

The effects of shelf-edge fishing on the demographics of the gag, *Mycteroperca microlepis*, population of the southeastern United States.

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INTRODUCTION

There is much misinformation circulating about the biology of gag grouper and the effects of fishing on the demographics of gag populations in the southeastern United States. Much of this misinformation, or misunderstanding of existing information, is understandable because the information is somewhat complex. This document is designed to provide the scientific facts and their inferences in a straight-forward manner so that informed decisions can be made as to the appropriate management measures for this nearly over-fished species¹ (GMFMC 1999). The information presented and discussed is either published or in press in peer-reviewed scientific journals, unless otherwise noted, and every attempt has been made to clarify the issues. A new synthesis of recent data is also presented that directly sheds light on the mechanism of sex ratio alteration by fishing. The information presented in this document applies equally to the gag population of the eastern Gulf of Mexico, and the South Atlantic Bight.

In the following I point out facts about the gag population. By “facts” I mean scientifically documented information that is gained in such a way as to leave little probability of an alternative explanation. Other words used throughout this document that refer to the nature of the information are “inference” and “anecdotal”. “Inference” is used to mean a conclusion derived from a rational extension of facts or a deduction based on a generalization. This word is not synonymous with “guess”, “surmise”, “suggest”, or “hint”. “Anecdotal” is used to mean information based on or consisting of reports or observations of unscientific observers.

BIOLOGY OF GAG

¹ Based on a static SPR of 18 – 23% with a overfished threshold of 20%, the RFSAP (August 1998 meeting) concluded that the gag fishery may be undergoing overfishing .

FACT: Gag aggregate to spawn.

Observations and video documentation of gag aggregations were made by Gilmore and Jones (1992) in the late 1970's in the south Atlantic off Ft. Pierce, FL (now the Experimental Oculina Research Reserve, EORR). In the Gulf of Mexico ROV observations of gag aggregations were made in 1994 within the area of the newly proposed 40 fathom reserve (see **Figure 14**) (NOAA cruise report, 1994). In March of this year (1999) NMFS Pascagoula and Panama City research personnel on board the R/V Oregon II surveyed the 40 fathom reserve and observed and collected gag in spawning condition.

FACT: Spawning gag concentrate on shelf-edge reefs (25 – 70 fathoms deep).

Fishery independent and fishery dependent observations in the Gulf of Mexico (Koenig et al. 1996, Coleman et al. 1996, Collins et al. 1998) and in the South Atlantic (McGovern et al. 1998) regions confirmed the presence of reproductively active gag on shelf-edge reefs and not in shallower water (<25 fathoms). The gag aggregations in the EORR occurred in the same depth zone (Gilmore and Jones 1992) as those in the Gulf of Mexico. Also, the depth distribution of male gag captured throughout the year (**Figures 1 and 2**) supports findings that spawning takes place exclusively on shelf-edge reefs.

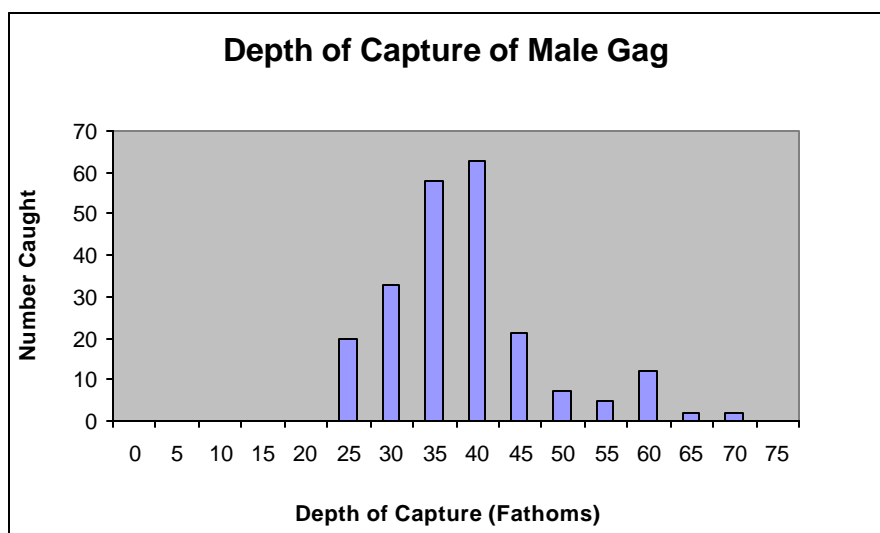


Figure 1. Commercial fisherman's log of depth of capture of male gag for the time period of the late 1970's to the early 1990's in the northeastern Gulf of Mexico.

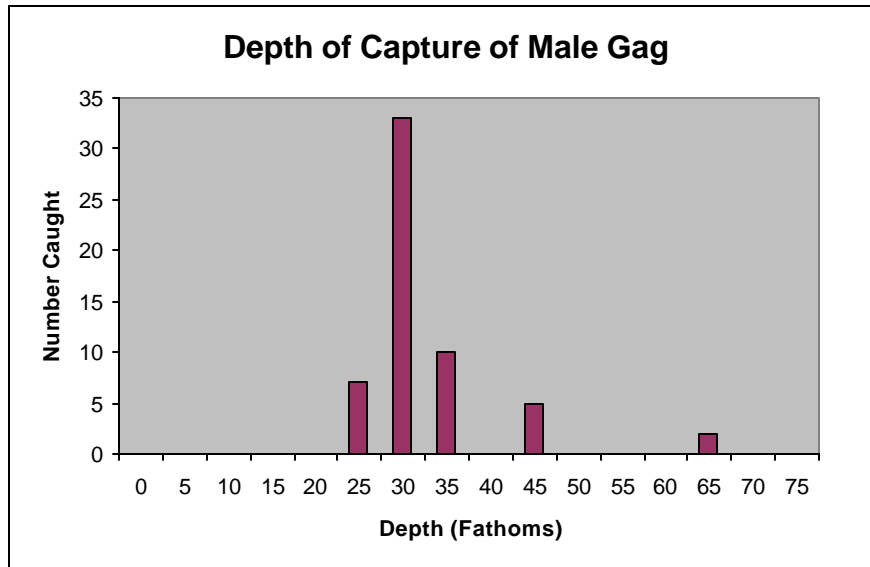


Figure 2. Depth of capture of male gag collected at all times of the year from the fish houses of Panama City Florida by NMFS-Panama City personnel from 1991 through 1994. Data in Collins et al. 1998.

FACT: Gag change sex from female to male (= protogyny).

The protogynous nature of gag was discovered long ago (McErlean and Smith 1964) and confirmed by subsequent studies (Collins et al. 1987, Hood and Schlieder 1992, Koenig et al. 1996, and Coleman et al. 1996). These data on gag reproduction conform to the criteria for determining protogyny presented by Sadovy and Shapiro (1987).

