THE RED GROUPER FISHERY OF THE GULF OF MEXICO:

ASSESSMENT 3.0

Michael J. Schirripa

Christopher M. Legault

and

Mauricio Ortiz

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Southeast Fisheries Science Center
Sustainable Fisheries Division
75 Virginia Beach Drive
Miami, FL 33149-1099

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EXECUTIVE SUMMARY

The first records of grouper landings of the west coast of Florida from the United States fleet date back to 1880. Annual records are sporadic from 1880 to 1927, but increase in consistency from 1927 to 1950. In 1850, Cuban sailing vessels known as “viveros” began fishing off Florida. Groupers and other reef fishes were caught using handlines with the catch being brought back to Havana. During this same it is documented that the U.S. red snapper/grouper fishing fleet operated in the eastern Gulf of Mexico. This fleet was made up of sail powered vessels that, like the Cuban vessels, were equipped with live well. In the mid 1940's the Cuban fleet, known as the “Flota del Alto”(Deep Water Fishing Fleet) converted to “neveros”, which are vessels capable of icing their catch. Also, 1940 is the first year that catch and effort estimates for the Cuban fleet were available. Starting in 1950 consistent records of Florida west coast grouper landings and gear specific operating units for the U.S. commercial fleet were kept. In 1955 the Cuban fleet consisted of a total of 68 vessels, 6 of which were sail powered and 62 of which had both motor and sail. Handline gear was still being used and red grouper made up approximately 90% of the total catch. The Cuban Gulf Fleet size increased from 65 vessels in 1963 to about 140 vessels in 1967; in 1967 there were 267 U.S. operating units. Although the traditional handline was the gear of choice for both fleets, bottom longline came into general use by the Cuban fleet about 1965 and remained their principle fishing gear. Estimated total landings of red grouper from the west coast of Florida for both the U.S. and Cuban fleets peaked at approximately 16 million pounds in the mid 1950s, but declined rapidly until 1965. After this year, perhaps due to the Cuban’s fleet deployment of bottom longline gear, the landings increased again until 1976, when the Cuban fleet was expelled from U.S. waters.

Present day Gulf of Mexico red grouper harvested by U.S. fishers are primarily caught in the eastern Gulf from Panama City, Florida, to the Florida Keys. The greatest part of the present commercial and recreational harvest is from Tampa southward and about half of the commercial harvest is landed in Tampa - St. Petersburg area. Commercial landings of red grouper have been separated from other groupers only since 1986. Before 1986 they were included in landings statistics along with other grouper species as “unclassified groupers”.

Prior to the introduction of bottom longline gear to the U.S. commercial fleet in the early 1980s, landings of all groupers exhibited a slow decline from about 7.5 million pounds (gutted weight) in 1962 to about 5 million pounds in the late 1970s. Handlines, and power-assisted (electric or hydraulic) reels accounted for almost all the landings during this period. With the expansion of bottom longline gear in the early 1980s, total grouper landings increased sharply to about 12.5 million pounds in 1982. This was the predominant gear employed for red grouper harvest to date. Traps increased in importance in the mid 1980s but contribute only a small proportion to the total grouper catch.

Red grouper accounted for nearly two-thirds of the total commercial grouper catch since 1986 and contributed about 7½ million pounds in 1989. If the proportion of red grouper in the total grouper catch was the same before species were separated in the landings, then the maximum U.S. commercial harvest for this species was about 8½ million pounds in 1982 while the total landed yield likely exceeded approximately 16 million pounds in the 1950s . Estimates of the recreational harvest of red grouper are highly variable but averaged about 2.6 million pounds (ca. 700,000 fish) from 1982-1989, or about 29 percent of the total harvest by weight.

Florida enacted an 18-inch (total length) minimum size for groupers in July 1985. This was increased to 20 inches in February 1990 after the Gulf of Mexico Fisheries Management Council (GFMFC) established conservation measures for groupers. These measures included a 20-inch minimum size and a 9.2-million pound (total weight) commercial quota for the shallow water groupers (which include red grouper) occurring in the waters of the Gulf of Mexico under GFMFC jurisdiction.

Red grouper landings by commercial fishermen increased slightly in 1986 after the 18-inch minimum size went into effect. Length frequencies of red grouper sampled from the commercial harvest provide little evidence that Florida's minimum size had any significant conservation effect on the commercial harvest. Commercial landings have shown a gradual decline since a current day peak in 1992.

Available data suggest an initial decline in the recreational harvest of red grouper from Florida state territorial seas after the 18-inch minimum size was established in Florida, however the total recreational harvest was little affected by this regulation with the bulk of the remaining recreational harvest of red grouper consisted of fish harvested from the EEZ. Most of these were less than 18 inches in length.

The regulations that became effective in 1990 at least in part, accounted for a 70-percent decline in the recreational harvest by number and a 41-percent decline by weight from the average of the two preceding years. Commercial harvest declined by 21 percent in 1990 from the two prior years. However, the decline could have been less than 15 percent if the fishery had not been closed before the quota had been reached. The effect of the 1990 minimum size is clearly evident in the length-frequency samples from all sectors of the fishery.

The estimates of 1997 recreational landings are the lowest since 1981. Considering the time since the introduction of bottom longlines to the U.S. commercial fleet in 1979, the estimates of the 1997 U.S. commercial landings are down approximately 55% from the high the U.S. fishery reached in 1982. Estimates of year and age-specific fishing mortality estimated in this assessment are similar to those estimated in the previous assessment. All estimates, based on population dynamic models with implicit or explicit stock-recruitment relationships imposed, indicate that current levels relative to estimates of biomass at maximum sustainable yield (B/Bmsy) are below 1.0 - M, indicating that the stock is overfished. All estimates of recent fishing mortality rates relative to the fishing mortality rate at maximum sustainable yield (F/Fmsy) are greater than 1.0, indicating that the stock is also undergoing overfishing. Other stock-recruitment relationships should also be examined in future assessments. Possible measures that could be taken to reduce fishing mortality on red grouper may require that the species is managed as a individual stock, rather than the current management which considers the stock as part of the larger “shallow-water grouper complex”.

INTRODUCTION

Red grouper (*Epinephelus morio*) is the most common species in the commercial and recreational grouper catch of the U.S. Gulf of Mexico. Most of the fishery for the species in U.S. waters of the Gulf of Mexico occurs within or immediately to the west of Florida's territorial sea. Although the species supports the bulk of the grouper harvest, it has received surprisingly little attention in the form of research or management prior to the first two assessments (Goodyear and Schirripa 1991 and 1993). The only major study of red grouper in the U.S. fishery was by Moe (1969) on material collected in the early 1960's. Rivas (1970) described the distribution of red grouper in the Gulf from 1950-1970 experimental sample collections made by the Exploratory Data Center, Pascagoula, Mississippi. There are descriptions of the fishery of the Yucatan Peninsula, Mexico (e.g., Ramirez 1970) where red grouper are also important. Also, a number of studies of the reproductive characteristics of the species and its importance to management exist (e.g., Bannerot 1984). Richardson and Gold (1993) examined the genetic structure of the stock using mitochondrial DNA. However, a number of aspects of the life history of the species and its fishery in the Gulf remain poorly understood or unknown.

Conservation measures were instituted in Florida in 1985 and in the EEZ in 1990. The 1985 Florida action was an 18-inch minimum size and did not extend to the EEZ. The 1990 measures adopted by the Gulf of Mexico Fishery Management Council included a 20-inch minimum size, 5-fish aggregate grouper bag limit for recreational fishermen, and a commercial grouper quota. Florida modified its regulations in 1990 to be in concert with the Federal regulations.

This study is an attempt to integrate existing knowledge about the species with data from the fishery to develop an evaluation of the current status of the resource. We believe it is a useful step toward that end.

BIOLOGICAL CHARACTERISTICS

DATA SOURCES

Meristic and growth characteristics were evaluated using a composite of length and other measurements of Gulf of Mexico red grouper that have been collected during research and monitoring programs throughout the years. Moe (1969) provides the most complete characterization of the species in the literature. We also employ data provided by Southern Offshore Fishing Association, Inc. (SOFA); other data collected during the trip intercept portions of the National Marine Recreational Fisheries Statistics Survey (MRFSS); the NMFS Headboat survey; and samples of commercial and recreational catches collected as part of the Trip Interview Program (TIP) of the State/Federal Cooperative Statistics Program. A biological profiles sampling program by NMFS Panama City (Florida) Laboratory provided additional sample data. These data sources were insufficient to describe all of the conversions between various measures needed to standardize lengths and weights to common bases, and we requested unpublished data from several investigators. The Caribbean Marine Research Center (CMRC, P. Colin, personal communication), and Florida DNR (L. Bullock, personal communication) supplied additional data to complete the data base used for defining length and weight conversions. Additional age and growth data for red grouper was provided by the NMFS Beaufort (North Carolina) Laboratory from the Atlantic Headboat fishery (M. Burton, personal communication) and University of Florida (C. Koenig, personal communication). Tagging data of red grouper caught off the west coast of Florida was provided by Mote Marine Laboratory (K. Burns, personal communication).

MORPHOMETRICS

Weight conversions. In 1964 the then Bureau of Commercial Fisheries established a policy of recording finfish landings in units of pounds, whole weight (Udall 1964). Since most grouper are landed in gutted condition, a conversion factor was required to convert the landed weight to its equivalent value in whole weight. A conversion factor of 1.18 was adopted for this purpose. The basis for this value is unknown.

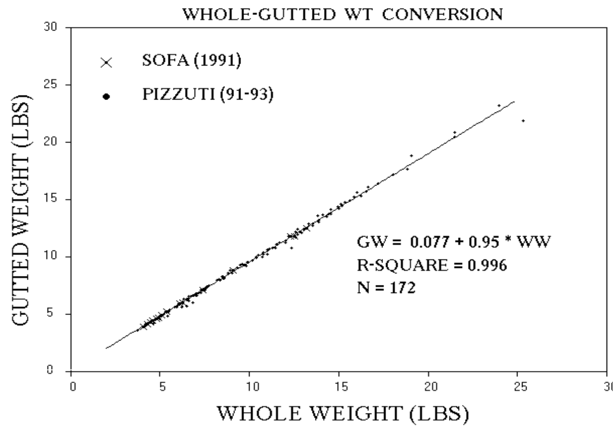

***Figure 1**. Scattergram of observed whole and gutted weights for red grouper and associated regression estimate of the conversion equation.*

The Florida grouper landings from 1986 to the present and those of all other states have been adjusted upward by this factor before entry into the computer files which constitute the historical data base for the grouper fishery. Florida landings prior to 1986 were never converted from landed to whole weight (Goodyear and Schirripa 1993).

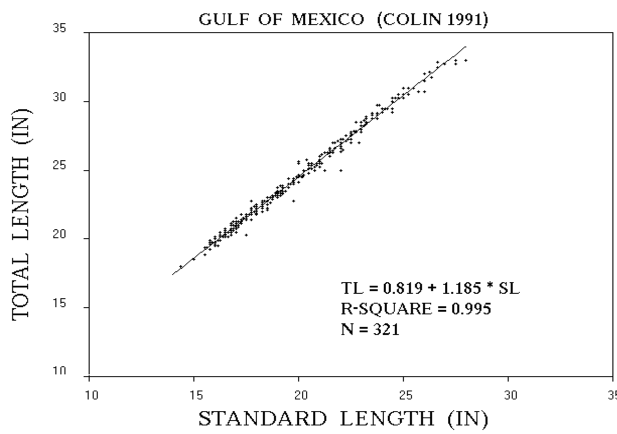

***Figure 2**. Scattergram of standard and total length for Gulf of Mexico red grouper and associated regression equation.*

The Southern Offshore Fishing Association, Inc. and J. Pizzuti provided data of red grouper gutted and whole weight measurements that indicated that the conversion factor should be on the order of 1.03 to 1.06, well below the 1.18 that has been used (Figure 1). The result of this analysis estimates a gutted to whole weight relationship with a slope of about 0.954. This corresponds to a conversion factor of about 1.048 (1/0.954). The relationship of Figure 1 was used in this assessment to convert between whole and gutted units with one exception. That exception is that the historical landings data were divided by 1.18 to convert the erroneously high whole weights recorded in the landings files back to gutted weight where appropriate.

