper are female and later some individuals eventually transform into males. Females are sexually mature as early as two years and as late as seven years although over half are mature by four years of age [22]. The sexual transformation occurs in individuals as young as five years, but the majority of individuals do not make the transformation until age 10-11 [20].

The mechanism for sex change in gag grouper has not been precisely determined. In most other protogynous species, the social environment provides the cue for sex change rather than size or age [23]. For example, in studies of wrasses and angelfish, the proportion of males to females in the reproductive population cues the females to convert sex [17]. Theoretically, a protogynous female will change sex when her reproductive success can be maximized by converting to male. The reproductive success of a male is determined by the abundance and fecundity of females at spawning aggregations [24]. In wrasses and angelfish, the males and female population coexist on the reef year-round. Therefore, the females can assess their reproductive success constantly. However, gag grouper are segregated during the most of the year. Females remain on near-shore shallow water reefs while the males typically inhabit the high relief, offshore spawning aggregation sites. In gag grouper spawning aggregations, females can only assess their potential reproductive success during aggregations, which last just a few days. Thus, a female will respond to a low proportion of males by switching sex for the next spawning aggregation. In the interim, the result is a transitional male (both male and female gonads) that will become a fully-capable reproductive male for the next spawning aggregation. Koening et al. [24] suggested that intense fishing pressure on spawning aggregations has reduced the abundance of males, which has altered the sex ratios in the gag grouper population and decreased overall reproductive success.

Discussion of Causes of Reduction in Proportion of Males and Management Implications

The mechanism of the sex change in gag grouper was central to the establishment of the Madison Swanson MPA. However, Koenig et al [6] and Trevor Kenchington [25] have differing opinions on the actual mechanism and the management implications of the mechanism.

Koenig et al [24] suggests that sex change is socially mediated in the gag grouper population. He argues that the social environment dictates the timing of the sex change rather than a predetermined genetic-based sex change at a particular age or size. A female will respond to a low proportion of males at the spawning aggregation by switching sex for the next reproductive bout. The change should be initiated during or immediately after the spawning aggregation. However, the change does not occur instantaneously and the fish will only be sexually mature for the next spawning aggregation. Interestingly, Koenig et al [26] reference studies of *Anthias squamipinnis* [27] to support the conclusion. Sex change is socially mediated in *Anthias squamipinnis* and the Koenig's data suggests that it could also be the case for gag grouper. However, one important distinction is that both male and female *Anthias squamipinnis* remain on the reef simultaneously, while gag grouper do not. Koenig et al [24] suggest that intense fishing pressure on spawning aggregations has led to the reduction in the proportion of males in the overall stock. Since males are mostly older and larger, fishermen prefer to harvest the males rather than the smaller, younger females. Koenig et al [24] suggests that increased removal of males during spawning aggregations is responsible for the overall reduction in males in the total population thus leading to the low numbers of functional males in the spawning aggregations.

However, Kenchington [25] offered a different hypothesis on the mechanism for the sex change in gag grouper. He contends that if the sex change is cued by the interaction of males and females at spawning aggregation sites and females observed a decreased abundance of males, then females would maximize potential reproductive success by changing sex for the next reproductive bout. Thus, if solely controlled by behavior, the sex ratio would be reset to its natural value each year. Because Koenig et al [26] observed only 2% males in the adult spawning population in 1996, compared to 21% male in the late 1970's, Kenchington [25] hypothesized that the sex change is controlled by some other factor, possibly age or size. He believes that the sex change could be cued by a combination of age, size, and social interactions. In the historical data [28], the youngest male was 11 years old, thus establishing a baseline transitional age. Data from the 1990s suggests that the age of sexual transition is younger than it was previously. Kenchington [25] contends that fishing pressure on all gag sizes has decreased the total number of females, thus limiting the number of fish that are physiologically capable of changing into male.

When formulating management strategies, it is important to consider the sex ratio and the mechanism used to initiate the sex change in protogynous species. The historical ratio should be preserved or at least an attempt made to reestablish the historical sex ratio. However, fishery managers must make a decision based on competing theories. Koenig et al claim that since the sex change is cued by the social environment (presence or absence of males), then managers should protect the spawning area to help ensure reproductive success. Kenchington, however, believes that sex change is a combination of factors and a decrease in the total number of females has led to the skewed sex ratio. He proposes limiting total gag landings to ensure that more females reach the age or size at which they are physiologically capable of changing sex.

Difficulties in Determining the Effectiveness of the Madison Swanson MPA

When we evaluate the success or failure of the Madison Swanson MPA, we need to consider recent work on the density dependent effects of gag grouper. Density dependence limitations will help protogynous modeling efforts to determine the efficacy of marine reserves when trying to rebuild gag grouper stocks. The combination of recent work on density dependent effects and protogynous modeling will help us realize some of the consequences of the precautionary approach.

A recent study by Lindberg et al [29] suggested that gag grouper in the Gulf of Mexico are limited by density-dependent factors when selecting habitat. Gag grouper prefer artificial and hard-bottom patchy habitats. Large mobile fish that occupy patchy habitats and exploit patchy resources will choose their location based on resource quality and density of competitors to maximize energetic benefits. Density-dependent habitat selection involves a combination of behavioral mechanisms (e.g. immigration, emigration, residency, home range, dispersal, etc) and resource use (e.g. shelter, food, and competition).

Lindberg et al [29] hypothesized that if gag grouper are limited by density-dependent habitat selection, then residency times and gag abundances should be greatest on reefs that offer the greatest individual net benefits. The researchers confirmed that colonization is density dependent and a function of habitat patchiness. Standard habitat units (SHU), spacing, and age of reef affected the gag abundance and the larger SHUs with the most space between habitat units aggregated fish much faster than the smaller SHUs spaced much closer together.

They also concluded that shelter volume on the reef limits gag abundance because prey abundance was constant, indicating that the gag must cue on shelter rather than food when initially selecting habitat. However, gag growth and condition were lower on the preferred habitat sites, indicating density-dependent effects.

Larger SHUs, adequate spacing, and age of the habitat structure determine where adult gag take residence. Since only a limited number of adult males will be at each site, it will limit the reproductive potential at each site. More interestingly, scientists [24] observed a low number of males at the spawning aggregation sites within the Madison-Swanson MPA. It possible that this is not far from the natural condition since only a few large, male gag grouper will be at each site. Based on our understanding of density-dependent habitat selection and use, the number of gag grouper that will inhabit a given area is limited by patch size and abundance of conspecifics. Therefore, a limited number of fish will be able to form spawning aggregations due to the space limitations. Density-dependant factors may also limit observed mean abundance at each site. The density dependence effects of habitat selection should be considered when conducting future stock assessments and while reviewing catch data. Also, the density dependence effects could limit the success of the Madison Swanson MPA since only a limited number of older, male gag grouper will take residence in the area.

St. Mary et al. [30] investigated the effects of density dependence and spatial segregation during life stages and the potential implications when planning marine reserves. The researchers focused on gag grouper in the Gulf of

Mexico because its complex life cycle is similar to most other harvested marine species. The authors separated the life cycle into two benthic stages, juvenile and adult, to evaluate the efficacy of marine reserves and they assumed that most mobile fish experience a large scale spatial segregation during the life history.

Further, St. Mary et al [30] identified two management goals: 1) maximize the fishable adult stock and 2) maximize the total adult stock. According to the results of the model, the best management scenario to accomplish the first goal was to only protect juvenile habitat. They projected that this would maximize the total amount of fish that would reach a size large enough to be harvested. On the other hand, to maximize total adult stock, adult habitat protection was the best strategy. Because the two management implications are in direct conflict, the authors evaluated the effects of combining the two management scenarios and found that combining management scenarios did not have a positive impact on fishable adult stock or total adult stock. The findings do not provide firm support or objection to the current use of an MPA for spawning aggregation protection. The authors conceded that the model may become a better predictor of management success or failure when more details about the gag grouper life history are known, thus allowing them to eliminate some assumptions within the model.

Heppell's Model of Protogynous Species and Management Options

Heppell et al. [31] developed an age-structured model with stage classifications to evaluate different management strategies for protogynous hermaphroditic fish, specifically gag grouper. The four stages represented the gag life cycle in different habitats during different parts of the year: stage 1, larvae and young of the year; stage 2, immature females; stage 3, mature females; stage 4, mature males (older than seven years that have undergone the sex change). Heppell et al. (2006) produced four permutations of the model by incorporating two levels of fertility (low and high) and two levels of fishing mortality (low and high).

