TAB 3A.

Population Assessment of the Gag, *Mycteroperca microlepis*, from the Southeastern United States

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November 1998

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ABSTRACT

Changes in the age structure and population size of gag, *Mycteroperca microlepis*, from North Carolina through the Florida Keys were examined using records of landings and size frequencies of fish from commercial, recreational, and headboat fisheries from 1986-1997. Population size in numbers at age was estimated for each year by applying separable virtual population analysis (SVPA) to the landings in numbers at age. SVPA was used to estimate annual, age-specific fishing mortality (F) for four levels of natural mortality (M = 0.10, 0.15, 0.20, and 0.25). We believe that the best estimate of M is 0.15. Landings of gag for the three fisheries have generally decreased in recent years, but minimum fish size regulations have resulted in an increase in the mean size of fish landed. Age at entry and age at full recruitment were age-0 and age-4 for 1986-1991 and age-0 and age-5 for 1992-1997. With M = 0.15, levels of fishing mortality (F) on the fully-recruited ages were 0.32 for 1986-1991 and 0.20 for 1992-1997. Spawning potential ratio (SPR) was 30% with M = 0.15 for the most recent time period, 1992-1997. However, a more conservative estimate of 27% resulted from incorporating a 50% release mortality on the undersized fish. The proposed size limit regulation of 24 inches could produce a SPR of 30% even with a 50% released fish mortality.

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INTRODUCTION

The gag, Mycteroperca microlepis, is a medium to large sized grouper (Family Serranidae) highly prized by both commercial and recreational fishermen. It is considered to be a seafood delicacy by many fishermen and restauranteurs. The species is found in tropical and warm temperate waters of the western Atlantic from Massachusetts (occurring as juveniles) to Brazil and the Gulf of Mexico. Adults prefer low- and high-profile bottom in waters 60 to 250 feet. Juvenile gag can be found in estuaries from Massachusetts to mid-Florida, but it is not known if these estuaries are primary nursery grounds (Manooch 1984).

The species is reported to live for more than 23 years (Harris and Collins In prep) and grow to more than 47 inches (1,200 mm) total length (TL). Gag are believed to aggregate in specific locations to spawn, and spawning takes place from December through mid-May off the southeastern United States (McGovern et al. 1998). Females become sexually mature between the ages of two and five years and lengths of 20 to 27 inches (McGovern et al. 1998).

The gag is a protogynous hermaphrodite, changing sex from female to male with increasing size (age). No males have been found less than five years old and less than 31.5 inches (800 mm) TL (Collins et al. 1987, Hood and Schlieder 1992, and McGovern et al. 1998). Very few transitional gag, those changing from female to male, have been collected in any of the reproductive studies. Transitional fish first occur around 30 inches TL (750 mm) and between four and five years of age.

In terms of commercial finfish value, the species ranked from 6th to 12th place for the entire southeastern United States from 1990-1997 (Table 1). Fishermen were able to sell gag at dockside for $2.10 to $2.59 per pound (Table 1). The species is particularly important to the commercial fisheries of Georgia, where it has ranked second or third for all finfish from 1990-1997, in South Carolina, where it has ranked first to fourth for those years, and for northeast Florida where it has ranked fourth to 10th (Table 2). By contrast, the gag is relatively less important to commercial fisheries off South Florida and North Carolina (Table 2).

Table 1. Gag ranking in commercial finfish value ($) for the southeastern United States.

Year	Rank	Value	$/Lb.
1990	12	1,728,778	2.10
1991	11	1,784,119	2.26
1992	8	1,929,978	2.30
1993	8	2,072,305	2.33
1994	7	2,416,418	2.34
1995	8	2,080,573	2.19
1996	6	2,488,738	2.50
1997*	9	2,031,253	2.59

*1997 data were not complete at time of this report.

Table 2. Gag ranking in commercial finfish value ($) by state/area.

	NC		SC		GA		NFL		SFL	
Year	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value
1990	13	436,135	4	658,611	3	94,425	10	469,529	34	70,078
1991	18	269,263	4	656,288	3	93,889	6	564,331	19	199,301
1992	17	352,284	2	739,321	2	72,711	6	521,020	18	244,642
1993	15	417,260	3	820,080	2	96,230	7	493,952	18	244,296
1994	12	847,768	3	762,215	2	107,416	9	508,528	22	189,658
1995	14	740,439	1	840,668	2	250,319	4	672,602	21	155,032
1996	13	636,032	2	765,581	2	157,550	5	632,124	15	296,663
1997	15	704,886	3	476,589	3	80,715	9*	769,063*		

*1997 data were not complete at the time of this report, and Florida data could not be broken down by county.

The SAFMC has taken actions to regulate the harvest of the species. The FMP for the snapper-grouper fishery was implemented on August 31, 1983. Amendment 4 to the FMP, effective January 1, 1992, required a 20-inch minimum size for both commercial and recreational fisheries, and a grouper recreational aggregate limit of five grouper per person per day. Amendment 9, which should be implemented in the near future, would establish a 24-inch minimum size.

This assessment of the gag stock from North Carolina (south of Cape Hatteras) through the Florida Keys was conducted to facilitate decision-making by the South Atlantic Fishery Management Council (SAFMC). Although the SAFMC Snapper-Grouper Fishery Management Plan (FMP)(SAFMC 1983) does include discussions of the species, and Huntsman et al. (1996) provided an assessment for the species using data from 1986 through 1993, that assessment was not able to fully analyze the impact of the minimum size regulations effective since 1992.

In this report we compute and document changes in the age structure and population size for the species. Specifically, given age-specific estimates of instantaneous fishing mortality rates and information on growth, sex ratios, maturity and fecundity, analyses of yield per recruit (YPR) and spawning potential ratio (SPR) are used to determine the status of the southeastern U.S. gag stock.

METHODS

Trends

For purposes of this report, gag are landed by three fisheries: Commercial, headboat, and other recreational (Marine Recreational Fisheries Statistical Survey -- MRFSS). Although landings are available for different years depending on fishery, only data from 1986-1997 were available for all three fisheries, and thus useful for our assessment.

The commercial fishery statistics are reported in three databases. General Canvas is the official record of landings; the Trip Interview Program (TIP) contains the length samples; and the Snapper-Grouper Logbook Program provides effort information and was initiated in 1992 as a pilot program. In that year, 25% of the snapper-grouper permittees reported their catch. Since 1993 100% have participated in the program (NMFS, Miami, Florida).

Headboats are those vessels usually carrying more than six passengers, charge on a per person basis, thus by the "head", and are considered separate for our analyses from the other recreational vessels. The headboat statistics include a landings database and a "bioprofile" (sampling) database each started in 1972 (NMFS, Beaufort, North Carolina).

The recreational fishery (MRFSS) includes hook and line fishing from shore or any platform other than headboats. The survey includes small private boats and charter boats (six passengers or less). The MRFSS statistics, available from 1981-1997, are also broken into two sets: Landings and intercept (on-site) sampling databases (NMFS, Silver Spring, Maryland).

Landings data and length samples were used to describe annual trends in catches, including catch in number, catch in weight, mean fish size, and mean fish age. Catch-per-effort were provided for the commercial data, the headboat data, the MRFSS data, and fishery-independent data. Whenever possible, the databases were stratified by state or area: North Carolina, South Carolina, Georgia, Northeast Florida (from the Georgia/Florida border south to and including Indian River County), and Southeast Florida (from St. Lucie County through the Atlantic portion of

Monroe County).

Because the MRFSS landings are recorded only by "sub-region" and state, we used the ratio of length samples by county from the intercept files to divide Northeast Florida from Southeast Florida. Also, Monroe County, FL landings are included in the west coast of Florida and had to be apportioned out and added to east coast Florida landings. For estimates of Monroe County, we used the proportion of gag from the county versus the rest of the west coast Florida. All Monroe County landings were considered to be part of the southeastern Atlantic landings.

Because of the common use of "black grouper" for _M._ _microlepis_ in Florida (instead of only for the true black grouper, _M._ _bonaci_), some of the commercial landings of gag seem to have been misidentified as black grouper. To correct this apparent misidentification problem in the landings, we examined the ratio of gag and black grouper from commercial samples in the TIP database from three areas of Florida: 1. Northeast Florida, 2. Southeast Florida exclusive of Monroe county, and 3. Monroe County. Based on the ratio of TIP samples from Northeast Florida from 1986 - 1992, 100% of the landings of black grouper were really gag, and thus added to the gag landings. After 1992, the very small amount of landings of black grouper were probably correct, and we did not add them to the gag landings. Due to the lack of samples from Southeast Florida, we also looked at the ratio of headboat samples, and determined that landings of gag to black grouper were approximately 80% to 20%. Therefore, we combined the landings of the two species and assigned 80% of them to gag. We used the water body codes of Monroe County to include only the Atlantic portion of gag and black grouper landings and TIP samples. The proportion of landings for the two species in Monroe County was appropriate, so we did not need to do any adjustments to the landings.

To draw conclusions about the gag population from fish that were sampled from catches, it is very important that samples were representative of the stock (e.g., size, sex, distribution, etc.), and were adequate in number. Although assumptions must be made for the former, biologists and managers should have some control over the latter. To evaluate the adequacy of sampling intensity for the three fisheries (headboat, recreational, and commercial), we used the informal criterion of 100 fish sampled per 200 metric tons of that species landed (USDOC 1996).

Age/Growth

Growth parameters, length-length conversions, weight-length relationship, and a fish age-fish length key were obtained from a recent study of gag (fish sampled from 1994-96) by Harris and Collins (in prep).

Development of Catch-in-Numbers-at-Age Matrix

Data used in the construction of the catch matrix for years 1986-1997 were derived from the sampling databases and landings databases discussed previously, and from the Harris and Collins (In prep) age-length key. The data covered the geographical area extending from North Carolina through the Florida Keys, which was then sub-divided into three regions: North Carolina and South Carolina, Georgia and Northeast Florida, and Southeast Florida.

Derivation of catch in numbers at fish age consisted of multiplying the catch in numbers (n, scalar) by the fish age-fish length key (A, matrix) by a length frequency distribution (L, vector) to obtain the catch in numbers by fish age (N, vector):

$$N_{ax1} = n \cdot A_{axb} \cdot L_{bx1} \quad \text{(Vaughan et al. 1992)},$$

where a is the number of ages (0 to 23 years), and b is the number of length intervals. The length frequencies were generated from each fishery by year, region, and gear. When samples were lacking for a particular strata (e.g., region, gear, year), we used samples from a previous year and region, or lumped same gear type samples across years. Since commercial landings are reported by weight only, the commercial catch of gag was converted to numbers by dividing the weight landed by the mean weight, stratified by year, geographical area, and gear. The mean weights were estimated from the length samples (TIP) converted to weights by the length-weight equation from Harris and Collins (In prep).

Mortality Estimates

Total Instantaneous Mortality (Z)

Total instantaneous mortality was estimated by analyzing catch curves (Beverton and Holt 1957) based on fully-recruited age fish. The fish age-fish length key was used to construct catch curves by assigning ages to the landed unaged gag. Mortality estimates under equilibrium assumption were obtained by regressing the natural log of the catch in numbers against age for fully-recruited fish (ages 4 through 22, or 5-22, depending on time period).

Natural Mortality (M)

Natural mortality is often estimated from relatively weak life history and ecological analogies, yet is a very important step in determining that portion of total mortality which may be attributed to fishing. Natural mortality can perhaps be best estimated by using bioprofiles characteristics as demonstrated by Pauly (1979) and later by Hoenig (1983).

Pauly (1979) used von Bertalanffy parameters (L_∞ and K) as well as mean water temperature (T ^{0}C) for the general habitat:

$$\log_{10}M = 0.0066 - 0.279 \log_{10}L + 0.6543 \log_{10}K + 0.4634 \log_{10}T.$$

Sea surface temperature readings from buoys operated by NOAA's National Oceanographic Data Center were used to calculate mean annual seawater temperature. Buoys recorded temperature every 30 minutes, and monthly averages were calculated at four different locations throughout the South Atlantic Bight (SAB). These monthly averages were averaged across locations and a SAB-wide value for mean annual temperature obtained. All data were from 1996 for all buoys except Edisto, where 1995 data were used for October through December. Buoys used and their locations are

1) Edisto - 32.5° N 79.1° W
2) Savannah - 31.9° N 80.7° W
3) St. Augustine - 29.9° N 81.3° W
4) Cape Canaveral - 28.5° N 80.2° W.

Hoenig (1983) utilizes the maximum age (t_{max}) in an unfished stock of a species:

$$\ln M = 1.46 - 1.01 \ln t_{max}.$$

Because this relationship is based on Z, rather than M, the maximum age in the virgin population (F = 0; M = Z-F) would provide an approximate estimate of natural mortality.

Hoenig (1983) also provides an estimate of Z which takes into account the sample size used in the study, the rationale being one has a greater chance of encountering the true maximum age of the fish with increasing sample size. The equation used is

$$Z = \ln (2n + 1)/t_{max} - t_c,$$

where t_c = first age fully represented in the catches.

Natural mortality was estimated following the methods of Roff (1984) which used optimal length at maturity, and Rikhter and Efanov (1977) using age at 50% maturity. For both methods, we incorporated the information from McGovern et al. (1998) to obtain length at 50% maturity, and then used the inverse of the von Bertalanffy growth equation to solve for the corresponding age at 50% maturity.

We also derived estimates of M from the empirical equation of Ralston (1987): M = 0.0189 + 2.06*K. This regression equation was developed by surveying the literature for instances in which the von Bertalanffy growth parameter K was jointly estimated with M. Nineteen populations of snapper and grouper species were used, and data were pooled to develop the regression. Another method to estimate M was the method of Alverson and Carney (1975), which allows prediction of M from estimates of maximum age and the Brody growth coefficient, K. One final method used to estimate M was the relationship developed by Alagaraja (1984): $S(t_\lambda) = e^{-Mt\lambda}$, where t_λ = maximum age and $S(t_\lambda)$ = survivorship to the maximum age.

Fishing Mortality (F) and Virtual Population Analysis (VPA)

Once natural mortality and total instantaneous mortality have been estimated, it is an easy exercise to obtain fishing mortality, F (e.g., Z = M + F; F = Z - M). The problem arises from the equilibrium assumption of constant F and recruitment. In this assessment, age-specific fishing mortality rates and estimates of gag age-specific population size were obtained by applying an uncalibrated separable virtual population analysis (SVPA) technique. However, because of the short time frame of the catch matrix (1986-1997) relative to the number of reported ages for the species (0-23), this was not completely successful. Two temporal periods (1986-1991 and 1992-1997) were required due to the minimum size limit imposed at the beginning of 1992. The SVPA methods are explained briefly below.

The catch matrix was interpreted using the separable virtual population analysis (SVPA) approach to obtain annual age-specific estimates of population size and fishing mortality rates. Virtual population analysis sequentially estimates population size and fishing mortality rates for younger ages of a cohort from a starting value of fishing mortality for the oldest age (Murphy 1965). An estimate of natural mortality, usually assumed constant across years and ages, was also required. The separable method of Doubleday (1976) assumes that age- and year-specific estimates of F can be separated into products of age and year components. There are obvious problems with applying this technique to the full time period, 1986-1997, because of the imposition of a 20-inch minimum size limit which was effective January, 1992. Therefore, the technique was applied separately to the two time periods (1986-1991 and 1992-1997). We used the FORTRAN program developed by Clay (1990), based on Pope and Shepherd (1982).

To address the question of catch-and-release mortality on fish smaller than the size limit in the second time-period (1992-1997), we took a proportion of the mean fishing mortalities at the corresponding, sub-legal ages from the first time period (1986-1991), and added the resulting F to the current mean F at age of the sub-legals.

i.e., Before minimum size limit: $Z = F + M$.

After minimum size limit: $Z' = F_{Pr} + F(1-P_r)(P_{rm}) + M$;

let $F' = F_{Pr}$ $\therefore P_r = F'/F$,

then $Z' = F' + F(1-F'/F)P_{rm} + M$;

where P_r = Probability keep under-sized fish, and

P_{rm} = Probability that released fish will die.

Yield Per Recruit

The yield per recruit model was used to estimate the potential yield in weight for gag and was based on the method of

Ricker (1975). The model estimates total weight of fish taken from a cohort divided by the number of individuals of that cohort that entered the fishing grounds. Because we do not have enough data to run the analysis on cohorts, we used the equilibrium assumption on the stock to run the model. Unlike the full-dynamic pool model (Beverton and Holt 1957), the Ricker-type model only requires parameters that are relatively easily obtainable: M, F, K, L_∞, t_r (age at recruitment to the fishery), and fishing at ages prior to full recruitment. All shape the response surface (i.e., how the gag yield per recruit reacts to various levels of fishing effort). The above-mentioned parameters were estimated as discussed previously.

Spawning Potential Ratio

Gabriel et al. (1989) developed percent maximum spawning potential (%MSP) as a biological reference point. The currently-favored acronym for this approach is referred to as equilibrium or static spawning potential ratio (SPR). A recent evaluation of this reference point is given in a report by the Gulf of Mexico SPR Management Strategy Committee (1996) for the Gulf of Mexico Fishery Management Council (see Mace and Sissenwine (1993), and Mace (1994)). Equilibrium, or static, SPR was calculated as a ratio of spawning stock size when fishing mortality was equal to the observed or estimated F divided by the spawning stock size calculated when F was equal to zero. All other life history parameters were held constant (e.g., maturity schedule and age-specific sex ratios). Hence, the estimate of static SPR increases as fishing mortality decreases. Estimates of released fish mortality were also incorporated into the models.

The SAFMC defines and explains static spawning potential ratio (SPR), also known as percent maximum spawning potential (%MSP), as "a measure of an average female's egg production over its lifetime compared to the number of eggs that could be expected if there was no fishing. When there is fishing pressure, a fish's life expectancy is reduced, and so is its average lifetime egg production. A species is considered overfished if its SPR drops below a level beyond which the ability of the stock to produce enough eggs to maintain itself is in jeopardy" (SAFMC 1996). The SAFMC considers a stock to be overfished if the SPR is < 0.30 (< 30%), and is recovering with SPR values ranging from 0.30-0.39 (30-39%). The target is to obtain an SPR of 0.40 or greater (> 39%) (Gregg Waugh, SAFMC, Charleston, SC, pers. comm.). Longevity, age-specific fecundity, and age-specific fishing mortality are critical to the derivation of SPR.

Because this species is a protogynous hermaphrodite, comparisons of age-specific spawning stock biomass were based on total (sexes combined) mature biomass. We derived the sexual maturity schedule for gag from information provided by McGovern et al. (1998).

RESULTS

Sampling Adequacy

We used an informal standard developed by the NMFS, Northeast Regional Stock Assessment Workshop (USDOC 1996) to determine the adequacy of biological sampling of gag landings (Table 3). According to this standard, 100 fish lengths should be recorded for each 200 mt of the species landed. Thus, a value less than 100 samples/200 mt indicates an inadequate sample. Using 1986-1997 data, we found that recreational (MRFSS) landings of gag were much less frequently sampled than were headboat or commercial landings (Table 3). Fewer than 100 fish were sampled region-wide for all years except 1990, and for seven of the 12 years sampling was inadequate under this criterion. In contrast, the other dockside sampling programs yielded hundreds (Headboat Survey) and thousands (commercial TIP) of gag measured annually (Table 3). The problem identified here for MRFSS-sampled gag holds true for three species for which recent population assessments have been prepared: Red snapper, <u>Lutjanus campechanus</u>, (Manooch et al. 1998a), scamp, <u>M</u>. <u>phenax</u> (Manooch et al. 1998b), and vermilion snapper, <u>Rhomboplites</u> <u>aurorubens</u>, (Manooch et al. 1998c). We continue to encourage an increase of biological sampling of reef fish by MRFSS personnel.

Table 3. Level of sampling per year by fishery for gag in the southeastern U.S. Adequate level of sampling is equivalent to 100 length samples per 200mt (the ratios in bold type indicate the year and fishery where samples were determined to be inadequate).