Length conversions. The length units in this document are all reported in inches, total length for convenience of the expected audience. Many of the original length measurements were recorded in metric units, often as standard or fork length. All conversions of length

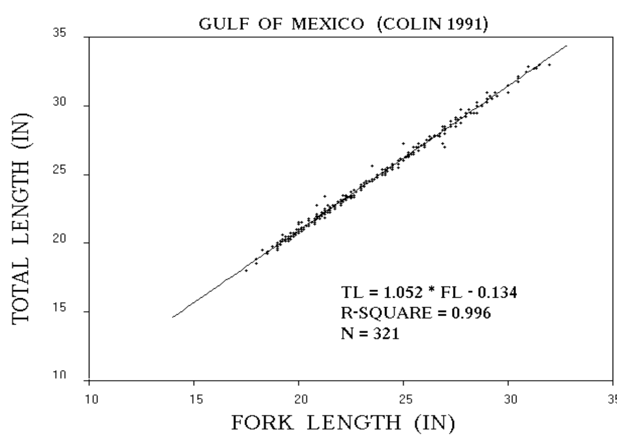

***Figure 3**. Scattergram of fork and total length for Gulf of Mexico red grouper and associated regression equation.*

measurements from metric to English units were made with greater precision than the original measurements to retain the initial precision. If length conversion was necessary, the lengths were converted first to inches and then to total length. The conversion relationships (Figures 2 and 3) were derived from data provided by CMRC (P. Colin, personal communication).

Length to weight conversions. All weights of landings in this document are reported as pounds, gutted weight. Many of the original weight measurements of individual fish were recorded in kilograms. Conversions from metric units to pounds was done with sufficient precision to maintain the precision of the original measurement.

Since lengths were more commonly measured than weights, it was often necessary to estimate weights from lengths. The propensity for samples to be measured in a particular unit varied among the fisheries sampling program. For example, headboat length samples were recorded as mm total lengths while MRFSS samples were in mm fork length. Where required, total lengths from the headboat survey were first converted to pounds total weight from the relation of Figure 4 and then to gutted weight using the relation of Figure 1.

The TIP samples were used to establish the relation between fork length and gutted weight (Figure 5) and total length and gutted weight (Figure 6). These two regression equations were used to assign weights from lengths for the commercial samples as appropriate. MRFSS intercept samples record lengths as fork length. Consequently, the MRFSS lengths were converted to gutted weight using the equation of Figure 5, as needed.

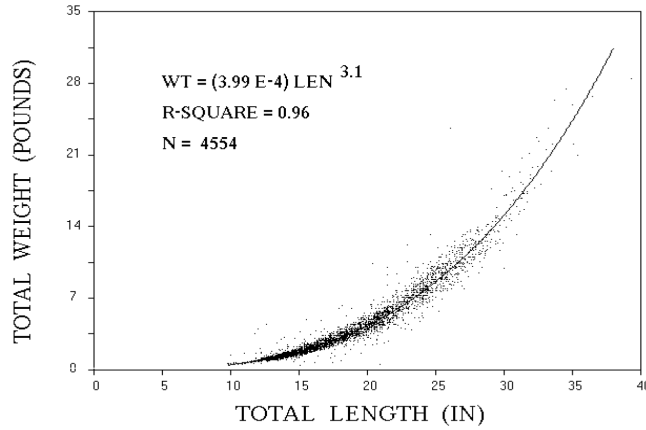

***Figure 4**. Total weight as a function of total length from length and weights collected by the NMFS headboat survey.*

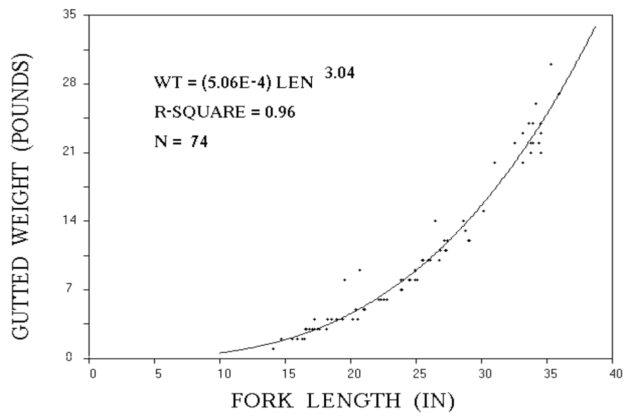

***Figure 5**. Relation between gutted weight and fork length for red grouper sampled from Gulf of Mexico commercial landings.*

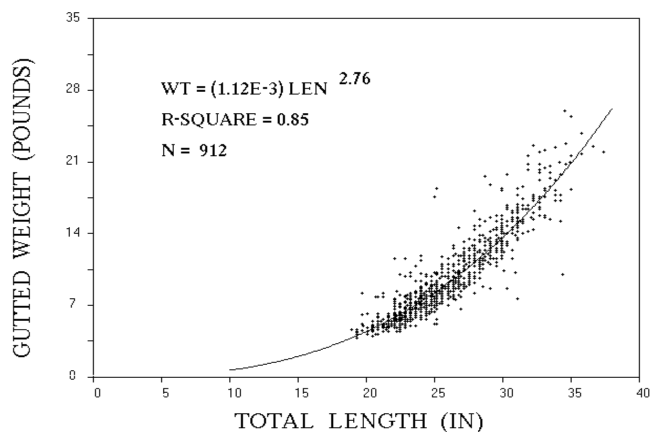

***Figure 6**. Relation between gutted weight and total length for red grouper sampled from Gulf of Mexico commercial landings.*

REPRODUCTION

Moe (1969) found that grouper off the west coast of Florida reach peak spawning in late spring; i.e., March to May. He also found no histological evidence to suggest that individuals spawned more than once a season; in fact early egg developers may retain their eggs for several months and spawn in late spring. In more recent work, Koenig (1993) concluded, based on oocyte diameters, that red grouper are batch spawners, releasing their complement of eggs over a protracted spawning season. Furthermore, neither egg diameter analysis nor back-calculation of spawning dates from otoliths revealed any indication of multiple annual spawning for the species. Gonadosomatic indexes (GSI=100*(gonad weight/total body weight) showed peaks in Mach thru May. GSIs by day of year from Koenig (1993) and mean egg diameter by month from Moe (1969) are shown in Figure 7.

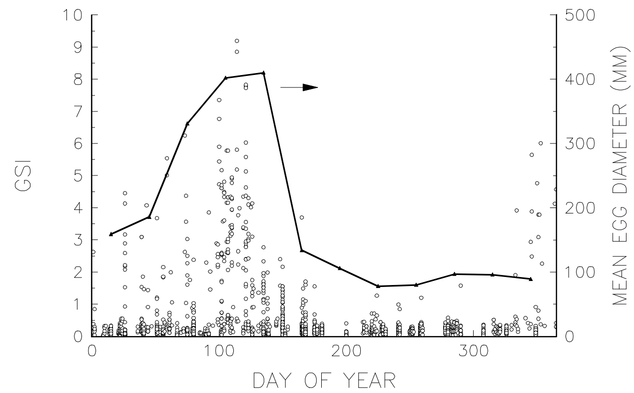

***Figure 9**. GSI (Koenig 1993) and mean egg diameter (Moe 1969) for red grouper as a function of day of year.*

The estimation of potential recruit fecundity [1] (required for estimation of SPR) is most accurately made based on the reproductive capacity of the female immediately prior to spawning (Goodyear (1989) noted that the estimation of potential recruit fecundity posed a problem for species that change sexes during their life history). Towards this end, an estimation of gonad weight as a [1] function of total length was made using all available data from female red grouper sampled in the months March, April, and May that were in stages 3 (Vitellogenesis),4 (Hydration), and 5 (Atretic) of development (although atretic gonads are generally viewed as post-spawning condition, very few were present in the analysis). Analysis of this data revealed that there existed a large range of gonad weights for any given length observation. This could have resulted from the gonads being sampled

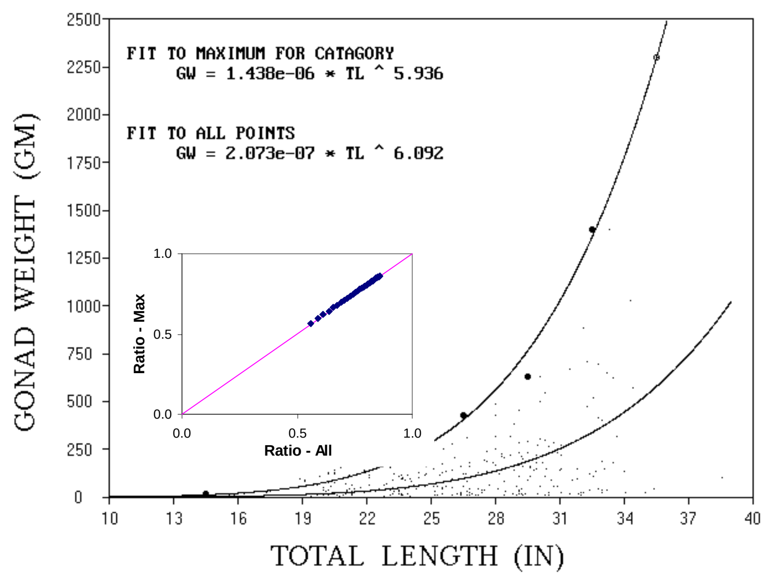

***Figure 8**. Gonad weight as a function of total length using only maximum gonad weight and all points. Insert plots ratio of successive points for both functions, indicating the rates of increase nearly identical.*

[1] Potential recruit fecundity is the expected lifetime production of eggs by the average female in the population in the absence of density-dependent suppression of growth or mortality. It is assumed that sufficient males will always be present.

within a wide range of hydration stages. Given these observations two fecundity functions were derived (1) using the maximum gonad weight for each of ten, three inch length intervals; (2) using all data points that fit the month/stage criteria outlined above (Figure 8).

When using a fecundity function to estimate age specific fecundity for such parameters as SPR or a stock-recruitment relation, it is not necessary that the absolute estimate of fecundity be accurate but rather the relative fecundity between ages be accurately depicted. This means that if two competing fecundity functions have the same shape then either can be used as both will result in similar SPR estimates for a given survivorship profile. To determine if the two fecundity functions in Figure 8 had similar shapes we plotted the ratio of the of estimated gonad weights between successive lengths using all data, against those estimated using the maximum gonad weight data. The plot of these ratios indicated high correspondence in shape since values were essentially on the 1:1 ratio line (Figure 8, inset). Given this result, estimates of SPR and stock-recruitment relations for any given survivorship profile will be nearly identical regardless of which fecundity function is used. For this assessment, the function fit to all available data points was used when estimating fecundity.

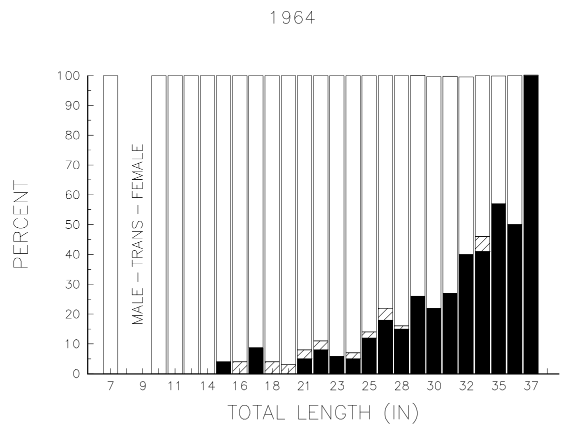

Figure 10*. Sex ratio as a function of length for red grouper in 1964 (from Moe 1969).*

Examination of the maturity schedule by length and age (Tables 1 & 2) could lead to several conclusions regarding the timing of sexual maturation for red grouper. There does not appear to be a minimum length or age at which the majority of females (during the peak spawning months of March though May) are found to be in the later stages of maturity. One possible explanation for this is that not all females spawn during any given year. Another explanation may be that females develop and cast their compliment of eggs during only a very short time interval, and that this time interval makes up only a small fraction of the entire spawning season. The first observation of 100% mature female was made at fish age 4 and total length of 450-499 mm, although this observation was only

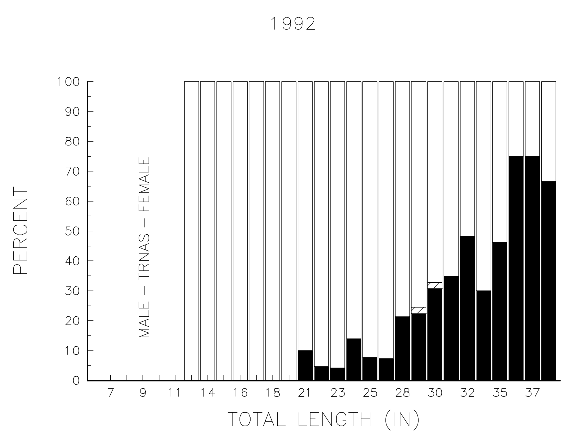

Figure 11*. Sex ratio as a function of length for red grouper in 1992 (from Koenig 1993).*

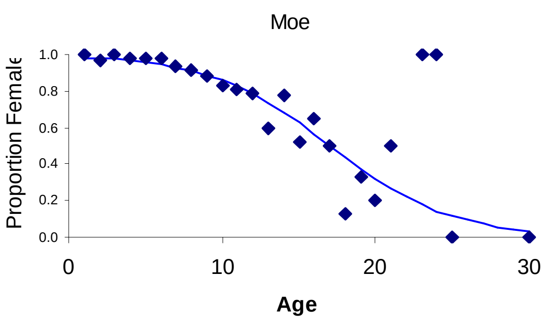

***Figure 13**. Proportion female and fitted function for red grouper collected in 1964 (Moe 1969).*

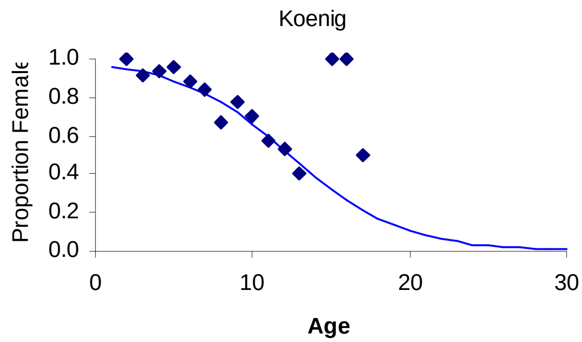

***Figure 14**. Proportion female and fitted function for red grouper collected in 1992 (Koenig 1993).*

made up of 5 fish. The next observation of 100% maturity was made for fish age 5 and total length of 400-449 mm, but this observation was made up of only 2 fish.