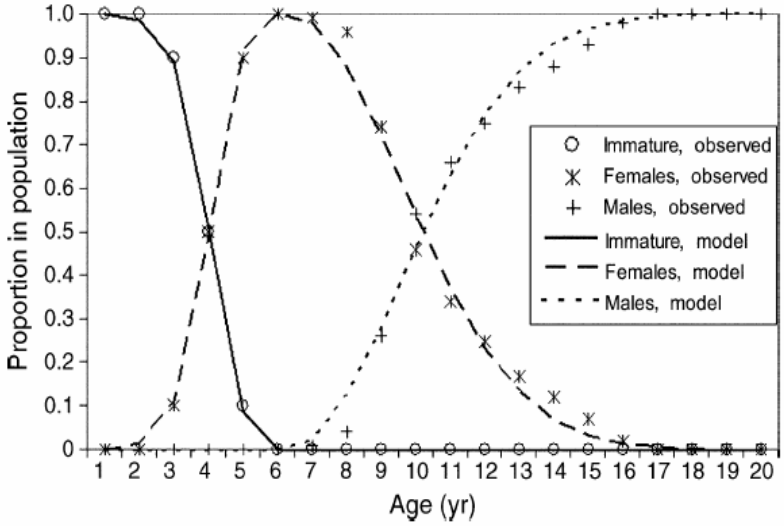

FIG. 2. Predicted and observed proportions for sex and maturational status (juvenile, female, male) by age in gag. Observed proportions are based on McGovern et al. (1998) (size converted to age using Eq. 3).

Figure 3:Sex Status in Gag Grouper[3]

Figure 2 shows the predicted and observed proportions of gag grouper in the different maturation phases. Juveniles dominate the 1-4 age class. Females dominate the 4-10 age class while males dominate the 10> age class.

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[3] Source: adapted from Heppell et al. 2006

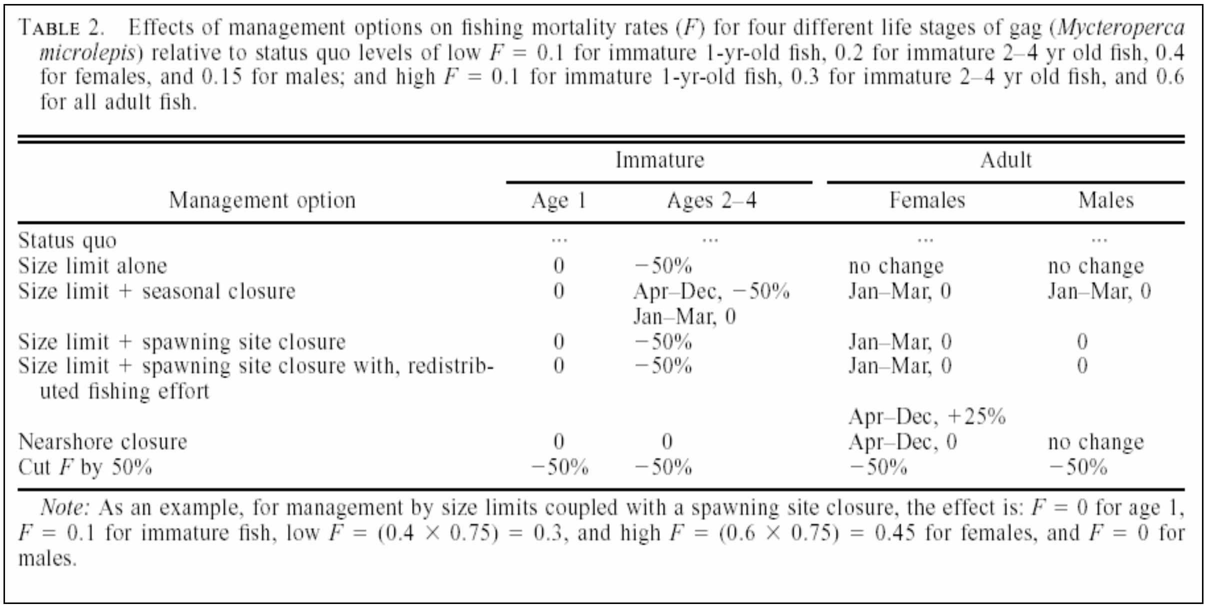

TABLE 2. Effects of management options on fishing mortality rates (F) for four different life stages of gag (*Mycteroperca microlepis*) relative to status quo levels of low $F = 0.1$ for immature 1-yr-old fish, 0.2 for immature 2–4 yr old fish, 0.4 for females, and 0.15 for males; and high $F = 0.1$ for immature 1-yr-old fish, 0.3 for immature 2–4 yr old fish, and 0.6 for all adult fish.

	Immature		Adult	
Management option	Age 1	Ages 2–4	Females	Males
Status quo	···	···	···	···
Size limit alone	0	−50%	no change	no change
Size limit + seasonal closure	0	Apr–Dec, −50% Jan–Mar, 0	Jan–Mar, 0	Jan–Mar, 0
Size limit + spawning site closure	0	−50%	Jan–Mar, 0	0
Size limit + spawning site closure with, redistributed fishing effort	0	−50%	Jan–Mar, 0 Apr–Dec, +25%	0
Nearshore closure	0	0	Apr–Dec, 0	no change
Cut F by 50%	−50%	−50%	−50%	−50%

Note: As an example, for management by size limits coupled with a spawning site closure, the effect is: $F = 0$ for age 1, $F = 0.1$ for immature fish, low $F = (0.4 \times 0.75) = 0.3$, and high $F = (0.6 \times 0.75) = 0.45$ for females, and $F = 0$ for males.

Figure 4: Effects of Management Options on Fishing Mortality[4]

Figure 3 shows the effects of different management options on fishing mortality rates at different stages of the gag grouper life cycle.

Heppell et al [31] found that most management options provided some improvement in population growth rate and in female stock spawning biomass. Based on their model, the most rapid population recovery and highest female stock spawning biomass occurred when females are protected in near-shore juvenile habitats. However, the most effective management strategy for improving sex ratios is spawning reserves.

Heppell et al. [31] also noted that small changes in the age of sex transition result in significant changes in sex ratio, population size, and population growth. If the mechanism for sex change is behaviorally induced, it is important to consider the age of sexual transition when attempting the increase the ratio of males to females. However, this is one of the disputed theories in gag grouper ecology. While the authors concede that the model is simplistic and the analysis

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[4] Source: adapted from Heppell et al. 2006

used limited data the framework is flexible allowing future modification as more data becomes available.

While fishery mangers wait on more data to become available, they can still use the findings of Heppell et al [31] to compare management decisions. Managers must first clearly identify a management goal, then take the action that best suits the goal. In this case, if the goal is to improve the sex ratio, the best management option would be to protect known spawning aggregations by establishing spawning reserves. However, if the goal is to increase female stock spawning biomass, the best management option would be to protect near-shore nursery habitat.

In order to discuss the consequences of scientific uncertainty and management policies in the case of gag grouper and the Madison Swanson MPA, it is important to review the policy framework that established the MPA.

Policy Background for Madison Swanson MPA

NOAA Fisheries (NOAA) and the Gulf of Mexico Fishery Management Council (Council) are responsible for management of fish species within the exclusive economic zone (EEZ), under the provisions of the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act). In order to manage a single species or group of species, the Council must compile a fishery management plan (FMP) and submit it to NOAA for approval of the Secretary of Commerce [32].

The Reef Fish FMP was the first plan developed by the Council. It was submitted to the Secretary of Commerce in June 1981, approved in June 1983, and implemented in November 1984. The goal was "to manage the reef fish fishery of the United States waters of the Gulf of Mexico to attain the greatest overall benefits to the Nation with particular reference to food production and recreational opportunities on the basis of maximum sustainable yield (MSY) as modified by relevant economic, social, or ecological factors" [1]. One of the main goals of the original FMP was to rebuild declining reef fish stocks in the Gulf of Mexico.

The Council manages the reef fish population of the Gulf of Mexico collectively under the Reef Fish FMP. In order to make changes aimed at specific species, such as gag grouper, the Council must amend the Reef Fish FMP.

Amendment 1 (1990) to the Reef Fish FMP was the first amendment that placed harvest restrictions on gag grouper in the Gulf of Mexico. Amendment 1, set a minimum size limit of 20 inches total length and a five fish recreational bag limit total on all grouper species. The amendment also enacted an 11 million pound grouper quota for the commercial sector. The quota included all grouper species in the Gulf of Mexico: black, gag, red, Nassau, yellowfin, yellowmouth, rock hind, speckled hind, scamp, misty, snowy, and warsaw. A framework was developed for total allowable catch and subsequent changes in the annual quota. The regulations were intended to increase grouper survival rate to achieve at least 20 percent spawning stock biomass per recruit (otherwise referred to as SPR) [1].