Year	MRFSS		Headboat		Commercial	
	# of samples/ mt	Equivalent	# of samples/ mt	Equivalent	# of samples/ mt	Equivalent
1986	15/20.5	146/200	659/60.8	2168/200	2013/519.4	775/200
1987	65/174.1	**75/200**	698/84.9	1644/200	3254/557.4	1168/200
1988	74/132.8	111/200	544/91.3	1192/200	1868/374.6	997/200
1989	81/195.2	**83/200**	470/78.7	1194/200	1727/374.6	634/200
1990	119/171.4	139/200	362/62.9	1151/200	980/427.2	459/200
1991	56/109.3	102/200	184/51.7	712/200	1673/375.1	892/200
1992	92/218.4	**84/200**	275/56.5	973/200	2303/404.1	1140/200
1993	70/246.8	**57/200**	282/55.1	1024/200	2497/416.9	1198/200
1994	98/247.8	**76/200**	288/43.0	1340/200	1751/477.7	733/200
1995	77/148.8	103/200	483/50.4	1917/200	2239/497.5	900/200
1996	45/139.8	**64/200**	222/30.1	1475/200	2342/458.2	1022/200
1997	38/127.0	**60/200**	199/27.9	1427/200	3061/362.7	1688/200

Trends - Landings

Commercial

The most reliable and uninterrupted time series for commercial landings is from the General Canvas and begins in 1986. From 1986-1997, landings averaged 944,400 pounds (N = 12) with catches exceeding 1,000,000 pounds in 1986, 1987, 1989, 1994, 1995, and 1996 (Table 4). We do not believe that landings reported for 1997 are complete at the time of this report.

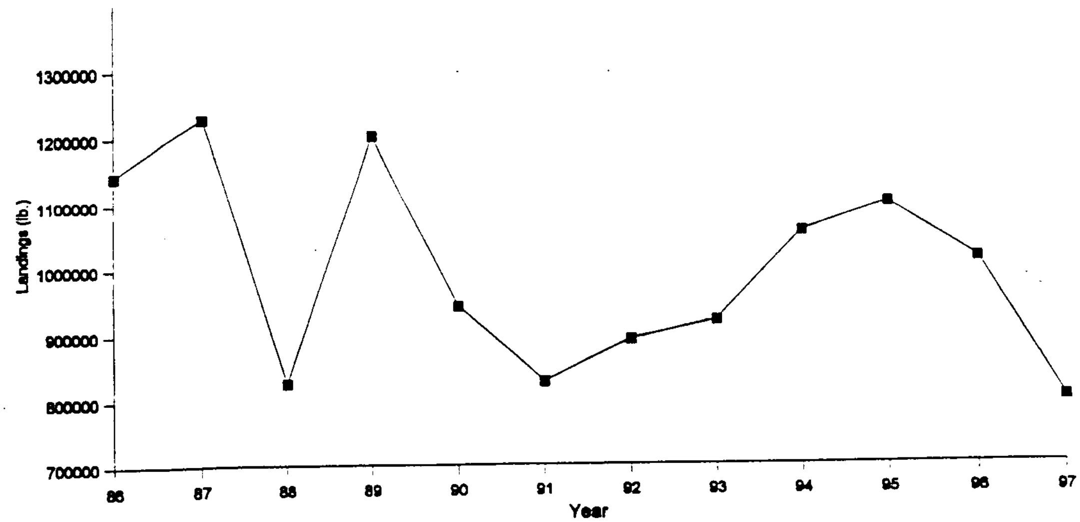
Table 4. Commercial landings (lb) of gag from the southeastern United States adjusted by percentage of black grouper landings considered to be gag in Florida.

Year	NC[1]	SC[2]	GA-NEFL[3]	SEFL[4]	Total
1986	300,270	253,499	461,406	129,080	1,144,255
1987	270,625	348,742	492,460	116,217	1,228,044
1988	197,460	277,038	252,176	98,650	825,324
1989	337,862	367,007	346,336	149,518	1,200,723
1990	236,057	298,523	307,497	99,168	941,245
1991	140,454	276,451	288,987	120,502	826,394
1992	169,537	322,505	289,232	108,935	890,209
1993	199,678	360,965	235,567	122,269	918,479
1994	393,977	327,181	242,399	89,131	1,052,688
1995	340,298	356,439	325,318	74,144	1,096,199
1996	290,016	305,021	299,442	115,100	1,009,579
1997	296,276	186,093	228,855	88,440	799,664

1. NC = North Carolina
2. SC = South Carolina
3. GA-NEFL = Georgia and Northeast Florida (south to and including Indian River County).
4. SEFL = Southeast Florida from St. Lucie County through the Atlantic portion of Monroe County).

Landings have generally increased since 1991 with the obvious exception of 1997, which may be incomplete (Figure 1). Most gag were landed at ports from North Carolina through Northeast Florida (unweighted mean = 89% of the southeastern U.S. catch for 1986-1997). Relatively few gag were landed in South Florida and the Keys (Table 4).

Figure 1. Southeastern United States gag commercial landings



Headboat

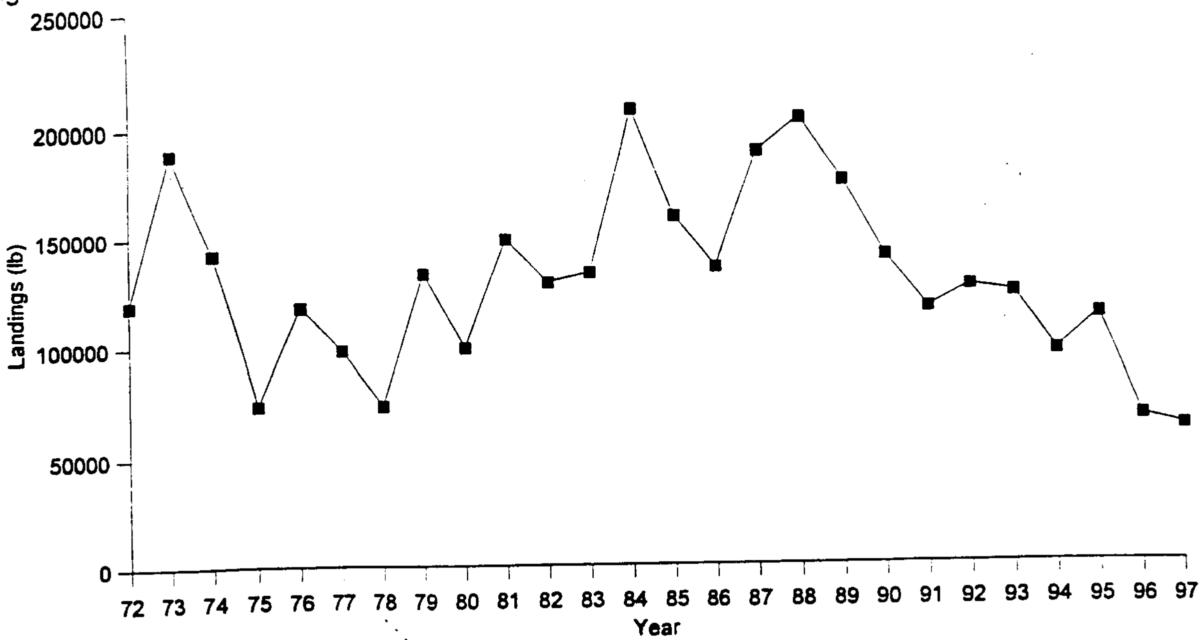
Headboat data are available for all geographical areas for the years 1981 through 1997 (Table 5; Figure 2). For the 17-year period, landings averaged 135,353 pounds. Catches generally increased from 1975 to 1984, peaking at 201,158 pounds in 1984. Since 1988 the catches have steadily declined to a low of 61,566 pounds in 1997 (Table 5; Figure 2). Overall, commercial landings of gag are approximately seven times greater than those reported by headboat anglers for 1986-1997 (Tables 4 and 5).

Most gag were landed by headboat anglers fishing out of North Carolina and Georgia/Northeast Florida ports with South Carolina ports coming in a close second. The species is less frequently caught off Southeast Florida.

Table 5. Headboat landings (number and lb) of gag from the southeastern U.S.

	NC		SC		GA-NEFL		SEFL		Total	
Year	Number	Weight	Number	Weight	Number	Weight	Number	Weight	Number	Weight
1972	6201	98559	1165	20789					7366	119348
1973	8252	150806	1997	38387					10249	189192
1974	6724	122512	974	10259					7698	145129
1975	2921	45368	1355	28422					4276	73790
1976	2113	33525	1521	24068	3131	59862			6765	117455
1977	3311	44936	907	14176	2808	38781			7026	97893
1978	2161	35635	492	6045	2879	31777			5532	73457
1979	4071	55144	824	12233	5029	65062			9924	132439
1980	1574	18995	1676	24090	5342	55488			8595	98572
1981	3419	31670	1392	12627	5551	59089	3544	44568	13906	147954
1982	2982	28515	946	8263	6318	72890	1592	18180	11838	127848
1983	3444	24950	3900	30961	6842	62755	2278	13511	16464	132177
1984	7708	59720	1289	14421	7349	106098	2340	25885	18686	206124
1985	6901	47487	1607	23158	5768	68241	1850	18889	16126	157775
1986	8513	51113	1599	18038	5917	53685	1324	11254	17353	134090
1987	10604	62036	2495	22351	7570	68575	3425	34238	24094	187201
1988	10969	66778	2486	18534	9497	107094	1261	8751	24213	201158
1989	12583	76005	1881	21941	6759	65681	1193	9852	22416	173527
1990	7933	51660	3581	37676	5397	44107	681	5214	17592	138694
1991	5455	36897	3504	40429	4253	33734	338	2831	13649	114687
1992	6146	40898	2358	21855	4880	56026	559	5673	13943	124485
1993	4842	34954	1793	14963	3984	54559	1179	16863	11795	121338
1994	4384	32551	1113	12973	3395	39859	922	9497	9814	94880
1995	4256	38596	881	13619	4224	44290	1180	14661	10541	111167
1996	3302	21857	587	7775	2988	31266	625	5426	7502	66324
1997	2667	22066	390	4901	3326	30830	471	3769	6854	61566

Figure 2. Headboat landings of gag from the southeastern U.S.



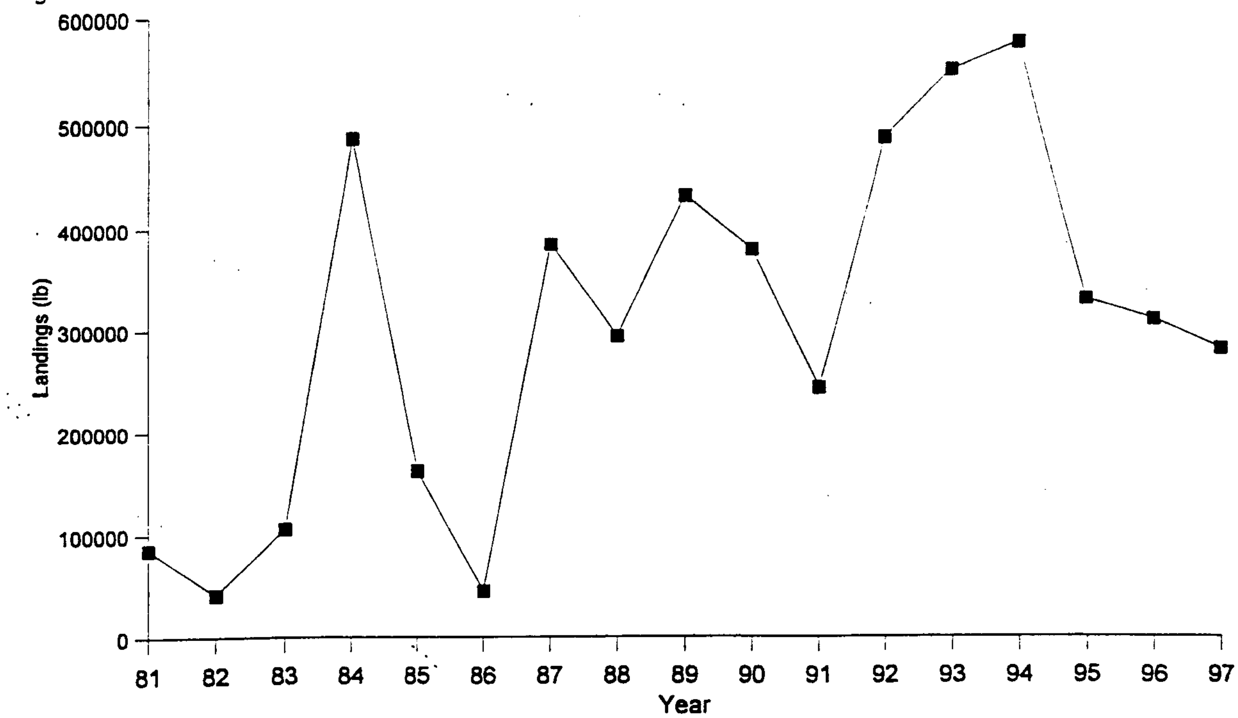
Recreational (MRFSS)

Recreational fishing statistics are available for 1981 through 1997. Landings of gag are presented by number and weight (pounds) in Table 6 by year and area. During the 17-year period, the average recreational catch was 303,791 pounds. Overall landings peaked in 1994 when approximately 570,200 pounds were landed, and then decreased to about half that by 1997 (Table 6; Figure 3). The landings recorded for 1984, 486,000 pounds, look strange indeed considering the relatively low landings in the year preceding (106,000 for 1983) and the following two years (161,000 for 1985 and 45,075 for 1986). Georgia and Florida landings contributed over 70% of the overall landings by weight, except from 1989-1992 when North Carolina and South Carolina landings increased to be about half of the overall catch.

Table 6. Recreational (MRFSS) landings (number and lb) of gag from the southeastern U.S.

	NC		SC		GA/NFL		SFL		Total	
Year	#	lb	#	lb	#	lb	#	lb	#	lb
1981	4066	10757			44613	75133			48679	85890
1982	3354	739					9305	40544	12659	41283
1983					19990	91037	2667	14832	22657	105869
1984	22456	116632	5003	32758			51562	336237	79021	485627
1985	11165	11697	11339	7870	5732	17073	33121	124429	61357	161069
1986			8106	9744	1417	547	11010	34784	20533	45075
1987	32009	85366	4345	12800	2547	14277	44568	271333	83469	383776
1988	17431	74930	3163	14677	571	4448	37324	198798	58489	292853
1989	23840	159422	7933	49892	24425	221022			56198	430336
1990	38229	290880	2594	14443			13441	72526	54264	377849
1991	13566	80397	8560	30582	1574	15149	15244	114765	38944	240893
1992	12130	116795	8417	92872	8363	75959	20163	197466	49073	483092
1993	13471	118282	7854	74836	20272	234525	9134	116544	50731	544187
1994	7049	48048	1411	12612	33405	360118	14364	149402	56229	570180
1995	7058	44454	4857	39845	21673	197789	6063	46034	39651	328122
1996	1958	12615	4071	37914	5705	39372	27789	218370	39523	308271
1997	3789	10048	770	14254	8768	95990	12975	159787	26302	280079

Figure 3. MRFSS landings of gag from the southeastern U.S.



Trends - Catch/Effort

Commercial

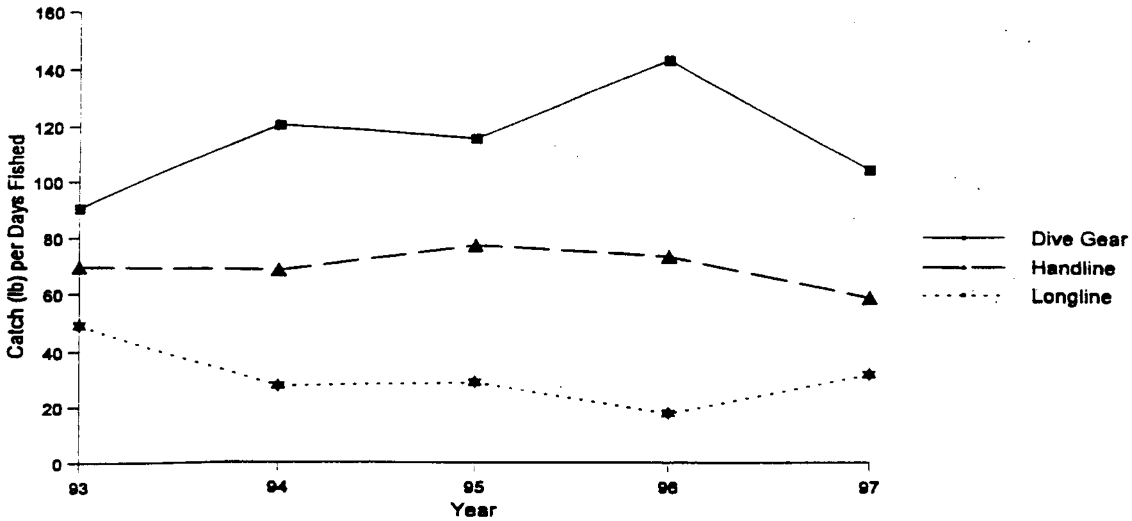
Commercial catch per unit effort (CPUE) data are available from 1993 through 1997 from the Snapper-Grouper Logbook Program. Effort was measured as pounds landed per number of days away from the dock. We used number of days away rather than number of trips as effort because "trips" were not standardized and could be any number of days long. CPUE was estimated for the three major types of gear used to catch gag: Dive gear (e.g., spears, powerheads, etc.), handlines (includes all vertical hook and line gear), and longlines. Because landings of gag in Southeast

Florida were small, we only used landings data from North Carolina through Northeast Florida (north of waterbody code 2679: St. Lucie Inlet) (note: 1997 data were incomplete at the time of this report). Due to the short span of years available, no trends were discernable (Table 7; Figure 4). Commercial effort, as reflected by logbook landings, has not changed much for 1993-1997.

Table 7. Commercial logbook landings (lb) of gag, number of days away on a trip, and catch per day by the major gear types employed: dive gear (spears, powerheads), handlines, and longlines. The data covers landings of gag from North Carolina through Northeast Florida (north of area 2679).

YEAR	GEAR	LBS. LANDED	DAYS AWAY	LBS. PER DAY
93	Dive Gear	66,240.2	731	90.6
94	Dive Gear	91,116.6	758	120.2
95	Dive Gear	83,374.3	723	115.3
96	Dive Gear	132,646.9	932	142.3
97	Dive Gear	106,289.5	1,026	103.6
93	Handlines	506,274.9	7,236	70.0
94	Handlines	605,421.9	8,824	68.6
95	Handlines	726,747.1	9,408	77.2
96	Handlines	707,338.8	9,649	73.3
97	Handlines	511,878.4	8,768	58.4
93	Longline	6,959.7	141	49.4
94	Longline	2,993.5	109	27.5
95	Longline	4,148.6	144	28.8
96	Longline	3348.0	190	17.6
97	Longline	4,536.9	143	31.7

Figure 4. Commercial catch (lb) per days fished for gag from Southeastern US by major gear type.



Headboat

Catch per unit effort data are available for 1972 through 1997 for North Carolina and South Carolina, for 1976 through 1997 for North Carolina through Northeast Florida, and since 1981 for North Carolina through the Florida Keys. Annual CPUE values for all areas combined are presented in Table 8 and Figure 5 as number of gag, or weight in pounds of gag, caught per angler day. Catch rates have decreased slightly since 1988 (Table 8; Figure 5). Relatively high catch rates were recorded in 1972 and 1973, 2.4 and 3.3 pounds per angler day, respectively. Catch rates dropped dramatically from the high in 1973 to an average of 0.50 pounds through 1997.

CPUE in number of fish and weight are presented by area (NC, SC, NEFL-GA, and SEFL) in Tables 9-12; Figures 6-9. Catch rates in North Carolina by number of gag fluctuated in the 70's, but then generally increased from 1982, 0.11 fish per angler day to 1989, 0.33 fish per angler day. After 1989, the number of gag landed per angler day has steadily decreased to 0.07 in 1997, a 79% drop. The catch rate in pounds of gag landed from North Carolina also fluctuated, but did not show the large rise in CPUE as did the number of gag. 1989 was the last peak in pounds per angler day, 1.97, and then decreased to 0.59 pounds per angler day in 1997, a 70% decline (Figure 6, Table 9).

CPUE for South Carolina headboat anglers followed a similar trend as the overall trend except for a large peak both in number of gag and pounds of gag per angler day in 1990: 0.06 fish and 0.66 pounds (Figure 7). Since 1990, CPUE has steadily dropped to a low of 0.006 gag (90% decline) and 0.08 pounds of gag (88% decline) per angler day in 1997 (Table 10).

CPUE in number of gag from Georgia and Northeast Florida headboat anglers has fluctuated from 0.04 to 0.09 from 1976-1997 (Figure 8). CPUE in pounds of gag landed shows a similar pattern ranging from 0.40 to 1.11 pounds.

Landings in Southeast Florida are low compared to the other areas because gag are less abundant there. CPUE in both number and weight have decreased from a peak in 1981 of 0.016 fish and 0.20 pounds to 0.004 fish and 0.03 pounds in 1997 (Figure 9).