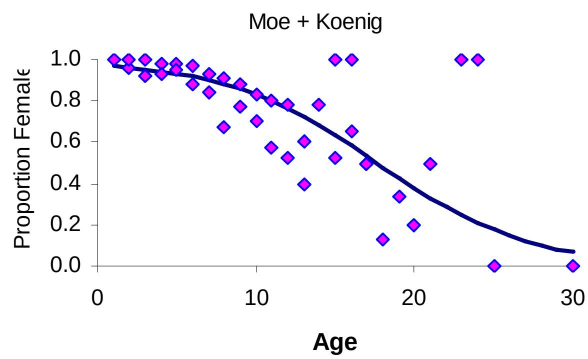

***Figure 12**. Proportion female and fitted function for red grouper using combined data sources.*

Grouper are among those species which have adopted a reproductive strategy involving sex change (e.g., Bannerot et al. 1986, Ghorab et al. 1986, Shapiro, 1986). Red grouper are categorize as protogynous hermaphrodites, which first mature as females and then change to males at an older age. Shapiro (1984) points out that there is no direct evidence to suggest that females change sex upon attaining a particular size, age, or stage of development. However, it is thought that the stimulus to change sex is controlled in part by social interactions that are inherently density dependent. The percentage of male, female, and transitional (female in the process of turning male) by length category from Moe (1969) and Koenig (1993) are shown in Figures 10 and 11, respectively. The values for these figures are given in Table 3.

The percent females by age for the two above mentioned studies are shown in Figure 16. A function to describe the percent female by age was calculated from Moe (1969) (Figure 12), Koenig (1993) (Figure 13), and the two data sets combined (Figure 14). The rates of change for the two data sets are given in Table 3. We used function fit to the combined data to represent the rate of change from female to male. This rate was then multiplied by the estimated gonad weight to arrive at an estimate of total fecundity (Table 4).

GENETIC STOCK STRUCTURE

Richardson and Gold (1993) used restriction length polymorphism (RFLP) to estimate evolutionary effective female population size $N_{f(e)}$ in red grouper from the Gulf of Mexico. Effective female population size is a measure of the genetic diversity within that particular stock of fish. Richardson and Gold report a $N_{f(e)}$ value for red grouper of 10,000, but no confidence intervals are given for the estimate.

FOOD HABITS

While not examined quantitatively, Moe (1969) noted the stomach contents of several specimens of red grouper. Food items consisted of small fish of many species, crabs (notably *Portunus* and *Calappa*), panulirids, scyllarids, shrimps, octopuses, squids, and unidentified crustaceans.

Bullock and Smith (1991) report findings on the diet of juvenile red grouper (18-25 mm) from Tampa Bay to consist of a variety of shrimp and amphipods. Larger individuals (300-500 mm) captured south-southwest of Ft. Myers during November 1987 regurgitated the following invertebrates: an octopus, various shrimps, and hermit crabs. Regurgitated fish included belted sandfish, tomtate, blue goby, yellowhead jawfish, and cardinal fish. This report goes on to cite work done by Hildebrand (1941) in the Dry Tortugas. These fish consumed fishes, octopuses, and crustaceans (including spiny lobster, shrimps, and stomatopods).

Food habits of juvenile red grouper from Campeche Bank, Yucatan, Mexico was reported by Brule et al. (1993). The stomach contents of a total of 163 fish were examined for contents. Of the total prey items, the dominant species was true crab *Pilumnus dasypodus*. In terms of relative importance, preferential prey consisted of reptant crustaceans, anomurans, and brachyurans. No size related preference nor regional variation was evident in the feeding habits.

GROWTH

Traditionally back-calculation of size-at-age from hard parts such as otoliths have been used to describe the growth red grouper (Moe 1969; Stiles and Burton 1994; Goodyear 1994; Johnson and Collins, 1994),. Goodyear and Schirripa (1991) noted that Gulf of Mexico red grouper were larger at age than found by Moe (1969) in the early 1960's. This was later verified by several other studies of red grouper growth (Eklund 1992; Goodyear and Schirripa 1993; Johnson and Collins, 1994). This apparent change in growth led to the use of a time-corrected growth model based on the von Bertalanffy growth equation to estimate the age composition of the catch (Goodyear and Schirripa 1993). Despite the use of the time-corrected growth model, virtual population analysis methods applied to the resulting catch at age data (Powers and Restrepo 1991) lead to a wide range of conclusions concerning the overall status of the stock (Goodyear and Schirripa 1993). It was later ascertained that size selective sampling within the fishery due to minimum legal size restrictions and various gear selectivities result in non-random sampling, which in turn can give rise to erroneous conclusions concerning growth (Goodyear, 1995). Because the vast majority of age and growth data used to assess the reef fish fisheries is from fishery-dependent sources, this lead to the conclusion that further verification of growth in all reef fish species was needed. In this section we describe growth of red grouper by estimating parameters of the von Bertalanffy growth equation from release-recapture observations. These estimates of growth are then compared to those estimated from various hard-part and back-calculation analyses.

Mote Marine Laboratory's (MML) Reef Fish Tagging Program encompasses a study area in the eastern Gulf of Mexico which extends from Pensacola to Naples, Florida. Most of the fish tagged were gag, red grouper, and greater amberjack. Volunteer taggers included biologists, charter boat captains, head boat personnel, as well as recreational and commercial fishermen. Two hundred twenty individuals have tagged at least one fish since October 1990; however, an active core group of approximately 30 fishermen has contributed the bulk of the tagging data. All fish were caught by hook and line. Before release, each fish was tagged with a single barbed Hallprint plastic dart tag, inserted at an angle under the anterior portion of the spinous dorsal fin. Information on the tags included the tag number printed twice (once near the barb and again at the end of the streamer), MML's mailing address, and an 800 telephone number. Data recorded for released fish included tag number, species, date, location (latitude and longitude, within 5 nautical miles), water depth (ft), fork length (in), gear type, bait, whether the abdomen was vented, and the condition of the fish before release. Data collected from recaptured fish included the tag number, species, recapture date, location (within 5 nautical miles), water depth (ft), fork length (in), gear type, bait, overall fish condition, condition around tag insertion site, and whether the fish was killed or re-released. Tag return information was obtained by mail or through direct telephone conversations with participants.

Red grouper otolith data available for this study were from samples collected from the Gulf of Mexico recreational and commercial fisheries and analyzed by either Moe (1969), Johnson and Collins (1994), or T. DeBruler (pers. comm., Mote Marine Laboratory) for age determination. Lengths were converted to total length (TL) using the conversions presented in Goodyear and Schirripa (1993). All age estimates were based on annuli counts.

The von Bertalanffy growth equation,

$$L = L_4(1 - \exp(-K(t-t_0))) \qquad (1)$$

where L is total length, L_4 is the asymptotic length, K is the rate at which L_4 is reached, and t_0 is the (theoretical) time at which the fish would have had zero length, was rearranged and t_0 dropped as follows:

$L_{rel} = L_4 - (L_4 - L_{rcap}) \exp(-Kt)$ (2)

where L_{rel} is total length at release, L_{rcap} is total length at recapture, and t is the time at large. Data were fitted to this model using the method described by Fabens (1965) and the SAS NLIN (SAS 1989) procedure. Only those fish that were at large long enough to express positive growth were used in the calculations. Equation 2 estimates L_4 and K of the of the von Bertalanffy equation, and describes the curvature of the growth function. The value of the third parameter of equation 1, t_0, was estimated by minimizing the sum of squares of the deviations between the growth curves estimated from the otolith data and the recapture data, thus maximizing agreement. Age at recapture was then estimated as the age at release plus the time the fish was at large.

Location of the release and recapture sites for red grouper are shown in Figures 15. From October 6, 1990, through December 1, 1994, 2,933 red grouper were tagged and released. Return rates 14.6% for red grouper.
To test for potential percent of error in measurements of returned fish, the size of recaptured fish at large for less than 30 days was compared to their size at release for all these species. It was assumed that these fish would exhibit little or no discernable growth within that time, consequently both measurements should have been approximately the same. Of 161 grouper (red or gag) with less than 30 days of freedom, 4 (2.5%) were reported to vary in size by greater than 25 mm.

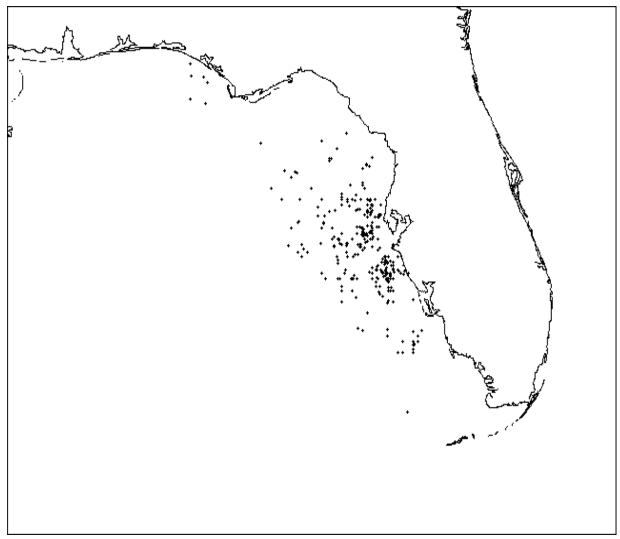

Figure 15. *Locations of Mote tag-recaptured red grouper used to describe growth.*

Two von Bertalanffy growth equations were either estimated or considered in this study: (equation 3) a release-recapture growth curve for red grouper based on this study;

$L = 43.74(1-\exp(-0.116(t+0.532)))$ (3)

and an otolith based growth curve for red grouper (Goodyear 1994, "all data") (equation 4)

$L = 31.81(1-\exp(-0.21(t+0.30)))$ (4)

The parameters of each of the above equations are in inches, total length. The estimated size at age are given in Table 4.

A very strong agreement exists between the curvature of the two lines the fitted von Bertalanffy growth curves for the release-recapture data and pooled otolith data (Goodyear 1994) for red grouper, which suggests that the observed rings in the otoliths are annuli. (Figure 16). The proportional error in the estimated size at age from the two growth curves are shown in Figure 17. The zero line represents the recapture growth curve and the symbols represent the deviation in size-at-age of the otolith growth curve from the recapture growth curve. The greatest deviation occurred at age 11 (-10.62%) and the least deviation at age 6 (0.51%).

The majority of red grouper observed in the fishery range from approximately age 5 to 8. In this range, the maximum deviation occurred at age 8 (-4.45%). Growth predicted by the two red grouper growth curves compared very favorably with a third data set of observed ages. These ages were estimated from otolith examination and were not used to estimate either growth curve.

