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A TAG AND RECAPTURE STUDY OF GAG, *MYCTEROPERCA MICROLEPIS*, OFF THE SOUTHEASTERN U.S.

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ABSTRACT

During 1995–1999, 3876 gag, *Mycteroperca microlepis* (Goode and Bean, 1879), were tagged off the southeastern U.S. from North Carolina to southern Florida, primarily from commercial fishing vessels. Prior to release, the swim bladder of tagged fish was deflated with a 16-gauge hypodermic needle. Approximately 11% of the tagged fish were recaptured. Many gag (36%) moved < 2 km, however, 23% of the recaptured gag moved > 185 km. Most of the gag that moved > 185 km were tagged off South Carolina and recaptured off Georgia, Florida, and in the Gulf of Mexico. Gag tagged at depths of 20–40 m showed the greatest degree of movement while gag tagged in deeper water appeared to be relatively sedentary. Recapture rate was greatest for gag tagged off southern Florida and gag tagged off Georgia and Florida were generally recaptured near the same area that they were tagged. Recapture rate declined with increasing depth of capture of tagged fish. Depth-related mortality of degassed fish was estimated to range from 14% at 15 m to 95% at 95 m. Recapture data from 1996–1997 for gag tagged in 1996 provided an estimate of fishing mortality = 0.27. The length of gag tagged was related to depth, with significantly larger individuals occurring in water deeper than 35 m. It was estimated that 3.6% of the gag tagged during 1995–1999 were male. The mean length of gag tagged and depth of capture was greatest during the spawning season (February–April) suggesting that commercial fishermen may have targeted spawning aggregations.

The gag, *Mycteroperca micropelis* (Goode and Bean, 1879), is a long-lived, protogynous hermaphroditic grouper that is of considerable commercial and recreational importance along the southeastern Atlantic coast of the U.S. and in the Gulf of Mexico. However, McGovern et al. (1998) reported that as landings along the southeastern Atlantic coast increased, there was a significant decrease in the mean length of fish landed, a decrease in the percentage of males in the population, and a smaller size at maturity for females. Similar changes were reported in the Gulf of Mexico (Coleman et al., 1996).

Gag may make annual migrations to specific locations to aggregate and spawn (Coleman et al., 1996). With the exception of studies by Van Sant et al. (1994) off the southeastern Atlantic and Heinisch and Fable (1999) in the Gulf of Mexico, other investigators have reported limited movement of gag (i.e., Beaumariage and Wittich, 1966; Moe, 1966; Huntsman et al., 1996). This study had the following objectives: to (1) document movement patterns; (2) estimate growth rates; (3) examine the effect of depth tagged on survival of released fish; (4) determine the effect of size and days at large on movement; and (5) estimate fishing mortality for gag off of the southeastern U.S.

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Methods

During 1995–1999, gag were captured by commercial fishermen aboard commercial fishing vessels and double tagged with a nylon barbed tag and an internal tag. Nylon barbed tags (14.5 cm long) were hooked on the pterygiophore of the third dorsal spine using a hollow, handle-mounted canula. Internal tags (10.5 cm) were inserted on the left side of the abdomen, ~1 cm above the ventral midline, at a midpoint between the base of the pelvic fin and the anus. Incisions were made with size 12 surgical scalpel blades. The insertion area, tag, and surgical tools were cleansed with a 75% iodine solution before the incision was made. Prior to release, the swim bladder was deflated with a 16-gauge hypodermic needle that was inserted through the body wall ~2.5 cm posterior to the base of the left pectoral fin.

Total length (TL), standard length, date, species, tag number, condition of specimen, depth of capture and release location were recorded on paper and video for each specimen. Fishermen were paid $0.50 per pound above market price to tag and release gag. Some gag were also captured with a chevron trap or hook and line gear from the R/V Palmetto and from chartered vessels. Other species included in the tagging project were greater amberjack *Seriola dumerili* (Risso, 1810), red porgy *Pagrus pagrus* (Linneaus, 1758), gray triggerfish *Balistes capriscus* Gmelin, 1789, vermilion snapper *Rhomboplites aurorubens* (Cuvier in Cuvier and Valenciennes, 1829), white grunt *Haemulon plumieri* (Lacepède, 1801), and black sea bass *Centropristis striata* (Linneaus, 1758).