Numerous amendments followed Amendment 1 in an attempt to protect the grouper in the Gulf of Mexico from overfishing. In spite of these efforts, in August 1998, the National Marine Fisheries Service reported that gag grouper was approaching an overfished status. Since gag grouper are protogynous hermaphrodites, the species is especially vulnerable to overfishing [18]. In an effort to alleviate strain on the spawning aggregations, scientists and environmental advocates advised the Council to take further action to protect gag grouper spawning aggregation sites. Proposals included changes in the total allowable catch, minimum size requirement, reduction in recreational bag limit, closures during peak spawning seasons, and closure of aggregation sites. Ultimately, the Council decided on two marine protected areas (MPA) to protect gag grouper spawning aggregation sites.

In order to establish the MPAs, the Council sought a regulatory amendment rather than an amendment to the Reef Fish FMP. Regulatory amendments are used to amend specific regulations and are allowed when addressing new information. However, the regulatory amendment must be consistent with the FMP. The Council sought a regulatory amendment because the public comment and agency review periods are shorter.

In March 1999, the Council proposed the Madison Swanson and Steamboat Lumps marine reserve sites. The sites would be closed to all reef fishing year-round in order to protect gag grouper spawning aggregations. In April 1999, before the regulatory amendment was published in the *Federal Register*, some members of the Council filed independent reports objecting to the amendment because the proposed restrictions were not distributed fairly and equitably among all sectors of the fishery and the proposed regulations were not based on the best scientific information [33]. Mainly, members of the Council objected on the following grounds:

> -*"Existing baseline data are inadequate to evaluate changes in gag populations that could be attributed to the closure"*
> -*"The duration of the closure (four years) is too short to expect measurable benefits and changes resulting from the closure"*
> -*"No criteria are proposed with which to judge the success or failure of the closure"*
> -*"The closure of the two areas to all fishing unnecessarily restricts fishing for species other than reef fish"*
> -*"The closure should apply only to reef fish fishing and bottom fishing with gear capable of catching reef fish" [34]*

In May 1999, the Council submitted the regulatory amendment to the National Marine Fisheries Service (NMFS). In June 1999, the Council held a public workshop in Panama City, Florida in an attempt to resolve some discrepancies in scientific information. Dr. Chris Koenig[5], a Florida State University ecologist, reiterated that gag grouper sex ratio had shifted and was in danger of collapse [6]. He went further to suggest that intense fishing on spawning aggregations in the past 20 years was responsible for the decline in adult males. Dr. Trevor Kenchington of Gadus Associates disputed Koenig's claim that intense fishing caused the skewed sex ratio.[6] He suggested that fishing pressure on the total population may have decreased the proportion of males and disputed Koenig's claim that fishing pressure on spawning aggregations had caused the decline. The public workshop did little to clarify the scientific information because of the competing theories on the cause of the decline. However, at the next meeting in July, the Council decided to move forward with the marine protected area regulatory amendment. The amendment closed fishing in the two areas to all fishing year-round and included a sunset provision for a period of four years. At the end of the sunset provision, the Council

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[5] Please refer back to the Gag Grouper Ecology section for discussion of divergent viewpoints.
[6] Please see Kenchington's argument on sex ratio in the Gag Grouper Ecology section.

intended to reevaluate the proportion of males in the gag grouper stock and more specifically, the effectiveness of the MPA.

In August 1999, the Council submitted the revised regulatory amendment to the NMFS. In January 2000, NMFS published the proposed rule in the *Federal Register* and the public comment period began. The Council received opposition and support for the proposed MPAs. Again, most of the opposition comments centered on the scientific uncertainty surrounding gag grouper ecology. In the end, the Council proceeded with caution regarding the discrepancies in scientific information.

On June 19, 2000, the final rule was implemented and the sunset provision was included. NMFS included the stipulation that if the marine reserves were to continue after June 19, 2004, then the final rule must come as an amendment to the reef fish FMP [9].

The distinct between a regulatory amendment and an FMP amendment is significant because each is generally used for different reasons. An FMP amendment changes the way a species is managed in a broad, sweeping way. It requires lengthy public comment periods and a formal review. However, a regulatory amendment is used to change regulations when new information is presented and that information has direct, immediate consequences. Regulatory amendments are used when the Council believes that a change in the regulations must occur rapidly. These amendments require some form of comment period, although it is generally shorter than a FMP amendment, and require final approve of the regional director of NMFS.

After the implementation of the final rule, opponents of the regulations filed legal challenges. As a result of the legal challenges, the Council passed Amendment 21 to the FMP, thus changing fishing restrictions within the MPA.

Legal Issues

The Council was faced with a difficult situation regarding gag grouper's overfished status and the decline in the proportion of males. The 'best available science' told the managers that a problem existed. The Council is required to formulate management strategies to fix the problem. However, in this case, the managers had to make the decision based on competing ecological theories and limited biological information. The Coastal Conservation Association, a recreational fishing organization, and the Ocean Conservancy, an environmental advocacy group, used the legal system to contest the final rule of the Gulf Council. In this case, the discussion illustrates the costs of the precautionary approach and how the federal fishery management system is impacted by the court.

Following the final rule, the Coastal Conservation Association (CCA) filed suit in federal district court in Tampa, FL against NMFS. The CCA argued that NMFS had made a rule that was arbitrary and capricious because it excluded recreational fishermen from catching highly migratory species within the MPA. A year later, the CCA and NMFS reached a settlement agreement in which NMFS agreed not to ban trolling for coastal pelagics in the closed area until research could determine if it was possible for recreational fishermen trolling on the surface to catch gag grouper [35].

NOAA research biologist, Andrew David, [36] used recreational fishing practices to determine if gag grouper could be caught while trolling in the

Madison-Swanson MPA. In his 2003 study, he used a variety of gear types and trolling speeds. He caught a total of 47 fish, 43 being reef fish which suggests reef fish could be caught by trolling. However, David's [36] methods allowed the bait to sink to the bottom of the seafloor in the location of spawning aggregations. The methods included heavy line weights, steel line and speeds of one to two knots or less. Although the vessel was technically underway during the trials and thus "trolling," the baits were allowed to sink into the lower portions of the water column and catch gag grouper.

Based on flawed research design, the Council rejected David's [36] findings and continued to allow surface trolling in the Madison-Swanson and Steamboat Lumps MPAs. As a result, in 2003, the Ocean Conservancy filed its own suit against the NMFS. The environmental group contested NMFS recommendations and sued because they believed, based on David [36], that NMFS was not adequately protecting gag grouper spawning aggregations. In a settlement reached by the Ocean Conservancy and NMFS, the judge required that NMFS conduct further trials to test gag grouper susceptibility to surface trolling [37].

The new study by David [38] contained strict gear, speed, and size restrictions to reflect typical recreational trolling practices[7]. The restrictions called for two natural baits and two artificial baits to be trolled at all times and trolling speed must be at least five knots and not greater than eight knots. The restrictions required monofilament fishing line and no more than 24 ounces of weight per line. The researchers conducted twenty trips to the Madison-Swanson

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[7] See Appendix 1 for a detailed report of the 2006 study.

MPA in the summer of 2006. The study yielded only highly migratory species: wahoo, dolphin (mahi-mahi), tuna, sharks, and king mackerel. The researchers did not catch any reef fish.

The findings from the David [38] were presented to the Council in December 2006. The Council accepted the findings and will continue to allow surface trolling for highly migratory species within the reserve in the non-spawning season from May 1 to April 30. The Madison-Swanson MPA is closed to all-fishing from November 1 to April 30 to decrease the risk of illegal fishing on spawning aggregations.

Scientific uncertainty was used as evidence in the two court cases discussed above. Attorneys working for the CCA questioned the validity of the findings made by David [36]. The CCA is a non-profit organization that represents the rights of recreational fishermen. They initially supported the closure for gag grouper, but wanted to be able to troll at the surface for pelagic species. Fred Miller, National Government Relations Committee Chairman for CCA said, “We are willing to work with NMFS on this issue. CCA is not opposed to closing areas to recreational fishing as long as there is scientific evidence that demonstrates recreational fishing is part of the problem, we believe the science indicates it is necessary to conserve gag. We simply refuse to be arbitrarily closed out of an area based on faulty research" [39].

Current Management Regulations

As a result of the two lawsuits, the Gulf Council implemented Amendment 21 to the FMP for the Reef Fish Resources of the Gulf of Mexico in June 2004.

The final regulation modified the fishing restrictions that apply to the Madison Swanson MPA and included a sunset clause, extending the restrictions through June 16, 2010.