FACT: Male gag have a distinctive coloration pattern.

Males have a distinctive color pattern (**Figure 3**) that includes dark pigment on the abdomen. Fishermen term male gag “copper bellies” or “charcoal bellies” in the Gulf of Mexico. Collins et al. 1998 confirmed that 95% of such pigmented gag are histologically recognizable males or transitionals (fish in the process of sex change, as determined by histological examination of gonads). Permanent pigmentation of male gag allow us to identify them in situ through the use of an ROV (remotely operated vehicle) or a submersible.

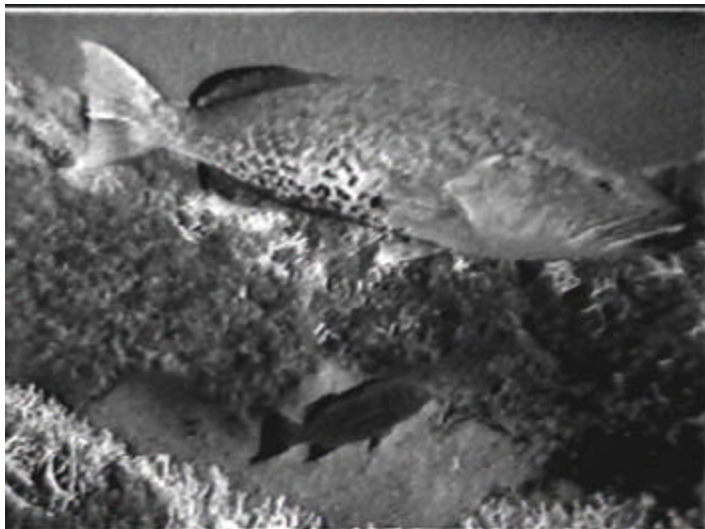


Figure 3. Male gag (note coloration) videotaped in a spawning aggregation in the Experimental Oculina Research Reserve off Ft. Pierce, FL in 1980 by Gilmore (Harbor Branch Oceanographic Institute (HBOI), Ft. Pierce, FL). Scamp spawning aggregations are in close proximity to gag aggregations (a scamp is below and behind the male gag).

INFERENCE: Sex change is controlled in gag by social cues rather than by age or size, and sex change is initiated during or just after spawning aggregation.

Sex change in virtually all of the protogynous species studied to date is socially mediated. That is, the social environment dictates the time of sex change rather than a rigid genetic-based sex change at a particular age or size (Warner 1988). These studied species include the small sea bass *Anthias squamipinnis*, representatives of wrasses of the genera *Thalassoma*, *Labroides*, *Bodianus*, and genera of angelfish such as *Centropyge*, and many more. A number of mechanisms have been proposed for sex change in the various species, but all are based on the social organization and the mating system (Ross 1990). Theoretically, a female in a protogynous social group changes sex when the social environment changes to give her increased reproductive success as a male. Reproductive success of males is determined by the number and fecundity of females with whom they spawn. So, in protogynous species that aggregate to spawn (like gag and scamp) females can only assess their future reproductive success as a male when they are together, as on the spawning aggregations. This theoretical view implies that sex change should be initiated during or immediately after spawning aggregation (Shapiro 1987). Although there are no direct studies on the sex change process in gag, the monthly frequency of males and transitionals is exactly what would be expected if sex change was initiated during spawning aggregation. See **Figures 7-10** which were derived from data of McGovern et al. 1998 and Collins et al. 1998.

FACT: The spawning season of gag extends from January to April with peak spawning in February and March.

The definition of the gag spawning season in the Gulf of Mexico is presented in Hood and Schlieder 1992, Koenig et al. 1996, Collins et al. 1998, and Koenig and Coleman 1998 from both the analysis of gonads and from the back-calculation of fertilization times from incremental analysis of juvenile otoliths. The spawning season in the south Atlantic region is slightly more protracted with the peak later, as determined by McGovern et al. (1998).

INFERENCE: Most, if not all, males remain in shelf-edge depths (25 – 70 fathoms) throughout the year.

That most, if not all, males remain in deep water in the Gulf of Mexico is inferred from catch records. This inference is supported by two independent sets of catch data, one from a commercial fisherman's log of male gag catch times and depths extending from the 1970's to the early 1990's (**Figure 1**), and the other is a record of fish house samplings in Panama City from 1991 to 1994 by the NMFS Panama City Laboratory personnel, reported in Collins et al. (1998) (**Figure 2**). The NMFS records usually

contained a range for depth of capture, so the minimum depths in the range were used in **Figure 2**, as opposed to the actual depths in **Figure 1**.

INFERENCE: Fish on gag spawning aggregations are derived from broad geographic regions.

The results of tagging studies in the South Atlantic Bight infer that gag migrate great distances (hundreds of miles) to spawning locations (Van Sant et al. 1994). Heinisch and Fable (1999) showed fall movements of gag from inshore St. Andrew Bay waters to shelf-edge depths in the northeastern Gulf of Mexico. Finally, gag tagged off South Carolina moved over 100 miles to Florida and some even moved to the Gulf of Mexico (McGovern and Miester 1998, **Figure 4**). Thus, gag spawning aggregations may be composed of fish derived from locations great distances from the aggregations.

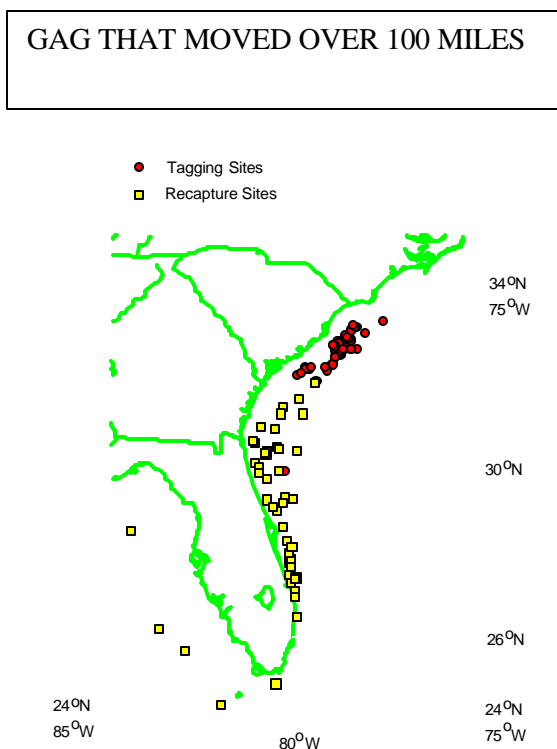


Figure 4. Movement patterns of gag tagged off South Carolina that moved over 100 miles. Figure from McGovern and Miester 1998 by permission from the authors.