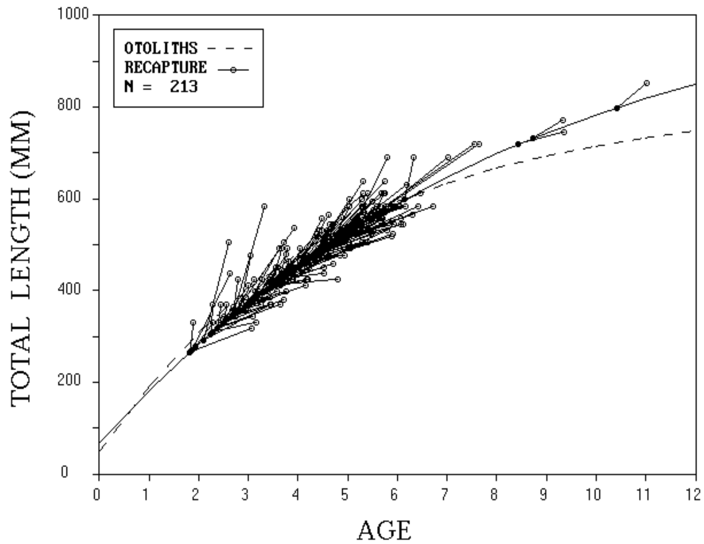

Figure 16. Estimated growth curve from otoliths and tag-recapture data for red grouper.

If the rings that were assumed to be annuli included such marks as spawning checks (i.e. several rings being formed each year) the two estimated growth curves would be radically different. Mainly, the agreement exhibited between the two curves adds confidence to the estimate of the parameters L_4 and K. What the agreement does not address is the confidence around the estimate of t_0 (i.e. the position of the growth curve relative to the X (time) axis.

One source of potential bias in the release-recapture data comes from the fact that fish that are less than the minimum legal size are more likely to be part of the release-recapture data set than those greater than legal size. This is directly opposite to the situation encountered in the usual backcalculation procedures that uses fishery dependent data. In the later situation, undersized fish are commonly not retained and thus absent from the age samples. This can lead to a "Lee's phenomena" (the phenomenon of back-calculated lengths for a given age group being smaller the older the fish from which they were calculated) which tends to over-estimate the size at age for younger fish.

In the case of the release-recapture data however, the bias may well be to select slower growing individuals which would tend to underestimate growth of younger fish. In the case of gag, release-recapture estimates yielded estimates of growth that were faster in the younger ages than did the hard-part estimates. However, in greater amberjack and red grouper estimates of growth via release-recapture were in fact slower than those estimated from hard-parts in the younger ages (Schirripa and Burns 1997). Because the shape of the curves depicting the proportional error of the two growth estimates are so different for each of the three species, no systematic bias seems to exist based on the two methodologies used to derive the growth curves.

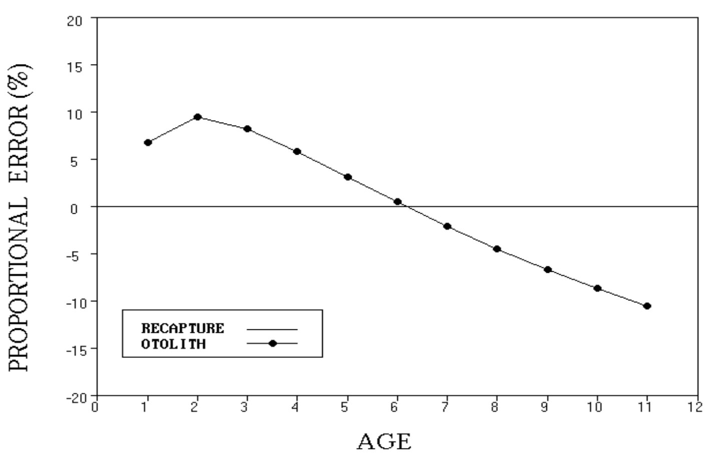

Figure 17. Proportional error (% disagreement) between the estimated otolith and tag-recapture growth curves.

In summary, we found that both hard-part and release-recapture data are useful means to estimate growth in these three species of fish. Greater confidence concerning the estimated growth curve may be able to be obtained if both types of data are available. The results of this study suggest that the most recent estimates of growth for red grouper are accurate and can be used with a reasonable degree of certainty.

DISTRIBUTION AND MOVEMENTS

Moe (1966, and 1969) and Beaumariage (1969) concluded from tagging studies and the size and age distribution of the harvest that red grouper spend the first 4-5 years of their life near shore and then migrate into deeper water off-shore upon reaching sexual maturity. Moe (1969) also noted a pattern of inshore movement of red grouper in the summer and offshore movement in the late fall. Rivas (1970) confirmed the gradient of increasing size with depth from exploratory surveys conducted in the Gulf from 1950-1970. His data also suggested a seasonal north-south pattern with a southerly movement of red grouper in the winter.

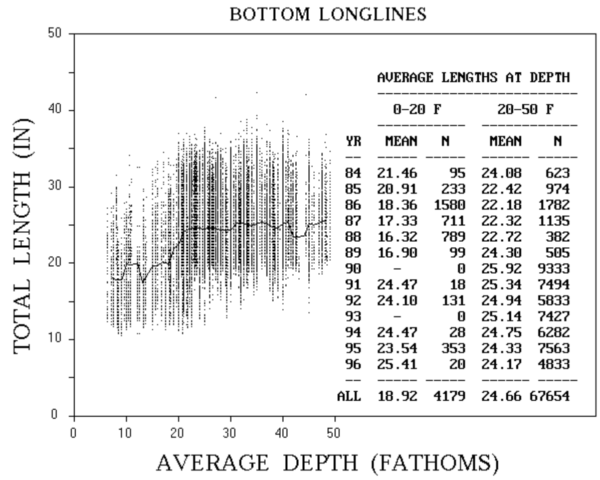

Figure 18. *Lengths of red grouper caught by bottom longline as a function of depth at capture.*

We examined the lengths of red grouper landed by various gears as a function of depth at capture from TIP samples of the commercial fishery during the period 1984-1991 (Figures 18 & 19). The line evident in each of the figures is a three point moving average of the average lengths of red grouper by depth. The samples from the bottom longline catches show a clear increase in mean lengths of red grouper from about 15 inches at the shallowest depths (about 5 fathoms) to nearly 25 inches at about 25 fathoms (Figure 18). The elimination of samples from catches from waters less than 20 fathoms indicates that the bottom longline fishermen moved further offshore in response to the 20-inch minimum size in 1990.

The same trend of increasing size with depth is evident for handlines (Figures 19). The distribution of the depths of samples from these gears also reflects the propensity for fishermen using handlines to fish in shallower waters than those using bottom longlines or power-assisted reels. Fishermen using handlines also appeared to move offshore into deeper water in response to the 20-inch minimum size.

These data suggest that a reduction in the catch of small fish by the commercial sector of the fishery has in part been accomplished by a movement of the fishery to deeper water offshore. However, the increase in mean lengths to slightly over 27 inches for waters greater than 20 fathoms in 1990 probably reflects the discard of undersized fish.

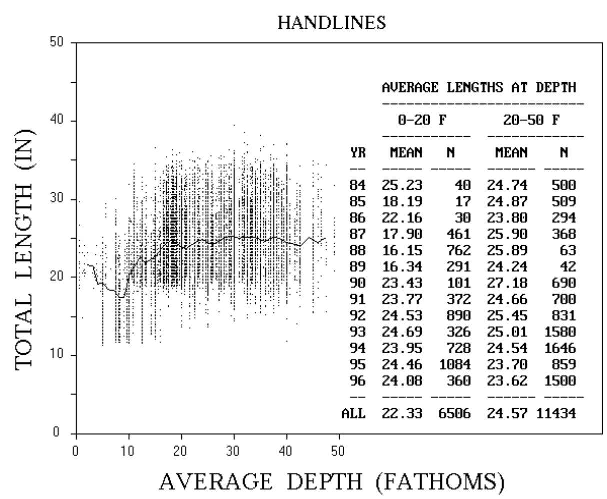

Figure 19. *Lengths of red grouper caught by handlines as function of depth of capture.*

Similar analysis was done on data provided from Mote Marine Laboratory tagging program. These data represent recreational hook and line fishing off the west coast of Florida (Figure 20). The same pattern of increasing size with increasing depth is evident here as well (Figure 20). The trend in this data set in probably more pronounced because fishermen participating in the tagging program recorded lengths of sub-legal fish as well, as they where presumably tagging all fish that were brought into the boat. Because of these mean lengths at capture are not biased by any minimum size regulations, the fact that this mean decreases on an annual basis for both depth categories could be of some significance. Despite the apparent trend of increasing size with increasing depth, the mean length of red grouper caught in the 20-50 fathom range in 1992 (17.41 inches) is still less than the mean for the 0-20 fathom range just two years previous (18.6 inches in 1990).

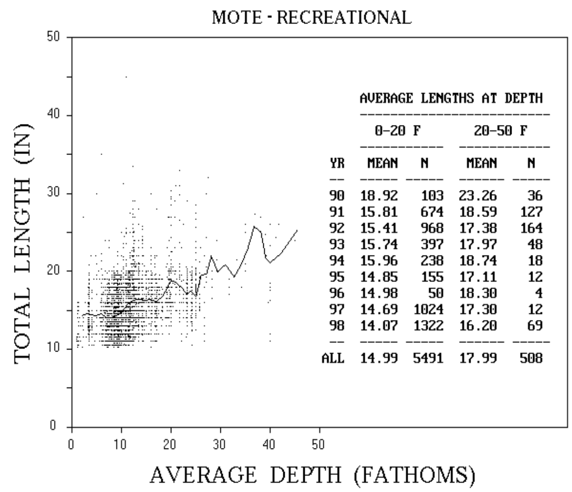

Figure 20. *Lengths of red grouper caught by recreational fishers participating in the Mote Tagging Program.*

From this same database, it can be seen that red grouper were generally recaptured at the same location in which they were tagged, suggesting that the species is very sedentary (Figure 21). Two exceptional animals did however travel over 70 miles while at large. The rate of movement (miles traveled / days at large) of tagged/returned red grouper is shown in Figure 22. As with distance traveled, the majority of fish had correspondingly zero rate of movement. But again, there was one exceptional individual that traveled an averaged of 0.8 miles per day.

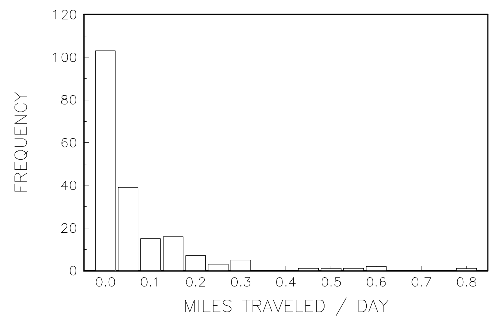

Figure 21. *Rate of movement (miles traveled/day at large) of tagged red grouper from Mote Marine Laboratory tagging program.*

GENERATION TIME

An estimate of generation time (G) for this stock is needed by the management plan for this species It is estimated as

$$G = \left[\sum_{a=1}^{n} a\, E_a P_a N_a \right] / \left[\sum_{a=1}^{n} E_a P_a N_a \right] \qquad (1)$$

where, a = age, n = number of ages in the unfished population, E_a = mean fecundity of females at age a, P_a is the probability of being female at age a, and N_a

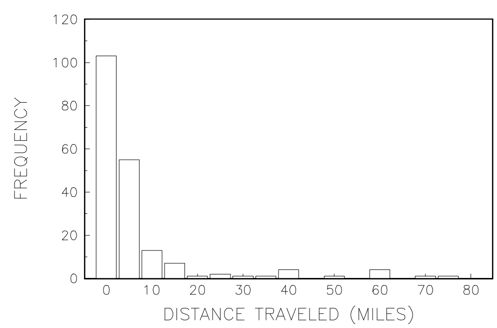

Figure 22. *Distance traveled for recaptured red grouper form Mote Marine Laboratory tagging program.*

is the average number of females alive at age a in the absence of fishing, i.e.,

$$N_a = N_1 \exp\left(- \sum_{j=1}^{a-1} M_j \right), \tag{2}$$

and M_j = Natural mortality of females of age a while they were age j. The maximum age considered was 100 years.

Expression 1 provides the same result for any constant value of N_1, so the values of N in expressions 1 and 2 are evaluated here on a per recruit basis ($N_1 = 1$). Inspection of the equations reveals that the other important parameters are fecundity and natural mortality. Fecundity per recruit and estimated generation times for M=0.15, M=0.20 and M=0.25 were 10.7 years, 9.6 years, and 8.7 years, respectively.