Both types of tags were blaze orange, marked with a number, address and reward message. Posters displaying information and rewards were placed at marinas from North Carolina to Florida. Anglers that returned tags were rewarded with a t-shirt or hat. There was also an annual draw of returned tags worth $500. Number on tag, length of fish, and location and date of capture were obtained from anglers by letter, phone, or e-mail.

Distance moved was examined as a function of total length, days at large, and depth using an analysis of variance (ANOVA). Recapture rate of gag associated with depth was compared to greater amberjack, *S. dumerili*, to determine if changes in recapture rate were due to depth-related mortality. The logit model was used to estimate depth-related mortality for gag (SAS, 1990).

Survival rate (S) during 1996–1997 was calculated as: $S = R_2/R_1$, where R_2 = the number of recaptures during 1997 that were tagged during 1996 and R_1 = the number of recaptures during 1996 that were tagged during 1996 (Ricker, 1975). Instantaneous mortality (Z) was determined by the equation: $Z = -(\log_e R_2 - \log_e R_1)$. Natural mortality ($M$) was estimated as: $M = 2.98/T_{max}$ (Hoenig, 1983) where T_{max} for gag = 26 yrs (Harris and Collins, 2000). Instantaneous mortality was estimated by catch curve analysis using the catch-at-age data for gag landed from North Carolina to eastern Florida during 1996. An age-length key (Harris and Collins, 2000) was applied to 1996 length frequency data of gag that were landed by commercial fishermen in South Carolina, commercial landings (North Carolina to Florida), headboat landings (North Carolina to Florida), and recreational landings (North Carolina to Florida) to produce a catch-in-numbers at age matrix. Landings of gag in 1996 were divided by 6.5 kg to estimate the number of individuals (Potts and Brennan, 2001). A regression was fitted to Ln-transformed numbers of fully recruited cohorts to determine Z (Ricker, 1975).

Using data from McGovern et al. (1998), the percentage of males at size was applied to lengths of gag tagged to estimate the number of male gag at depth. The percentage of males at size was also applied to the length frequency of gag that were landed by commercial fishermen in South Carolina to examine trends in the percentage of males landed. Age-length data from Harris and Collins (2000) was used to partition the lengths of gag tagged into age categories. Growth (mm d^{-1}) for each age group was determined as: growth = (recapture TL – tagged TL)/number days at large.

Results

During 1995–1999, 3876 gag were tagged off North Carolina, South Carolina, Georgia, and along the east coast of Florida from St. Augustine to Key West (Fig. 1; Table 1) with most gag (81%) tagged off South Carolina (> 32° N). Of the fish tagged, 11.2% (n = 436) were recaptured. The longest period of time that a specimen was at large was 2066 d (Table 2) and the greatest distance moved was estimated at 1767 km. Tagged fish were at large for an average of 366 d and moved an average distance of 150 km. The number of days at large had a significant effect on distance moved (Table 2). ANOVA and the Scheffe Multiple Range Test indicated that the distance moved was significantly related to the depth (Table 3) with gag captured between 21 and 40 m moving the greatest distance.

For gag tagged at all latitudes, 36% moved more than 37 km (Table 2). Many gag (36%), moved ≤ 2 km. The highest percentage of gag that moved more than 185 km were tagged off South Carolina and moved south to Georgia, east Florida, the Florida Keys, and west Florida (Fig. 2). Two individuals moved north more than 185 km from