Specifically, Amendment 21: [1]

1. prohibits the possession of Gulf reef fish year-round, except for possession aboard a vessel in transit with fishing gear stowed.
2. During November through April, all fishing is prohibited, and possession of any fish species is prohibited, with exceptions for highly migratory pelagic species (billfish, sharks, swordfish, and tunas other than blackfin) and for fish possessed aboard a vessel in transit with fishing gear appropriately stowed;
3. During May through October, surface trolling is the only allowable fishing activity. Surface trolling is defined as fishing with lines trailing behind a vessel which is in constant motion at speeds in excess of four knots with a visible wake. Such trolling may not involve the use of downriggers, wire lines, planers, or similar devices.
4. For the purpose of this section, transit means non-stop progression through the area; fishing gear appropriately stowed means-
    a. A longline may be left on the drum if all gangions and hooks are disconnected and stowed below deck. Hooks cannot be baited. All buoys must be disconnected from the gear; however, buoys may remain on the deck.
    b. A trawl net may remain on deck, but trawl doors must be disconnected from the trawl gear and must be secured.
    c. A gillnet must be left on the drum. Any additional gillnets not attached to the drum must be stowed below deck.
    d. A rod and reel must be removed from the rod holder and stowed securely on or below deck. Terminal gear (i.e., hooks, leader, sinker, flasher, or bait) must be disconnected and stowed separately from the rod and reel. Sinkers must be disconnected from the downrigger and stowed separately.

The result of Amendment 21 is a multi-use MPA in the Gulf of Mexico. While it may seem rather obvious that surface trolling will not impact reef fish within the MPA, the Council was worried in the planning stages that a multi-use MPA would be difficult to enforce, especially since the area is 50 miles offshore [40]. The Council was correct to question the enforceability. David [38] made

20 trips to the MPA in 2006 and observed illegal fishing activities on 9 of the trips. Chris Koenig [41] also observed illegal fishing activities while he was conducting a gag grouper monitoring study.

Enforcement

Enforcement is difficult for a number of reasons. First, the area lies approximately 50 nautical miles from the closest port. Since it lies outside of state waters, the US Coast Guard has the responsibility to enforce the regulations. However, the fisheries enforcement is not a primary objective of the US Coast Guard. Second, it is difficult for enforcement officials to determine if a boat is fishing in the box or on the edge. If enforcement officials determine that a boat is indeed fishing within the box, it is also difficult for the officials to determine if the boat is bottom fishing or trolling [36]. In David's study [36], he conducted trials in conjunction with law enforcement officials at various distances to determine if law enforcement could accurately determine what type of fishing activity a vessel was engaged in. He found that law enforcement must be within 100 yards of the vessel in question before an accurate determination could be made. Fisherman could change gear and fishing tactics to comply with the fishing restrictions before enforcement officials could precisely determine fishing activities. The current regulations added some regulations such as gear restrictions and expanded the definition of 'trolling' in an effort to help enforcement efforts.

Currently, NOAA and the US Coast Guard are working together to increase enforcement. The US Coast Guard established daily monitoring of the MPA using a Falcon jet. The plane makes daily flights in the summer months (May-

October). If bottom fishing activities are observed, the pilot takes a picture of the vessel documentation number and relays the message to the US Coast Guard. NOAA developed sensor buoys that would relay a message to a central database when a vessel entered the MPA [42]. However, this method would likely achieve little actual enforcement, but it would give an accurate estimate of vessel traffic in the area. The sensor buoys are not currently being used due to a large investment cost. Another option is the use of radar at Tyndall Air Force Base, located near Panama City, FL. Tyndall Air Force Base uses sophisticated radar systems for flight monitoring and training. The technology is capable of detecting traffic in the MPA from the land-based station. If the radar shows a high amount of sedentary vessels within the MPA, then the US Coast Guard could deploy a fisheries enforcement vessel to check the situation [43].

In this case, enforcement costs must be realized when trying to understand the consequences of the precautionary approach. Enforcement of the regulations is difficult because of the location of the reserve and the shifting priorities of the US Coast Guard. The MPA was implemented in an effort to alleviate strain on the male gag grouper population. However, illegal fishing activity was observed and further enforcement is costly and practically difficult. Fishery managers should consider these consequences when attempting to deal with uncertainty in future management decisions.

Current Status of Gag Grouper in the Gulf of Mexico

While the legal and enforcement issues have complicated the situation surrounding the Madison Swanson MPA, the current status of the gag grouper in the Gulf of Mexico raises further uncertainty.

Amendment 1 (1990) of the Reef Fish Fishery Management Plan defines overfishing as: a reef fish stock or stock complex is overfished when it is below the level of 20 percent Spawning Potential Ratio (SPR) (Please see Definitions and Implications of SPR in Box 1 for further explanation) [7]. The original definition of overfished condition was a single set of parameters that applied to all reef fish. However, following the 1999 SEDAR report [7] and under the Sustainable Fisheries Act Generic Amendment, the Gulf Council decided to change the SPR threshold for gag grouper. The Council increased the threshold to 30% SPR (Discussed in detail later in the section) based on concerns over the reproductive habitats of gag grouper.

According to the 2006 Southeast Data, Assessment, and Review (SEDAR) report, the gag grouper in the Gulf of Mexico is undergoing overfishing [32]. The status of grouper and other federally managed fisheries in the Southeastern United States is periodically reviewed by a panel of fishery experts known as SEDAR. The population assessments are rigorously reviewed during three separate workshops. The first workshop focuses on data analysis and review. The second workshop develops and refines the quantitative methods. The third and final workshop is conducted by a panel of experts that are not associated with NOAA Fisheries Service (NOAA) or the Gulf Council. After the panel validates the quantitative methods, they issue a status determination. The 2006 SEDAR report determined that the population is being fished at a rate that would not produce the maximum amount of fish over time.

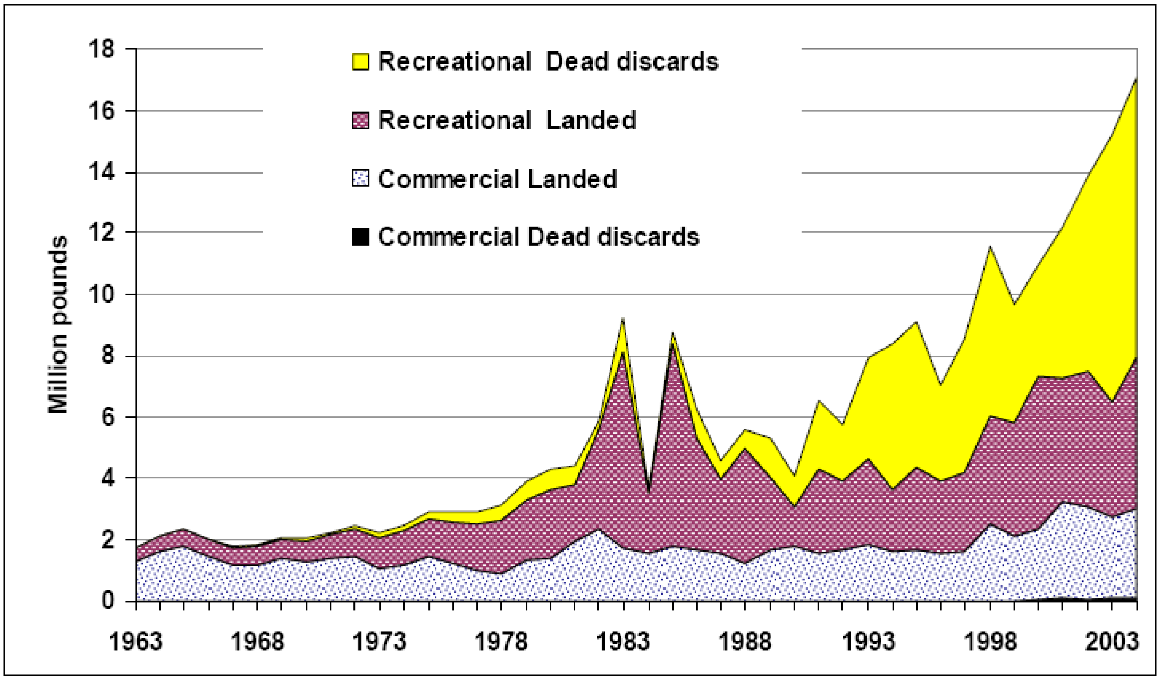

Figure 5. Gulf of Mexico gag grouper landings and dead discards by commercial and recreational fisheries in pounds gutted weight.

Figure 5 represents the annual fishing mortality in terms of commercial and recreational landings. The commercial and recreational landed is the amount brought to the dock for sale and the dead discard is an estimate of undersized fish that were not retained. The graph shows a dramatic increase in total landings from 1963 to 2003.