Headboat effort (angler days) has decreased since the 1980's. Effort for 1997 was 39% less than it was in 1987 (Table 8). The same trend in effort applies to individual geographic areas (Tables 9 - 12).

Table 8. Headboat CPUE of gag from the southeastern United States.

YEAR	NUMBER	WT LB	ANGDAYS	CPUE-#	CPUE-LB
1972	7366	119348.23	48989	0.15036	2.43622
1973	10249	189192.16	57917	0.17696	3.26661
1974	7698	145128.82	84431	0.09118	1.71890
1975	4276	73790.17	92450	0.04625	0.79816
1976	6765	117454.80	150047	0.04509	0.78279
1977	7026	97893.12	150900	0.04656	0.64873
1978	5532	73457.27	171593	0.03224	0.42809
1979	9924	132439.36	150886	0.06577	0.87774
1980	8595	98572.08	155424	0.05530	0.63421
1981	13906	147994.76	376927	0.03689	0.39264
1982	11838	127883.20	387611	0.03054	0.32993
1983	16464	132213.28	367406	0.04481	0.35986
1984	18686	206180.39	385172	0.04851	0.53529
1985	16126	157818.26	378191	0.04264	0.41730
1986	17353	134126.24	415475	0.04177	0.32283
1987	24094	187252.13	447108	0.05389	0.41881
1988	24213	201212.52	420663	0.05756	0.47832
1989	22416	173527.06	418250	0.05359	0.41489
1990	17592	138694.19	423286	0.04156	0.32766
1991	13649	114687.22	388940	0.03509	0.29487
1992	13943	124485.36	367491	0.03794	0.33874
1993	11798	121371.19	344214	0.03428	0.35260
1994	9814	94905.63	342704	0.02864	0.27693
1995	10541	111197.40	303644	0.03471	0.36621
1996	7502	66341.59	289924	0.02588	0.22882
1997	6854	61583.03	270602	0.02533	0.22758

Figure 5. Headboat CPUE of gag from the southeastern US.

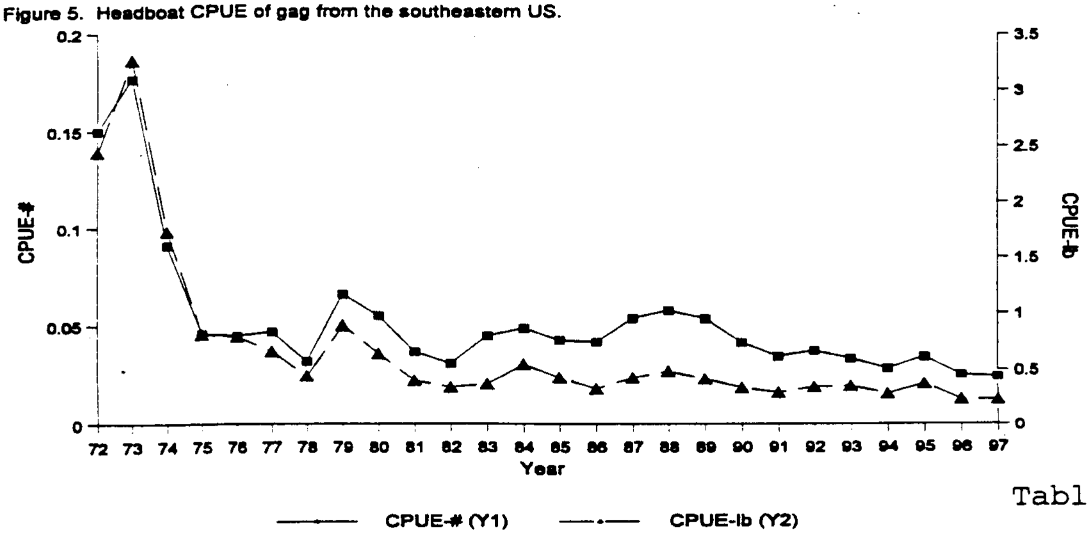


Table 9

Headboat CPUE for gag from North Carolina.

YEAR	TOTNUM	TOTLB	TOTANG	CPUENUM	CPUELB
1972	6201	98558.85	30659	0.20226	3.21468
1973	8252	150805.66	37080	0.22255	4.06704
1974	6724	122511.83	32047	0.20982	3.82288
1975	2921	45368.46	31225	0.09355	1.45295
1976	2113	33525.35	30325	0.06968	1.10554
1977	3311	44936.36	22660	0.14612	1.98307
1978	2161	35635.15	26032	0.08301	1.36890
1979	4071	55143.66	26490	0.15368	2.08168
1980	1574	18994.83	23714	0.06637	0.80100
1981	3419	31678.84	19372	0.17649	1.63529
1982	2982	28522.74	26939	0.11069	1.05879
1983	3444	24956.89	23830	0.14452	1.04729
1984	7708	59736.54	28865	0.26704	2.06951
1985	6901	47500.30	31346	0.22016	1.51535
1986	8513	51127.10	31187	0.27297	1.63937
1987	10604	62053.20	35261	0.30073	1.75983
1988	10969	66796.55	42421	0.25857	1.57461
1989	12583	76025.98	38678	0.32533	1.96561
1990	7933	51674.30	43240	0.18346	1.19506
1991	5455	36906.75	40936	0.13326	0.90157
1992	6146	40909.17	41177	0.14926	0.99350
1993	4842	34963.13	42785	0.11317	0.81718
1994	4384	32559.67	36693	0.11948	0.88735
1995	4256	38607.04	40294	0.10562	0.95813
1996	3302	21863.02	35142	0.09396	0.62213
1997	2667	22071.82	37189	0.07171	0.59350

Figure 6. Headboat CPUE of gag from North Carolina.

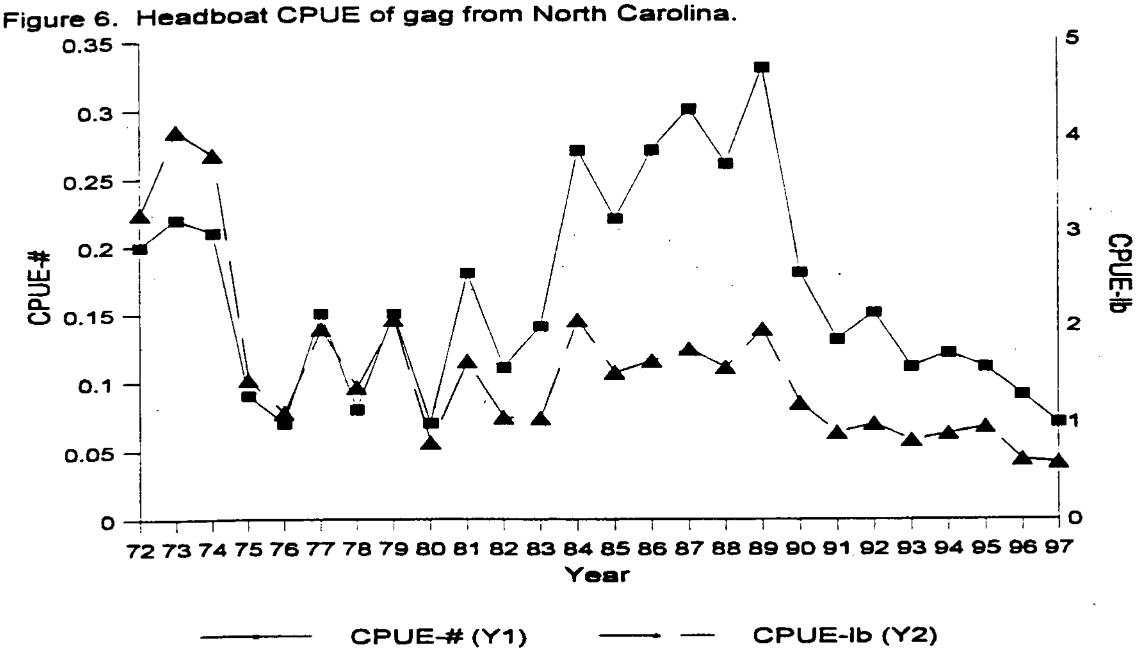


Table 10. Headboat CPUE of gag from South Carolina.

YEAR	TOTNUM	TOTLB	TOTANG	CPUENUM	CPUELB
1972	1165	20789.38	18330	0.063557	1.13417
1973	1997	38386.50	20837	0.095839	1.84223
1974	974	22616.99	52384	0.018593	0.43175
1975	1355	28421.70	61225	0.022131	0.46422
1976	1521	24067.62	61318	0.024805	0.39250
1977	907	14175.58	69910	0.012974	0.20277
1978	492	6045.01	67462	0.007293	0.08961
1979	824	12233.33	56935	0.014473	0.21486
1980	1679	24089.66	64244	0.026135	0.37497
1981	1392	12630.37	59030	0.023581	0.21397
1982	946	8264.95	67539	0.014007	0.12237
1983	3900	30969.74	65713	0.059349	0.47129
1984	1289	14424.74	67313	0.019149	0.21429
1985	1607	23164.27	66001	0.024348	0.35097
1986	1599	18042.59	67227	0.023785	0.26838
1987	2495	22357.55	78806	0.031660	0.28370
1988	2486	18539.33	76468	0.032510	0.24245
1989	1881	21947.08	62708	0.029996	0.34999
1990	3581	37686.16	57151	0.062659	0.65941
1991	3504	40439.57	67982	0.051543	0.59486
1992	2358	21860.55	61790	0.038162	0.35379
1993	1793	14967.14	64457	0.027817	0.23220
1994	1113	12976.85	63231	0.017602	0.20523
1995	881	13623.02	61739	0.014270	0.22065
1996	587	7776.73	54929	0.010687	0.14158
1997	390	4902.59	60147	0.006484	0.08151

Figure 7. Headboat CPUE of gag from South Carolina.

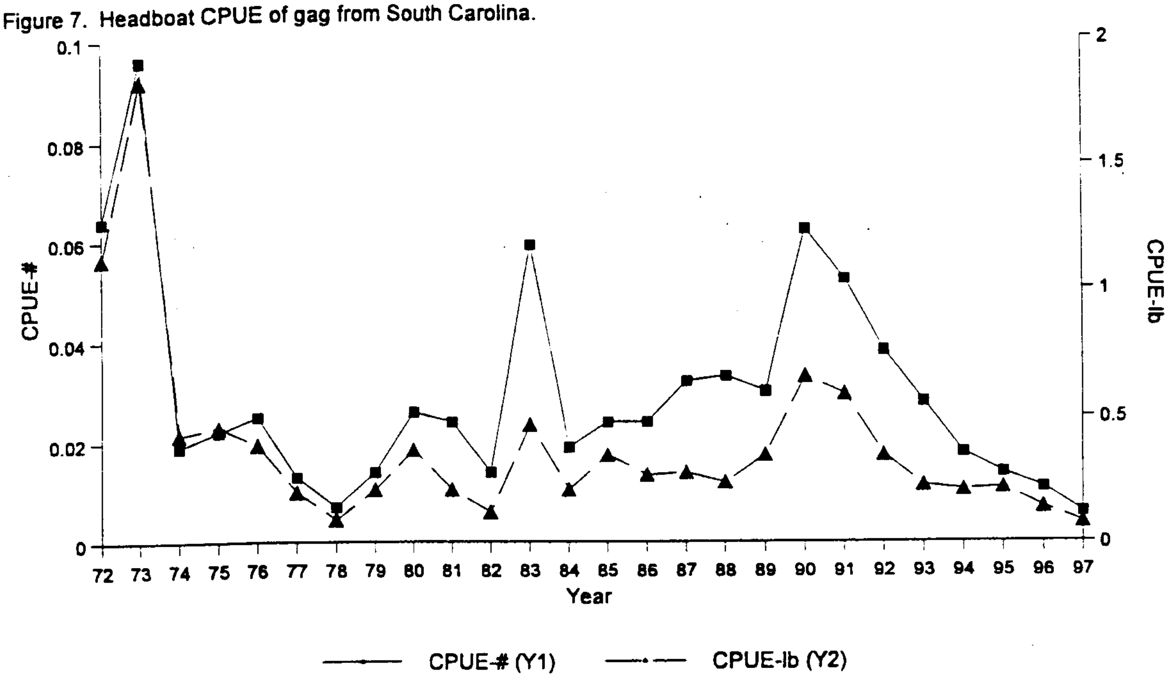


Table 11. Headboat CPUE of gag from Georgia and northeast Florida to Fort Pierce, FL.

YEAR	TOTNUM	TOTLB	TOTANG	CPUENUM	CPUELB
1976	3131	59861.83	58404	0.053609	1.02496
1977	2808	38781.18	58330	0.048140	0.66486
1978	2879	31777.10	78099	0.036863	0.40688
1979	5029	65062.38	67461	0.074547	0.96444
1980	5342	55487.58	67466	0.079181	0.82245
1981	5551	59105.40	72069	0.077023	0.82012
1982	6318	72910.29	66961	0.094353	1.08885
1983	6842	62771.72	83499	0.081941	0.75177
1984	7349	106127.09	95234	0.077168	1.11438
1985	5768	68259.53	94446	0.061072	0.72274
1986	5917	53699.62	113101	0.052316	0.47479
1987	7570	68593.81	114144	0.066320	0.60094
1988	9497	107123.63	109156	0.087004	0.98138
1989	6759	65698.98	102920	0.065672	0.63835
1990	5397	44118.70	98234	0.054940	0.44912
1991	4253	33743.50	85111	0.049970	0.39646
1992	4880	56041.44	90810	0.053739	0.61713
1993	3984	54573.48	74494	0.053481	0.73259
1994	3395	39869.60	65745	0.051639	0.60643
1995	4224	44302.08	59104	0.071467	0.74956
1996	2988	31274.85	47236	0.063257	0.66210
1997	3326	30838.74	52756	0.063045	0.58455

Figure 8. Headboat CPUE of gag from Georgia and northeast Florida.

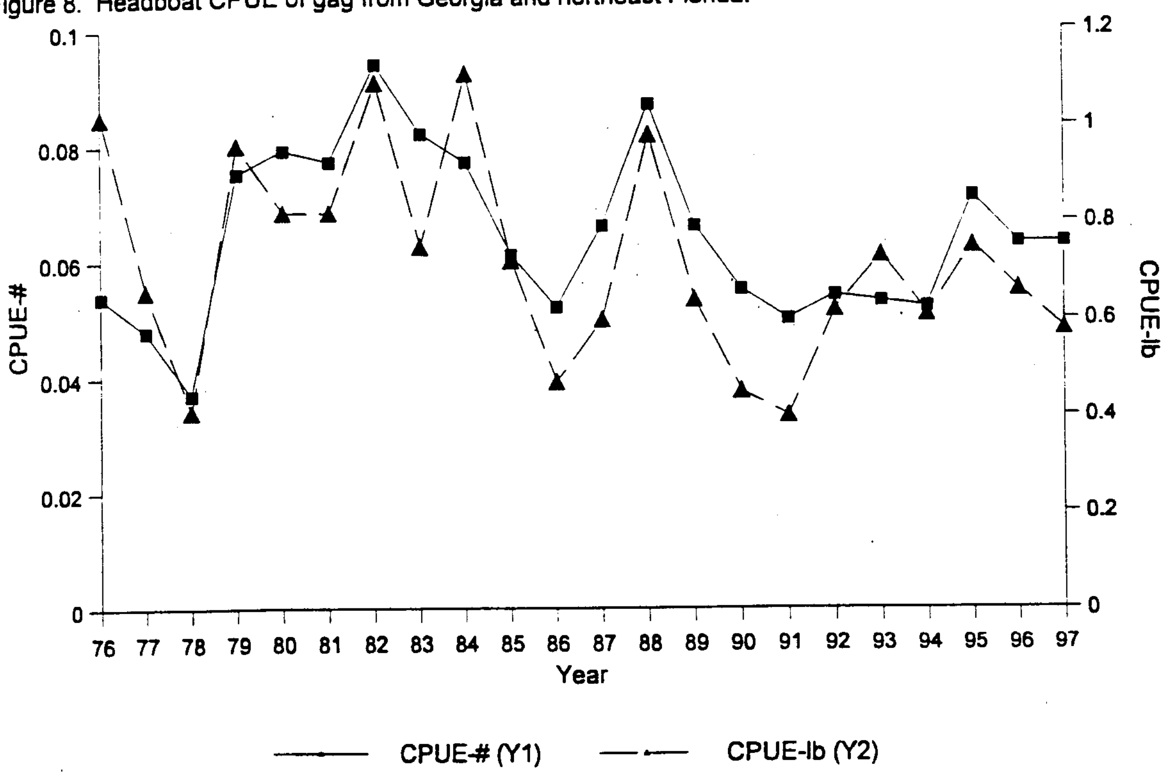
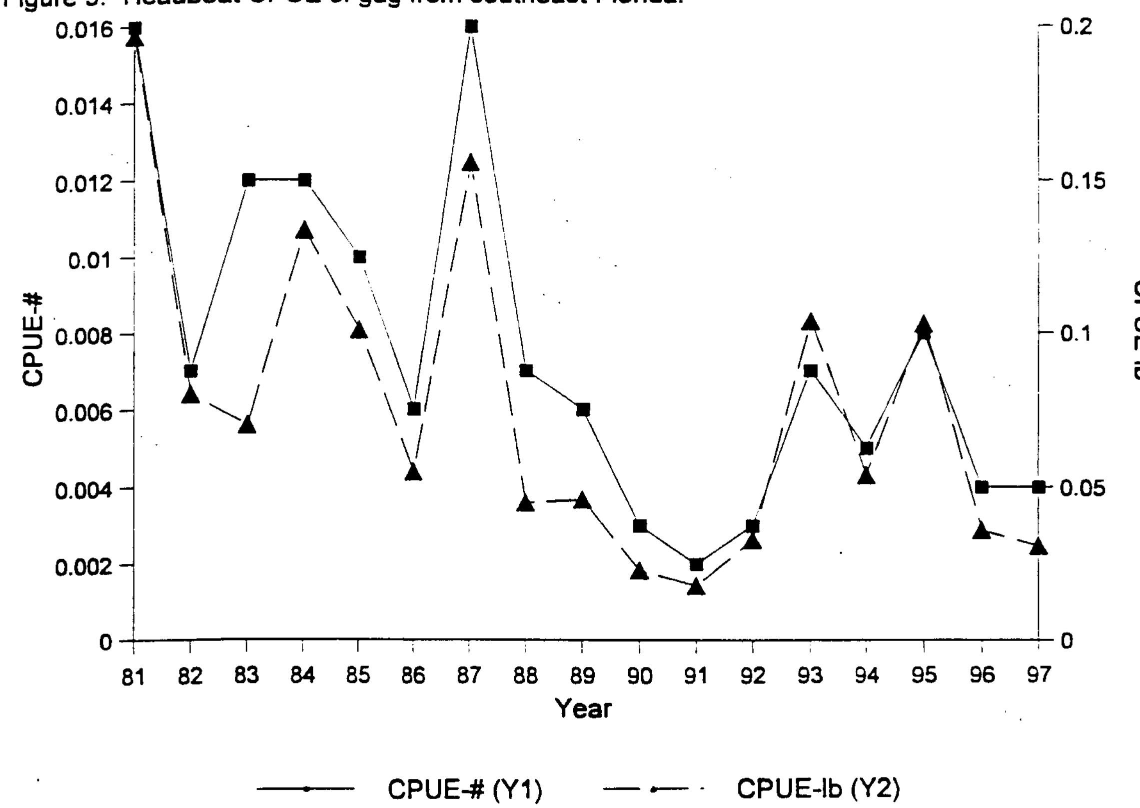


Table 12. Headboat CPUE of gag from southeast Florida including the Florida Keys and Dry Tortugas.

YEAR	TOTNUM	TOTLB	TOTANG	CPUENUM	CPUELB
1981	3544	44580.15	226456	0.015650	0.19686
1982	1592	18185.21	226172	0.007039	0.08040
1983	2278	13514.93	194364	0.011720	0.06953
1984	2340	25892.02	193760	0.012077	0.13363
1985	1850	18894.16	186398	0.009925	0.10136
1986	1324	11256.92	203960	0.006491	0.05519
1987	3425	34247.56	218897	0.015647	0.15646
1988	1261	8753.01	192618	0.006547	0.04544
1989	1193	9855.02	213944	0.005576	0.04606
1990	681	5215.03	224661	0.003031	0.02321
1991	437	3597.40	194911	0.002242	0.01846
1992	559	5674.20	173714	0.003218	0.03266
1993	1179	16867.44	162478	0.007256	0.10381
1994	922	9499.51	177035	0.005208	0.05366
1995	1180	14665.26	142507	0.008280	0.10291
1996	625	5427.00	152617	0.004095	0.03556
1997	471	3769.89	120510	0.003908	0.03128

Figure 9. Headboat CPUE of gag from southeast Florida.