HARVEST TRENDS

HISTORY OF REGULATIONS

The red grouper fishery is regulated at both the state and federal waters. The state waters on the west coast of Florida extend 10 miles out from shore and are managed by the Florida Marine Fisheries Commission (FMFC). Beyond the 10 mile contour is the Exclusive Economic Zone (EEZ) which extends another 200 miles from shore. Fishing in the EEZ is managed by the Gulf of Mexico Fisheries Management Council (GMFMC). The 20 inch minimum size regulation (in both state and federal waters) of 1990 moved the fishery into predominately federal waters. Currently, red grouper harvest is regulated by a commercial shallow-water quota of 9.8 million pounds. This quota is reviewed for modification on an annual basis. A history of pertinent fishing regulations put forth by both FMFC and GMFMC have been outlined on the preceding page.

COMMERCIAL HARVEST

Data sources. Landings statistics for commercially caught grouper were available from 1962 to 1997 (computer files maintained by the Fishery Dependent Data Group (FDDG), Research Management Division, Southeast Fisheries Center (SEFC), Miami). The U.S. portion of the landings used in this assessment were separated from foreign catches by a location code in the data file. Also available were records of commercial catch and effort of the Cuban grouper fishery on the west coast of Florida from 1950 to 1976 (E. Klima, pers. comm.). Groupers were not separated to species prior to about 1986 but were included in a category termed "unclassified grouper." In addition to these data, a reeffish logbook reporting program was initiated in 1990 as a part of Amendment 1 to the Gulf of Mexico Reef Fish Management Plan of the Gulf of Mexico Fishery Management Council (Gulf Council). All trap fishermen and a sample of other fishermen landing reeffish were required to report their landings. These data were used to estimate the distribution of the total 1990-1997 red grouper landings by gear and area of capture.

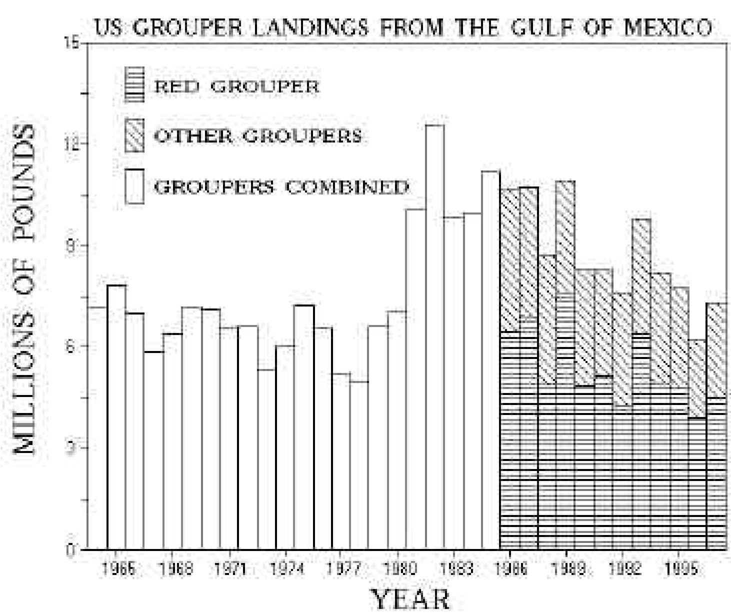

__Figure 23__. U.S. commercial landings of all groupers from U.S. waters of the Gulf of Mexico.

As noted elsewhere, the landings data in the files represent a mixture of records. The weights recorded for Florida records prior to 1986 are in units of gutted weight, whereas all of the other records in the files were converted to whole weight using a factor of 1.18. For the purpose of this assessment we unconverted the "whole weights" back to gutted weight by dividing the appropriate records by 1.18.

TIP data were obtained from FDDG to characterize the size composition of red grouper landed by different commercial gears in different areas and time. These data were supplemented by other similar data gathered by the NMFS Panama City Laboratory's bioprofile sampling program. Data from these sources were available from 1984 through 1992, with a few records for other years.

Temporal trends in commercial landings. Because grouper landings were not separated by species prior to 1986 we are unable to track red grouper separately before that time. Total grouper landings from the U.S. Gulf of Mexico exhibited a slow decline from about 7.5 million pounds in 1962 to about 5 million pounds in the late 1970s (Table 6, Figure 23). Handlines and power-assisted (electric and hydraulic) reels accounted for almost all the catch prior to the introduction of longlines in the early 1980s (Figure 25). With the expansion of the bottom longline gear in the 1980s the total grouper landings increased sharply to a maximum of about 12½ million pounds in 1982 (Figure 25). The contribution of fish traps to the total grouper catch increased in the mid-1980s but never achieved a large share of the combined landings (Figure 25).

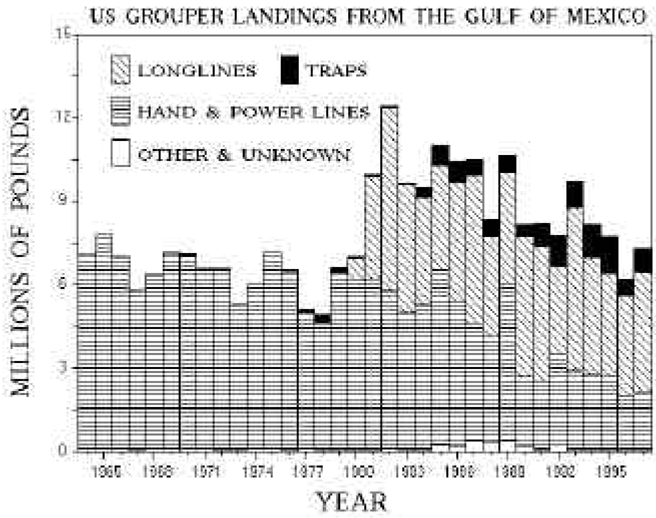

__Figure 24__. Total U.S. commercial harvest of groupers from U.S. waters of the Gulf of Mexico by method of capture.

Most of the U.S. Gulf of Mexico grouper catch for all species has been landed in Florida at least since 1962 (Table 6). The commercial U.S. catches of red grouper since 1986 are almost entirely landed in Florida (Table 5). Red grouper also make up a large proportion of the total grouper landings since 1986 (Figure 23, Tables 5). However, the relative dominance of the various grouper species vary by state and year (Tables 8-35).

A very substantial portion of the commercial harvest in the 1950's is attributable to the Cuban grouper fishery operating off the west coast of Florida at that time (Figure 25). The Cuban fishing effort was directed at red grouper, which constituted approximately 90-percent of the total catch (Abascal 1968, as cited in Tashiro et al. 1977). The principle gear used was bottom longline. Estimates of harvest during this time period ranged

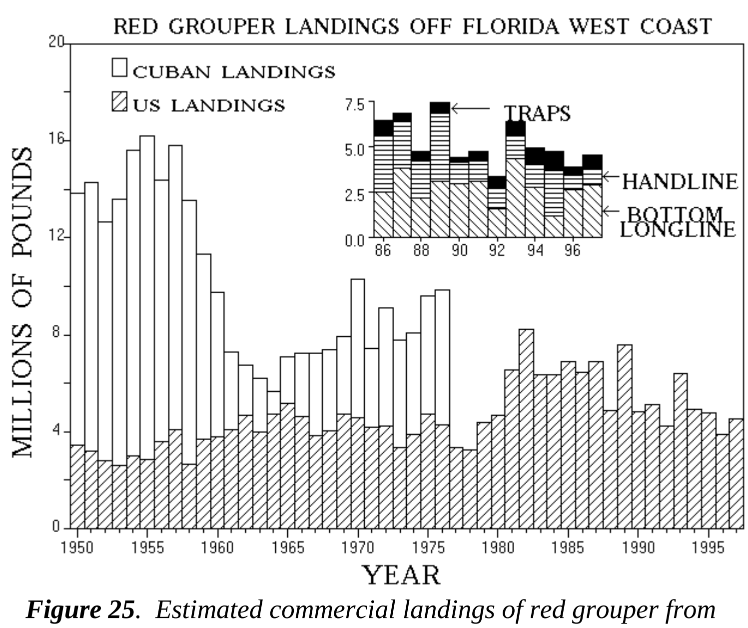

__Figure 25__. Estimated commercial landings of red grouper from Florida West Coast since 1950 and method of capture since 1986.

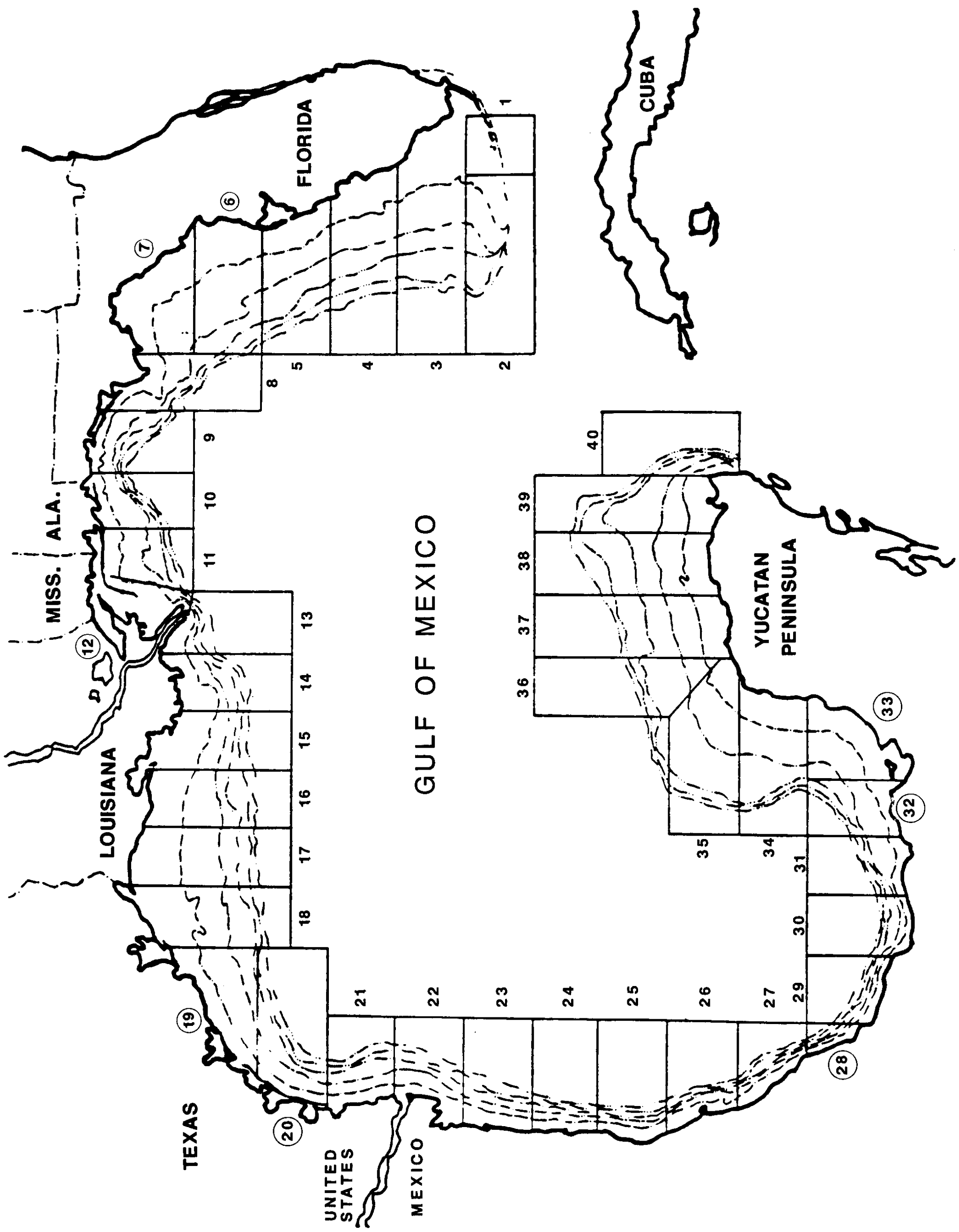

Figure 26. Statistical grids for the Gulf of Mexico used in this study.

from 7 to 13 million pounds; approximately double the U.S. landings for the same time period. In the 1960's the Cuban catch dropped off to approximately 2-3 million pounds per year and then increased again in the 1970's to 4-5 million pounds, very close to the U.S. landing estimates for that time. None of the Cuban fleet's catch of grouper were exported, but rather remained in that country for domestic consumption. The Fishery Conservation and Management Act of 1976 prohibited foreign countries from fishing within the Fishery Conservation Zone (extending 200 nautical miles off shore) after March 1, 1977 without a U.S. fishing permit.