FACT: Juvenile gag are tightly associated with estuaries for the first 5-6 months of their lives.

This has been documented in the Gulf of Mexico and in the South Atlantic Bight by numerous studies including Keener et al. 1988, Ross and Moser 1995, Mullaney and Gale 1996, Koenig and Coleman 1998, and others.

FISHERY EFFECTS

FISHING PATTERNS AND EFFECTS

FACT: Fishermen target gag spawning aggregations.

The targeting of gag spawning aggregations is apparent in the commercial landings data of the west coast of Florida (Koenig et al. 1996, **Figure 5**, and Schirippa and Legault 1997, see their Figure 5), and through anecdotal accounts of commercial fishermen. Gag aggregations can easily be targeted by both commercial and recreational fishermen on the east coast of Florida where the shelf is narrow, but primarily by commercial fishermen on the west coast of Florida where the shelf is far broader and the shelf-edge reefs are much further offshore. The aggregations are targeted because catch per effort increases (**Figure 6**), especially during the peak spawning months of February and March.

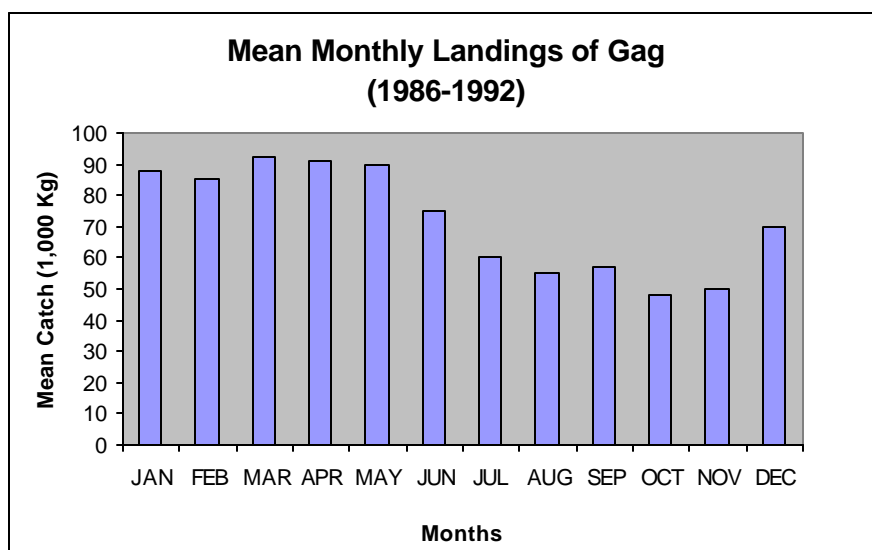


Figure 5. Mean monthly landings of gag from 1986 to 1992 from the eastern Gulf of Mexico. Data from Koenig et al. 1996.

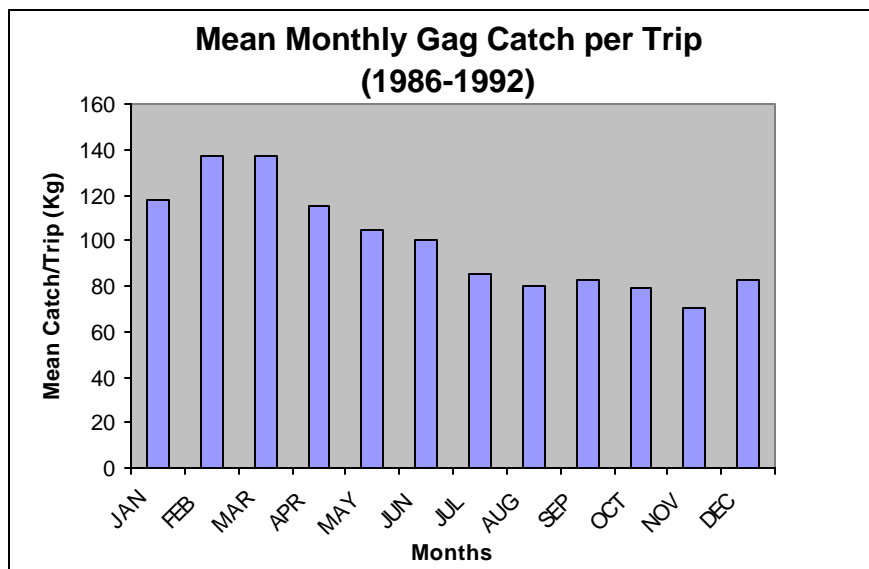


Figure 6. Mean monthly catch per trip of gag from 1986 to 1992 from the eastern Gulf of Mexico. Data from Koenig et al. 1996.

FACT: Demographic changes in the gag population (lowered male:female sex ratio and truncated size structure) have occurred over the last 20 to 25 years in both the Gulf of Mexico and the South Atlantic Bight.

A statistically significant decline in the proportion of males in the gag population in the Atlantic (McGovern et al. 1998) and in the Gulf of Mexico by Koenig et al. 1996, Coleman et al. 1996 and Collins et al. 1998 has been reported. In addition, the size structure in the Gulf fishery reflects the loss of large fish (Koenig et al. 1996 and Coleman et al. 1996). The decline in the proportion of males was hypothesized to be the result of a combination of the effects of fishing on shelf-edge reefs and the timing of sex change induction (Koenig et al. 1996). This hypothesis will be discussed in detail using recent information from the Atlantic and Gulf of Mexico later in this document.

Other demographic changes occurring over the last two decades in the gag population of the South Atlantic Bight have been shown, including a change in size at maturity (McGovern et al. 1998) and a change in size at age (Harris and Collins in press).

A recent (1998) memo by Fitzhugh (NMFS Panama City Laboratory) about catches from long-line vessels fishing on the shelf-edge off southwest Florida has inappropriately found its way into the Gulf of Mexico Fishery Management Council's documents after a direct request from Fitzhugh that the data not be presented because it was not comparable to historical hook and line data. These gag sex ratio data are not comparable to historical records because of the different gears used and because the long-line fishing occurred in areas off southwest Florida, an area where we have no historical records of shelf-edge catches of gag. In other words, for comparisons among years to be valid the same fishing areas and the same fishing gears (with the same biases) must be compared (and the same temporal distribution of samples should be made; discussed later), but this was not the

case with the data in the Fitzhugh memo. The male gag proportion of 10% that came from that memo should not be used in any serious discussion of the facts that relate to historical and present sex ratios. Only hook and line data are compared in this document.