Recreational (MRFSS)

Recreational CPUE data are available for the southeastern United States from 1981 through 1997 (Table 13 and Figure 10). Catch rates were recorded as number of gag caught per angler trip. Annual CPUE values were high compared with the headboat CPUE data. This difference is at least partially due to the way CPUE was calculated. An angler trip from MRFSS data was included only if gag was identified as the primary or secondary species sought on that trip. The headboat angler day was from every trip whether gag were landed or not.

Recreational catch rate for gag peaked in 1981 (4.88 fish/angler trip) and again in 1983 (3.83 fish/angler day). All other years stayed fairly steady between one and two fish per angler day. However, since 1986, a slight upward trend can be noted. Total effort (angler trips) has decreased since 1995 (Table 13).

Fishery-Independent Data (SCDNR)

From 1988 through 1997 South Carolina Department of Natural Resources personnel used baited chevron traps to capture gag and other species of reef fish in the South Atlantic Bight (Table 14; Figure 11). Data were reported as number of gag caught per trap hour (CPUE). CPUE by number was relatively high in 1990, and has generally decreased since then (Table 13; Figure 10). These data have limited value for our purpose, as so few gag were caught.

Table 13. Recreational (MRFSS) catch per effort for gag from the southeastern United States.

Year	Total catch (#)	Total Angler Trips	CPUE
1981	61123	12520	4.88
1982	7452	13589	0.55
1983	21802	5696	3.83
1984	76574	78023	0.98
1985	78389	57443	1.36
1986	45911	83832	0.55
1987	102240	87312	1.17
1988	62742	60665	1.03
1989	123535	114571	1.08
1990	72866	46685	1.56
1991	65649	64030	1.03
1992	80798	65140	1.24
1993	86016	46535	1.85
1994	136867	73021	1.87
1995	123302	95417	1.29
1996	93729	82297	1.14
1997	89771	62916	1.43

Figure 10. MRFSS catch per angler trip for gag from the southeastern US.

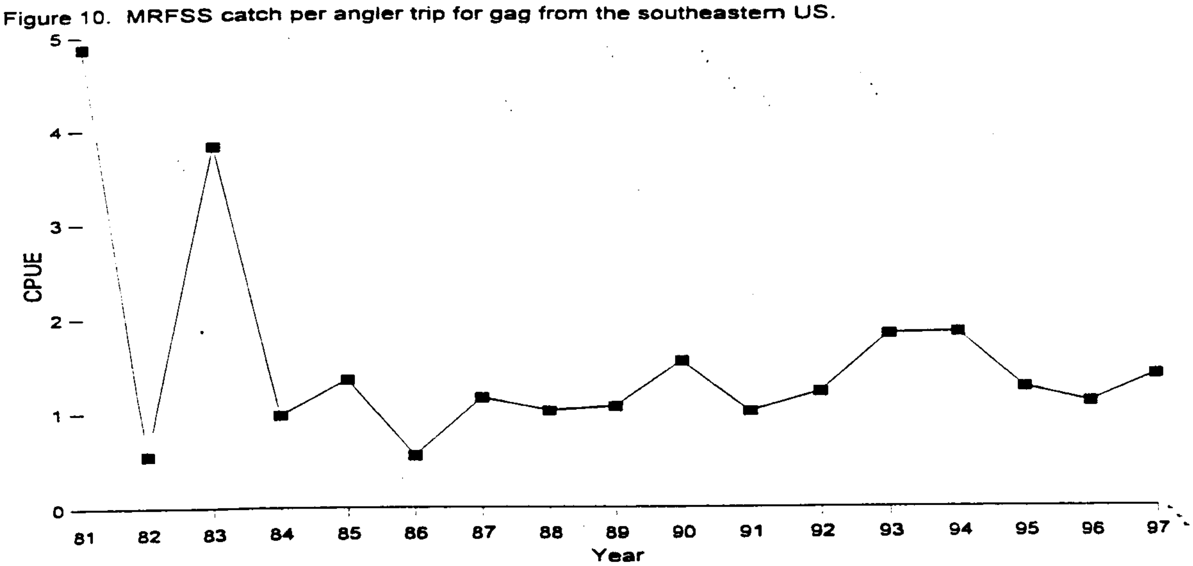
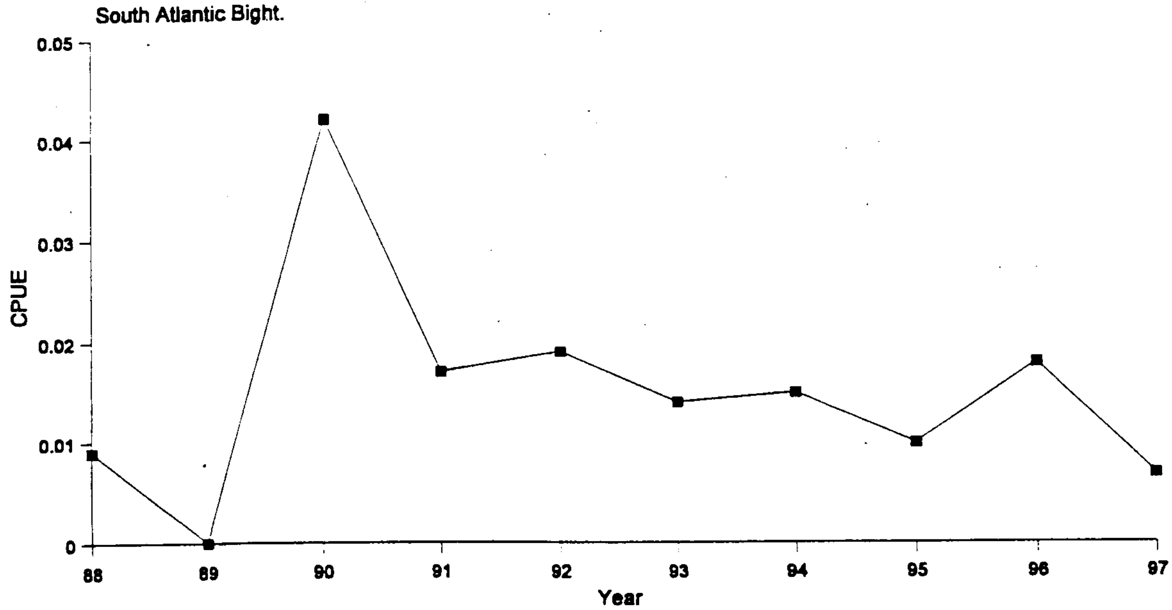


Table 14. Fishery-independent CPUE in number of gag collected by chevron traps in the South Atlantic Bight (SCDNR, MARMAP, Charleston, SC).

Year	Number of gag	Number of sets	CPUE	SE
1988	1	102	0.009	0.009
1989	0	79	0.000	0.000
1990	25	350	0.042	0.010
1991	8	299	0.017	0.006
1992	10	320	0.019	0.008
1993	9	411	0.014	0.005
1994	10	403	0.015	0.006
1995	5	326	0.010	0.004
1996	15	503	0.018	0.005
1997	6	505	0.007	0.003

Figure 11. Fishery-independent CPUE for gag collected in chevron traps in the South Atlantic Bight.



Trends - Mean Weights

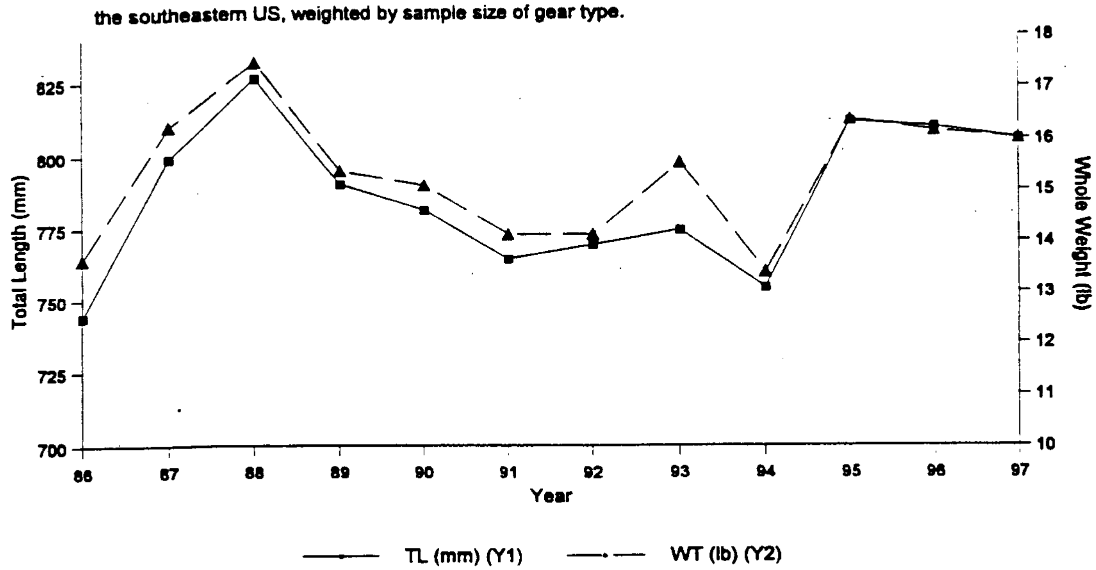
Commercial

Mean size data are available for the commercial fishery from 1986 through 1997, and are presented in Table 15 and Figure 12 by lengths and weights. For all areas combined, mean size for gag was largest in 1988 (17.5 pounds) and smallest (13.4 pounds) in 1994. Overall mean sizes have not changed very much since 1986. They have actually increased since 1994. By area, Georgia and Northeast Florida had the largest gag. In 1997, the average fish for that area weighed more than 23 pounds. Gag tended to be smaller from North Carolina and South Carolina. Anecdotal information suggests that gag aggregate to spawn, and one area identified with high spawning activity is off Northeast Florida. In McGovern et al.'s (1998) study, 91 of 143 males (the largest gag) were captured off Northeast Florida. Commercial fishermen have the expertise to find these spawning aggregations, and know how to fish them (Dixon Harper, pers. comm.). The higher percentage of males in the landings off Northeast Florida may explain why the mean weights from that area are highest. Overall, the minimum size limit does not appear to have had a large impact on commercial landings, because commercial fishermen catch much bigger fish than do recreational anglers.

Table 15. Commercial mean weight (kg) and mean total length (mm) of gag landed in the southeastern United States, weighted by sample size of gear types.

Year	NC/SC		GA/NFL		SFL		Overall	
	TL	LB	TL	LB	TL	LB	TL	LB
1986	742	13.56	761	15.43	-	-	744	13.67
1987	797	16.20	835	17.92	749	12.65	799	16.29
1988	830	17.75	803	15.92	767	13.91	826	17.53
1989	787	15.21	830	17.22	705	13.51	790	15.41
1990	771	14.64	858	18.65	662	8.44	781	15.12
1991	753	13.49	817	17.00	710	13.10	764	14.15
1992	711	11.51	862	19.22	807	15.30	769	14.15
1993	706	13.10	868	19.33	830	16.67	774	15.56
1994	720	11.73	844	18.01	838	17.55	754	13.40
1995	763	13.69	892	21.01	850	18.10	811	16.38
1996	786	14.86	863	19.31	810	15.85	809	16.16
1997	798	15.63	923	23.17	817	16.14	805	16.01

Figure 12. Commercial mean weight (lb) and mean total length (mm) of gag from the southeastern US, weighted by sample size of gear type.



Headboat

For all areas combined, mean weights of gag caught by headboat anglers were generally largest from 1972 through 1982. However, in recent years, the mean weights have increased slightly since 1991. This increase is most probably caused by the size restriction intended to reduce the harvest of smaller fish. Mean weight, which was 10-18 pounds for 1972-1982, declined to 7 to 11 pounds for 1983-1991, and has increased to 9 to 11 pounds for 1992 through 1997 (Table 16; Figure 13).

The same pattern of moderate increase in mean weights since 1991 prevailed for each geographic area (Tables 17-20; Figures 14-17). On average, the largest gag have been landed in Georgia and Northeast Florida. However, since 1994, South Carolina anglers have been catching gag slightly larger than the ones from Georgia and Northeast Florida.

Table 16. Headboat mean weight (lb) of gag from the southeastern United States.

Year	Mean Weight (lb)	N	Year	Mean Weight (lb)	N
1972	12.58	151	1985	9.91	945
1973	17.35	233	1986	7.10	645
1974	18.12	143	1987	7.22	681
1975	16.68	237	1988	7.54	543
1976	17.01	250	1989	7.23	454
1977	16.06	333	1990	7.02	339
1978	14.40	308	1991	7.43	161
1979	13.61	276	1992	8.57	217
1980	12.21	308	1993	9.71	255
1981	10.67	416	1994	10.22	266
1982	10.41	582	1995	11.16	442
1983	8.37	871	1996	9.62	220
1984	10.70	1219	1997	9.41	189

Figure 13. Headboat mean weight of gag from the southeastern US.

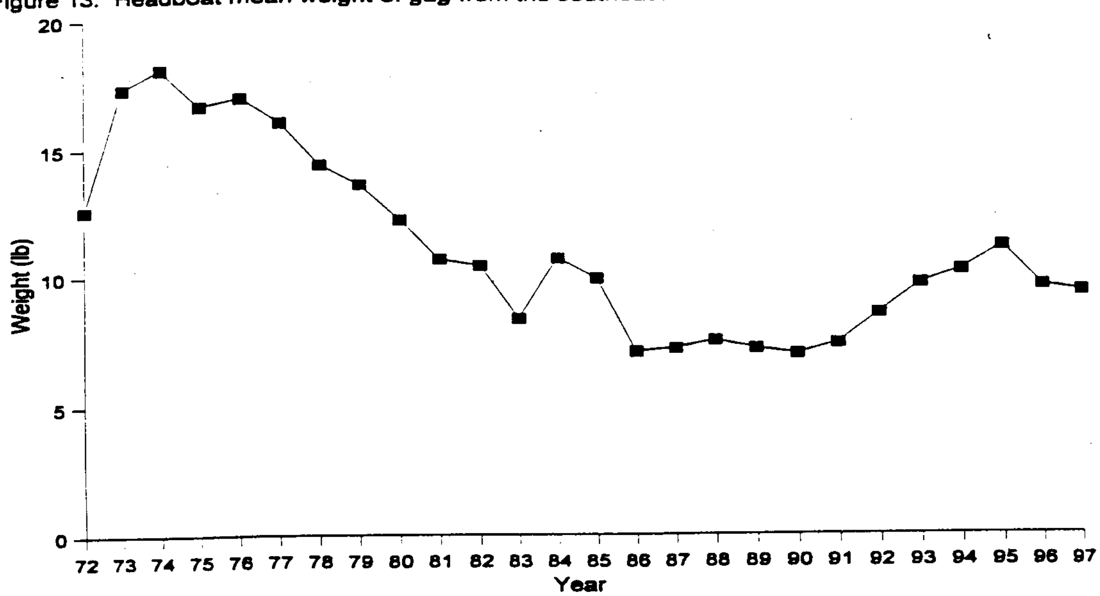


Table 17. Headboat mean weight (lb) of gag from North Carolina.

Year	Mean Weight (lb)	N	Year	Mean Weight (lb)	N
1972	10.31	118	1985	6.66	359
1973	17.48	126	1986	5.78	325
1974	15.31	97	1987	5.61	346
1975	15.65	185	1988	6.27	322
1976	16.34	200	1989	5.73	254
1977	15.92	234	1990	6.09	158
1978	17.15	158	1991	6.98	85
1979	14.77	90	1992	7.63	120
1980	13.12	164	1993	7.41	96
1981	8.96	93	1994	7.60	65
1982	9.05	231	1995	8.20	127
1983	7.07	281	1996	6.55	76
1984	7.60	504	1997	8.74	54

Figure 14. Headboat mean weight of gag from North Carolina.

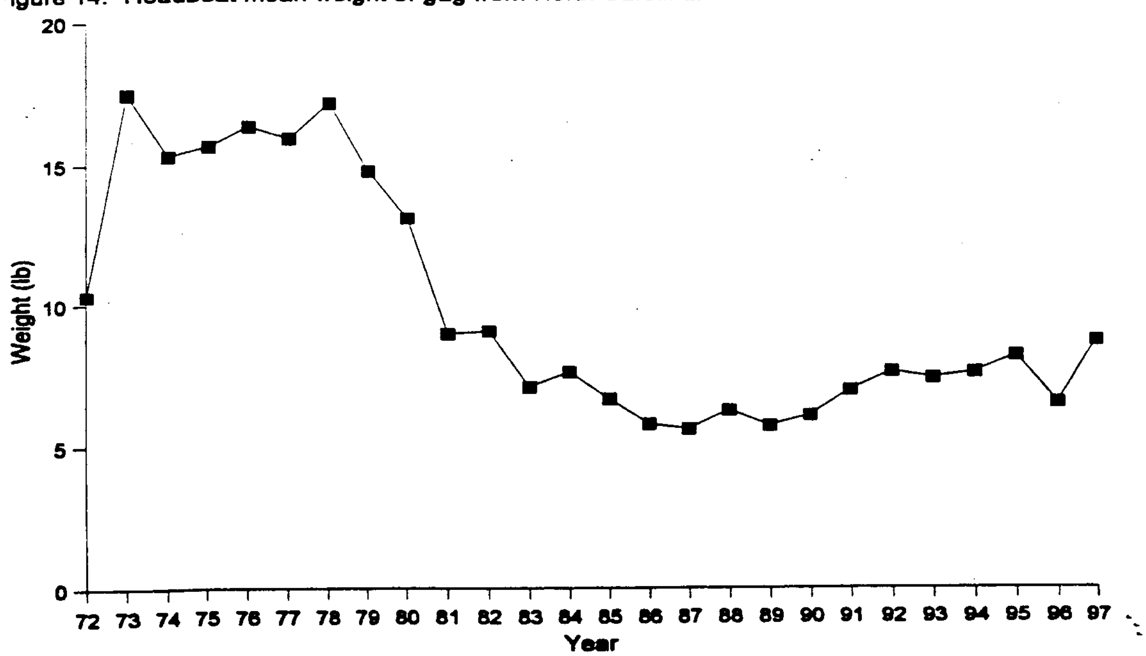


Table 18. Mean weight (lb) of gag from headboats operating off South Carolina.

Year	Mean Weight (lb)	N	Year	Mean Weight (lb)	N
1972	20.71	33	1985	15.15	45
1973	17.19	107	1986	10.18	27
1974	24.04	46	1987	9.77	86
1975	20.38	52	1988	9.84	60
1976	20.22	29	1989	8.77	35
1977	15.35	35	1990	6.73	26
1978	12.55	23	1991	8.17	35
1979	11.26	14	1992	8.13	39
1980	14.20	9	1993	8.79	78
1981	8.27	1	1994	10.90	114
1982	8.17	15	1995	14.40	156
1983	9.61	67	1996	12.95	42
1984	11.06	82	1997	12.96	16

Figure 15. Headboat mean weight of gag from South Carolina.

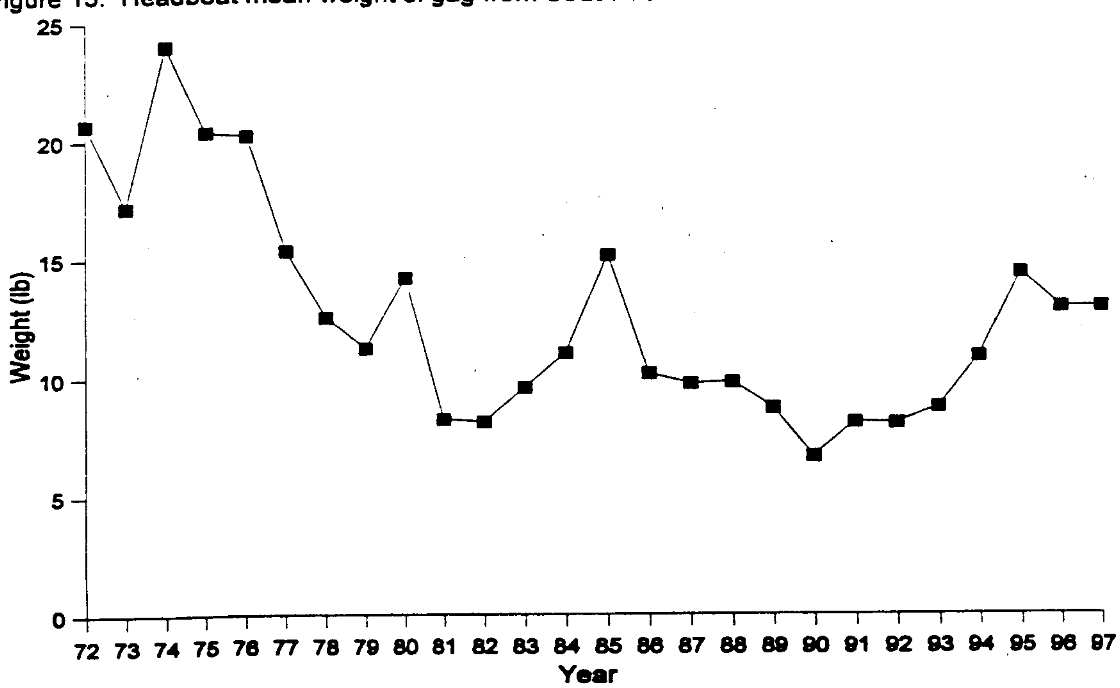


Table 19. Mean weight (lb) of gag from headboats operating off Georgia and Northeast Florida.