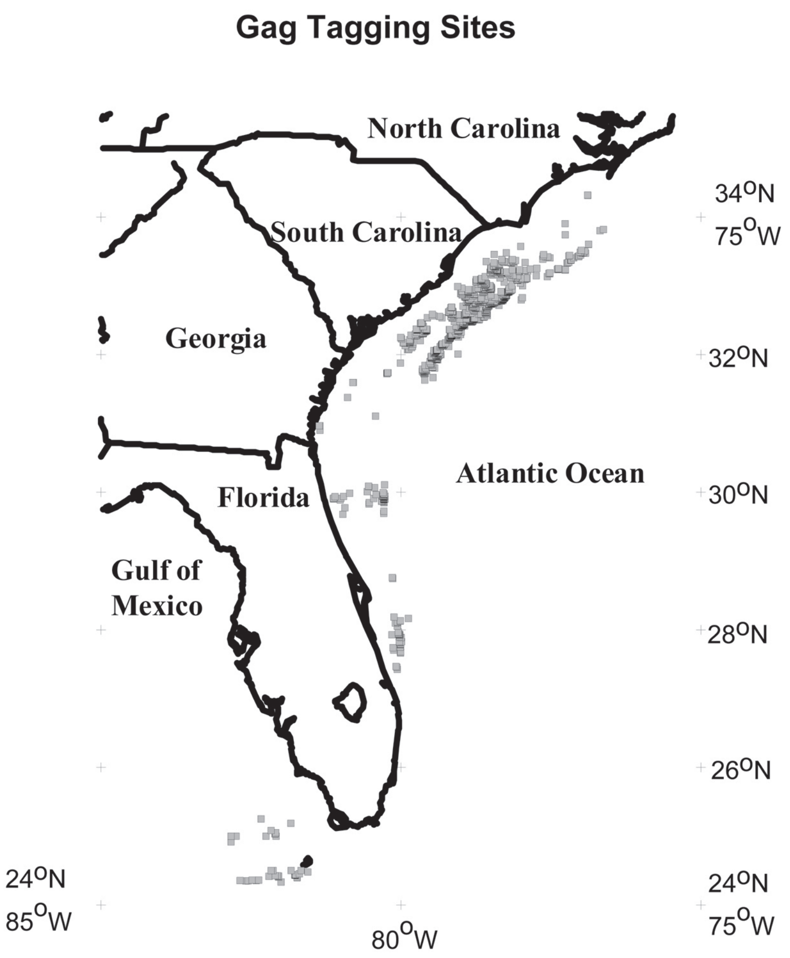

Figure 1. Locations off the southeastern U.S. where gag were tagged during 1995–1998.

Table 1. Number of gag tagged and recaptured by latitude.

			Latitude recaptured (°N)										
Lat. tagged (°N)	No. tagged	No. recap (%)	33	32	31	30	29	28	27	26	25	24	No data*
33	582	87 (15)	41	16	2	3	4	3	5	0	2	3	8
32	2,558	275 (11)	6	163	15	24	10	11	17	4	1	2	22
31	321	14 (4)	0	0	9	1	1	0	0	0	0	0	3
30	15	2 (13)	0	0	0	2	0	0	0	0	0	0	0
29	127	12 (9)	0	0	0	1	10	0	0	1	0	0	0
28	21	2 (10)	0	0	0	0	0	2	0	0	0	0	0
27	53	3 (6)	0	0	0	0	0	0	3	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0
25	93	30 (32)	0	0	0	0	0	0	0	1	29	0	0
24	84	11 (13)	0	0	0	0	0	0	0	0	4	7	0
No data*	22	0											
Total	3,876	435 (11)	47	179	26	31	25	16	25	6	36	12	33

*Represents situation where no data were recorded on either latitude tagged or latitude recaptured.

Table 2. Distance moved, number of specimens recaptured (Rec), mean total length (TL) tagged, average length recaptured, mean days at large for tagged gag that were recaptured, mean depth (m) of fish tagged (does not include specimens without depth data). Length of tagged fish did not have a significant effect on distance moved (ANOVA; P > 0.05). Distance moved was significantly related to the number of days at large. Asterisk indicates significant (ANOVA and Scheffe Multiple Range Test; P < 0.0001) difference in days at large.