It is important to keep in mind that the true sex ratio is unknown (and possibly unknowable) and all we have is the apparent sex ratio based on the particular selection characteristics of the gear, the location of sampling, and the distribution of the samples throughout the year. We may be able to more closely approximate the true sex ratio by visual (ROV) sampling, however even this is subject to bias based on the behavioral differences of the genders and the time of sampling. The important consideration is the functional sex ratio, that is, the apparent sex ratio at the time of spawning.

INFERENCE: Increased targeting of gag spawning aggregations throughout the 1980's is responsible for the observed size and sex ratio changes.

Anecdotal reports from commercial fishermen and documentation from Gilmore (Harbor Branch Oceanographic Institute, Ft. Pierce, FL, personal communication) support the log data indicating that fishing increased on the shelf-edge reefs of Florida and on gag spawning aggregations during the 1970's through the 1990's. Observations in the EORR both before and after closure provide strong support that fishing the aggregations is the cause of the observed demographic changes in the gag population. Since bottom fishing was prohibited with the EORR closure in 1994, the frequency of occurrence of males has increased from none observed in 1995 and 1996, to one observed in 1997, and three observed in 1999.

FACT: Gag spawning aggregations can be and have been fished to extinction.

Loss of a gag spawning aggregation by fishing has been observed directly in the Experimental Oculina Research Reserve (EORR). Spawning season observations made before (late 1970's) and after (mid 1990's) a period of intense fishing (Grant Gilmore, Harbor Branch Oceanographic Institute, Ft. Pierce, personal communication; Koenig unpublished data) illustrates aggregation loss through fishing. Such loss is also implied on the northern shelf-edge reefs (south, southeast of Panama City) off the west coast of Florida where we have observed no aggregations to date, even though the habitat consists of high relief (1-15 m) reefs throughout that area. Similar losses of grouper spawning aggregations have been documented for Nassau grouper throughout the Caribbean (Sadovy 1994), and for jewfish in the southeastern U.S. (DeMaria, commercial fisherman, Key West, FL),

PROPORTION OF MALES AND TRANSITIONALS IN THE CATCH

FACT: Many more males and transitionals are removed from the gag population by fishing at non-spawning times than at spawning times.

Male and transitional gag are captured at higher rates after the spawning season in both the South Atlantic region (McGovern et al. 1998, **Figures 7 - 9**) and in the Gulf of Mexico (Collins et al. 1998, **Figure 10**, and from a commercial fisherman's records, **Figure 11**). Clearly, a closed season would do nothing to preserve the sex ratio of the

gag spawning aggregations because males are reduced in abundance by fishing at non-spawning times.

INFERENCE: The monthly proportion of males and transitionals in the gag population indicates that sex change is under social control and is induced during spawning aggregation

Figures 7 through 11 shed considerable light on the nature of gag sex change. It is immediately obvious that all these figures (**Figures 7 – 9**, from the Atlantic and **Figures 10 and 11** from the Gulf of Mexico) are similar in appearance. The proportion of males and transitionals in the catch during the spawning season (January to April) is low, then there is a dramatic increase in males/transitionals in the months following the spawning season followed by a more gradual decline to the lowest frequency in the following spawning season. The rapid increase in the proportion of males and transitionals just after spawning is exactly the pattern of male/transitional abundance that would be expected if sex change is initiated during the time of spawning and sex change is under social control. The time for sex change to reach completion once initiated is therefore probably on the order of one to several months.

INFERENCE: The monthly capture rates of males and transitionals indicate that the sex ratio of gag is in disequilibrium.

Figures 7 through 11 also shed considerable light on the impact of the fishery on the sex ratio and the sex-change process. The best data set is presented first in **Figures 7 – 9** (data from McGovern et al. 1998). These data resulted from samples taken from commercial fishermen required by a U.S. Department of Commerce emergency rule to land their gag catch whole (i.e., ungutted) so that gonads could be sampled and the sex ratio assessed. That rule was enacted because of concern about the Atlantic stock of gag showing a similar decline in the proportion of males as was shown in the Gulf of Mexico gag stock (Koenig et al. 1996, Coleman et al. 1996). In **Figure 7** the number of samples (N) is indicated above the bars; the heaviest sampling was done during the spawning season and the lightest in August through October. **Figure 8** clearly shows transitionals in greatest abundance just following the spawning season which indicates that the population is producing many males, apparently to compensate for males lost during non-spawning times. This figure also infers that fishing on the shelf-edge reefs in non-spawning times keeps the proportion of males low by extracting the newly transformed males from the population before they can function as males in the following spawning season. The population is in a constant state of sex ratio disequilibrium, and it is fishing on shelf-edge reefs at non-spawning times that keeps it that way. Clearly, a spawning season closure would be ineffective in restoring the proportion of males in the population, and therefore in protecting the integrity and productivity of the spawning aggregations. The possibility that some male behavior at the time of spawning, such as no feeding or non-association with the aggregated females, negatively effects the apparent sex ratio is contrary to the in situ observations of Gilmore and Jones (1992, and personal communication) and contrary to the historical data (**Figure 12**). These researchers observed that males are indeed in association with the females in the aggregations and that males feed heavily at this time and could readily be caught on hook and line. In addition, the very high proportion of transitionals, which is at least 10% of the catch

(**Figure 8**), and at least 20% of the large (890-1050 mm TL) adults (**Figure 9**), shows directly that the rate of sex change is extremely high in this population. The conclusion that the sex ratio in the gag population is in dynamic disequilibrium is inescapable.

Figure 10 illustrates a similar pattern of male abundance in the catch, this time in the Gulf of Mexico stock. In 1994 the fish houses of Panama City, FL were sampled intensely each month (L. A. Collins, personal communication) so that as many males as possible could be collected. Clearly, the most males appeared in the fish houses just after spawning and declined throughout the rest of the year to a minimum level in the following spawning season. No males were collected during the spawning months. Koenig et al. (1996). Unlike the former figures in which the data are presented as percent of catch, these data are a direct estimate of the monthly capture rates of males in the Gulf commercial fishery.

Figure 11 displays a similar pattern, this time the catch is the long-term record of a single commercial fisherman operating out of Panama City, FL. These long-term records extend from the late 1970's to the early 1990's. The pattern again shows a rapid increase in the catch rate of males after spawning with a gradual decrease to the spawning time the following spawning season.

Figures 7 - 11 also demonstrate that sex ratio is not a static measure in the gag population, but a dynamic compensation for the loss of males from the shelf-edge population (the habitat of males, see earlier discussion). Therefore, to determine an overall sex ratio one must define when the samples were taken. For example, if the larger proportion of samples were taken in the several months following spawning, the proportion of males would appear high, but if they were taken in the late fall, it would appear low. Of course, the important consideration is the proportion of males is at the time of spawning aggregation, and future estimations of sex ratio should only be made on gag caught at shelf-edge depths in the spawning season. In all observed cases in the 1990's the proportion of males on the aggregations is low, a condition that must be corrected.