Year	Mean Weight (lb)	N	Year	Mean Weight (lb)	N
1976	19.00	21	1987	7.88	158
1977	16.95	64	1988	10.46	105
1978	11.35	116	1989	9.77	132
1979	12.46	112	1990	8.35	119
1980	11.02	80	1991	7.94	38
1981	10.47	229	1992	11.22	54
1982	12.23	254	1993	13.72	73
1983	9.65	329	1994	11.57	73
1984	14.50	381	1995	10.18	131
1985	11.67	302	1996	11.40	89
1986	8.26	156	1997	9.26	100

Figure 16. Headboat mean weight (lb) of gag from Georgia and Northeast Florida

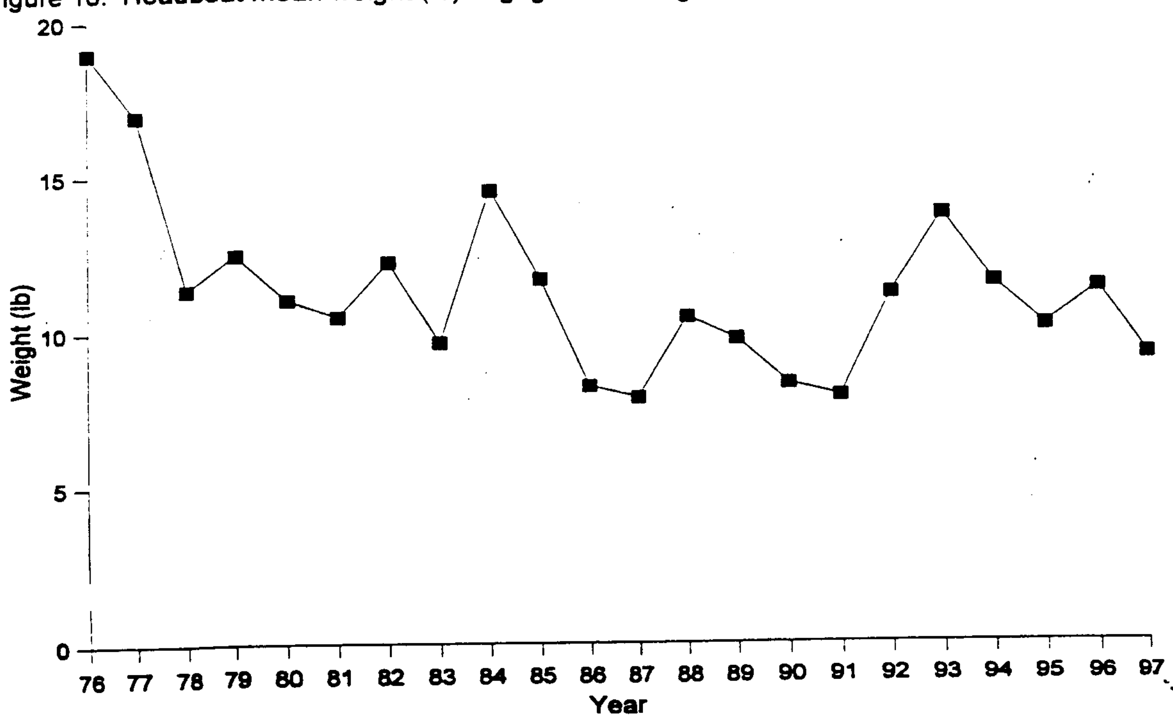
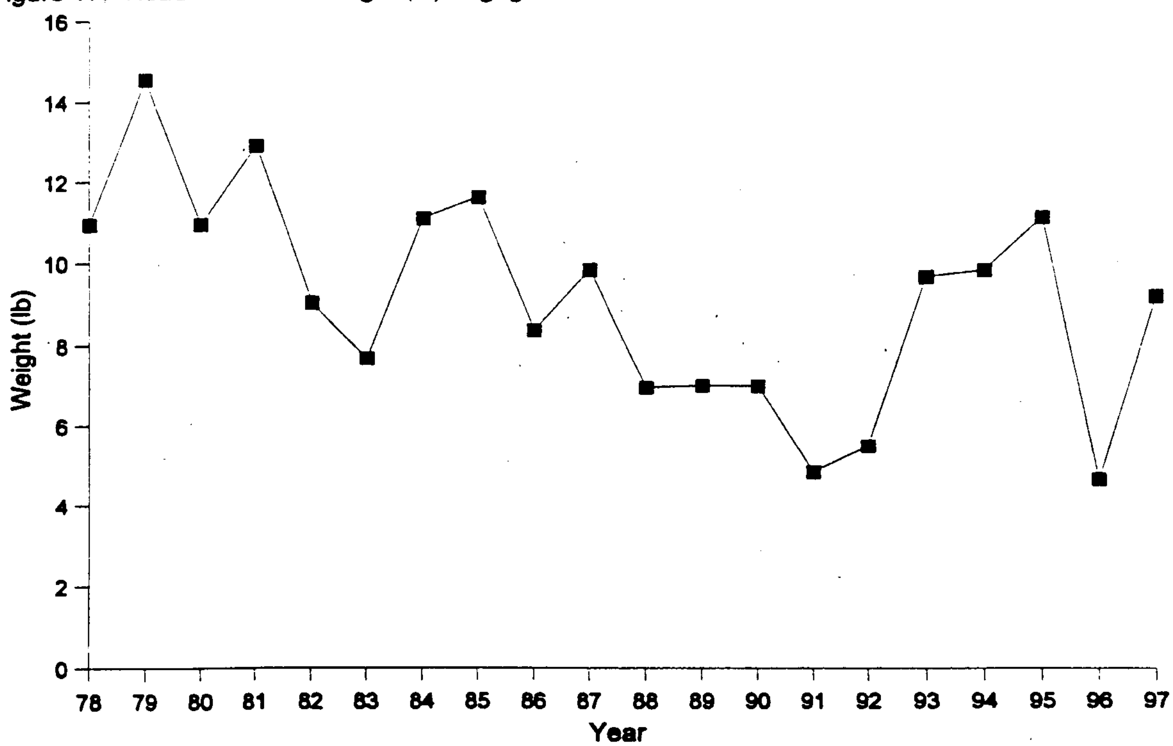


Table 20. Mean weight (lb) of gag from headboats operating in Southeast Florida.

Year	Mean Weight (lb)	N	Year	Mean Weight (lb)	N
1978	10.95	11	1988	6.91	56
1979	14.56	60	1989	6.96	33
1980	10.94	55	1990	6.95	36
1981	12.88	93	1991	4.82	3
1982	9.01	82	1992	5.46	4
1983	7.66	194	1993	9.61	8
1984	11.06	252	1994	9.76	14
1985	11.59	239	1995	11.05	28
1986	8.33	137	1996	4.63	13
1987	9.79	91	1997	9.13	19

Figure 17. Headboat mean weight (lb) of gag from Southeast Florida.



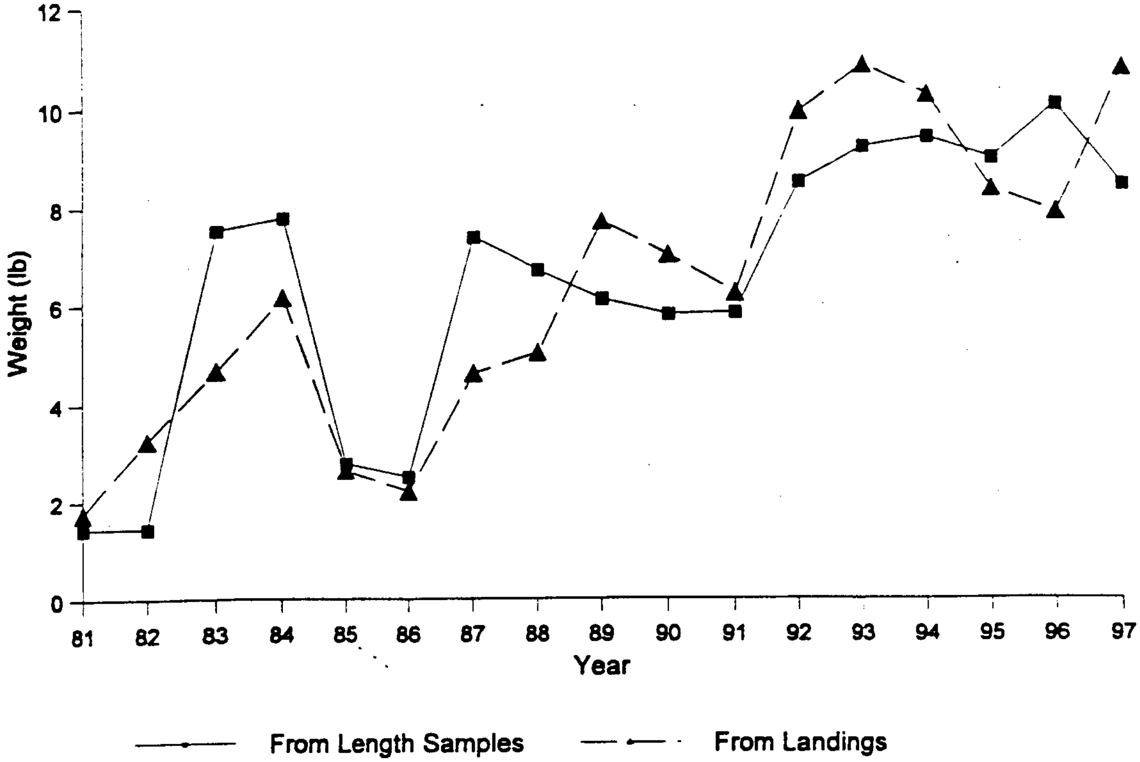
Recreational (MRFSS)

Mean size was generated for the recreational fishery from 1981 through 1997 from the MRFSS length samples converted to weight by the length-weight conversion equation and from the landings (Table 21; Figure 18). These data were not stratified by geographic area because of the small sample size of lengths. Less than 20 gag were sampled for the entire southeastern United States for each of the years: 1981, 1982, 1983, and 1986 (N = 10, 6, 9, and 15, respectively). And, less than 100 fish were sampled in all years except 1996 (N = 119). Both sources of mean weights, length samples and landings, show similar trends. The mean weights have generally increased, and since 1987, have been similar to the mean weights from the headboat fishery.

Table 21. Recreational (MRFSS) mean weights of gag landed in the southeastern United States, generated from the length samples (sample size is in parenthesis) and length-weight relationship and from the landings.

	Mean Weight (lb) - Source			Mean Weight (lb) - Source	
Year	Length Samples (N)	Landings	Year	Length Samples (N)	Landings
1981	1.44 (10)	1.76	1990	5.76 (119)	6.96
1982	1.45 (6)	3.26	1991	5.79 (56)	6.19
1983	7.51 (9)	4.67	1992	8.44 (92)	9.84
1984	7.77 (42)	6.15	1993	9.12 (70)	10.73
1985	2.77 (32)	2.63	1994	9.31 (98)	10.14
1986	2.49 (15)	2.20	1995	8.88 (77)	8.28
1987	7.35 (65)	4.60	1996	9.93 (45)	7.80
1988	6.65 (74)	5.01	1997	8.35 (38)	10.65
1989	6.07 (81)	7.66			

Figure 18. MRFSS mean weight of gag from the southeastern US.



Age/Growth

Harris and Collins (In prep) conducted an age and growth study of gag because previous studies were either outdated (Manooch and Haimovici 1978; Collins et al. 1987) or from a different geographic region (Hood and Schlieder 1992). Manooch and Haimovici's study (1978) included gag from the southeastern U.S. landed by headboat anglers. They aged the fish by examining whole otoliths, and the maximum discernable age was only 13 years. The von Bertalanffy growth parameters from their study were L_∞ = 1290 (TL, mm), K = 0.122, and t_0 = -1.13. Collins et al. (1987) found gag otoliths to be difficult to read whole and thus sectioned them. Their samples were collected from 1976-1982 from the commercial fishery and from MARMAP cruises, a fishery-independent survey. The oldest fish from their study was 22 years old, but they do not offer von Bertalanffy parameters. Hood and Schlieder (1992) aged gag from the Gulf of Mexico collected from 1977 through 1980. They also used sectioned otoliths and found that gag lived to be 21 years old. The von Bertalanffy parameters from their study were L_∞ = 1190, K = 0.166, and t_0 = -0.62.

Harris and Collins (In prep) collected gag from 1994 - 1996 from MARMAP cruises and the commercial fishery operating in the South Atlantic Bight. They aged gag from 1 to 26 years, although few fish lived longer than 13 years. The back-calculated lengths from the most recently formed annulus were used to estimate the von Bertalanffy growth parameters: $L_t = 1092\ (1-e^{-0.188(t + 1.33)})$ (Figure 18). Fish lengths were converted to fish weights and vice versa using the following equation: $W = 2.22 \times 10^{-5}\ (L)^{2.92}$, where W = whole weight in grams, and L = total length in millimeters. When landings data were reported in fork lengths, instead of total lengths, we converted them using an equation presented by Harris and Collins (In prep): TL = 1.04(FL) - 3.33. We constructed an age-length key from the Harris and Collins age data by taking fish total lengths in millimeters at time of capture, stratifying them in 25-mm length classes (i.e., 100-124, 125-149, etc.) and reporting the percentage each age contributed in a length class (Table 22). We compared the Harris and Collins age-length key with the Collins et al. (1987) data from the early 1980's and found them to be very similar.

Figure 19. Comparison of theoretical growth curves for gag from the southeastern U.S. and Gulf of Mexico (Manooch and Haimovici 1978; Hood and Schlieder 1992; Harris and Collins In prep).

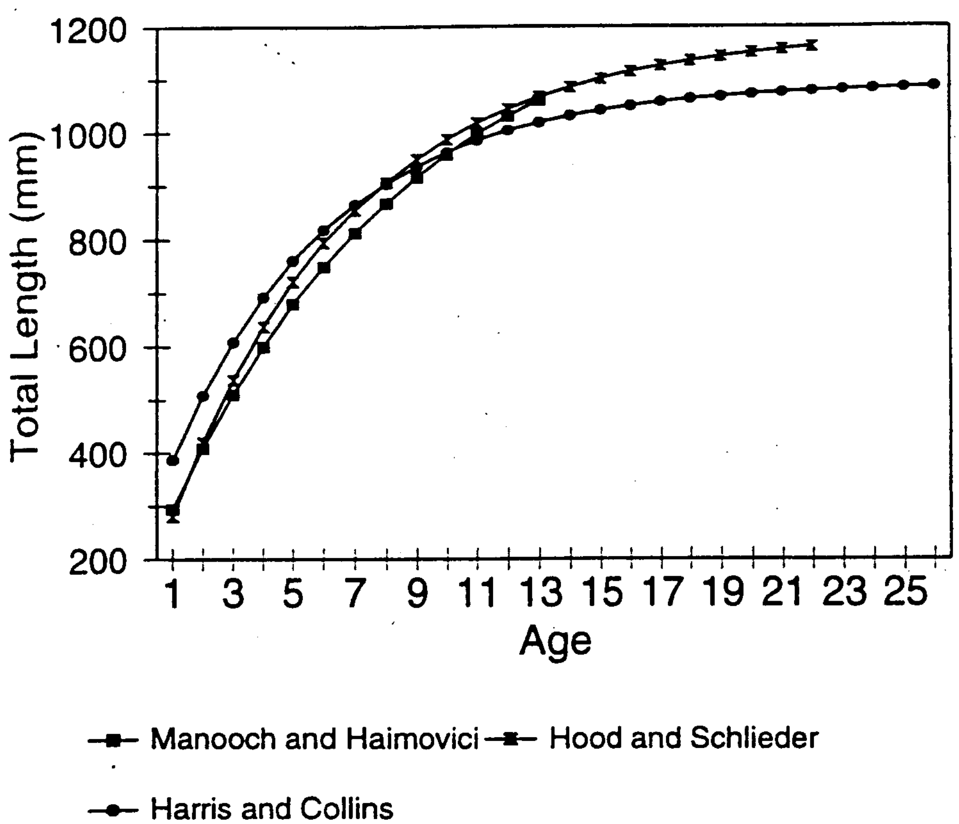


Table 22. Age - length (TL, mm) key of gag from the southeastern United States.

TL Class	n	Age 0	1	2	3	4	5	6	7	8	9	10	11	12	13
150	5	1.00													
175	4	1.00													
200	1	1.00													
225	2	1.00													
250	3	0.50	0.50												
275	1		1.00												
300	3		1.00												
325	2		1.00												
350	1		1.00												
375	5		0.40	0.60											
400	9		0.44	0.56											
425	8		0.12	0.88											
450	9			0.91	0.09										
475	8			0.50	0.50										
500	9			0.55	0.33	0.11									
525	10			0.40	0.60										
550	31			0.16	0.61	0.23									
575	31			0.07	0.72	0.17	0.03								
600	41			0.05	0.63	0.27	0.05								
625	63				0.38	0.59	0.03								
650	69				0.30	0.64	0.04	0.01							
675	98				0.24	0.64	0.09	0.02							
700	116				0.10	0.09	0.65	0.14	0.02						
725	96					0.70	0.26	0.03	0.01						
750	132					0.52	0.41	0.07	0.01						
775	161					0.40	0.45	0.11	0.03	0.02					
800	224					0.29	0.43	0.18	0.06	0.03					
825	203					0.16	0.38	0.28	0.14	0.03					
850	193						0.36	0.31	0.23	0.08	0.02				
875	125						0.26	0.28	0.32	0.11	0.03				
900	129						0.17	0.29	0.23	0.16	0.09	0.02	0.02	0.01	0.01
925	98						0.11	0.28	0.27	0.16	0.12	0.03	0.02		0.01
950	80						0.03	0.13	0.24	0.30	0.15	0.11	0.01	0.03	0.01
975	55							0.04	0.24	0.44	0.16	0.04		0.05	0.04
1000	62							0.02	0.16	0.27	0.32	0.15			0.03
1025	43								0.09	0.30	0.16	0.09	0.07	0.07	0.07
1050	62									0.06	0.13	0.16	0.03	0.11	0.02
1075	26										0.15	0.12	0.08		0.04
1100	18										0.11	0.17		0.11	0.06
1125	9										0.11			0.11	0.11
1150	4														
1175	2														0.50
1200	2														

Table 22 (cont). Age - length (TL, mm) key of gag from the southeastern United States.

TL Class	n	Age 14	15	16	17	18	19	20	21	22	23
150	5										
175	4										
200	1										
225	2										
250	3										
275	1										
300	3										
325	2										
350	1										
375	5										
400	9										
425	8										
450	9										
475	8										
500	9										
525	10										
550	31										
575	31										
600	41										
625	63										
650	69										
675	98										
700	116										
725	96										
750	132										
775	161										
800	224										
825	203										
850	193										
875	125										
900	129										
925	98										
950	80										
975	55										
1000	62	0.02		0.03	0.02						
1025	43	0.05	0.02	0.02	0.07	0.02					
1050	62	0.10		0.11	0.08	0.10	0.05	0.05			
1075	26	0.12	0.08	0.12	0.04	0.08	0.08	0.12			
1100	18		0.11	0.06	0.06	0.06	0.17		0.06	0.06	
1125	9		0.11		0.11		0.11	0.11	0.11		0.11
1150	4	0.25	0.25		0.25				0.25		
1175	2										0.50
1200	2				0.50						0.50

Development of Catch-in-Numbers-at-Age Matrix

Annual application of the catch-in-numbers-at-age matrix equation (see Methods section) to each fishery (commercial, recreational, and headboat) was performed separately by region and gear and tabulated for each year. Thus annual estimates of catch in numbers for different ages for 1986-1997 were obtained and produced a weighted catch matrix (Table 23).