Dist. moved (km)	# Rec	Mean TL tagged (mm) (range)	Mean TL recaptured (mm) (range)	Mean days at large (range)	Mean depth (m) tagged (range)
No Data[1]	35				
< 2	158	711 (260–1,027)	739 (260–1,080)	228 (1–2,066)	33 (11–66)
2–37	87	736 (274–1,115)	796 (436–1,100)	284 (10–1,627)	37 (16–71)
38–93	35	766 (443–1,145)	849 (443–1,016)	457* (10–1,807)	37 (22–62)
94–185	21	712 (532–883)	827 (538–1,067)	643* (56–1,402)	31 (18–55)
> 185	99	784 (238–939)	860 (711–1,067)	492* (30–1,882)	30 (16–62)
Total	435	739 (238–1145)	796 (260–1,100)	366 (1–2,066)	33 (11–71)

[1] No recapture location was recorded for 35 individuals.

Key West, Florida to the Gulf of Mexico. A third individual moved from shallow water off Charleston, South Carolina (32° N) to the shelf edge at the North Carolina/South Carolina border (33° N).

Recapture rate was greatest (35%) for gag tagged off the Florida Keys (25° N; Table 1). These fish were at large for an average of 103 d. Gag tagged off South Carolina (32–33° N) showed the most movement with 29% of the tag recaptures occurring from Georgia to Florida and 25% moving to locations off Florida. Fish tagged off Georgia and Florida were generally recaptured near the same latitude that they were tagged (Table 1). Gag tagged off South Carolina (32°–33° N) were at large for a significantly longer time and moved greater distances (mean = 399 d; 173 km) than gag tagged off Florida (mean = 184 d; 38 km).

The recapture rate declined with increasing tagging depth from 19.4% for individuals tagged from 11–20 m depth (midpoint = 15 m) to 0% for fish tagged from 85 m depth (Table 4). The maximum depth from which a gag was tagged and later recaptured was 73 m. Greater amberjack, another species tagged during the study, did not show any trends in recapture rate with respect to depth (Table 5). Depth-related mortality for gag was estimated to range from 14.2% at 15 m to 94.8% at 95 m (Fig. 3;

Table 3. Depth at tagging, mean length tagged, mean total length (TL) recaptured (rec), mean distance moved, mean days at large and sample size for gag tagged off NC and SC (32°–33° N). Values in parentheses represents the standard deviation. Asterisk indicates significant (ANOVA and Scheffe Multiple Range Test; P < 0.0001) difference in distance moved.

Depth (m)	Mean TL (mm) tagged	Mean TL (mm) rec	Mean dist (km) moved	Mean days at large	N
11–20	578 (166)	647 (157)	43 (119)	316 (440)	49
21–30	709 (119)	781 (124)	209* (323)	424 (395)	181
31–40	771 (105)	827 (92)	219* (291)	356 (310)	88
41–50	828 (77)	868 (87)	39 (127)	324 (407)	76
51–60	842 (81)	894 (68)	91 (241)	301 (317)	23
61–70	832 (56)	891 (68)	85 (251)	225 (183)	16
71–80	787	_	9.0	355	1