Mississippi and Alabama once landed modest amounts of unclassified groupers many of which were caught in foreign waters (Table 7). These early landings declined the early 1970s and remain low. Recent grouper landings from these two states are almost entirely from U.S. waters but most are still not recorded as to species (Tables 6 and 7). It is possible that red grouper were an important part of the early grouper landings from these two states but most of the production was from foreign waters.

Louisiana grouper landings have been significant only since about 1984 (Table 6). A large fraction of grouper in the Louisiana catch remains unclassified to species (Table 7), but of the more than half that has been classified since 1986 (Tables 8-35) only a few thousand pounds have been classified as red grouper. It seems unlikely that red grouper were ever an important part of the Louisiana grouper catch.

Texas grouper landings from U.S. waters also increased about 5-10 fold in the early 1980s over the prior decade, however the last two years of record (1991 and 1992) show a decrease back to the pre 1980's levels (Table 5). Large numbers of these groupers also remain unclassified to species (Table 7). However, less than 500 pounds of those classified to species were classified as red grouper (Tables 8-35).

From these observations, we doubt that red grouper was ever a large part of the domestic catch of Gulf of Mexico grouper fishermen west of Florida. It is clear that at the present time almost all of the U.S. Gulf of Mexico red grouper harvest is from Florida (Table 5). Red grouper accounted for an average of 69 percent of the total classified grouper landings for the 5 years where they can be separated into species (range 63 to 74 percent). Moe (1969) noted that red grouper composed about 60 to 75 percent of the total grouper catch. Although he did not specify the period for which this estimate applied, we presume that he was referring to the period in the early to mid 1960s when his data were collected. These data indicate that the red grouper proportion of the total grouper harvest has been relatively constant, at least since the 1960s. Based on this assumption, we estimate the red grouper catches for each year prior to 1986 as the product of the total annual unclassified grouper landings and the mean proportion of red grouper in the 1986-1990 landings (Figure 31).

Trends in landings by gear. Red grouper are commercially harvested with a variety of gears throughout the Gulf of Mexico. Based on the grouper fishery as a whole the predominant historical gear among these are "handlines" (Figure 25). These include lines that are operated either manually or with the assistance of electric or hydraulic power. The landings from all of these gears have been reported under a single gear code. Consequently, they cannot be partitioned into more discrete categories and are referenced herein as "power and hand lines." Bottom longlines have been replacing handlines as the primary gear used to harvest groupers since the early 1980s.

The red grouper landings in the data files were already partitioned into gear and grid for 1986 through 1989, but data since 1990 are only available by month and port of landing. I estimated the spatial distribution of the 1990-1997 red grouper by gear from the logbook reports. We assumed that the entire trap catch was reported in the logbooks and the remaining catch was distributed in proportion to the catches reported in the logbooks (Table 36). This allowed partitioning the 1990-1997 catch estimated from the Florida Trip Ticket Program into catch by gear and location of capture. This permitted construction of tables of catch by location and gear from 1986 through 1997 (Tables 36-42). It is clear from these data that the trend of increased use of bottom longline gear continued into 1990 when it became the principal gear employed for red grouper.

Spatial distribution. The bulk of the 1986-1997 commercial catch of red grouper was from the eastern Gulf of Mexico to the west and south of Tampa - St. Petersburg, Florida, with a decided peak in grid 5 (Figure 26 & 27; Table 36).

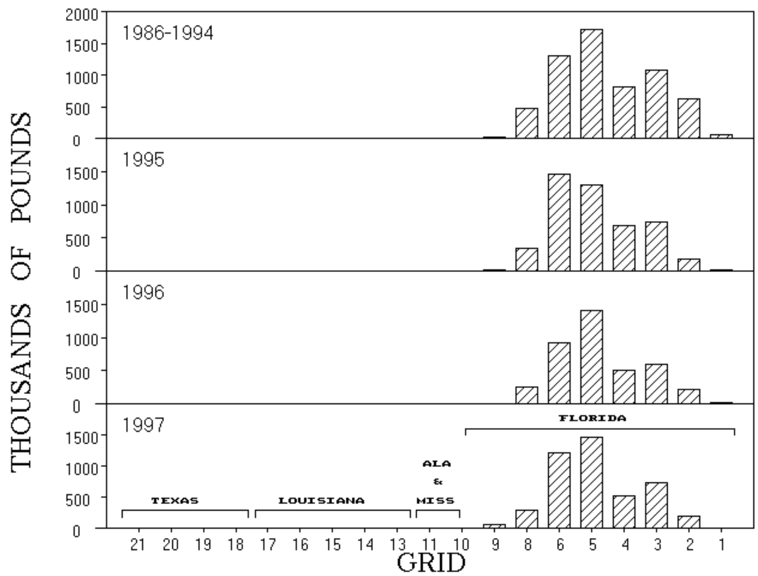

***Figure 27**. Spatial distribution of the 1986-1992 average U.S. Gulf of Mexico red grouper catch.*

Most of the red grouper trap catch through 1989 was in the southern part of the fishery in grids 2 and 3 (Table 36). These fish were landed primarily in Collier and Monroe counties (Table 43), where they contributed up to half the counties' red grouper landings. Taylor and McMichael (1983) report that red grouper was the most abundant target species in the Collier County trap fishery, making up 91% of the target weight and 73% of the target number. Starting in 1990 however an expanding trap fishery was established in grids 6 and 7. In 1992 more red grouper were caught in grid 6 than grids 2 and 3. Furthermore, the trap fishery landed as much fish in Citrus county as it did in Collier that year. The trap catch diminished in importance in 1990, but landings increased again in 1991 and 1992 to near previous levels. We expect that some small trap landings had existed in these areas previously but were not coded properly in the landings files. The other principal gears showed no spatial affinity for a particular subset of the grids from which most red grouper were harvested (Tables 39 and 40). However, most of the landings in counties north of Tampa - St. Petersburg were taken with handlines (Tables 38 and 43).

RECREATIONAL HARVEST

Data sources. The recreational harvest estimates for red grouper are derived from a combination of three sources. The primary data source for the recreational harvest of red grouper is MRFSS, which covers the period 1981-1997. This survey provides estimates of the numbers of red grouper harvested during bimonthly periods (waves) by state and mode (shorebound, private/rental boats and party/charterboats), with several exceptions. There were no estimates of harvest for wave 1 (January-February) in 1981. Texas boat mode was not sampled from 1982-1984. Texas was not included in the survey from 1986-1988. Party boat (headboat) sampling was discontinued after 1985 for all waves and states.

The suspension of the party boat sampling by the MRFSS coincided with an expansion of the NMFS headboat survey conducted by the NMFS Beaufort Laboratory (data courtesy G. Huntsman, SEFC Beaufort

Laboratory) to include U.S. Gulf of Mexico ports. These latter data provide estimates of landings by partyboats for all states after 1985 and constitute the second source of recreational harvest estimates.

The third source of recreational harvest estimates is the Texas Parks and Wildlife Department (TPWD) coastal sport fishing survey (data provided by TPWD). This survey provides estimates for numbers harvested by boat modes, exclusive of party boats, for Texas for 1986-1992. Harvest by shorebound fishermen has not been included in the estimates since 1985.

The combination of these three sources provided estimates for all areas, modes, and periods except for wave 1 of 1981, the 1982-1984 Texas boat modes, and Texas shore modes after 1985. The harvest of red grouper from the shore is minimal, and no attempt was made to include this missing stratum in the final estimates.

Values for the other missing strata were estimated from their respective proportional contributions for years when they were sampled. Specifically, the 1981 wave 1 estimates were derived from the 1981 totals using the mean fraction of the annual harvest that occurred in wave 1 in other years. Similarly the harvest by boat modes in Texas in 1982-1984 was estimated from the gulfwide landings in those years and the average proportion of the annual gulfwide landings contributed by the Texas boat modes in years when they were sampled.

Intercept data from MRFSS provide length measurements for samples of fish encountered during the interviews. These data permit characterization of the length frequencies and weights. Similar and more extensive data were gathered in the 1986-1992 headboat survey, and other data were provided by the TPWD annual coastal sport fishing survey, TIP, and the NMFS Panama City Laboratory bioprofiles sampling. These data sources were pooled to estimate mean weights of landings by fishing mode.

The biomass of the annual recreational harvest was estimated as the sum of the products of the estimated number of red grouper harvested by mode and the estimated mean weight of the grouper harvested by that mode during the year. The mean weight of grouper for a given year was estimated as the mean weight of all grouper measured during the intercept portions of all surveys for the year (Table 46). However, if fewer than 50 individuals were measured during the year for a particular mode, then the annual mean weight for all modes was substituted for the mean weight for the mode. This convention affected the biomass estimates for shore mode fishermen each year and the other modes in occasional years.

Recreational catch estimates. Red grouper harvest estimates by state, year, and distance from shore are given in Tables 44, 45, and 47. These data confirm the impression obtained from the commercial data that the red grouper fishery is primarily confined to the waters off Florida. The estimates are highly variable over the period but average about 550 thousand individuals and 2.4 million pounds from 1982-1989. The 1990 landings declined about 70 percent by number and 41 percent by weight, primarily as a result of the 20-inch minimum size.

It is also clear from Table 45 the recreational harvest occurs offshore, away from the state inshore waters. Much of the recreational harvest was in Florida's territorial sea before Florida enacted an 18-inch minimum size in July 1985 (Figure 28). The numbers of red grouper in the recreational harvest initially declined after this measure went into effect, primarily in the territorial sea. However, the harvest recovered to about the prior average in 1989 and 1990, with almost all the growth occurring in the EEZ. Similarly, in 1990 the catch declined after the minimum size was increased to 20 inches, but a recovery would seem to be underway as the catch increased the next two years. Most of this increase was again in the EEZ.

As expected from the life history of red grouper, shore-based fishermen catch a small fraction of the recreational harvest (Table 45). Because of survey design, the recreational harvests from charter and party boats were combined before 1986. For most years before 1990, anglers fishing from private or rental boats accounted for most of the recreational harvest of red grouper. However, when the conservation measures adopted by the Gulf Council became effective in 1990 the private/rental component of the harvest declined sharply while the charter/partyboat harvest remained nearly constant (Figure 29). Closer inspection reveals that the partyboat sector also declined sharply while the charterboat harvest remained essentially constant in 1990 (Table 44). After 1990 private-rental boat harvest started to increase again while party and charter vessel harvest remained fairly constant.

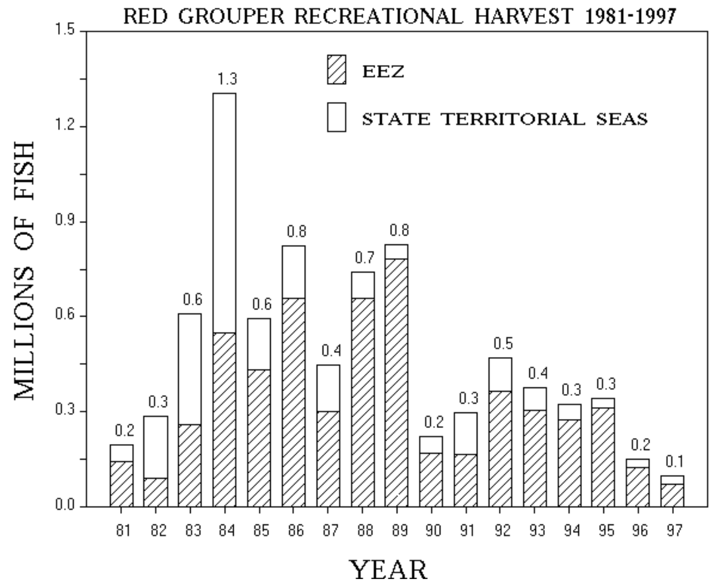

Figure 28. Estimated numbers of red grouper harvested by recreational fishers in Florida territorial seas and the EEZ, 1981-1997.

The 1990 conservation measures may have reduced the angler harvest in several ways. The 20-inch minimum size required a large portion of the catch to be released, which may in turn have reduced the motivation to target the species. In addition, if a large number of anglers had been selling their catch, the new requirement for a reef fish permit may have eliminated part of the "recreational" effort.