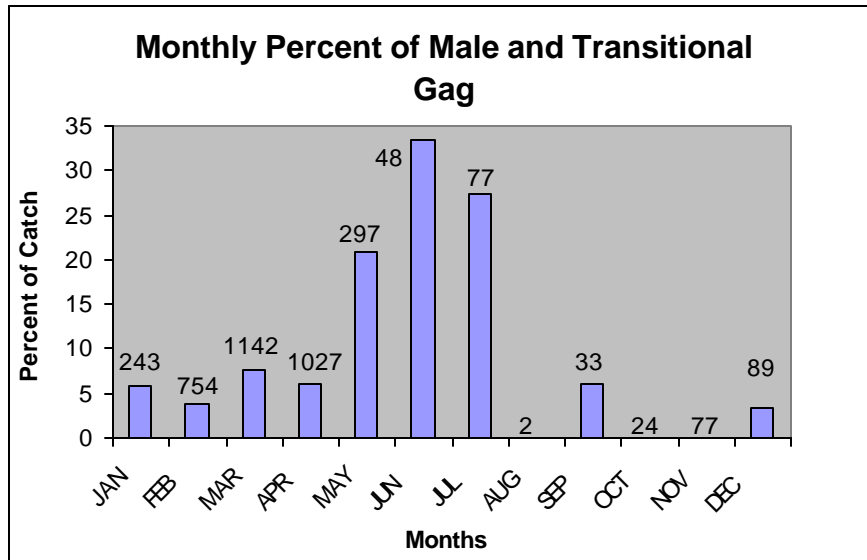


Figure 7. Monthly percentage of male plus transitional gag in the commercial catch from the South Atlantic Bight in 1994 and 1995. Data from McGovern et al. 1998. Numbers above bars represent the sample size for that month.

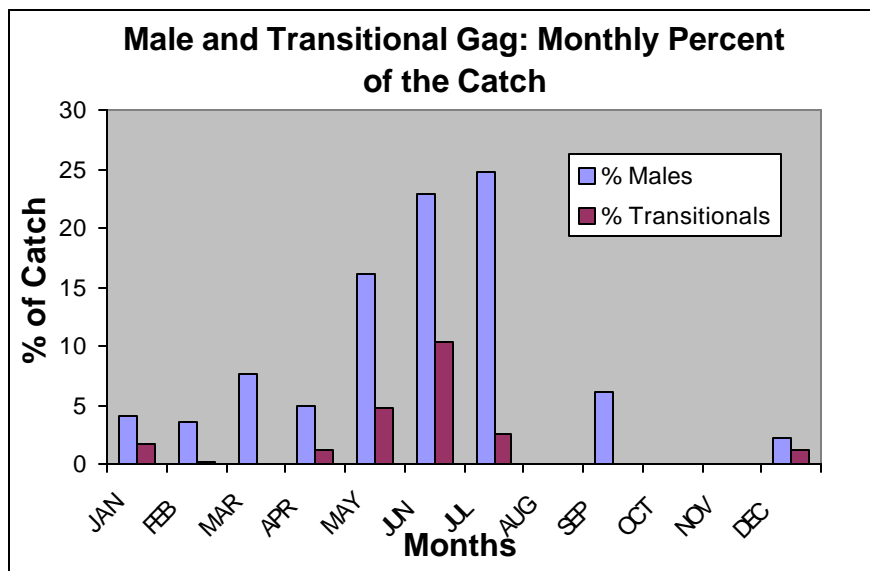


Figure 8. Male and transitional gag from the South Atlantic Bight commercial fishery, 1994 and 1995, expressed as percent of the monthly catch. Data are the same as in Figure 5 (McGovern et al. 1998) except that males and transitionals are represented separately.

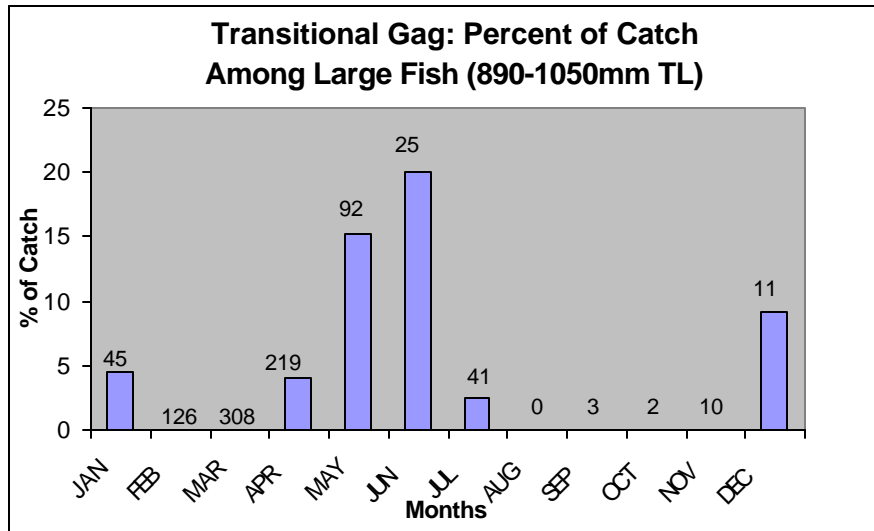


Figure 9. Transitional gag in from the South Atlantic Bight commercial fishery, 1994 and 1995, expressed as percent of monthly catch of fish between 890 and 1050 mm TL. Data derived from McGovern et al. 1998. Numbers above bars represent sample size.

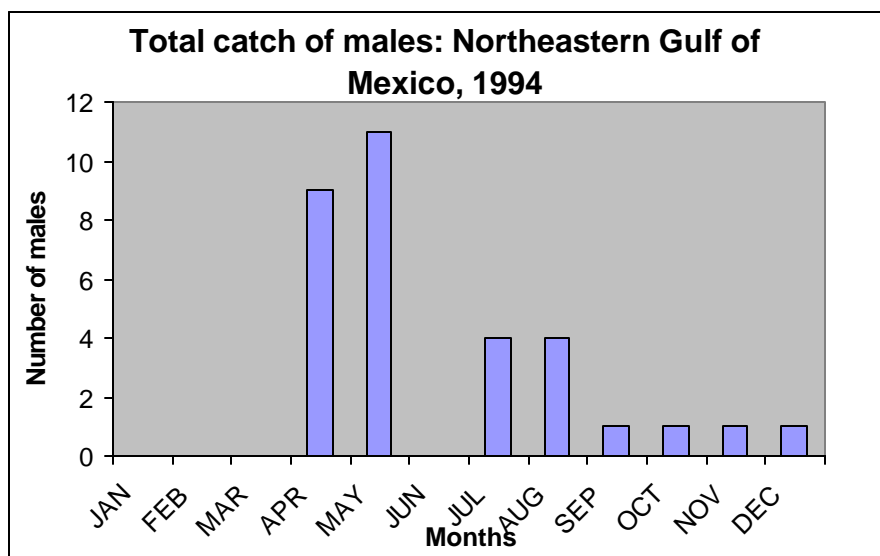


Figure 10. Total monthly catch of male gag collected from the Panama City, FL fish houses by NMFS Panama City Laboratory personnel in 1994. Data from Collins et al. 1998.