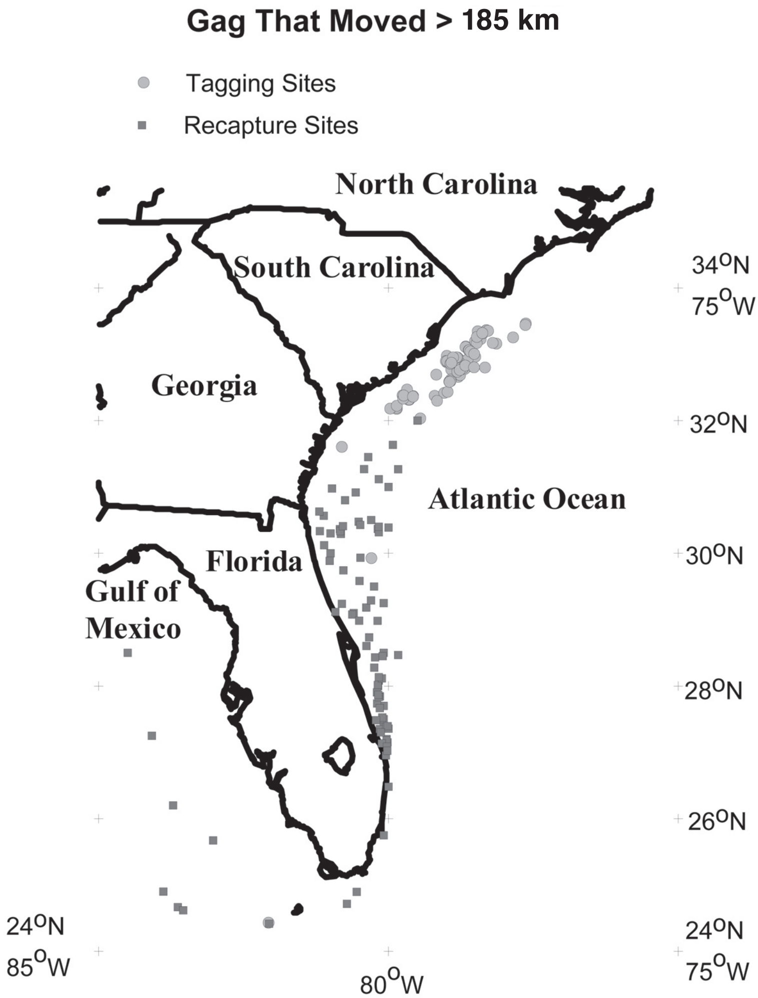

Figure 2. Tag and recapture locations off the southeastern U.S. for gag that moved south > 185 km.

Table 4). Recapture data from 1996–1997 for gag tagged in 1996 provided an annual survival (*S*) of 0.68 and instantaneous mortality (*Z*) of 0.38. Natural mortality of gag was estimated as 0.11 using the formula $M = 2.98$ max age^{-1} (Hoenig, 1983) and fishing mortality (*F*) was determined as 0.27. A catch curve analysis from 1996 data provided similar estimates, $Z = 0.40$ and $F = 0.29$ (Fig. 4).

The length of gag tagged was related to depth with significantly larger individuals occurring in water deeper than 35 m (Table 6). Using data from McGovern et al. (1998), the percentage of males at size was applied to length frequency of tagged fish to estimate the number of males at depth. The percentage of males tagged was greatest in water deeper than 55 m. It was estimated that 3.6% of the gag tagged during 1995–1999 were males. The estimated percentage of males landed by commercial fishermen in South Carolina decreased from 33.3% in 1976 to 3.7% in 1996. The

Table 4. Depth (midpoints), number of gag tagged, number recaptured, percent recaptured, mortality (number) determined by logit analysis, and percent mortality at depth determined by logit analysis.

Median tagging depth (m)	Number tagged	Number recaptured	Percent recaptured	Fitted logit mortality (number)	Fitted logit mortality (percentage)
15	253	49	19.4	36.04	14.2463
25	1,221	181	14.8	281.16	23.0274
35	730	88	12.1	255.58	35.0113
45	871	76	8.7	428.90	49.2420
55	357	23	6.4	227.04	63.5966
65	321	16	5.0	243.58	75.8801
75	39	1	2.6	33.15	84.9966
85	57	0	0	51.91	91.0728
95	11	0	0	10.43	94.8377

mean length of gag tagged and depth of capture was greatest during February–April and least during May–July (Table 7).

An age-length key from Harris and Collins (2000) was used to partition recaptured gag into age categories. Growth rates determined from tagged and recaptured gag decreased from 0.29 mm d^{-1} for age 1 fish to 0.11 mm d^{-1} for age 7 fish (Table 8).

Discussion

Data presented here indicate that gag are capable of extensive movement and this contributes to genetic exchange between the Atlantic Ocean and Gulf of Mexico. One individual that was tagged off South Carolina moved 1767 km to the Gulf of Mexico. Gag that showed the greatest movement were tagged at depths of 21–40 m off North Carolina and South Carolina. Movement to areas off Florida may have been related to spawning activity, however, we were unable to identify a seasonal component to gag that moved > 185 km since these individuals were at large for an average of 492 d and were collected throughout the year. Van Sant et al. (1994) speculated that movement of three gag from South Carolina to Georgia and Florida may have been related to spawning activity and the present data support this. South of 32°N (South Carolina), gag were usually recaptured within the same latitude that they

Table 5. Depth (midpoints), number of greater amberjack (*Seriola dumerili*) tagged, number recaptured, and percent recaptured. Note that there is no trend in the percent recaptured with depth.