Table 23. Catch-at-age matrix for gag landed in the southeastern United States by all fisheries from 1986-1997 (boxes indicate modal age for each year).

Year/Age	0	1	2	3	4	5	6	7	8	9	10	11
1986	3144	8634	15569	17674	23223	19145	10215	7311	5178	3137	1610	486
1987	2904	12532	24145	30768	32024	31421	16995	11860	7667	4070	1753	852
1988	154	6620	18502	21603	26763	24900	13471	9050	5065	2548	1014	364
1989	5040	9432	20496	24525	36061	27916	12851	8175	4959	2394	1039	305
1990	1543	10223	19503	22288	30735	24492	11199	7122	4111	2072	891	272
1991	2758	5247	12707	17879	23644	21274	10649	6973	3904	1833	702	226
1992	23	281	11179	28536	30706	25961	13206	8631	4558	2006	768	251
1993	915	377	7391	28022	34327	27165	11863	7474	4157	1917	764	230
1994	0	155	8148	28308	42881	34251	14722	9230	5053	2146	849	254
1995	8	312	7786	20781	29503	29323	14157	8901	4853	2392	997	294
1996	131	186	5745	17838	22654	26249	14689	10257	5748	2615	1012	327
1997	0	709	4817	15349	17672	18721	12147	9212	5115	2546	961	278

Year/Age	12	13	14	15	16	17	18	19	20	21	22	23
1986	595	504	574	255	564	538	405	321	319	47	25	96
1987	696	601	580	313	448	639	322	253	250	105	15	199
1988	384	356	277	194	279	281	201	226	185	99	28	37
1989	449	380	290	211	259	268	193	214	140	76	35	49
1990	357	341	237	160	238	229	172	189	116	60	33	47
1991	263	266	134	77	149	151	104	108	61	34	20	32
1992	314	278	186	108	179	179	131	126	103	39	15	49
1993	304	298	189	108	176	171	128	120	95	41	15	60
1994	327	306	229	102	220	192	152	117	123	9	8	53
1995	344	379	304	166	266	312	178	157	133	39	17	167
1996	410	436	245	146	206	234	149	137	103	45	18	121
1997	397	425	265	203	226	314	153	189	163	149	16	146

Mortality Estimates

Total Instantaneous Mortality

At first inspection, catch curves using data for 1986-1991 were somewhat different from those calculated for 1992-1997. We believe this to be mainly attributable to the minimum size limit implemented in 1992, as smaller (younger) fish could be landed in the earlier period. Also, the modal catch at age began to shift from age-4 to age-5 in 1995, and was completely shifted in 1996 and 1997. Overall, fewer gag were landed in the 1992-1997 time period than in the earlier time period.

Total instantaneous mortality for each year was estimated by regressing Ln(catch at age) on age. The regression analyses for 1986-1991 were based on gag aged 4-22 years; those produced for 1992-1997 were based on fish aged 5-22 years (Table 24; Figures 19 and 20). We stopped the regression at age-22 years because the few fish larger than any of those in the age-length key were lumped into the age-23 category. The mean total instantaneous mortality estimates were similar for the two periods: Z = 0.33 for 1986-1991; and Z = 0.35 for 1992-1997.

Table 24. Estimates of Z from regression analysis of catch curves of gag landed in the southeastern U.S. from 1986-1997.

Year	Z	S.E.	r^2
1986	0.30	0.03	0.85
1987	0.34	0.03	0.89
1988	0.32	0.03	0.86
1989	0.32	0.03	0.87
1990	0.32	0.03	0.87
1991	0.36	0.03	0.88
1992	0.36	0.03	0.88
1993	0.36	0.03	0.88
1994	0.40	0.04	0.88
1995	0.35	0.03	0.88
1996	0.35	0.03	0.89
1997	0.31	0.04	0.82

Figure 20. Natural log of the catch-at-age for gag from the southeastern U.S. landed from 1986-1991.

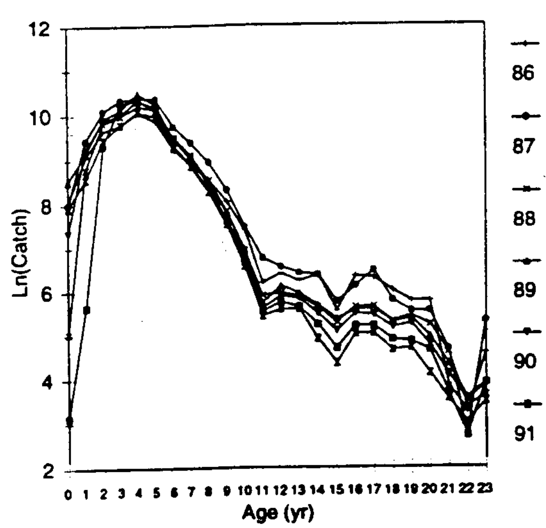
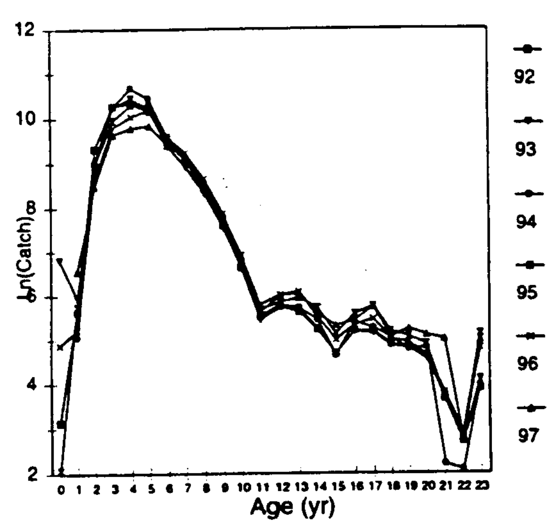


Figure 21. Natural log of the catch-at-age for gag from the southeastern U.S. landed from 1992-1997.



Natural Mortality

There is often great uncertainty in deriving a value for natural mortality, M. Yet this is an important parameter input into stock assessment analysis, and ultimately dictates the selection of the initial values of fishing mortality, F, to be used in the analyses. Caution suggests using a range of possible values for M in the analyses, and that is what we have done in this assessment. We estimated natural mortality using several methods, and then four values were chosen as a range to use in the SVPA runs. Methods used to estimate M and their resulting values are

Hoenig (1983) -	original equation -	0.16
	adjusted for sample size -	0.33
Pauly (1979) -		0.20
Ralston (1987) -		0.41
Roff (1984) -	using length at 50% maturity -	0.43
	using length at 100% maturity -	0.81
Rikhter and Efanov (1977)-		0.69
Alverson and Carney (1975) -		0.10
Alagaraja (1984) -	survivorship to max age = 1 %	0.18
	survivorship to max age = 2 %	0.15
	survivorship to max age = 5 %	0.12

Both Hoenig (1983) and Alverson and Carney (1975) use maximum age in their equations for calculating M. We used a maximum age of 26 years from the Harris and Collins study, although they found only four fish that were older than 22 years. The Hoenig method relates maximum observed age to total mortality and sample size, and assumes random sampling. Since most of the samples from the Harris and Collins age-growth study came from commercially landed gag and from MARMAP sampling, we feel this assumption is met. The Alverson and Carney (1975) method utilizes von Bertalanffy growth equation parameters as well as the oldest fish in the population to estimate T_{max}, the age at which a cohort attains its maximum biomass in the absence of fishing. Since our data came from a fished stock, the estimate of M = 0.15 seems reasonable.

The Rikhter and Efanov (1977) method produced an estimate of M that is unrealistically high (0.69). However, this estimate was not unexpected for an equation that is based solely on age at sexual maturity. Also, because this method does not address the problem of hermaphroditic fish, we do not believe the estimate of M is usable.

The value for the Pauly (1979) estimate, M = 0.20, is the same that Huntsman et al. (1991 and 1992) used in the original assessments of gag. The Alverson and Carney (1975) equation gave an estimate of M = 0.10, and is what Huntsman et al. (1996) used in a more recent stock assessment. Our mean seawater temperature input into Pauly's (1979) equation was 21.95° C.

Roff (1984) predicts M using the Brody growth coefficient K and the optimal length at maturity. Uncertain as to the true optimal size at maturity, we utilized lengths corresponding to both 50% and 100% maturity. The respective estimates of M = 0.43 and 0.81 are unreasonable, again for the same reason as that explained for not using the Rikter and Evanov equation. These estimates are very high for a species with a lifespan of 26 years.

The empirical equation of Ralston (1987) yielded a value of M = 0.41. This is high, but is partly explained by the fact that Ralston used pooled data from 14 snapper stocks and five grouper stocks in developing his regression. Sample sizes for the grouper stocks were small by his own admission. An estimate of natural mortality for a serranid derived from a regression developed from a pooled data set, dominated by lutjanid data, could result in artificially high values.

We derived a final estimate of M using the equation of Alagaraja (1984), which utilized a predetermined survivorship criteria (percent of initial cohort surviving to maximum age). It seems unlikely that survivorship to this maximum age would be 5%, as recently applied by Ault et al. (1998), so we derived estimates of M using three levels of survivorship for comparative purposes: 1, 2, and 5%. The respective values of M were 0.18, 0.15, and 0.12, and they all agree reasonably well with each other, and with our estimate that we believe the most appropriate for gag (M = 0.15).

Our estimates of M generally fall into the range 0.10 to 0.33. It seems unlikely that a long-lived serranid would have an M greater than 0.40, therefore we discount the estimates returned by Rikhter and Evanov (1977), Roff (1984), and Ralston (1987). We believe that the true value of M for gag falls between 0.10 and 0.25. To provide evaluation latitude in our analyses, we choose to run theanalyses with a range of values for natural mortality from 0.10 to 0.25.

Fishing Mortality and Virtual Population Analysis

For the separable VPA runs, two catch matrices were analyzed consisting of catch in numbers for ages 0 through 22 for fishing years 1986-1997. Modal ages for the two time segments were age-4 for 1986-1991, and age-5 for 1992-1997. For the SVPA, starting values for F were based on the mean estimates of Z from the two time periods (0.33 yr^{-1} for 1986-1991 and 0.35 yr^{-1} 1992-1996). Sensitivity of estimated F to uncertainty in M was investigated by conducting the above SVPAs with alternate values of M (0.10, 0.15, 0.20, and 0.25).

Because of the short duration of the catch matrix and large number of ages, mean values only for the pre- and post-minimum size limit were considered. Mean values of age-specific estimates of F were obtained from the separable VPA applied to the catch at age data (Table 23) using the uncalibrated separable (SVPA). Estimates of F were averaged over fully-recruited ages (ages 4-22 for 1986-1991 and ages 5-22 for 1992-1997), weighted by catch in numbers for those ages (referred to as full F). Employing the uncalibrated separable approach (SVPA) with M of 0.15, we obtained mean estimates of full F were 0.32 for 1986-1991 and 0.20 for 1992-1997 (Table 25 and 26).

Table 25. Spawning potential ratio (SPR) and yield per recruit (YPR) of gag from the southeastern United States landed during 1986-1991, previous to the implementation of the 20-inch size limit.

Natural Mortality (M)	Full F	SPR	YPR (lb)
0.10	0.40	10.01%	7.12
0.15	**0.32**	**18.50%**	**5.36**
0.20	0.26	29.02%	3.86
0.25	0.16	48.28%	2.38

Table 26. Spawning potential ratio (SPR) and yield per recruit (YPR) of gag from the southeastern United States landed during 1992-1997: 0% release mortality, 20% release mortality, and 50% release mortality.

Release Mortality	Natural Mortality (M)	Full F	SPR	YPR (lb)
0%	0.10	0.26	17.53%	7.69
	0.15	**0.20**	**29.97%**	**5.20**
	0.20	0.14	46.15%	3.22
	0.25	0.09	64.08%	1.74
20%	0.10	0.26	16.50%	7.50
	0.15	**0.20**	**28.27%**	**5.14**
	0.20	0.14	44.65%	3.22
	0.25	0.09	62.72%	1.76
50%	0.10	0.26	15.23%	7.25
	0.15	**0.20**	**26.61%**	**5.05**
	0.20	0.14	42.60%	3.22
	0.25	0.09	61.32%	1.79

Because of the minimum size limit in place since 1992, we incorporated two levels of released fish mortality. One estimate of release mortality, 20%, was estimated from shipboard observations made during headboat fishing trips (Robert Dixon, NMFS, Beaufort, North Carolina). If the released fish floated at the surface, or was attacked by a predator near the surface, the fish was considered dead. Because conclusive observations of fish that begin their descent to the bottom, but then fade from sight, are impossible to make, we felt that 20% release mortality was low. Therefore, we also ran the YPR and SPR analyses using a 50% released fish mortality.

The ages of fish in the catch which were most affected by the minimum size limit were zero, one, and two years (Figure 22). Age-3 fish were impacted by the regulation but not at the same levels as the other ages. Gag aged older than age-3 were above the minimum size limit. For ages 0-3, we used P_{rm} = 20%, and then 50%, to adjust F from the post-regulation time period (Table 27).

Figure 22. Catch-at-age of gag less than 500-mm total length. The minimum size limit of gag has been in affect since January 1, 1992: 20-in (~500-mm).

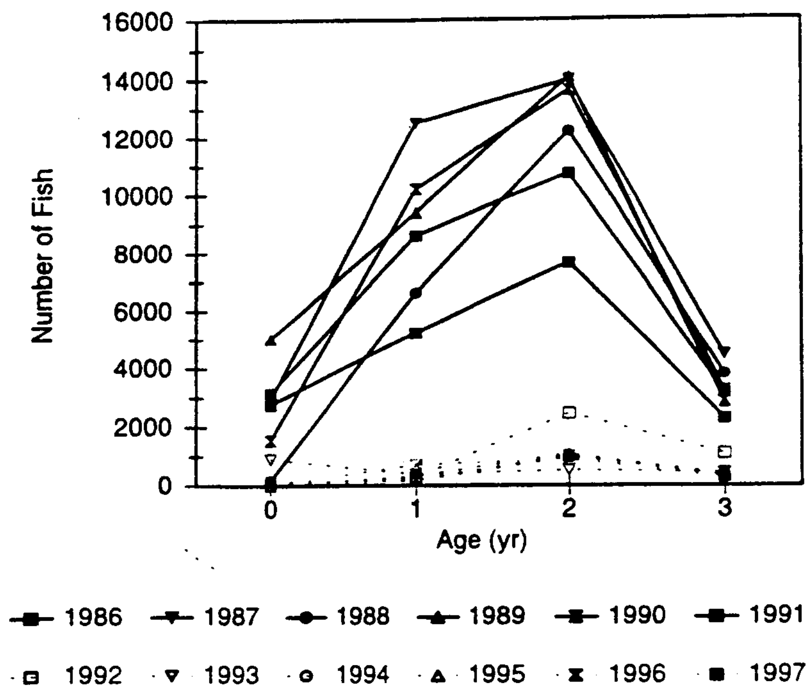


Table 27. Mean fishing mortality by age of gag (M=0.15) from 1986-1991 (full F at ages 4-22) and 1992-1997 (full F at ages 5-22) with 0% release mortality, 20% release mortality, and 50% release mortality.

Year	Release	Age					
	Mortality	0	1	2	3	4	5
1986-91	0%	0.004	0.029	0.077	0.126	0.32	
1992-97	0%	0.000	0.001	0.028	0.105	0.180	0.200
1992-97	20%	0.001	0.007	0.038	0.110	0.180	0.200
1992-97	50%	0.002	0.015	0.053	0.116	0.180	0.200

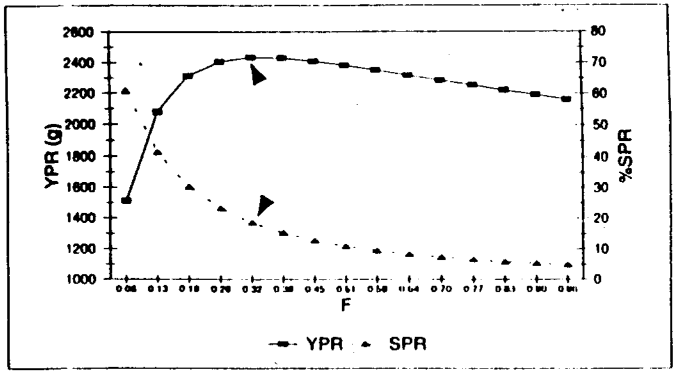
Yield Per Recruit

Yield per recruit remained approximately the same for 1986-1991 and 1992-1997 at M = 0.15: 5.36 and 5.20 pounds, respectively (Tables 25 and 26). This similarity is most probably due to the decreased fishing mortality on the fully-recruited ages in the later time period. Data are presented graphically in Figure 23a-d. We incorporated adjustments for released fish mortality (20% and 50%) in 1992-1997 to determine what impact these values would have on yield at entry to the fishery. The resulting yield per recruit dropped only slightly in the presence of release mortality: 5.14 pounds with 20% release mortality and 5.05 pounds with 50% (Table 26).

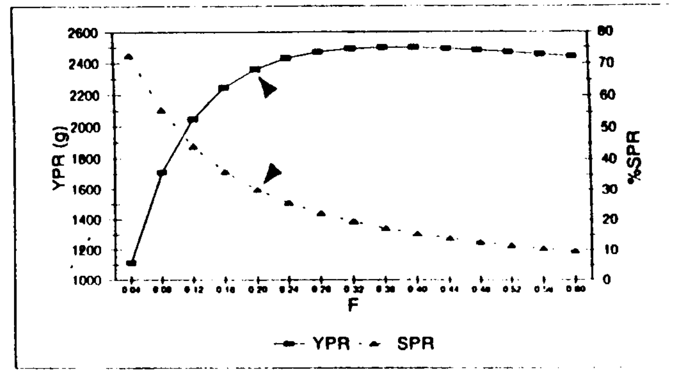
Before the minimum size limit was imposed, yield per recruit of gag ranged from 2.38 to 7.12 pounds depending on level of M (Table 25). After the regulations were in place yield per recruit ranged from 1.74 to 7.69 pounds (Table 26).

Figure23. Ricker yield per recruit and spawning potential ratio for gag landed in the southeastern U.S. previous to the 20-inch size limit and after the implementation of the size limit, as well as two levels of released mortality (RM) of sublegal fish (M = 0.15).

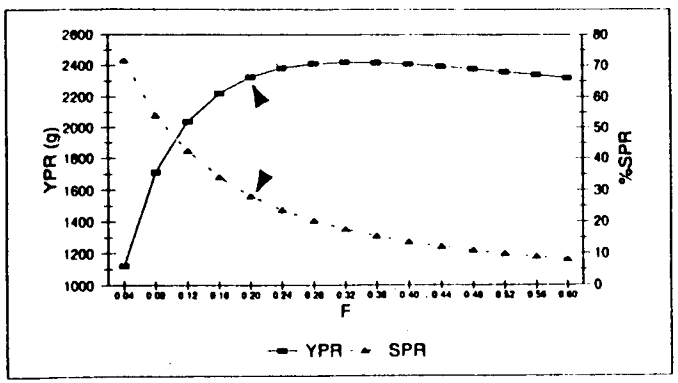
a. 1986-1991: M=0.15, F=0.32



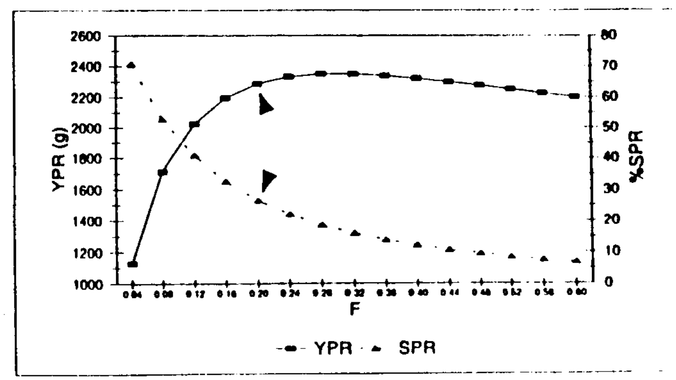
b. 1992-1991: M=0.15, F=0.20, RM=0%



c. 1992-1997: M=0.15, F=0.20, RM=20%



d. 1992-1997: M=0.15, F=0.20, RM=50%



Spawning Potential Ratio

A comprehensive reproductive study of gag from the southeastern United States was completed by McGovern et al. (1998). The study was requested by the SAFMC and involved cooperation between the NMFS and the states to obtain samples from commercial and recreational fishermen. We used the maturity schedule from that study: 0% mature at age-0; 0% mature at age-1; 0% mature at age-2; 28% mature at age-3; 51% mature at age-4; and 100% mature at age 5. The schedule is the same used by Huntsman et al. (1996). However, to be conservative in our estimates of spawning potential ratio, we used total maturity (sexes combined), because this species is a protogynous hermaphrodite, and we do not know if males are the limiting factor to reproductive success.