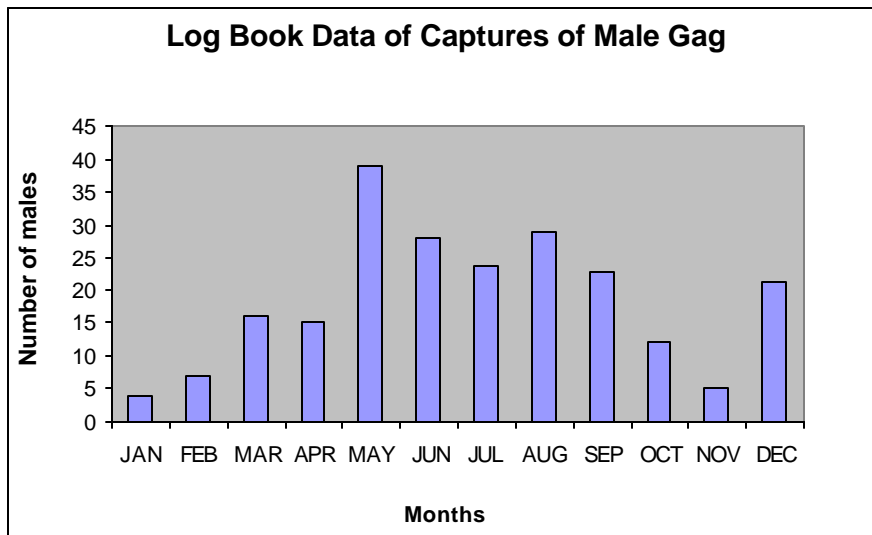


Figure 11. Commercial fisherman's log of monthly captures of male gag for the time period of the late 1970's to the early 1990's in the northeastern Gulf of Mexico.

INFERENCE: Gag aggregations that are presently being fished on the shelf-edge reefs of the eastern Gulf of Mexico and South Atlantic Bight are dysfunctional.

In March 1999, aboard the NOAA ship Oregon II, NMFS personnel from the Pascagoula Laboratory and the Panama City Laboratory made ROV observations on 8 sites (two hours of video recorded observations per site) within the newly proposed 40 fathom reserve (**Figure 14**). This was the time of peak spawning for gag; many females were observed, but not a single male. Male behavior is aggressive and curious (Gilmore and Jones 1992 and Gilmore video, and Koenig personal observation); it appears likely that they would be seen if they were present. These observational data support the inference that presently fished gag aggregations are dysfunctional.

Gag sex ratio data collected by Hood and Schlieder (1992) in the late 1970's in the northeastern Gulf of Mexico show a pattern of male and transitional abundance that is much less pronounced than that of **Figures 7 through 11**, the recent pattern. In the late 1970's the average percentage of males and transitionals in the catch during spawning months (January through April) was 16%. In the same fishing area, using the same gear, in the gag spawning months of 1992, Koenig et al (1996) showed a percentage of males and transitionals of 1.7%. The presence of males in the commercial catch during the gag spawning season of 1994 was so low in the fish houses of Panama City, FL that Collins et al. (1998) could not collect any. Comparison of these two patterns, historical and present, infers that the proportion of spawning males declines in direct response to shelf-edge fishing intensity and with the general knowledge of aggregation sites.

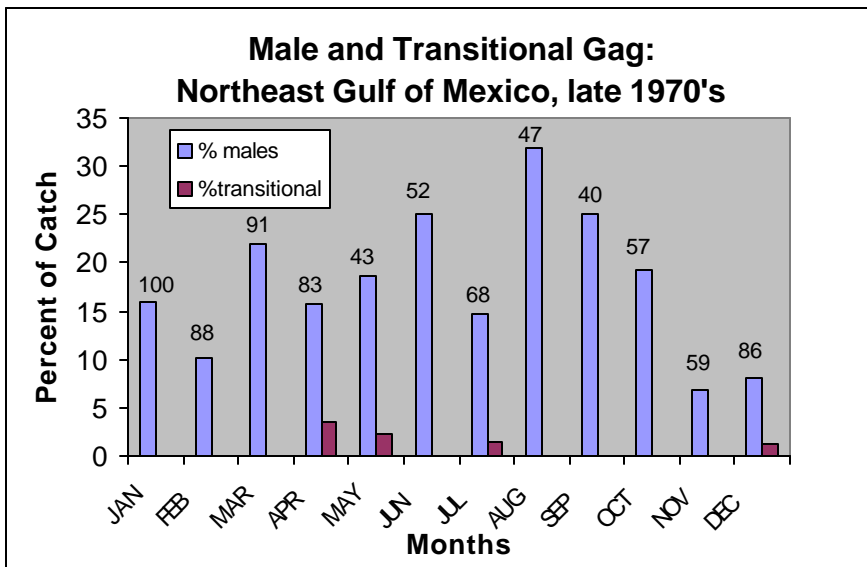


Figure 12. Percent male and transitionals in the commercial gag catch from the northeastern Gulf of Mexico, taken in the late 1970's. Data from Hood and Schlieder 1992, provided by Peter Hood. Numbers above bars are the total sample of mature fish for that month.

INFERENCE: Male gag will increase in proportion within a shelf-edge area closed to bottom fishing, but will not increase in response to a closed season.

This year (1999) in the EORR researchers from NMFS, FSU, and HBOI aboard the NOAA research vessel Oregon II observed three male gag. Only one male gag was observed in 1997, no observations were made in 1998, and three male gag were observed in 1999. These males were most likely associated with spawning aggregations but poor visibility (< 6 m) precluded their observation. These data support the use of shelf-edge reserves in restoring gag sex ratio, but do not support the use of a closed season. Closed seasons will not protect male gag, as most are caught after spawning aggregation in both the Gulf of Mexico and in the Atlantic (**Figures 7 – 11**). Without sufficient males the “seasonally protected” aggregations will remain dysfunctional.