Depth (m)	Number tagged	Number recaptured	% recaptured
15	11	3	27.3
25	12	1	8.3
35	94	10	10.6
45	332	42	12.7
55	719	138	19.2
65	451	63	14.0
75	293	33	11.3
85	244	33	13.5
95	53	10	18.7

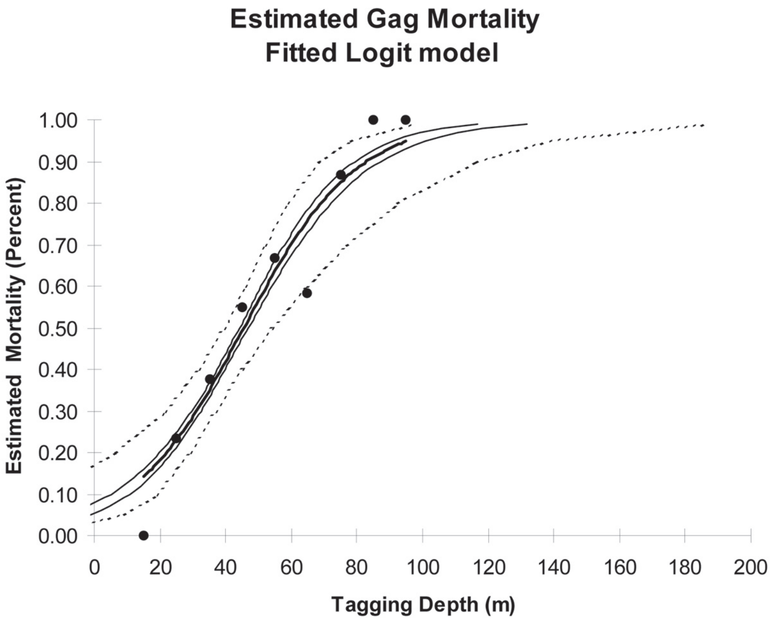

Figure 3. Logit analysis of gag recapture rate with depth showing estimated depth-related mortality (thick line) as well as 95% (thin lines) and 99% (dashed lines) confidence intervals.

were tagged. It is possible that gag off Georgia and Florida are not making extensive migrations for spawning or are caught before they have the opportunity to migrate.

Recapture rate of gag in the Florida Keys was higher than points north suggesting that gag may be subject to more fishing pressure by commercial fishermen, recreational fishermen, and sport divers off Florida due the very narrow continental shelf. Furthermore, 25% of the recaptured gag that were tagged off South Carolina and North Carolina were recaptured off Florida. The average number of days at large for fish tagged off Florida was significantly less than for gag tagged off North Carolina and South Carolina, further supporting higher fishing mortality in the south. In ad-

Table 6. Depth (midpoints) for 10 m increments, number of gag tagged, mean total length (TL) in mm at tagging, estimated number of males, percentage of fish tagged estimated to be males. Values with different letters were significantly different (ANOVA, Scheffe Multiple Range Test; P < 0.0001).

Depth (m)	Mean TL (mm) tagged (SE)	Number of fish tagged	Number of males	% males
15	573^{C} (10)	253	1	0.4
25	720^{B} (3)	1,221	5	0.4
35	794^{A} (4)	730	16	2.2
45	848^{A} (0.3)	871	49	5.6
55	874^{A} (0.5)	357	30	8.4
65	875^{A} (0.5)	321	30	9.3
75	858^{A} (2.2)	39	4	9.0
85	869^{A} (0.9)	57	4	6.5
95	853^{A} (4.3)	11	1	9.7
overall	780	3,876	140	3.6