Spawning potential ratio (SPR), or percent maximum spawning potential, of gag was calculated for two time periods (1986-1991 and 1992-1996) based on mean age-specific fishing mortality from SVPA analysis using the four different levels of natural mortality (Tables 25 and 26). Released fish mortalities of 20% and 50% (pers. comm. Robert Dixon, NMFS, Beaufort Laboratory) were incorporated into the SPR model for the latter time period.

Percent maximum spawning potential was lowest for the earlier time period, 18.5% (M = 0.15) (Figure 23a; Table 25).

This value is similar to the static SPR presented by Huntsman et al. (1996) (~18%) for fishing year 1991 and M = 0.10. Original estimates of static SPR using 1988 and 1990 fishing years and M = 0.20 were 32% and 35%, respectively (Huntsman et al. 1991 and 1992). The estimates obtained from the two analyses are not accurate because the age - length key used was from Manooch and Haimovici (1978), which included fish only aged to 13 years, and the maturity schedule was unknown and based on the proxy of age at ½ L_∞.

Since the implementation of a 20-inch minimum size limit in 1992, the estimate of spawning potential ratio has increased to 30% when M = 0.15 (Figure 23b; Table 26). Better estimates of the SPR from the post-regulation time period, as provided in this analysis, which incorporate 20% and 50% release mortalities of undersized fish, are 28% and 27%, respectively (Figure 23c-d; Table 26). These values are similar to the static SPR for the 1996 fishing year, 27% at M = 0.15, reported by Potts et al. 1998.

Two management options are evaluated in Table 28 that could each increase SPR to 40%. The two options are reduce F or increase minimum size, thus raising the age at entry to the fisheries. This evaluation currently applies to the species only if M = 0.15. The two options can be visualized in Figure 24b-c, and one can see how the stock has improved from the earlier time period (Figure 24a). The soon to be implemented size limit of 24 inches will potentially raise the SPR to 30% with release mortality as high as 50% (or reduce full F by 10%). To get SPR to 40% a minimum size of 30 inches would be required, or reduce full F by as much as 40%.

Table 28. Two management options that could result in SPR values of gag raised to 30% and 40%, based on 1992-1997 data.

a. No release mortality of sub-legal fish incorporated.

M	Full F	Current SPR	% Reduction in F to achieve		Raise minimum size (age) to achieve	
			30%	40%	30%	40%
0.15	0.20	30%	N/A	30%	N/A	30" (5yrs)
0.20	0.14	46%	N/A	N/A	N/A	N/A

b. 20% release mortality of sub-legal fish incorporated.

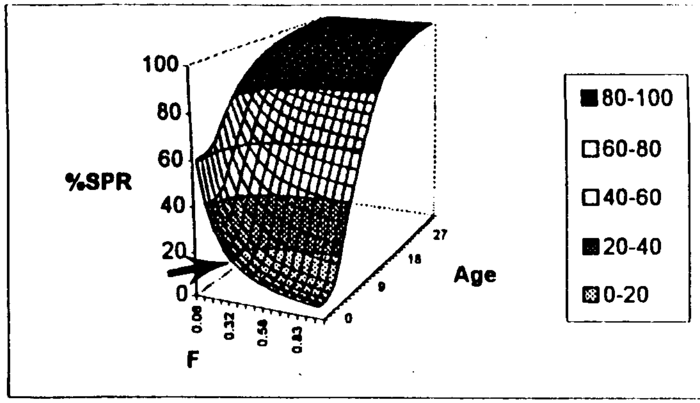
M	Full F	Current SPR	% Reduction in F to achieve		Raise minimum size (age) to achieve	
			30%	40%	30%	40%
0.15	0.20	28%	8%	35%	24" (3yrs)	30" (5yrs)
0.20	0.14	45%	N/A	N/A	N/A	N/A

c. 50% release mortality of sub-legal fish incorporated.

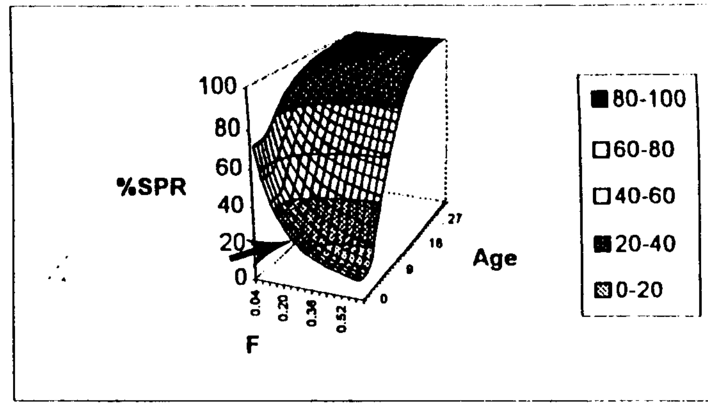
M	Full F	Current SPR	% Reduction in F to achieve		Raise minimum size (age) to achieve	
			30%	40%	30%	40%
0.15	0.20	27%	10%	40%	24" (3yrs)	30" (5yrs)
0.20	0.14	43%	N/A	N/A	N/A	N/A

Figure 24. Spawning potential ratio of the gag population from the southeastern U.S. previous to the 20-inch size limit (1986-1991) and after the implementation of the size limit (1992-1997), and incorporating two levels of release mortality on sub-legal fish.

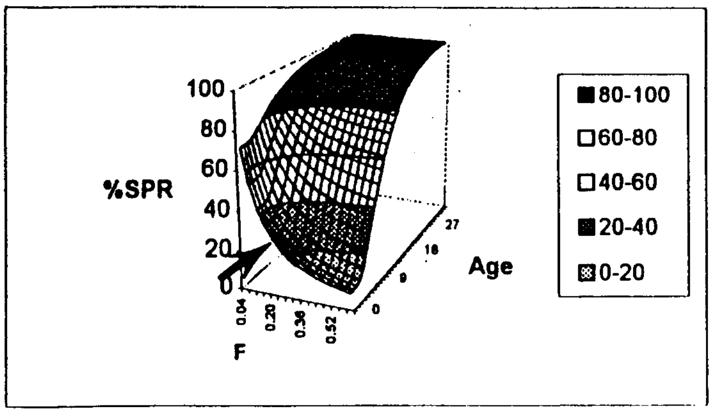
a. 1986-1991: M=0.15, Full F = 0.32



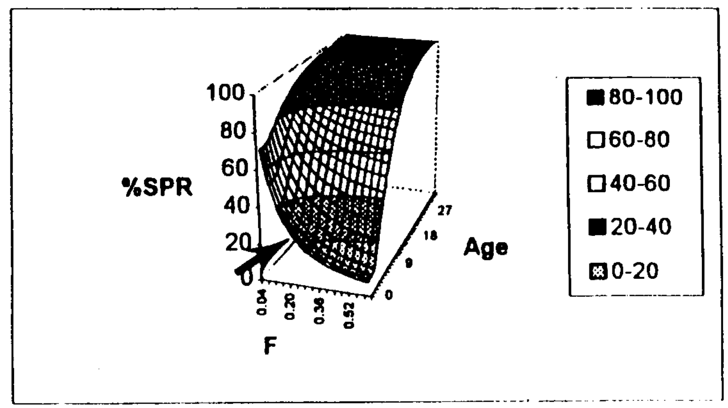
b. 1992-1997: M = 0.15, Full F =0.20



c. 1992-1997: M = 0.15, Full F = 0.20, Release Mortality = 20%



d. 1992-1997: M = 0.15, Full F = 0.20, Release Mortality = 50%



CONCLUSIONS

We believe that our assessment of gag is flexible enough in its presentation to allow the reader to independently judge the status of the stock. This is because we present different fishing pressure response scenarios based on four different estimates of M.

The longest time series of landings of gag is from the Headboat Survey, and the landings have decreased since 1988. However the commercial landings have been increasing since 1991, and MRFSS landings were also increasing until a dramatic drop in 1994. The mean size of gag landed has generally increased in the most recent years, since a low in the late 1980's, and catch per unit effort has remained fairly steady since the 1980's. The population of gag seems to be stable at this time. Overall, fishing mortality has decreased since 1992, and the fully-recruited age to the fisheries has shifted from four years to five years. Female gag are 100% mature for age-5. These observations indicate that the size limit imposed in 1992 is having a favorable impact on the stock.

SPR values were derived using natural mortality (M) values of 0.10, 0.15, 0.20, and 0.25. We believe that the most accurate estimate of M is 0.15. For the most recent time period, an M of 0.15, including 50% release mortality of undersized fish, resulted in an SPR value of 0.27. The soon to be imposed 24-inch size limit could potentially raise SPR to 30%. A natural mortality of 0.20 predicts the gag population is well above the target level of 40%.

We conclude that the gag stock is in an improved condition. Management actions taken by the SAFMC have been instrumental in the process of rebuilding the stock.

Some problems were encountered while preparing this stock assessment and should be addressed: Misidentified landings of gag and black grouper in the General Canvas; inadequate sampling from the MRFSS; and incomplete landings and sampling information from various states reporting the commercial fishery landings data in 1997. Georgia 1997 length samples were not in the TIP database, and North Carolina 1997 commercial length samples were very low or incomplete. Florida General Canvas landings were not complete for 1997 in that they were not assigned county codes, which is crucial to our analysis. Near the completion of our analysis, we were supplied with gag and black grouper commercial landings for Florida by county, so we could include the 1997 fishing year in our catch matrix, though we do not believe the 1997 landings were complete at the time of this report.

ACKNOWLEDGMENTS

We would like to thank Doug Vaughan and Jim Waters, NMFS, Beaufort, NC for helping with the analysis of released fish mortality and being a "sounding board" for any problems with the data that may have arisen. We would also like to express our appreciation to Jack McGovern, SCDNR, Charleston SC, for providing MARMAP fishery-independent data. Our thanks are extended to Joe Powers, NMFS, Miami, FL, and to Dean Ahrenholz and Jim Waters, NMFS, Beaufort, NC for providing comments on drafts of the document.

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MARINE BIOTECHNOLOGY

TAB 3B.

Stock Identification of Gag, *Mycteroperca microlepis*, Along the Southeast Coast of the United States

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Abstract: The gag grouper *Mycteroperca microlepis* is an important component of commercial and recreational fisheries along the South Atlantic coast of the United States and in the Gulf of Mexico. Over the past two decades, this species has experienced significant declines in abundance and an increasing skew in sex ratios. Analysis of microsatellite DNA variation in this species shows mosaic patterns of population subdivision and significant departures from Hardy-Weinberg equilibrium in all sampling locations. Given the length of the pelagic stage (egg and larvae), the prevailing current patterns, and the migratory capabilities of the adults, it is unlikely that these observations are the result of restricted gene flow among genetically differentiated populations. The apparent structure of gag populations most likely reflects inbreeding in size-limited populations. Population declines, skewed sex ratios, and perhaps variance in female fecundity appear to have acted in concert to limited the number of individuals that contribute to a given year class. These data are reinforced by studies of other fish stocks that have experienced precipitous declines over the past two decades.

Key words: gag grouper, *Mycteroperca microlepis*, population decline, inbreeding, sex ratio, stock identification

Introduction

Many species of epinephelinc fishes, commonly called groupers, undertake annual migrations to well-defined locations to spawn (Colin et al., 1987; Shapiro, 1987; Carter, 1989; Waschkewitz and Wirtz, 1990; Sadovy et al., 1994). In some cases these migrations are believed to be to natal waters, which are thought to possess favorable hydrographic conditions that enhance survival of larvae (Richards and Lindeman, 1987; Waschkewitz and Wirtz, 1990). Grouper spawning aggregations are often heavily fished (Craig, 1969; Carter, 1989), and this may reduce population abundance throughout the range if most individuals are spawning in a few locations. Fishing of spawning aggregations can have serious deleterious effects on the population size, genetic diversity, and behavior of species that aggregate (Craig, 1969; Nelson and Soule, 1987; Carter, 1989), and special management for spawning areas should be considered.

Gag, *Mycteroperca microlepis*, is the most frequently landed grouper in commercial and recreational reef fish fisheries in South Carolina. Although many aspects of gag life history have been described (e.g., Collins et al., 1987; Keener et al., 1988; McGovern et al., 1998), information from the Atlantic Coast of the southeastern United States on spawning location, recruitment sources, and stock identification is limited or lacking. Tagging data suggest that some gag off South Carolina may migrate to southern

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Florida (Van Sant et al., 1994; MARMAP unpublished results). Although very limited, these data are supported by observations from commercial fishermen and sport divers in southern Florida (Ben Hartig and Bill Parks, personal communications), who describe a historical pattern of migration of gag to the narrow east Florida shelf near West Palm Beach, in winter. If such a spawning migration does occur, the ramifications for management of gag would be significant. Careful management of the species requires that life history be well understood, and that the species be afforded protective management such that reproduction is ensured.

Over the past two decades, gag populations have declined by as much as an order of magnitude in some areas (McGovern et al., 1998), female-to-male sex ratios have changed from about 8:1 to about 30:1 (Coleman et al., 1996; Koenig et al., 1996), and age of sexual maturity has declined substantially. Declines in abundance, changing sex ratios, and evidence of a spawning migration suggest that a proposed spawning season closure might be necessary, but only in the waters off Florida. The spawning migration suggested by limited tagging data (Van Sant et al., 1994) would result in a single genetic stock of gag if all fish from the region migrate to narrowly defined spawning areas off Florida.

The objective of this study was to use microsatellite variation to identify stocks of gag along the southeast Atlantic Coast and in the Gulf of Mexico. We hypothesized that a single population of gag occurs in the Atlantic between Cape Fear and South Florida (south of Cape Canaveral), with a separate stock in the northeastern Gulf of Mexico. Another component of this study was motivated by the population declines, skewed sex ratios, early onset of sexual maturity, and sex reversal. Collectively these features could impact the distribution of genetic variation in the species owing to their effects on effective population sizes (N_e).

One difficulty in interpreting the results of multilocus data is that some loci may indicate that populations are genetically distinct and other loci will indicate genetic homogeneity. Likewise, some loci may indicate that a population does not conform to the expectations of Hardy-Weinberg (HW) equilibrium, while others do not show significant deviations. The question becomes, which loci do we believe? Are the populations genetically distinct? Are the samples taken from Mendelian populations? We have developed a procedure using a maximum likelihood approach to examine these problems. The procedure allows one to examine the likelihood that some portion of the loci will, by chance, suggest population subdivision or deviations from Mendelian ratios.

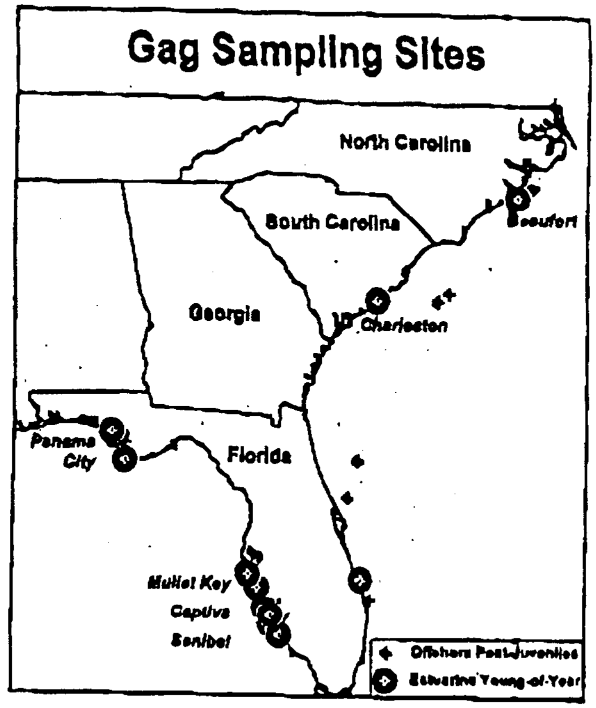

Figure 1. A map of the sampling locations for *Mycteroperca microlepis* taken during this study.

Materials and Methods

DNA samples were obtained from gag that were collected by research surveys and port sampling of commercial catches, from Beaufort, North Carolina, to Panama City, Florida (Figure 1). Tissue samples included heart tissue as well as blood and fin clips from tagged and released fish. The tissue was immediately placed in a 1.5-ml centrifuge tube containing 1 ml of a sodium dodecy sulfate (SDS)/urea lysis solution (1% SDS/6 M urea). The samples were then transported to the laboratory and stored at room temperature. DNA was isolated using standard protocols (White and Densmore, 1992), and 5 µl of each isolation was separated on a 0.8% agarose gel in TAE buffer to confirm the presence of an adequate amount of high molecular weight DNA. The final concentration of DNA in each sample was about 10 to 100 ng/µl.

Eight sets of microsatellite primers (Table 1) were developed for gag, by cloning nuclear DNA segments that

Table 1. Nucleotide Sequences of Microsatellite Primer Sets Designed to Amplify GT-Repeat Regions of the Gag Nuclear Genome*

Primer designation	Sequence	Result
GAG007F	5'-CTGTAATAGACAACCCACTGTAC	P
GAG007R	5'-CCTGTAGCATCTTCACTAGCTG	
GAG010F	5'-CTAGAGGATCATTTGACAATGTAG	P
GAG010R	5'-CCTGACTAATCCACAGTAATTGC	
GAG013F	5'-TTTGACACCACAGAAGAAGAAGG	M
GAG013R	5'-TGTCCAATCACAGCACATCAG	
GAG023F	5'-GCATTTGTGTTAGGATGACACT	P
GAG023R	5'-CACATGGACAGGATTGAGGA	
GAG031F	5'-TGATAGAAACACGCATTCAC	M
GAG031R	5'-ATGCTGCTTCAACAGTGT	
GAG038F	5'-CCCCACCTCCCTTAACA	P
GAG038R	5'-GCTGAATTGAGGAAATGAG	
GAG045F	5'-GTGTGCATGTGAGAGAAAGT	P
GAG045R	5'-GCCTTAACGGATGTCTTTCT	
GAG049F	5'-ACTCTAATCTACAGCATATTCT	P
GAG049R	5'-CAGCTCGCCTGAAAGACT	

*F indicates forward primer; R, reverse primer; P, polymorphic locus; M, monomorphic locus.

showed GT repeats, and by sequencing DNA segments flanking the region containing variable lengths of GT repeats (i.e., microsatellites). Microsatellites were identified according to the protocol of Tautz (1989), and polymerase chain reaction (PCR) primers were designed for clones containing at least eight repeats. These primers were used to amplify samples of gag DNA to identify those loci that contained sufficient polymorphism to meet the study objectives.

Amplification conditions were 2 µl of template DNA, 5 µl of 10× buffer (0.67 M Tris, 0.166 $(NH_4)_2SO_4$, and 10 mM β-mercaptoethanol), 200 µM dNTPs, 100 µM of each primer, 32.5 µl of water, and 2 mM $MgSO_4$) for 35 cycles (one cycle = 30 seconds at 94°C, 30 seconds at 53°C, 2.5 minutes at 72°C). An initial screening for levels of variation was conducted on 4% metaphor (FMC, Inc.) gels. This screening indicated that dinucleotide repeats could easily be discerned on this gel system. To verify the consistency of scoring, samples containing all of the allelic variant identified by metaphor gels were amplified using a radiolabeled primer, and the products were separated on sequencing gels. These results confirmed patterns we had observed on metaphor gels, and the simpler metaphor gel was used to separate microsatellite alleles. Five of the eight microsatellite loci developed for this study proved to be polymorphic (Table 1); however, two of these (GAG007 and GAG023) were difficult to score owing to stuttering and were not included in the database.