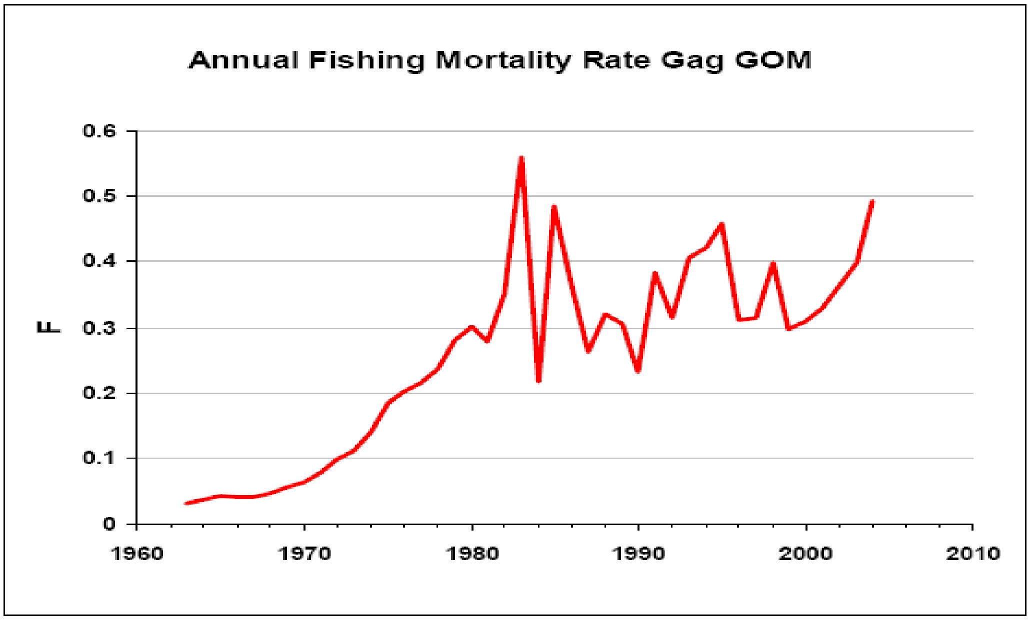

Figure 6. Estimated annual fishing mortality on gag grouper in Gulf of Mexico.

Figure 6 shows annual fishing mortality of gag grouper in the Gulf of Mexico from 1960 to 2004. F represents fishing mortality as a proportion of the total stock. Fishing mortality increased significantly from 1963 to 1980 and has fluctuated since 1981. F_{MSY} is the fishing mortality at a level that will produce the maximum sustainable yield of the stock. F_{SPR} 30% is the fishing mortality at a level that will reduce the spawning potential ratio to a given percentage of the maximum spawning potential ration, in the absence of fishing.

The average fishing mortality rate from 1981 to 2003 is 0.36. The current (2004) annual fishing mortality rate on this stock is estimated as 0.49. The current proxy for F_{MSY} is F_{SPR} 30%, estimated as 0.30. Since the F_{SPR} is currently 0.49, which is greater than the proxy for F_{MSY}, overfishing is occurring in the gag grouper population in the Gulf of Mexico.

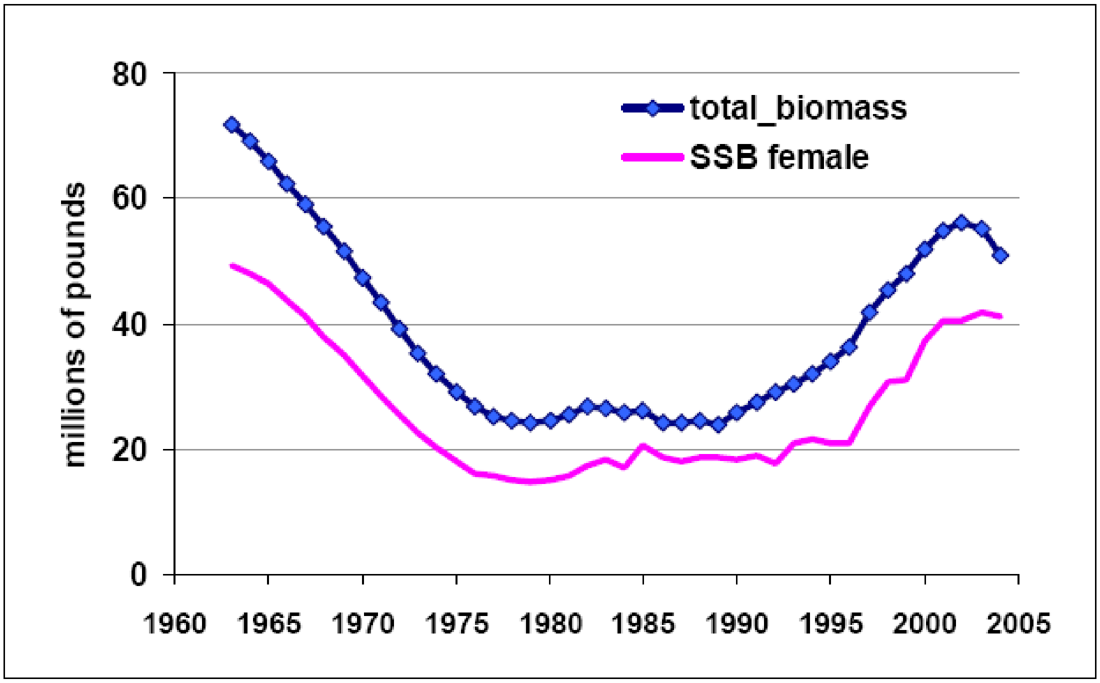

Figure 7. Estimated biomass of gag grouper in Gulf of Mexico showing total biomass and spawning stock biomass (SSB, mature females) in gutted weight.

Figure 7 shows the estimated total biomass and spawning stock biomass of the stock. Spawning stock biomass (SSB) is the total weight of the fish in a stock that are old enough to spawn. SEDAR used SSB to estimate egg production in the gag grouper stock. Biomass decreased in the 1960s and 1970s but began to increase in 1990, possibly due to higher recruitment (SEDAR). The report noted that the SSB is near the historic maximum which may show signs of a healthy reproductive population. The panel also suggested that if the gag grouper SSB fell below 20 million pounds the stock recruitment would be impaired.

Currently, overfishing is occurring in the gag grouper stock because the annual fishing mortality rate is 0.49, which is above the recommended F_{MSY} of 0.30. However, the SSB is near the historical maximum which may indicate a healthy reproductive stock.

The competing information in the 2006 SEDAR report and the concern over the decline in males in the population further clouds the Madison Swanson MPA. This stock is currently undergoing overfishing and the Council must formulate a plan to stop overfishing. They used caution when implementing the Madison Swanson MPA and incurred the costs of legal challenges and enforcement.

Where do we go from here?

At this point, the main question regarding the Madison Swanson MPA is where do we go from here? In this case, researchers have differing opinions on gag grouper ecology and each has its own management implication. However, fishery managers chose to use a MPA to protect gag grouper spawning aggregations. Having established the MPA based on competing information, we have paid legal and enforcement costs associated with the establishment of the MPA. Since we have paid such costs, managers should evaluate the effectiveness of the Madison Swanson MPA and interpret the successes or failures of the establishment.

It is hard to avoid the 'world view' that science is capable of fully revealing and understanding the complexities of nature [5]. Lauck et al [5] suggest that rather than trying to obtain data requirements needed to validate an ecological model, researchers should realize the practical and theoretical limitations of science. Lauck et al adds that "full understanding and predictability of anything as complex (and should we add unobservable) as a marine ecosystem will forever remain a chimera" [5]. The authors recommend that fisheries researchers should focus on ways to deal with uncertainty rather than dwell on increased research in marine biology.

In fact, Smith et al [44] incorporated some of Lauck's suggestions into a recent study on the effectiveness of the Madison Swanson MPA. The researchers performed a retrospective evaluation to determine the effectiveness of the Madison Swanson MPA using log data from commercial fishermen. Theoretically, the effectiveness of a fishery MPA could be determined by testing whether or not the harvestable biomass increased. The harvestable biomass outside the reserve should increase enough to offset the reduction in harvestable biomass that is closed off within the reserve. Since total harvestable biomass is unobservable, Smith et al used commercial catch statistics as an proxy of harvestable biomass. In order to isolate the policy effects of MPAs, they considered whether the fishermen fished near or far from the MPA. Specifically, Smith et al found that isolating the effects of MPAs requires: "knowledge of the spatial scope of reserve spillovers, full accounting of multiple gear technology, heterogeneity in vessel captain skill, spatial heterogeneity of the fish stocks, seasonal patterns in abundance, the effects of coexisting management policies, and the possibility that the harvest sector anticipates the establishment of a reserve" [44]. The real value of their work highlights the types of information that future researchers will need and incorporates empirical issues that previous studies did not.