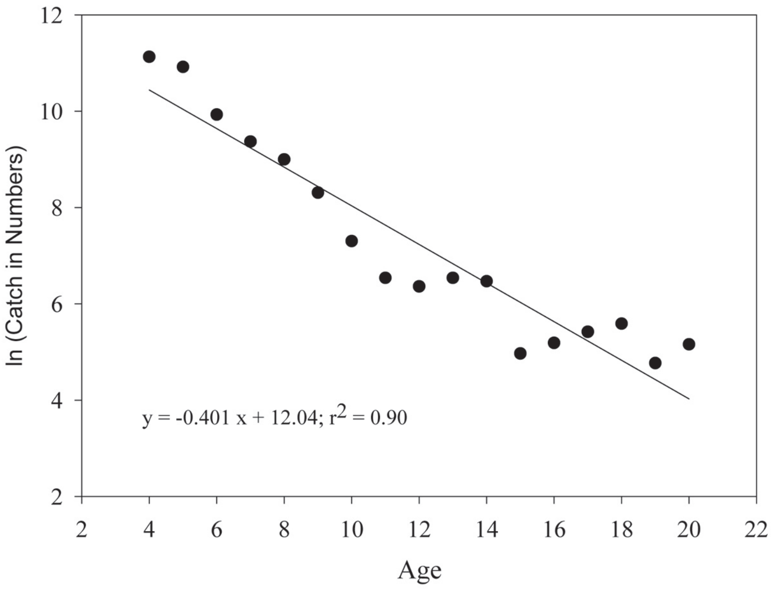

Figure 4. Catch curve analysis of 1996 data for gag caught off the southeastern U.S.

dition, gag spawning aggregations at depths of 49–91 m (McGovern et al., 1998) are probably more easily accessed by fishermen off Florida than areas north due to the narrow continental shelf. This narrow continental shelf off Florida may increase fishing mortality for many other species by "funneling" them close to shore in the vicinity of the high human population.

The recapture rate of tagged gag decreased with increasing depth, however, these trends were not evident for greater amberjack. All gag and greater amberjack had air removed from their swim bladders prior to release. Gag are demersal, whereas greater amberjack move throughout the water column. Therefore, depth-related mortality may be responsible for the trend in decreased recapture rate with depth. Several investigations indicated that mortality of released fishes can be high and generally increases with depth (Parker, 1991; Gitschlag and Renaud, 1994; Wilson and Burns, 1996; Collins, 1996). Assuming that there was no release mortality of gag at 0 m, we used the tag recapture data to estimate depth-related mortality ranging from 14% (11–20 m) to 85% (71–80 m). If swimbladders of gag had not been deflated prior to release of the fish, it is likely that mortality would have been much higher because many gag would not have been able to return to depth. Collins (1996) estimated that

Table 7. Number, average total length (TL) in mm at tagging, and average depth (m) for gag tagged during February–April, May–July, August–October, and November–January. February–April represents period of peak spawning for gag. Months with different letters were significantly different (ANOVA, Scheffe Multiple Range Test; $P < 0.0001$).

Quarter	Number tagged	Mean TL (range)	Mean depth (range)
February–April	535	822^{A} (230–1169)	49.8 (7–90)^{A}
May–July	1,249	766^{C} (230–1190)	35.1 (15–73)^{D}
August–October	1,562	785^{B} (238–1145)	38.2 (16–93)^{C}
November–January	531	784^{B} (322–1139)	41.0 (11–92)^{B}

Table 8. Estimated growth rate (mm d^{-1}) from Harris and Collins (2000) for data collected during 1994–1995 and growth rate (mm d^{-1}) determined from tagged and recaptured gag. TL = total length.

Age (yr)	Range TL (mm)	Growth rate (Harris and Collins, 2000)	Growth rate (this study)
1	<541	-	0.29
2	542–615	0.18	0.26
3	616–702	0.22	0.28
4	703–784	0.25	0.21
5	785–846	0.20	0.19
6	847–892	0.14	0.17
7	893–935	0.11	0.11
8	936–974	0.13	-
9	975–1,006	0.09	-
10	≥ 1,007	0.08	-

57% of groupers (*Mycteroperca* spp. and *Epinephelus* spp.) that were caught by hook and line in 46–54 m floated when released and probably died. Huntsman et al. (1996) and Potts and Manooch (1998) stated that at least 20% of gag caught by headboat fishermen that were not degassed could not return to depth after being released and later died. Collins et al. (1999) determined that deflation of swimbladders of black sea bass provided significant reductions in mortality and the benefits of deflation increased with depth. The recapture of a gag that was tagged from 73 m further supports the benefits of swim bladder deflation and indicates that at least a portion of degassed fish survived the trauma of capture even in deep water.