GENETIC STRUCTURE

INFERENCE: The apparent genetic structure of the gag population of the southeastern U.S. reflects inbreeding.

Analysis of microsatellite DNA variation in gag, conducted recently by Chapman et al. (In press) infers inbreeding in the Atlantic and the Gulf of Mexico stocks.

INFERENCE: Apparent inbreeding in the gag population is likely the result of an abnormally low proportion of males during the spawning season, the loss of spawning aggregations, and a reduction in the population size in general.

All three of these consequences have been inferred to result from fishing the gag spawning aggregations, especially the first two. Inbreeding would result from fewer and fewer individuals contributing to subsequent year classes and those individuals in turn mating with their offspring (Chapman et al. In press). This is most easily explained by the loss of males.

INFERENCE: The genetic structure of the gag population could be seriously compromised if fishing patterns that existed in the past are allowed to continue.

The inference of inbreeding in the gag population is a major cause for concern because inbreeding inevitably leads to the loss of genetic diversity (Nei et al. 1975) and therefore the loss of potential for survival. Appropriate conservation measures must be instated as soon as possible to avert the loss of genetic diversity in the gag population (Chapman et al. In press). From the foregoing discussion relating to **Figures 7 through 11**, it is clear that the appropriate conservation measure is to close to fishing large areas on shelf-edge habitat.

JUVENILE ABUNDANCE

FACT: Juvenile gag abundance at seagrass reference sampling stations in the northeastern Gulf of Mexico has been relatively low from 1994 through 1998.

Seagrass is prime habitat for early juvenile gag. Over the past 10 years, we (Koenig and Coleman 1998) have been monitoring the abundance of juvenile gag in the seagrass beds of the west coast of Florida with a focus on developing a juvenile abundance-based recruitment-forecasting model. We have sampled the areas north of the Big Bend since 1989 and have developed a time-series of data for that region (**Figure 13**). This time series for the Panhandle shows that gag display an on-off year pattern of juvenile recruitment which we could trace back to 1985 using the age structure of the stock (Johnson and Koenig in press). But the pattern of recruitment that persisted from 1985 to 1993 did not persist from 1994 through the present, but instead remained low (**Figure 13**). Because of the relatively short time-series and because recruitment is highly variable it cannot be said that there is a statistically significant trend in recruitment. Nevertheless, the implication is that the described changes in the gag spawning stock are responsible for this low recruitment. Because of the extremely high fecundity of gag (Collins et al. 1998), fortuitous recruitment events should still occasionally occur, even if reproduction is supported by very few functional aggregations. However, as the Chapman et al. (in press) data infers, there are dire genetic consequences that result from a dependence on a very low number of spawners.

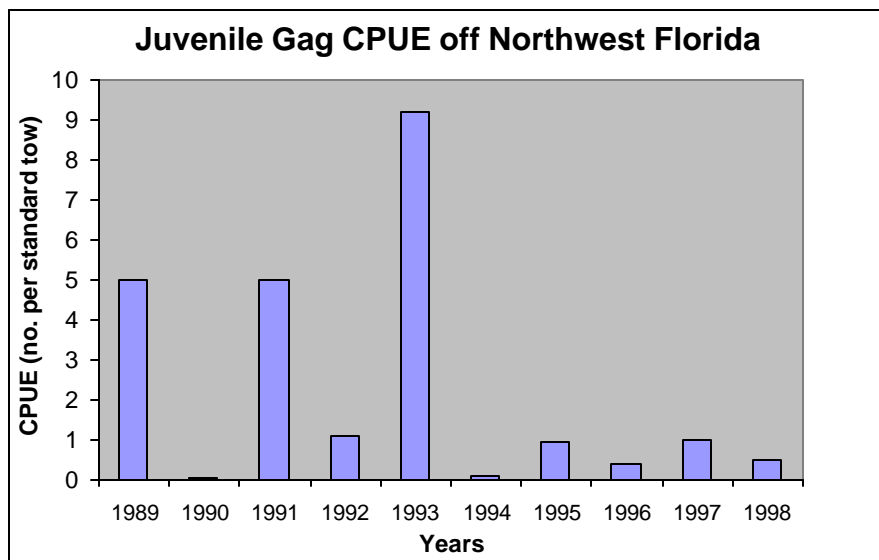


Figure 13. Catch per unit effort (CPUE) of standard trawl tows in reference seagrass beds of northwest Florida, north of the Big Bend. Data from Koenig and Coleman 1998.

SUMMARY AND DISCUSSION

Fishing on gag spawning aggregations is a common practice among commercial fishermen of the Gulf of Mexico and the South Atlantic Bight and is probably common among recreational fishermen on the east coast of Florida. Male gag, produced exclusively from females, are deficient in number on shelf-edge spawning aggregations that are targeted by fishermen. This deficiency likely renders the fished aggregations dysfunctional and eventually leads to the extinction of the aggregations. The practice of aggregation fishing has jeopardized the entire gag fishery, both commercial and recreational, and has threatened the genetic makeup of the gag population.

All the data on the sex ratio of gag indicate that the spawning population is in disequilibrium with respect to the proportion of males. That is, spawning aggregations are deficient in males because social sex change processes that compensate for the loss of males and equilibrate the spawning sex ratio are, in a sense, short-circuited through the removal of those males at non-spawning times of the year at shelf-edge depths. The conclusion from all this is inescapable; shelf-edge areas closed to fishing are required for the management of the gag fishery. Without them the dysfunctional aggregations will persist (or become extinct) because the removal of males will persist outside the closure period. Because we don't know the movement patterns of males within shelf-edge depths, a few large closed areas would be preferable to many small ones. A spawning season closure would do nothing to protect males and therefore the sex ratio at the time of spawning, but it would reduce F on the spawning stock at a time when they are aggregated and most vulnerable.

The conclusion that shelf-edge reserves are necessary for the management of the gag fishery is clear in light of the information presented in this document. The proposed 40-fathom reserve (**Figure 14**) centers on prime gag spawning habitat and NMFS observations (NOAA R/V Oregon II, March 1999) in that area show that reproductive gag are still present. Other shelf-edge reefs to the northwest of the 40-fathom reserve are high relief (1 – 15 m), but are relatively depauperate in groupers and other economically important reef fish of any kind (NOAA R/V's Chapman and Oregon II, early spring, 1994-1999). According to anecdotal accounts from commercial fishermen, aggregations were there in the past, but are not now. If indeed they were present on those reefs in the past it would be important to determine through fishing closure if they would return in the future. It is possible that restoration of grouper spawning aggregations and fish community structure on depleted shelf-edge reefs can be accomplished through the establishment of reserves. The observation of the recovery of scamp aggregations and the increased frequency of occurrence male gag the EORR (NOAA R/V Oregon II cruise, February 1999) supports the idea that recovery is possible through fishing closure.