However, the results of the study are important because it helps managers with further regulations and helps deal with scientific uncertainty. Smith et al [44] observed that the net policy effect was -14% in reef fish catch outside of the reserve. The results show that MPAs cause a decline in harvestable fish biomass. It seems counterintuitive that the model would show such results. Smith et al [44] suppose that the time frame of the study was sufficient to reveal the loss of fishing area but not long enough to reveal catch benefits. This is likely because of the long-lived nature of reef fish, gag grouper, in particular. The overall conclusion, based on the model, is that the MPA is not generating net benefits to the fishery. The MPA could yield benefits in the future, once offspring are allowed to enter the harvest fishery. For example, the Madison Swanson was closed in 2000. The offspring from the first year of the closure had likely reached minimum harvest size, 22 inches, when the data was recorded. However, the data missed the second, third, and fourth year offspring because those individuals had not reached harvestable size. Therefore, those individuals are absent in the catch statistics.

This study further may help resolve some scientific uncertainty surrounding the Madison Swanson MPA. Fortunately, the model can be rerun once more catch data becomes available. This is excellent news for another retrospective analysis that could be conducted near the end of the current sunset provision in June 2010. At that time, managers would have a better idea of what is actually happening.

In the case of the Madison Swanson MPA, the precautionary approach can help relieve some of the scientific uncertainty surrounding the gag grouper. Fishery managers have chosen this regulation and should leave the policy in effect until another retrospective evaluation can be conducted near the end of the sunset clause in June 2010. In the meantime, fisheries biologists can continue to study the sex change mechanism in gag grouper and the spawning effects of a reduction in the proportion of males in the population. However, when managing gag grouper in the future, fishery managers should realize the aforementioned consequences and costs of the precautionary approach as well as competing theories on gag grouper ecology in the case of the Madison Swanson MPA.

In order to determine the potential success of the Madison Swanson MPA, we need to revisit the recommended criteria for establishing a marine protected area with the goal of protecting fisheries. Lauck et al [5] recommend that the following be priorities when managing fisheries using MPAs:

1. The area included in the reserve should be large enough to protect the resource in the event of overfishing in the unprotected area. Mathematical models suggest that reserves need to include up to 50% of the original population in order to hedge successfully against overfishing.
2. The reserve area should serve as a source capable of replenishing the exploited stock in the event of its depletion. In particular, the reserves should protect spawning grounds and other areas critical to the viability of the population.
3. The reserve area should be rigorously and completely protected. Typically, reserve areas will contain greater concentrations of fish than exploited areas, making them prime targets for poaching.

The Madison-Swanson MPA protects approximately 1/20th of the total gag grouper spawning aggregations in the Gulf of Mexico [45]. Modeling efforts predict that in order to adequately protect gag grouper spawning aggregations from overexploitation using MPAs the areas should protect at least 1/5th of total spawning aggregations [6, 31, 45]. In the initial planning stages, researchers at Florida State University and fishery biologists at NOAA proposed eight reserve sites that encompassed approximately 721 square miles.

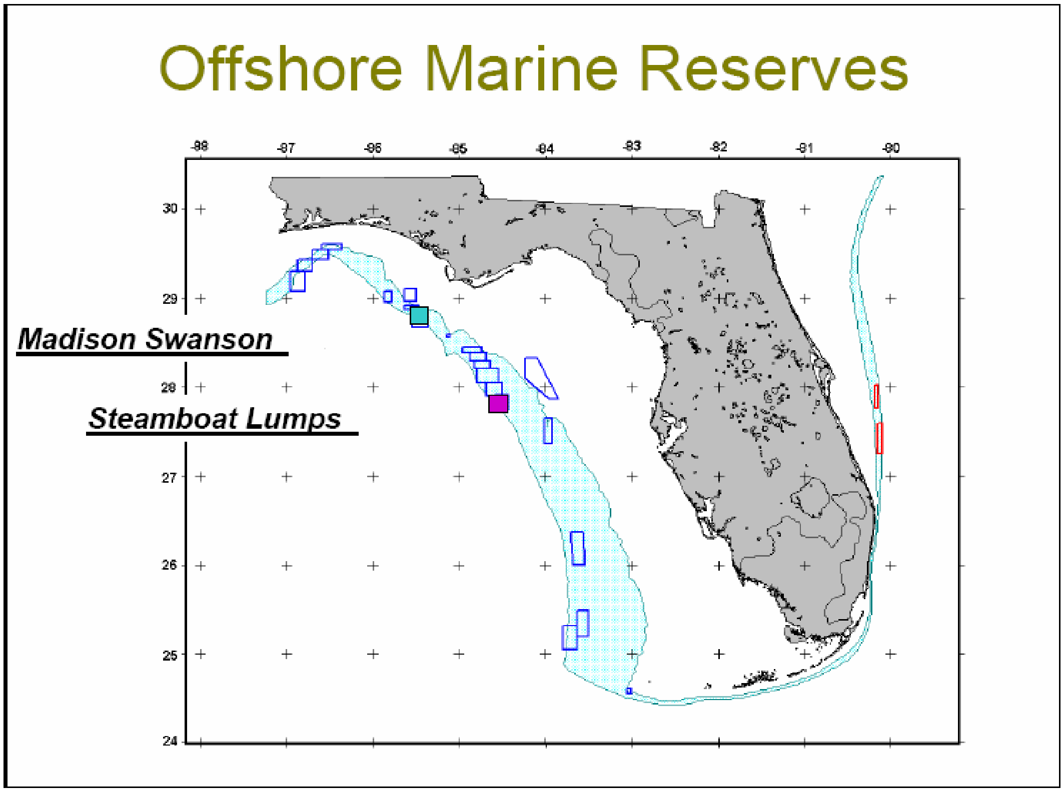

Figure 8: Potential offshore marine reserves. The blue boxes encompass known gag grouper spawning aggregations.

This proposal would likely adequately protect gag grouper using MPAs, based on previous modeling efforts. But, opposition among council members led to the reduction in total area that we have today. Also, immediately after the MPAs were implemented, attorneys used the judicial system to allow surface trolling in the area.

In reference to Lauck et al first and second recommendations, the Madison Swanson only protects about 5% of the total gag grouper spawning aggregations in the Gulf of Mexico. This is well below Lauck et al recommendation of 50%. It is also well below the 20% recommendation. If MPAs are to be used further in the future to increase the number of males in the gag grouper population, the MPAs should at least encompass 20% of the total spawning aggregations.

Amendment 21 currently allows surface trolling by recreational fishermen in the area during the non-spawning season. This is in conflict with Lauck et al third recommendation that the reserve area should be rigorously and completely protected. As the authors [5] warned, illegal fishing has been observed in the Madison Swanson MPA. However, NOAA and the US Coast Guard are working to curb the illegal activity. Once again, the enforcement costs must be realized as a consequence of the precautionary approach.

At the end of the sunset clause on June 16, 2010, fishery managers should conduct another retrospective evaluation of the effectiveness of the Madison Swanson MPA. Also, at that time, biologists may have a better idea of the mechanism for sex change in the gag grouper. They may be able to determine if the percentage of males has increased in the reserve compared to fluctuations outside of the reserve. Once those determinations are made, fishery managers should also realize the consequences of the precautionary approach, such as aforementioned legal challenges and enforcement costs. At that point, fishery managers can evaluate whether or not MPAs have the potential to be a successful tool for gag grouper protection in the Gulf of Mexico.

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Appendix 1: Madison Swanson Marine Protected Area Surface Trolling Trials

NOAA and The Ocean Conservancy (TOC) reached a settlement agreement which required the evaluation of common surface trolling techniques on catch rates of reef fish in the Madison Swanson MPA. The three factors were lure type, trolling speed, and trolling weight. Each factor had two levels. The variables are summarized in Table 1.

Factor	Variable	Variable
Lure Type	Artificial	Natural
Trolling Speed	High: 6.01-8.00 kt	Low: 4.01-6.00 kt
Trolling Weight	Heavy: 24 oz.	Light: 12 oz.

Table 1. Summarized Trials Variables.

The factor and variable combinations gave eight possible combinations. In the trials, we omitted the high speed/artificial lure/heavy weight and high speed/natural lure heavy weight combinations because the heavy weight at high speed would yield enough drag to break the monofilament fishing line. Therefore, only light weight combinations were used during the high speed trials. The heavy weight combinations were tested only during low speed trials.

The settlement agreement required a total of twenty trips. In an effort to distribute the trials throughout the open fishing season, the settlement required 10 trips between May 1 -- July 31 and the remaining 10 trips between August 1 - October 31. Each trip included four hours of trolling trials with a total of eighty hours of trolling time for the entire study. Trolling time was divided evenly among the six trolling speed, trolling weight, and lure type combinations.

Methods

The methods used in the study attempted to duplicate common fishing techniques used while trolling for pelagic species in the Gulf of Mexico.