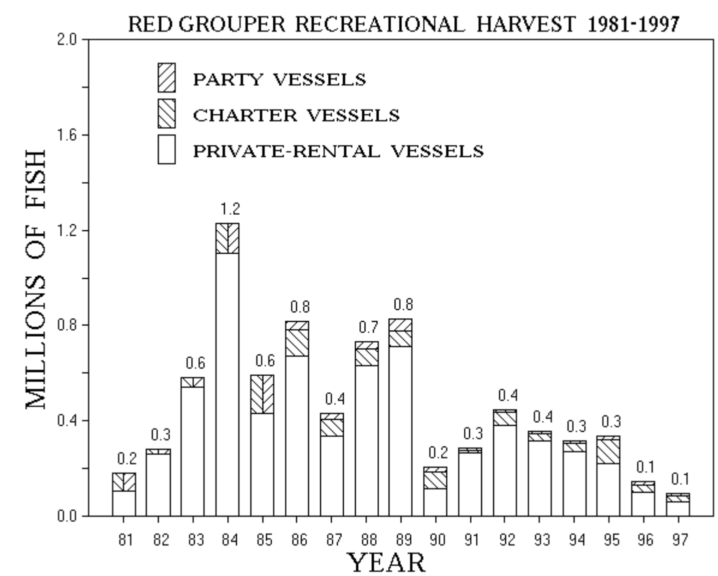

Figure 29. Estimated numbers of red grouper harvested by anglers fishing from private or rented boats and from charter or partyboats, 1981-1997.

The MRFSS estimates include estimates of fish that were released as well as those that were harvested. Data are available for private/rental and shore mode anglers for harvest and releases from 1979 through 1992 (Table 45, Figure 30). These data show that a clearly increasing fraction of the total catch has been reported to be released over the time period, from about 3 percent in 1979 to more than 91 percent in 1991. There was a slight decrease to about 86% by 1992. However, the estimate of total catch (including both harvested and released fish) for the years following the 20-inch minimum size increased in

1992 to levels higher than any prior year.

These data suggest no significant decrease in recreational effort directed at red grouper between 1989 and 1997, despite the permit requirement for the sale of reef fish imposed by the Gulf Council in 1990.

COMBINED HARVEST

Because recreational harvest estimates are available only since 1981, it is possible to estimate the combined harvest of red grouper only for the period 1981-1997 (Figure 31). The estimate of combined harvest increased from 1981to a high in 1984 of just over 10½ million pounds. However, from 1984 to 1990 landings declined every year with one exception in 1989. The decrease from 1985 to 1987 was entirely the result of a decline in the estimate for the recreational fishery, probably in response to Florida's 18-inch minimum size. Landings declined in 1990 but is presumable due to the increase in minimum size that year. Annual increases for 1991 and 1993 brought the combined harvest back up to 8.7. million pounds for the last year. Although the increased minimum size may have partly contributed to the increased landings from 1991 to 1993, landings again declined from 1993 to a low in 1996 of 4.9 million pounds. The 1997 estimated landings of 5.2 million pounds are the second lowest of the time series.

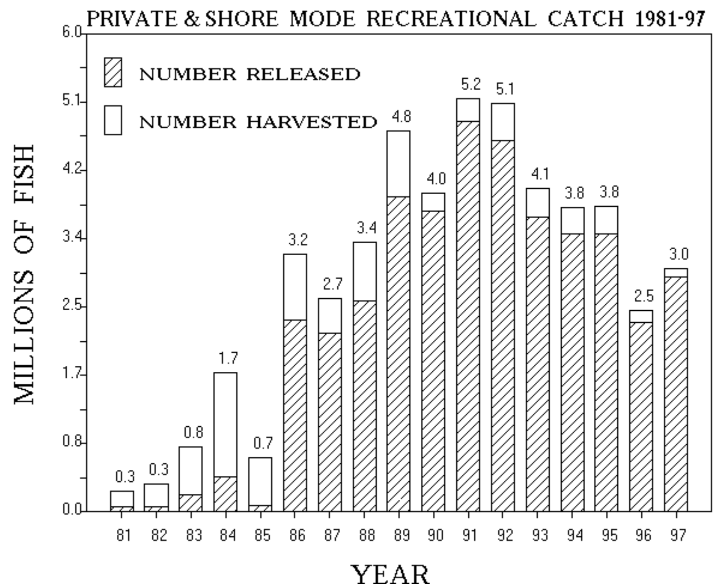

Figure 30. *Disposition of red grouper caught by anglers fishing from shore or private/rental vessels, 1981-1997.*

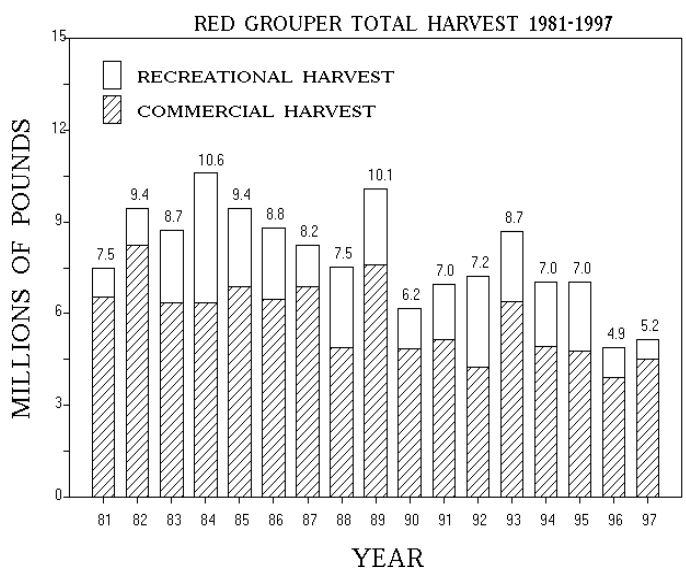

Figure 31. *Estimated total harvest of red grouper from U.S. water of the Gulf of Mexico, 1981-1997.*

In an effort to fully utilize all available commercial landings data it was necessary to have some estimate of recreational landings for the same time period (1940-1981), even though no formal estimates were available. The first step in estimating historic recreational landings was to estimate recreational effort for the same time period. This was done by establishing that a strong correlation existed between the U.S. Census Bureau population estimates for the west coast of Florida and the number of private angler trips estimated from the

MRFSS data (Figure 32). From this relationship is was assumed that the recreational catch of red grouper off the west coast of Florida should also be a function of, among other things, west coast population size. A ratio of catch-to-population was then established for the years prior to the 20 inch minimum size (1981-1989) and then applied to the estimated west coast population size to estimate total recreational landings of red grouper from Florida's west coast (Figure 33). Although this method of estimating recreational has many assumptions associated with it, such as constant recruitment and stable stock size, estimates the years 1940-1980 are so small that information about this time period will be dictated by the relatively more reliable commercial data.

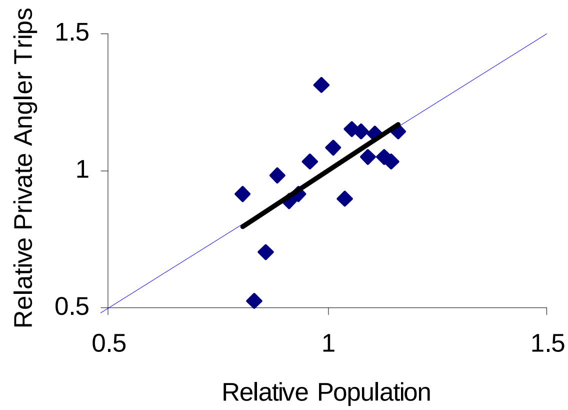

Figure 32. *Relation between relative Florida Gulf coast population size and relative private angler trips, 1981-1997(diamond) solid line - model fit; light line - perfect correspondence.*

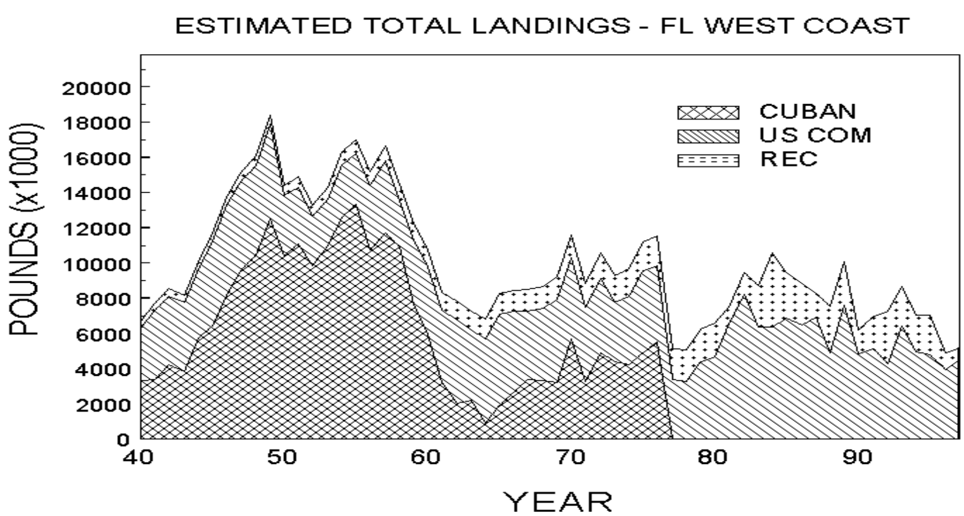

Figure 33. *Estimated total landings of red grouper from Florida west coast, 1940-1997.*

SEASONAL DISTRIBUTIONS

The average seasonal distributions of the commercial and recreational harvests are shown in Figure 34. The most recent year (1990) was not included in the mean for the commercial sector because of the implementation of a quota in 1990. The seasonal distribution of the recreational catch was estimated as the monthly sums of the estimated catches from the three surveys. Where an estimate for a cell spanned more than a month (as in the bimonthly waves of the MRFSS) the estimate was divided equally among the applicable months.

The commercial harvest showed a summer peak in landings but the seasonal variation in landings was not great. The recreational harvest also exhibit a summer peak and midwinter minimum. However the recreational harvest in November and December were about as high as they were in any other month.

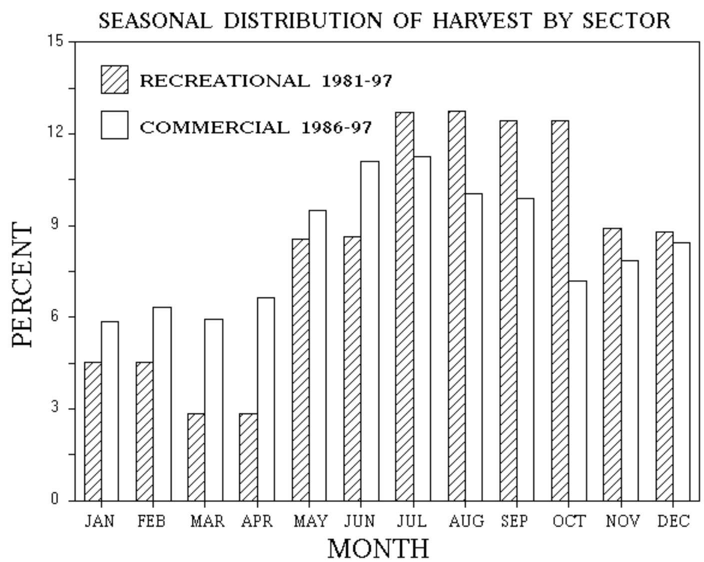

Figure 34. *Average seasonal fractions of the commercial and recreational harvest of red grouper in the U.S. Gulf of Mexico.*

SIZE DISTRIBUTION OF THE HARVEST

COMMERCIAL SIZE COMPOSITION

Figure 35 is a scattergram of all length samples from the commercial fishery from 1984-1997 by day of sample. Inspection of these data reveals a significant decline in sample size that began in mid 1988 and extended through 1989. The impact of the 20-inch minimum size is also apparent from the samples from 1990-1997.

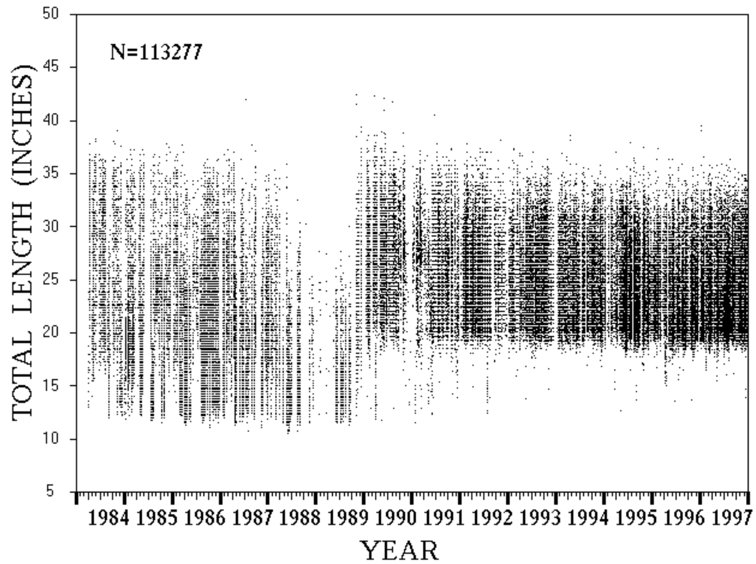

__Figure 35__. Scattergram of length samples from the commercial fishery for red grouper, 1984-1997.

These data and other samples taken by investigators from the NMFS Panama City Laboratory in 1980 and 1981 were used to construct length frequencies of red grouper by gear type and year of capture (Figure 36).