Using gag recapture data from 1996–1997, Z was estimated to be 0.38. Catch curve analysis of 1996 landings data provided a similar value (Z = 0.40). If M was at or near 0.11, as we estimated and as Huntsman et al. (1996) suggested, then F was between 0.27 and 0.29 during 1996–1997. If M = 0.15 as suggested by Potts and Manooch (1998), then F was between 0.23 and 0.25 during 1996–1997. Huntsman et al. (1996) found that F (at M = 0.1) had risen from 0.25 during 1986–1988 to 0.36 during 1993. In contrast, Potts and Manooch (1998), reported that F (at M = 0.15) had decreased from 0.32 during 1986–1992 to 0.20 during 1992–1997. Huntsman et al. (1996) stated that although a F = 0.36 did not appear to be extraordinarily high for gag when compared to other fisheries, it is the ratio of F to M that is most important. For successful management of a fishery, the value of F should be similar to the value of M (Huntsman et al., 1996). Our tagging data indicated that F was 2.5 times greater than M in 1996–1997. Severe overfishing can occur when F is three to four times M (Huntsman et al., 1996).

McGovern et al. (1998) reported that the percentage of males decreased from 19.6% during 1978–1982 to 5.5% in 1995. Applying the percentage of males at size to the length frequency of gag tagged by primarily commercial fishermen and commercial length frequency data showed a similar reduced percentage of males in recent years. Reduced percentage of males, smaller size of individuals landed, smaller size and age at maturity (Coleman et al., 1996; McGovern et al., 1998; Harris and Collins, 2000), increased size-at-age (Harris and Collins, 2000), decreased population sizes (Huntsman et al., 1998), loss of genetic diversity, and possible inbreeding (Chapman et al., 1999) suggested that gag were overfished during 1996–1997. The mean size of gag tagged was significantly larger and capture depth was significantly deeper during the spawning season, suggesting that fishermen were targeting spawning aggregations.

Actions have been taken to reduce fishing mortality, especially the removal of males from spawning aggregations. In 1998, the South Atlantic Fishery Management Council implemented an increase in the minimum size of gag from 20″ (51 cm) to 24″ (61 cm) and a spawning season closure during March and April. A slight increase in the mean length of gag captured and a decrease in the landings in recent years suggests that there has been a response to the restrictions that have been imposed. McGovern et al. (1998) stated that only 50% of gag females are sexually mature at 24″ (61 cm) with 100% maturity occurring when fish attain sizes of 30″ (75 cm). Although an increase in the minimum size to 61 cm reduced the removal of smaller individuals, some immature fish continue to be removed from the population before they have a chance to spawn. A March–April spawning season closure decreases the number of males taken during the closure but males may continue to be lost during the open season. In addition, aggregations are probably not restricted to March and April since gag are in spawning condition from December through May (McGovern et al., 1998). Due to a loss of income during March and April, fishermen may increase fishing effort on aggregations during the part of the spawning season that is not closed or shift effort to other species. Furthermore, bycatch of gag may be high since other species that have spatial coincidence with spawning gag are targeted and release mortality is significantly related to depth. There is also substantial movement of gag to areas off Florida where fishing mortality is probably higher than off the rest of the southeast U.S. coast. As the continental shelf off Florida is very narrow, gag and other reef species are subject to intense fishing pressure. A closed area off southern Florida, as has been implemented in the Gulf of Mexico, may help to conserve gag stocks.

Clearly, gag are very vulnerable to overfishing since they are protogynous and live for many years. In addition they form spawning aggregations at depths where release mortality is high (49–91 m), are larger in deep water than in shallow water, and tend to be more sedentary with increasing depth. Marine fishery reserves in shelf-edge habitats where gag are most vulnerable to fishing pressure used in concert with other management strategies may be an appropriate method to help protect population age structure, genetic diversity, and supply of recruits to exploited areas (Bohnsack, 1993).

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