Aggregation fishing likely has a large effect on regional fishing mortality (F). If gag on the aggregations are derived from large geographic areas as the tagging data suggest (**Figure 4**), then aggregation fishing effects the gag resources from large geographic areas. That gag return to a home location after aggregation is unknown. However, if they do then fishermen in one location may experience a significant decline in their adult gag resources, even though they practice strict conservation measures, and never realize that fishing practices tens to hundreds of miles away are the cause. Clearly, a large step toward decreasing F regionally would be to stop fishing on the spawning aggregations from January through April. The greatest negative impact of aggregation fishing in the Gulf may very well be on the recreational fishery. This fishery takes 78% in number, but less in weight, of the combined commercial and recreational catch (Schirripa and Goodyear 1994) and fishes on relatively shallow west Florida shelf reefs. Adult gag derived from such reefs may be caught on the aggregations and therefore not return.

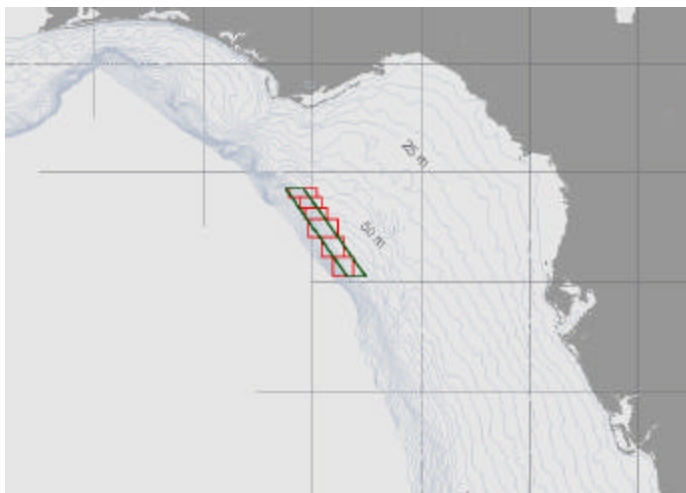


Figure 14. The proposed shelf-edge reserve off the Big Bend coast of Florida. The series of rectangles is the original proposal which was simplified to a single parallelogram centered on the 40 fathom isobath (superimposed).

It is important to recognize that the northeastern Gulf of Mexico, centering on the Big Bend, is the center of abundance for gag. Ninety-nine percent of the gag landed in the Gulf of Mexico come from the west Florida shelf (Schirripa and Goodyear 1994) and this production is several times greater than that of the South Atlantic Bight. “Center of abundance” means that all the necessary habitats and conditions for the completion of the life cycle of this species are optimal. For gag such habitats include shelf reefs for adult habitat, shelf-edge reefs for spawning habitat, seagrass for juvenile habitat, suitable pelagic habitat for larvae, and shelf current patterns that transport of larvae to the estuaries. A phenomenon known as the “Green River” increases the nutrient content of the shelf-edge waters in the spring potentially providing optimum pelagic habitat for developing larvae. Thus, production can be very high in this species (and presumably others) if there are no bottlenecks to that production, like fishing out the spawning aggregations and rendering the remaining aggregations dysfunctional. Parker (1983) estimated that about 17% of the west Florida shelf is reef habitat, and the seagrass resource is arguably the largest continuous, most unaltered warm-temperate seagrass habitat in the United States. The Big Bend comprises over 1/3 of the seagrass resources of the U.S. Gulf of Mexico (Zieman and Zieman 1989). The production potential for gag in this region appears extremely high if reproduction is allowed to operate unimpeded.

It is also important to recognize that gag, although a very important fishery species, is merely the flagship species for the entire reef community. Gag has been studied intensively over the last decade and the results of this research demonstrate the value of reserves for fishery purposes. The spawning groups of many other reef species are concentrated at the shelf-edge depths including scamp, red grouper (Coleman et al. 1996), red porgy (Doug DeVries, NMFS Panama City Laboratory, personal communication), and possibly red snapper. Scamp shows similar demographic changes as gag (Coleman et al. 1996). We know very little about the reproductive ecology of these and other economically important reef species, but as can be seen from close inspection of shelf-edge fishing effects on gag, reserves may be absolutely necessary for their continued production as well. The red porgy in the South Atlantic Bight is a good example; this is a protogynous species that spawns on shelf-edge reefs, like gag. The South Atlantic Fishery Management Council recently closed the red porgy fishery by emergency rule as the population continues to decline regardless of the traditional management measures imposed. Red porgy recruitment is essentially zero (Doug Vaughn, NMFS Beaufort Laboratory, personal communication and his most recent red porgy stock assessment report). In short, shelf-edge reserves provide protection for species like gag (and maybe red porgy) that absolutely require it, but also provide insurance against our ignorance of the reproductive ecology of other economically important reef species and the ecological community that supports them.

The value of shelf-edge reserves to fishery production can be determined in the future through the monitoring of the demographics of shelf-edge aggregations, and the monitoring of subsequent recruitment of those species. With respect to gag, observations of the occurrence of males, the size of fish in the aggregations, the number of fish in the aggregations, and the formation of new aggregations would provide strong inference of the importance of such reserves on gag production. Additional support would come from the ongoing monitoring of seagrass habitat of the west coast of Florida. Increased juvenile recruitment would provide correlative evidence that the reserves are accomplishing their intended purpose. However, the most powerful support for the production value of the reserves would come from establishing a genetic connection between gag spawners in the reserves and seagrass-associated progeny of those spawners. With such a genetic analysis it would be possible to estimate of the contribution of the reserve to the juvenile gag recruitment of the west coast of Florida (Bob Chapman, South Carolina Department of Natural Resources, Charleston, SC, personal communication).

It is unfortunate that the burden of proof of aggregation fishing is on the scientist and not on the commercial fishermen who are affecting the resource (see Dayton 1998), particularly since the adverse impacts of aggregation fishing have been known for a long time (Shapiro 1987, Sadovy 1994), and signs of problems in the gag population were brought to the attention of the two southeastern fishery management councils by Koenig in 1993 and in subsequent years. The South Atlantic Fishery Management Council responded by establishing the EORR and closing it to bottom fishing in 1994. The Gulf of Mexico Fishery Management Council responded in 1999 and voted to close the 40 fathom reserve (**Figure 14**). This decision is now being reconsidered by that council. Now is the time for both fishery management councils to make clear, informed decisions based on the scientific facts and inferences, which are condensed in this brief document. A new level of thinking is needed to solve our fishery resource problems. Albert Einstein said it best, “You can’t solve a problem with the same level of thinking that created the problem.”

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