All statistical analyses reported here were performed on the GENEPOP program of Raymond and Roussett (1995a). The tests for deviation from HW equilibrium were conducted for any deviation, rather than the alternative hypothesis of heterozygote deficiency (Raymond and Roussel, 1995b). In addition, we conducted global tests for HW equilibrium across all loci for each population and across all loci for the total sample following Raymond and Roussett (1995b). We refer the interested reader to the GENEPOP manual for the details of the methods used in computing the various statistics reported here. The significance levels assigned to multiple simultaneous tests among populations at individual loci were determined by the sequential Bonferroni procedure (see Rice, 1989). Although this procedure can be quite conservative, it does provide an indication of the level of significance of individual tests. The significance of allele frequency differences in pairwise comparisons of populations across all loci was estimated by a new approach, which computes the likelihood that r of n tests would exceed the 0.05 level by chance. This probability can be calculated from the likelihood function

$$L = \sum_{i=r}^{n} C(1-\alpha)^{n-r}(\alpha)^{r},$$

where n is the total number of tests, r is the fraction of significant tests at a given α, C is the factorial constant $(n!/(r!(n-r)!)$, and we sum from r to n. We have adopted this approach because we wish to examine the likelihood that r of n loci would exhibit significantly different gene frequencies between two populations by chance. This test can easily be extended to examine the probability that r of n tests for HW equilibrium at multiple loci and across multiple populations. It therefore serves as an independent check on the global tests for HW equilibrium derived by Raymond and Roussett (1995b). For convenience, we have calculated these probabilities for $\alpha = 0.05$ and up to 10 tests (Table 2).

t2

Results

The numerical solutions to the maximum likelihood equation (see above) suggest that when about a third or more of

Table 2. The Results of the Likelihood Function for the Probabilities That a Speficied Number of Tests Would Be Significantly Different from Expectations at $\alpha = 0.05$[a]

Number of simultaneous tests	Number of significant tests								
	2	3	4	5	6	7	8	9	10
0	0.9025	0.857375	0.814506	0.773781	0.735092	0.698337	0.66342	0.630249	0.598737
1	0.095	0.135375	0.171475	0.203627	0.232134	0.257282	0.279335	0.298539	0.315125
2	0.0025	0.007125	0.013538	0.021434	0.030544	0.040623	0.051456	0.06285	0.074635
3		0.000125	0.000475	0.001128	0.002143	0.003563	0.005416	0.007718	0.010475
4			6.25E-06	2.97E-05	8.46E-05	0.000188	0.000356	0.000609	0.000965
5				3.13E-07	1.78E-06	5.92E-06	1.5E-05	1.69E-06	6.09E-05
6					1.56E-08	1.04E-07	5.36E-07	5.92E-08	1.07E-06
7						7.81E-10	5.94E-09	2.54E-08	2.41E-08
8							3.91E-11	3.34E-10	3.17E-10
9								1.95E-12	1.86E-11
10									9.77E-14

[a]To obtain the likelihood that r (or more) of n tests are significant by chance, simply sum the values in a column for all rows equal to and greater than r. See text for explanation of the likelihood function.

the loci involved in independent tests exceed $\alpha = 0.05$, we should conclude that populations were genetically distinct (Table 2). Likewise for tests of HW equilibrium in a population, we should conclude that the sample was not drawn from a Mendelian population under the same conditions. The analysis does assume that loci are not genetically linked and are responding in a similar fashion to the pressures of mutation, migration, drift, and selection.

The gene frequency distributions for each population at each locus are presented in Table 3. We labeled the alleles according to their molecular weights, and the loci proved to be perfect dinucleotide repeats ranging from bases 132 to 146 (GAG010), 104 to 114 (GAG038), and 138 to 152 (GAG045). Overall the GAG010 and GAG045 loci are typical of microsatellites in that the most frequent alleles are in the center of the molecular weight range and the frequency distribution of alleles plotted against their molecular weighs is, more or less, bimodal. GAG038 is unusual in that the most common allele is the smallest.

The p values reported in Table 3 indicate the degree of conformity of genotypic distributions to HW proportions. These values are significantly different from expectations for all populations at the GAG010 and GAG045 loci, even when corrected for multiple simultaneous tests by the Bonferroni procedure. At the GAG038 locus, only Florida East Coast and West Coast populations differ from Mendelian expectations. The global test results for conformity to HW equilibrium across loci for each population using the Raymond and Rousset approach (Table 3) are all significant and strongly indicate that that these samples are not drawn from Mendelian populations. This conclusion is supported by examination of Table 2; we see that the chance probability of two or more loci deviating from HW proportions is less than 0.01. Thus we can safely conclude that none of the sampling locations appears to have Mendelian populations.

The F_{it} values reported in Table 3 indicate that there is an excess of homozygotes in all cases where significant deviations from HW equilibrium were noted. This could indicate the presence of "null" alleles, and we estimated the frequency of null alleles as $r = .2245$ using the calculation of Brookfield (1996, eq. 4). We would expect 12.4 null homozygotes in the total database if null alleles were this common, and we observed none. A portion of the individuals collected during this study (not included in the data) did fail to amplify, but the failures were at two or more of the loci and attributed to degraded DNA or sample contamination. For these reasons, we consider it unlikely that null alleles made a substantial contribution to F_{it}, but cannot dismiss the possibility.

Other potential contributors to the large F_{it} values are the possibility the individuals that were heterozygous for alleles that differed by a single repeat were incorrectly scored as homozygotes for one of the alleles, and the po-

Table 3. Gene Frequency Distributions at the Indicated Loci in Samples of *Mycteroperca microlepis*

Locus	Alleles*	North Carolina	South Carolina	Florida East Coast	Florida West Coast	Panama City, Florida	Total
GAG010	132	0.000	0.036	0.027	0.050	0.060	0.037
	134	0.040	0.027	0.113	0.025	0.050	0.059
	136	0.160	0.179	0.253	0.013	0.220	0.181
	138	0.220	0.134	0.260	0.175	0.420	0.246
	140	0.320	0.339	0.167	0.188	0.130	0.217
	142	0.240	0.259	0.033	0.313	0.090	0.163
	144	0.020	0.027	0.113	0.075	0.010	0.057
	146	0.000	0.000	0.033	0.163	0.020	0.041
	N	25	56	75	40	50	246
	p	0.0131	0.0001	0.0001	0.0041	<0.0001	0.0005
	F_{is}	0.441	0.401	0.300	0.325	0.363	
GAG038	104	0.840	0.875	0.827	0.850	0.790	0.835
	106	0.100	0.107	0.100	0.113	0.130	0.110
	108	0.060	0.018	0.040	0.025	0.070	0.041
	110	0.000	0.000	0.013	0.013	0.000	0.006
	112	0.000	0.000	0.013	0.000	0.010	0.006
	114	0.000	0.000	0.007	0.000	0.000	0.002
	N	25	56	75	40	50	246
	p	1.000	1.000	0.0002	0.0326	0.5635	1.000
	F_{is}	−0.120	−0.114	0.044	0.066	0.050	
GAG045	138	0.020	0.045	0.033	0.075	0.050	0.045
	140	0.100	0.214	0.180	0.213	0.320	0.213
	142	0.100	0.250	0.353	0.150	0.310	0.262
	144	0.180	0.223	0.300	0.213	0.160	0.228
	146	0.120	0.125	0.127	0.125	0.090	0.118
	148	0.200	0.107	0.007	0.175	0.050	0.085
	150	0.220	0.036	0.000	0.050	0.020	0.043
	152	0.060	<0.0001	<0.0001	<0.0001	<0.0001	0.006
	N	25	56	75	40	50	246
	p	0.0131	0.0001	0.0001	0.0040	0.0001	0.0131
	F_{is}	0.021	0.238	0.118	0.142	0.301	

*N indicates the sample size; p, the probability of departure from Hardy-Weinberg expectations; F_{is}, the inbreeding coefficient for each population.

tential that smaller alleles are favored in PCR and could result in incorrect scoring of heterozygotes containing the larger alleles as homozygotes for the smaller allele. In the former case, we would expect that heterozygotes whose alleles differed by a single step would be the largest contributor to the overall heterozygote deficiency. In Figure 2, we have plotted the deviation from HW at the GAG010 locus as *D* according to Selander (1970) for heterozygotes that differ by 1, 2, 3, and 4 or more repeats. It is clear from this illustration that heterozygotes that differ by 3 or more repeats are the largest contributors to the overall heterozygote deficiency. In addition, heterozygotes that differed by a single step were actually overrepresented compared with the expectation for this locus. Results were similar for the GAG045 locus, except that single-step heterozygotes were underrepresented. Nonetheless, heterozygotes that differed by two or more repeats were the largest contributors to the overall heterozygote deficiency.

Examination of the potential for PCR bias as a contributor to heterozygote deficiency is not as straightforward as the test for misscoring of adjacent size classes. We cannot compute the heterozygote deficiency associated with the

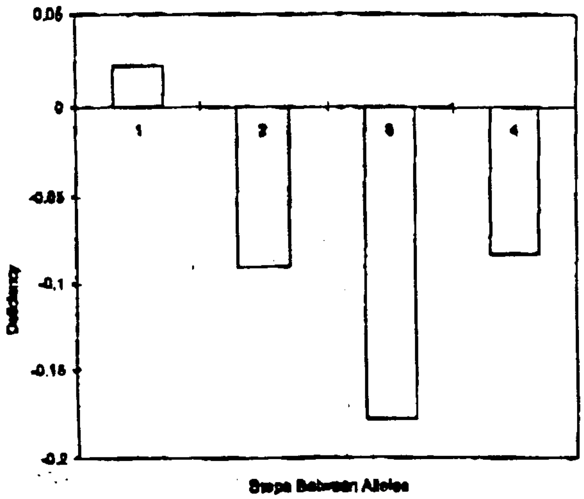

Figure 2. The deviation from HW equilibrium for heterozygotes at the GAG010 locus, where the alleles differ by 1, 2, 3, and 4 or more GT repeats. The deviations are reported as D according to Selander (1970).

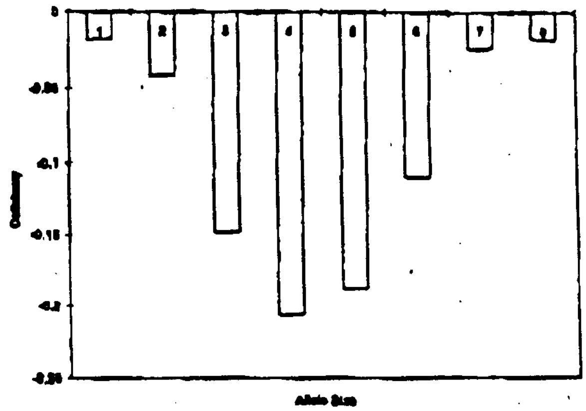

Figure 3. The deviation from HW equilibrium attributable to each allele at the GAG010 locus (see text for details). The deviations are reported as D according to Selander (1970).

smaller alleles and compare it with the deficiency associated with larger alleles because these estimates are not independent. We can examine the problem by computing the homozygote excesses associated with each allele (which are by definition F_{ij} estimates and independent) and converting these to heterozygote deficiencies. We have plotted these estimates for each allele for the GAG010 locus (Figure 3). Figure 3 shows that the overall heterozygote deficiency does not appear to be associated with allele size class. The correlation coefficient was 0.54 and not significant. Thus we can discount misscoring of single-step heterozygotes and amplification bias as major contributors to the heterozygote deficiency.

Pairwise tests for gene frequency differences among populations at the GAG010 locus show that all populations were significantly different except North Carolina and South Carolina populations (Table 4). None of the populations differed at the GAG038 locus, while all comparisons were significant at the GAG045 locus, except those involving South Carolina and Gulf of Mexico populations (Table 4). For the pairwise comparisons of populations, we require $p < .05$ for at least two of the three loci. From Table 4, we see that all comparisons meet this criteria, except those involving South Carolina, which differs only from the East Coast of Florida at two or more loci.

The partitioning of genetic variance within and between populations (Table 5) reinforces conclusions that might be drawn from HW tests and pairwise comparisons of gene frequencies. Here is it shown that variation within populations is, by far, larger than the component attributable to differences between populations. This should not be taken to imply that the differences among samples lack significance (see Table 4). Wright (1943) designed the F statistics to partition the total genetic variance (F_{it}) into within population (F_{is}) and between population (F_{st}) components analogous to analysis of variance. The fact that F_{is} is larger then F_{st} does not mean that the allele frequency differences among samples are not statistically significant. Clearly, they are.

An assessment of the genotypic linkages among loci for each population and in the total data (Table 6) shows that none of the loci are linked in any of the populations. The only value that is even close to significance (West Coast Florida, GAG038 vs GAG045) is not significant when adjusted for multiple tests. These comparisons are important because they validate the independence assumptions in the global HW equilibrium tests conducted by GENEPOP (Raymond and Roussett, 1995a) and the likelihood approach derived from the maximum likelihood equation (above).

Discussion

We have shown here that there are pronounced allele frequency differences (Table 4) among *M. microlepis* samples taken from the Atlantic and Gulf of Mexico. In addition,

Table 4. Comparison of Gene Frequencies at the Indicated Loci Among Populations*

	South Carolina	Florida East Coast	Florida West Coast	Panama City, Florida
GAG010				
North Carolina	.7780	<.0001	<.0001	.0030
South Carolina		<.0001	<.0001	.0001
Florida East Coast			<.0001	.0020
Florida West Coast				<.0001
GAG038				
North Carolina	.3733	.9589	.7604	.9248
South Carolina		.5623	.7562	.1255
Florida East Coast			.9469	.6934
Florida West Coast				.3737
GAG045				
North Carolina	.0013	<.0001	.0190	<.0001
South Carolina		.0011	.5710	.3072
Florida East Coast			<.0001	.0051
Florida West Coast				.0103

*The values indicate the probability that the populations are statistically identical at the indicated loci.

these samples do not conform to HW expectations, suggesting that they are not Mendelian populations (Table 3). These observations are open to at least two interpretations. First, taken at face value they would indicate substantial population structure throughout the range of this species. This interpretation would demand some biological or physical restrictions of gene flow. Second, and most disturbing, is that the data may reflect the genetic consequences of current population declines and changing sex ratios (McGovern et al., 1998; Coleman et al., 1996). We should stress that the available information may not provide a strong conclusion regarding the relative merits of either of these interpretations and there is no a priori reason why they should be mutually exclusive.

We find it difficult to believe that the present data actually reflect strong population subdivision in *M. microlepis*. Restricted gene flow could easily promote the gene frequency differences noted among samples. It is difficult to understand how gene flow could be restricted in this species or how such restrictions could underlie the significant departures from HW equilibrium noted in each collection. The distribution of *M. microlepis* along the Gulf and Atlantic Coasts is not substantially interrupted by long stretches of unsuitable habitat, and there are no obvious physical barriers. Adults are known to migrate over hundreds of kilometers (Van Sant et al., 1994), and juvenile *M. microlepis* are known to appear off Long Island, New York, hundreds of kilometers from the nearest known spawning aggregation (K. Able, personal communication). This suggests that restricted movements of adults and early life stages do not appear to be plausible explanations for the observed differences among sampling locations.

Table 5. *F* Statistics for the Microsatellite Loci Examined in *Mycteroperca microlepis*

Locus	F_{is}	F_{st}	F_{it}
GAG010	.3530	.0136	.3618
GAG038	.0045	−.0011	.0035
GAG045	.1760	.0066	.1815
All loci	.2242	.0084	.2307

Significant departures from HW accompanied by heterozygote deficiencies (positive F_{is} values) can result from a number of factors including inbreeding owing to limited population size, selection, assortative mating, the presence of null alleles, and the Wahlund effect (Wahlund, 1928). One or more of these features has been invoked to account for these observations in marine species (Koehn et al., 1984; Benzie and Stoddard, 1992; Karl and Avise, 1992; Hare and Avise, 1996). We have suggested above that null alleles are

Table 6. Tests for Linkage Disequilibrium Among Loci for Each Sampling Location and in the Combined Data for *Mycteroperca microlepis*

Location	Locus 1	Locus 2	*P* value
North Carolina	GAG010	GAG038	.6855
North Carolina	GAG010	GAG045	.2551
North Carolina	GAG038	GAG045	.4187
South Carolina	GAG010	GAG038	.2127
South Carolina	GAG010	GAG045	.7631
South Carolina	GAG038	GAG045	.7335
East Coast Florida	GAG010	GAG038	.2017
East Coast Florida	GAG010	GAG045	.0995
East Coast Florida	GAG038	GAG045	.4343
West Coast Florida	GAG010	GAG038	.4545
West Coast Florida	GAG010	GAG045	.2641
West Coast Florida	GAG038	GAG045	.0362
Panama City, Florida	GAG010	GAG038	.1714
Panama City, Florida	GAG010	GAG045	.4659
Panama City, Florida	GAG038	GAG045	.2407
Total data	GAG010	GAG038	.27478
Total data	GAG010	GAG045	.27998
Total data	GAG038	GAG045	.19633

not likely to account for heterozygote deficiencies noted in these data and selection and assortative mating are not likely to be the factors influencing the distribution of alleles at microsatellite loci (Lander, 1989). If the Wahlund effect were a likely candidate, it would have to be operating on a microgeographic scale.

In some studies (Avise and Shapiro, 1986), data such as those presented here have been actively pursued. One hope was that such information would indicate inbreeding effects that would promote kinship among juveniles and support a variety of sociobiological inferences regarding the behavior of serranid species (J.C. Avise, personal communication). While the data did not support close kinship among individuals, a number of problems associated with the sampling could have precluded a positive result (Avise and Shapiro, 1986). Ruzzante et al. (1996) presented data on *Gadus morhua* that are remarkably similar to ours. Larval cod were shown to have significant heterozygote deficiencies and gene frequency differences among cohorts, but these deviations from HW expectations disappeared within cohorts judged to be the same age.

The observations described above were taken to indicate kinship with age groups and support the genetic "sweepstakes hypothesis." This hypothesis proposes that most of the offspring produced in a given cohort are the progeny of a very restricted portion of the spawning population. This process can lead to diminished genetic variation, gene frequency differences among cohorts, and kinship among individuals within cohorts. The basic tenets of this hypothesis can be extracted from a number of lines of reasoning and are supported by a variety of empirical data (see Hedgecock, 1994; Ruzzante et al., 1996; Li and Hedgecock, 1998). In this light, the present data are perfectly understandable because the number of adults that contribute to a given year class could be limited by (1) decline in overall abundance (McGovern et al., 1998), (2) extremely skewed sex ratios compared with historical values (Coleman et al., 1996; McGovern et al., 1998), (3) variance in reproductive success owing to high fecundity of individual females (Collins et al., 1987; Hedgecock, 1994), and (4) the segregation of spawning grounds and nursery areas (Collins et al., 1987; Keener et al., 1988; Coleman et al., 1996; McGovern et al., 1998). Collectively these phenomena should lead to inbreeding and significant differences among samples and homozygote excesses.

The genetic ramifications of population declines have been understood for some time (see Nei et al., 1975; Nelson and Soule, 1987) and do not need to be discussed further. The significance of increasing skew in sex ratios (Coleman et al., 1996; McGovern et al., 1998) may not be so obvious. It has been suggested that fishing pressures preferentially remove the larger, more aggressive individuals from grouper spawning aggregations (Gilmore and Jones, 1992), and these individuals are, for the most part, males. This could substantially reduce N_e according to the well-known formula of Wright (1931), and further the loss of genetic variability associated with population declines. We have no evidence that genetic variation has declined in *M. microlepis*, as this is the first study of genetics in this species, and the process is likely to be delayed owing to the length of the generation time (Nei et al., 1975). A restriction on the number of males in spawning populations would have more immediate effects on the genetic relationships among progeny. We would expect that offspring would be more likely to be genetically related and exhibit large, positive F_{is} values such as those noted in this study.

From the conservation point of view, the suggestion that gag populations may be exhibiting the initial genetic consequences of population declines and changes in sex ratios is ominous. Nei et al. (1975) have shown that such population bottlenecks inevitably lead to loss of genetic diversity, even though the process may be delayed by the organism's generation time. The loss of genetic diversity at microsatellite loci is not likely to affect the long-term survival of a species, as the adaptive significance of such loci is questionable (see Lander, 1989). However, if such losses are driven by population bottlenecks, they will almost certainly result in the loss of variation at loci that are of adaptive significance unless the process is countered by strong balancing selection (see Wright, 1931). In the final analysis, we view the data presented here as an exclamation point to the studies on declining population numbers (McGovern et al., 1998) and changing sex ratios (Coleman et al., 1996) in this species. Collectively, they underscore the need to increase conservation measures for this resource.

Acknowledgments

We appreciate the efforts of T. Brandt and J. McGovern in collecting many of the samples used in this study. The comments of two anonymous reviewers improved an earlier version of the manuscript. The research was partially supported by MARFIN grants NA37FF0052 and NA57FF0058, S-K grant NA57FD0030, NMFS-MARMAP grant 50WCNF606013, and by The South Carolina Sea Grant Consortium, grant R/F-1C. This is contribution 98-6 to the Cooperative Institute of Fisheries Molecular Biology and contribution 415 to the South Carolina Department of Natural Resources, Marine Resources Division.

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