Tackle

The rods were custom-manufactured, fiberglass poles with roller tip guides. The reels were Penn International™ 80W and Shimano Tiagra™ 80W two-speed models. The reels were spooled with Ande™ 100lb test monofilament line. The terminal tackle was 30ft Jinkai™ 175lb test monofilament shock leader on all bait and lure combinations. The artificial lures used 10 ft Malin™ 480lb test 49 strand wire cable leaders while the natural lures used 10 ft Malin™ 220lb test single strand stainless steel wire leaders. The artificial lures were Yozuri™ Bonita model F53DH model diving plugs. The lure had a red body with a black head and each lure had two 8/0 hooks. The lures were 8 3/8 inches in length and weighed 10 oz. The natural lures were frozen, select size ballyhoo (*Hemiramphus brasiliensis*) rigged with a single Mustad™ 10/0 needle eye hook and an Illand™ Hoo-La Hood model trolling head. The trolling heads had a blue/white skirt and were 7 1/8 inches long and weighed 1 7/8 oz. The lure types are illustrated in Figure 1a and 1b. The trolling weights were 12 oz lead weights. One weight per line was used on the light weight trials and two weights were used on the heavy lines for a total of 24 oz. The trolling weights were attached between the monofilament line and the shock leader using ball-bearing snap swivels.

Figure 1a. Artificial Lures.

Figure 1b. Natural Lures.

Vessel and Trolling Methods

NOAA contracted the fishing vessel *M/V Freedom* (USCG Documentation Number 649855) to conduct the trolling trials. The vessel is a USCG certified and inspected 44ft Henriques sportfisherman operated in Panama City Beach, Florida. Captain Jim Guinn owns and operates the vessel as a for-hire charter boat specializing in bottom and pelagic fishing trips. For the purposes of the study, Captain Jim Guinn and two hired deckhands were present on each of the twenty trolling trips. The deckhands were Jimmy Otwell (18 trips), Larry Lemieux (9 trips), Todd Ware (8 trips), and Shane Long (5 trips). In an effort to eliminate researcher bias, the professional deckhands conducted all rigging, setting and checking lines, and fighting of fish. Captain Guinn piloted the vessel and assisted in landing or releasing the fish.

The main purpose of the study was to simulate normal, common pelagic fishing practices to determine if a vessel could capture reef fish while trolling. On a typical charter pelagic fishing trip, Captain Guinn would use seven lines simultaneously. His tactics would vary, but in general he would use a maximum of 24 oz of weight on the trolling lines. Also, three of the seven lines would never use weight. Therefore, no more than four weighted lines would be deployed. Captain Guinn used outriggers to separate the fishing lines and prevent entanglement. The crew attached rubber-bands to the fishing line and used an outrigger clip to separate each line at the appropriate distance. During the low-speed trials, the heavy weight lines were deployed inboard and the light weight lines were deployed outboard. The outboard lines were set further behind the inboard lines. Many professional fishermen believe that this is the most effective technique because it simulates a moving school of baitfish.

Each trolling trip departed Panama City Beach, FL between 0230 and 0300 CDT. The MPA is approximately 50 miles from the point of departure and the one-way travel time is 3 hours while traveling at 17 kts. The trips were scheduled to coincide with the peak daily feeding times of the target species. Most pelagic species forage most actively in the early morning and late afternoon hours, although less active foraging takes place throughout the day [46]. Each trip accomplished four hours of trolling time with four lines in the water. Thus total fishing time was sixteen hours for each of the twenty trips. In the settlement agreement reached by NOAA and TOC, the study must conduct a minimum of 80 hours of total fishing effort and a maximum of 320 hours of effort. The four line trolling arrangement should have yielded the maximum of 320 hours. However, the actual total time was 301 hours and 3 minutes. The discrepancy is attributed to time fighting fish, checking the lures, clearing floatsam from the lines, and retrieving lures when fish were hooked on other lines to avoid entanglements.

The settlement agreement required that effort be distributed evenly between the first and second halves of the open fishing season, May 1-October 31. The total time in the first half was 151 hours 27 minutes (50.3%) and the total time in the second half was 149 hours 36 minutes (49.7%). The deckhands checked each line at a minimum of every thirty minutes to ensure bait quality and prevent fouling. If the bait checked consumed less than one minute of time out of the water, then the trolling trial was not ended. Bait checks that consumed more than one minute were considered to be the end of a trial. Once the bait was in proper condition, it was redeployed and a new trial began. Researchers decided to omit these checks to avoid redundancy in the final data set. At the beginning of each trial, time and position were recorded. Times were recorded to the nearest minute, while positions were recorded to the nearest hundredth of a minute of latitude and longitude.

1st Half of Trolling Trial May 1-July 31					
Speed	**Lure**	**Weight**	**N**	**Total Time (Minutes)**	**Range (Minutes)**
Low	Natural	Heavy	44	1442	3 - 83
Low	Artificial	Heavy	22	1497	6 - 172
Low	Natural	Light	42	1507	3 - 83
Low	Artificial	Light	18	1572	18 - 184
High	Natural	Light	48	1518	1 - 101
High	Artificial	Light	34	1551	3 - 104

Table 1. Trolling time trials for the 1st half of the study by speed, lure type, and weight.

2nd Half of Trolling Trial August 1-October 31					
Speed	**Lure**	**Weight**	**N**	**Total Time (minutes)**	**Range (minutes)**
Low	Natural	Heavy	28	1365	6 - 153
Low	Artificial	Heavy	23	1404	6 - 153
Low	Natural	Light	30	1442	1 - 164
Low	Artificial	Light	23	1477	12 - 164
High	Natural	Light	37	1635	2 - 96
High	Artificial	Light	39	1653	7 - 99

Table 2. Trolling time trials for the 2nd half of the study by speed, lure type, and weight.

Depth of Trolled Lure					
Speed	**Lure**	**Weight**	**Length**	**N**	**Depth of Lure (mean ± standard deviation)**
Low	Natural	Heavy	Short	49	9.55 ± 1.05 ft
Low	Artificial	Heavy	Short	52	12.73 ± 1.44 ft
Low	Natural	Light	Long	56	6.86 ± 1.08 ft
Low	Artificial	Light	Long	45	6.99 ± 1.28 ft
High	Natural	Light	Long	67	3.51 ± 1.08 ft
High	Artificial	Light	Long	54	4.82 ± 0.66 ft
High	Natural	Light	Short	70	5.25 ± 0.98 ft
High	Artificial	Light	Short	102	6.27 ± 1.15 ft

Table 3. Depth of trolled lure by speed, lure type, weight, and length of the line.

Catch

Reef fish and highly migratory species were not caught in the study. However, the researchers caught numerous coastal migratory species and one coastal shark. The species caught were wahoo (*Acanthocybium solanderi*), barracuda (Sphyraena barracuda), mahi-mahi (Coryphaena hippurus), king mackerel

(Scomberomorus cavalla), bonita (Euthynnus alletteratus), blackfin tuna (Thunnus atlanticus), and spinner shark (Carcharinus brevipinna). Fourteen of the twenty trolling days yielded fish. Thus, only six days of the twenty yielded no catch. A summary of catch is shown in Table 4.

Early Season (May 1 – July 31)		
9	**Wahoo**	(8 dead, 1 released alive)
5	**Barracuda**	(all released alive)
2	**King Mackerel**	(1 dead, 1 released alive)
1	**Mahi Mahi**	(released alive)
1	**Bonita**	(released alive)
Late Season (August 1 – October 31)		
9	**Wahoo**	(all dead)
1	**Blackfin tuna**	(released alive)
1	**Bonita**	(released alive)
1	**Mahi Mahi**	(released alive)
1	**Shark**	(released alive)

Table 4. Summary of catch for the trolling study.

The goal of the study was to determine reef fish susceptibility to surface trolling using common pelagic trolling techniques. The researchers made an effort to troll over areas of high relief hardbottom that are known to have gag grouper spawning aggregations. While Captain Guinn generally trolled over the known gag grouper spawning aggregations, he also observed weed lines and convergence zones within the MPA. When such oceanographic features were observed, Captain Guinn targeted those areas and slightly deviated from the high relief hardbottom areas. Targeting these ephemeral phenomena is common practice while targeting highly migratory species and coastal pelagic species [47].

Catch per unit effort is a common metric calculation used to estimate the amount of catch per unit of time. In the calculations, I took the total catch for each variable combination and divided the catch by time in hours. The results are summarized in Table 5 and Table 6.

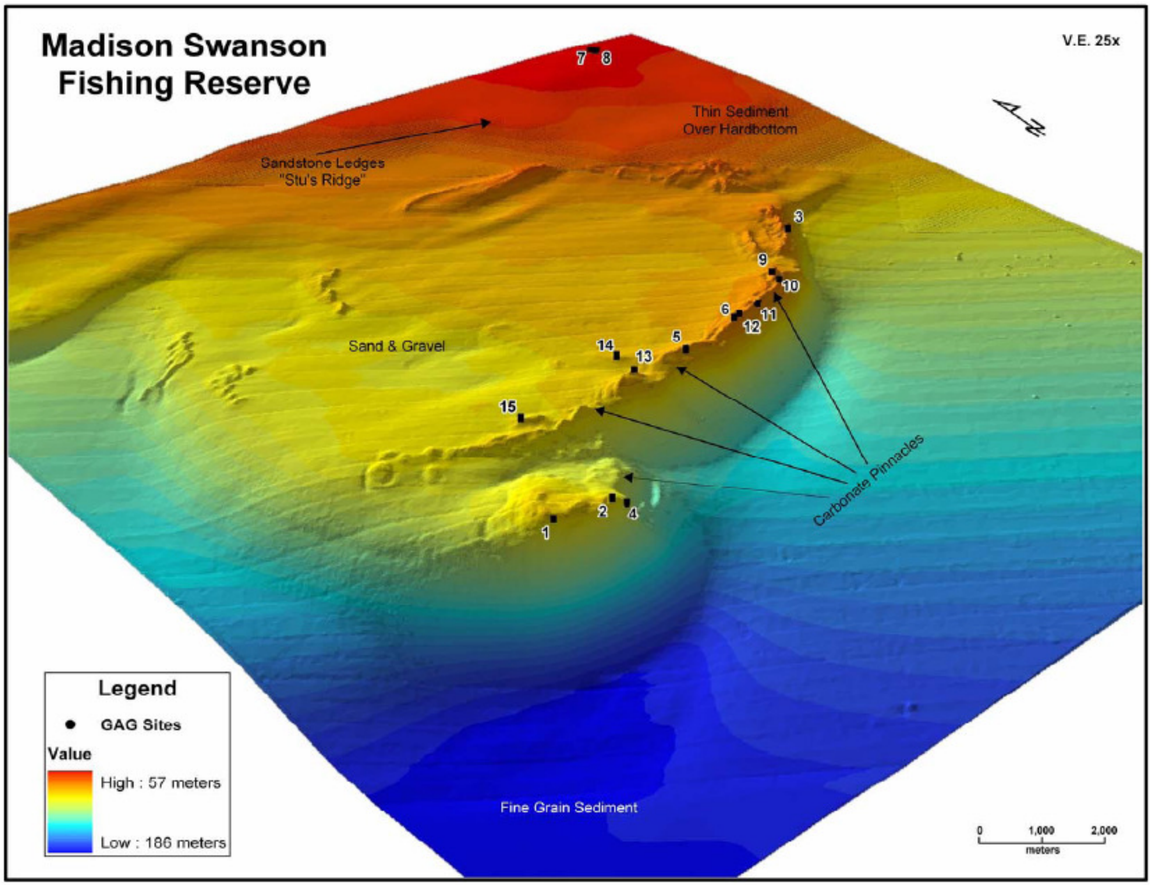
Catch Per Unit Effort (CPUE)				
Early Season				
Speed	**Lure**	**Weight**	**Catch**	**CPUE**
High	Artificial	Light	2 wahoo	0.077
High	Natural	Light	3 wahoo, 1 bonita, 1 barracuda	0.198
Low	Artificial	Light	2 wahoo	0.076
Low	Natural	Light	3 barracuda, 1 wahoo, 1 mahi-mahi	0.199
Low	Artificial	Heavy	2 king mackerel, 1 wahoo	0.120
Low	Natural	Heavy	1 barracuda	0.042
All Combinations			No Reef Fish	0.000

Table 5. Catch Summary and Catch per Unit Effort calculated as catch per hour.

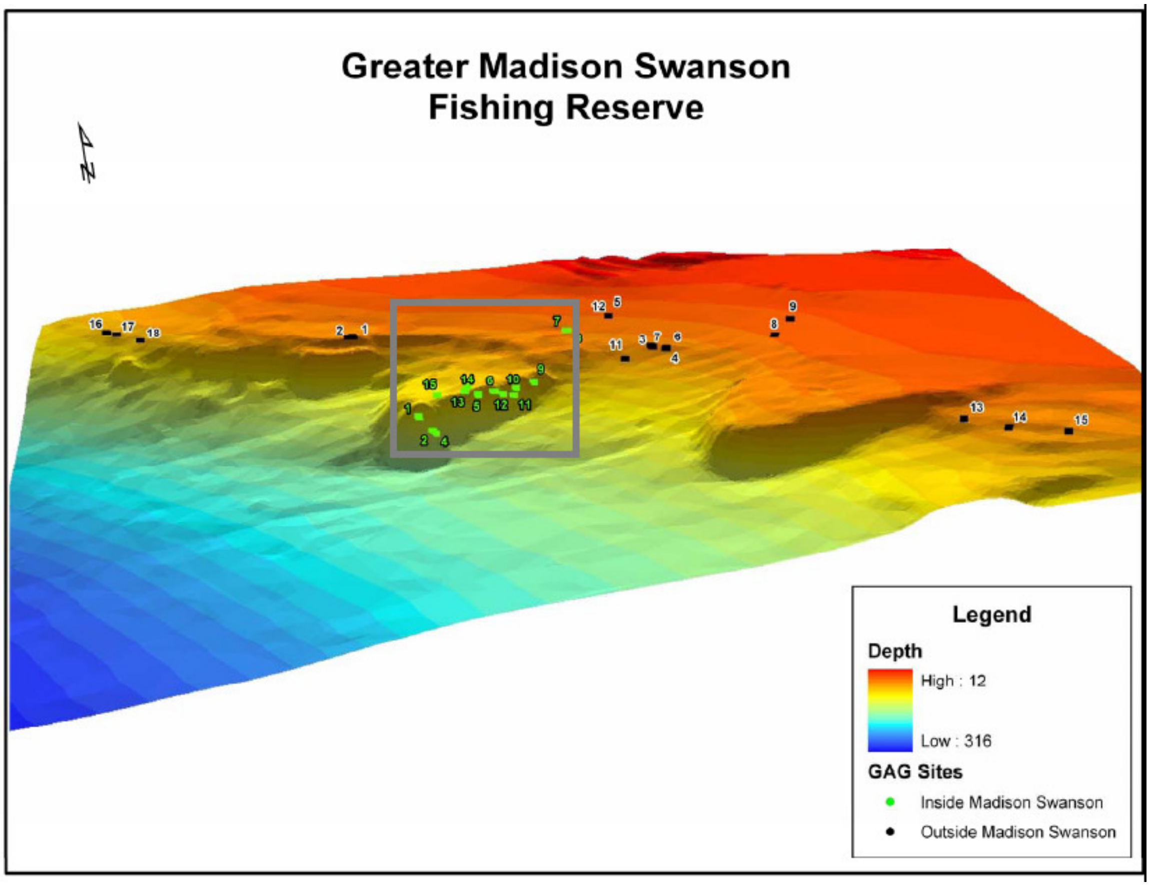
Catch Per Unit Effort (CPUE)				
Late Season				
Speed	**Lure**	**Weight**	**Catch**	**CPUE**
High	Artificial	Light	2 wahoo	0.073
High	Natural	Light	3 wahoo	0.110
Low	Artificial	Light	No catch	0.000
Low	Natural	Light	2 wahoo, 1 blackfin tuna, 1 bonita, 1 mahi-mahi	0.208
Low	Artificial	Heavy	1 wahoo	0.043
Low	Natural	Heavy	1 wahoo, 1 spinner shark	0.088
All Combinations			No Reef Fish	0.000

Table 6. Catch Summary and Catch per Unit Effort calculated as catch per hour.

The highest and lowest CPUEs occurred in the late season trolling trials. The low speed, natural lure, light weight combination yielded the highest CPUE, 0.208 per hour. The low speed, artificial lure, light weight combination yielded the lowest CPUE, 0.000 per hour. The trolling trials did not yield any reef fish, therefore the CPUE for all reef fish was 0.000 per hour.



Map 1. Madison Swanson Fishing Reserve Bathymetry.



Map 2. Greater Madison Swanson Fishing Reserve.

Madison Swanson MPA Boundaries	
Northwest Corner	29 [deg] 17' N. Lat., 85 [deg] 50' W. Long.
Notheast Corner	29 [deg] 17' N. Lat., 85 [deg] 38' W. Long.
Southwest Corner	29 [deg] 06' N. Lat., 85 [deg] 50 W. Long.
Southeast Corner	29 [deg] 06' N. Lat., 85 [deg] 38 W. Long.

Table 7. Madison Swanson MPA Boundaries, given in degrees and minutes, Latitude and Longitude.