Red grouper sampled from trap landings are decidedly smaller on average than those sampled from the other fisheries in every year for which samples are available except 1988. Inspection of the 33 observations from traps in 1988 revealed that they were a sample from a single trip in the Florida Keys. The 20-inch minimum size caused an upward shift in the modal size of the trap catch, but red grouper below the minimum size continued to be harvested with traps, although observations of these undersized fish eventually dissipated. There is no indication in these data that the 1985 Florida 18-inch minimum size had any effect on the size composition of the landings.

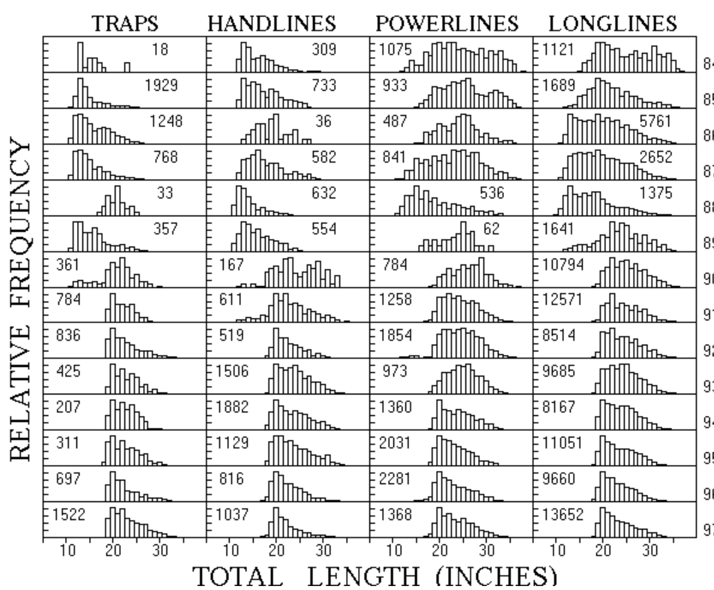

__Figure 36__. Length frequencies of red grouper from commercial gears, 1984-1997.

Red grouper caught with handlines were somewhat larger than those caught with traps but were smaller than those caught with power-assisted reels or longlines from 1984-1986 (Figure 36). As with the trap fishery, sub-legal size fish were still being harvested the first two years of the regulation (1990 and 1991), but were essentially eliminated from the samples by 1992. Also as in the trap fishery, there is little indication that Florida's minimum size had any effect on the size composition of the harvest.

Samples of the catch from power-assisted reels and bottom longlines were larger than with the other gears (Figure 36). A decreasing trend in the relative abundance of red grouper 30 inches and greater is evident for both of these gears. These samples also reflect the impact of the 20-inch minimum size but do not indicate any effect of Florida's minimum size.

A primary reason for inspection of these data is to identify the most reasonable way to aggregate the data to estimate the size composition of the harvest. If the samples from the fishery were simple (adequate) random samples of the catch, then they could be used directly to estimate the size composition of the catch. Unfortunately, such is not the case.

It is clear from Figure 36 that true handline gear catch a different size distribution of red grouper than do power-assisted reels. Unfortunately, in the landings files handlines and power-assisted gears are reported under a single gear code (610), and we must, therefore, estimate the length frequency for the combined catch for these two gears. Consequently, we sought a way to stratify the observations so that we could

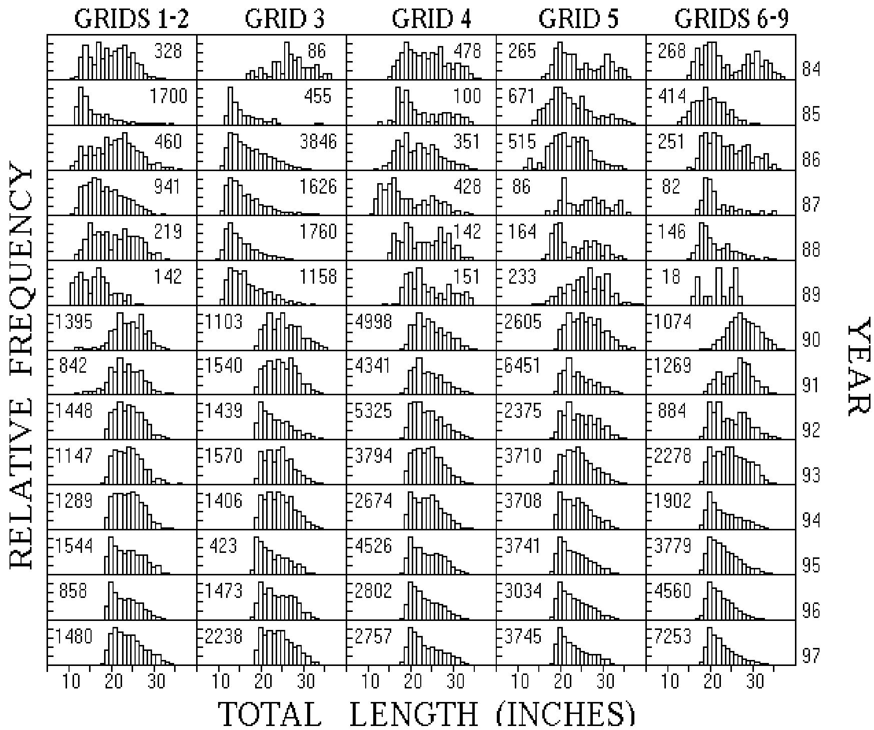

***Figure 37**. Length frequencies of commercial red grouper landings by area of capture, 1984-1997.*

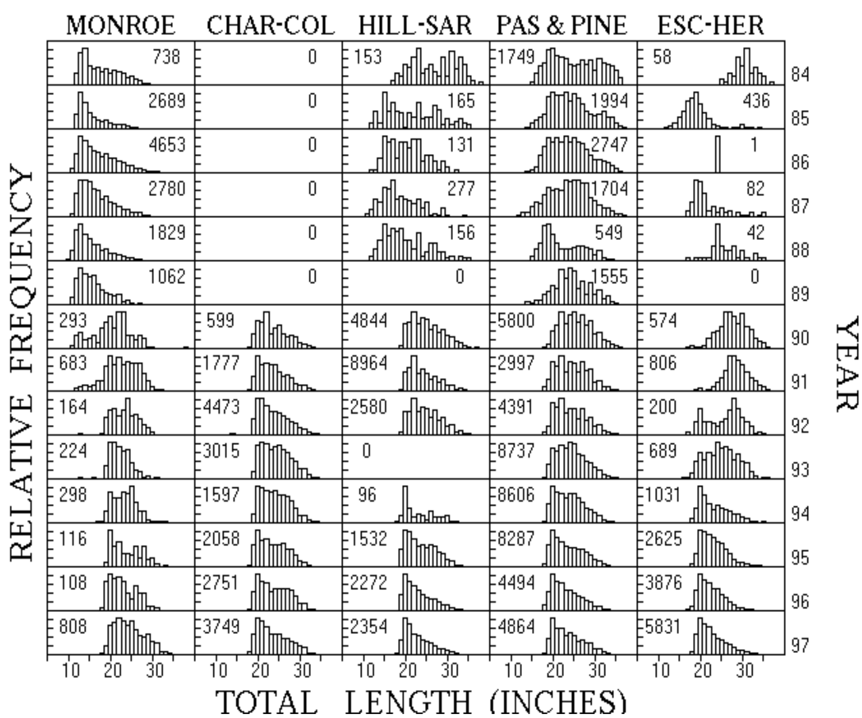

***Figure 38**. Length frequencies of red grouper catches by counties where they were landed, 1984-1997.*

develop an estimate of the length frequency of the harvest from some weighted combination of gear/area strata which would accurately reflect the total harvest.

The length frequencies of the samples by location of capture are presented in Figure 37 and by location of landing in Figure 38. The samples by county (Figure 38) clearly reflect the paucity of sampling effort in 1989 and the lack of effort directed at the catch from Charlotte to Collier counties.

The samples arranged by area of capture (Figure 37) provide more complete coverage, but still retain disproportionate representation by gear.

This data lead us to stratify the samples by gear and area of capture, which we believe to be the best compromise with the available data. Although the effect of this convention on the estimate of the length frequency of harvest is uncertain, we feel the estimate to be reasonable.

RECREATIONAL SIZE COMPOSITION.

Figure 39 is a scattergram of all length samples from the recreational fishery from 1981-1997 by day of sample. Inspection of these data reveals a gradual increase in sample size through the years. An important part of the increase was the result of the institution of the headboat survey in the Gulf in 1986. As with the commercial data there is a clear signal of the impact of the 20 minimum size in the 1990-1997 samples. There is also a drop in the sample size in the latter half of 1985 that might indicate a response to Florida's 1985 18-inch minimum size.

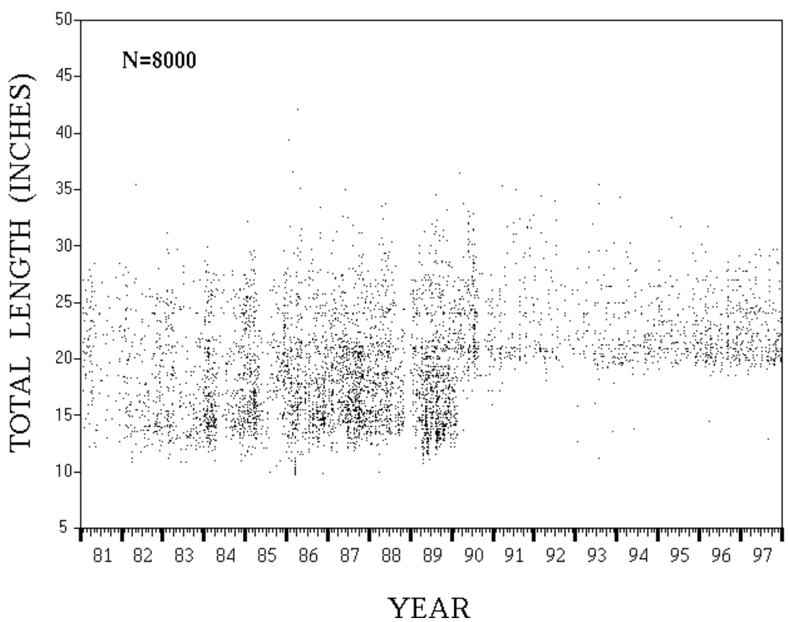

Figure 39. *Scattergram of length samples from the recreational fishery of red grouper, 1981-1997.*

Inspection of annual variation in the length frequencies of red grouper sampled by mode indicate a mode of 12-15 inches for headboats from 1982 to 1989 with a pronounced shift to a mode of about 20 inches in 1990 (Figure 40. Samples from charterboats are also quite sparse but fairly similar to the headboat samples from 1986-1989 and 1990-1997. The 1990 sample of the charter catch is very small but clearly reflects the 1990 minimum size. The length frequencies from the private/rental mode follow similar trends.

The length frequencies of the recreational harvest by mode and area summed over years is given in Figure 40 These data also reflect the scarcity of observations in the western Gulf of Mexico. All of the six observations from west of Alabama were from anglers fishing from private vessels in Texas.

The paucity of intercepts of red grouper in interviews with shorebound fishermen in Figure 40 reflects the preference of red grouper for the deeper waters offshore. It is possible that some of these records for shorebound fishermen may reflect data entry errors rather than actual observations of red groupers harvested by anglers fishing from shoreline structures.

There is a trend of increasing average size of red grouper harvested by anglers as one moves northward along Florida's west coast (Figure 41). This trend is most apparent in samples from the headboat fishery but is also evident in samples from anglers fishing from charter boats and from private or rental craft (Figure 40).

The length frequencies of red grouper sampled from the recreational harvest by fishing area and year are given in Figure 41. These data suggest that the trend of increased mean size in the more northerly areas was present at least as long ago as the early 1980s. This trend, which was also apparent in the commercial landings, suggests small red grouper are comparably more scarce in the northern part of the fishery.

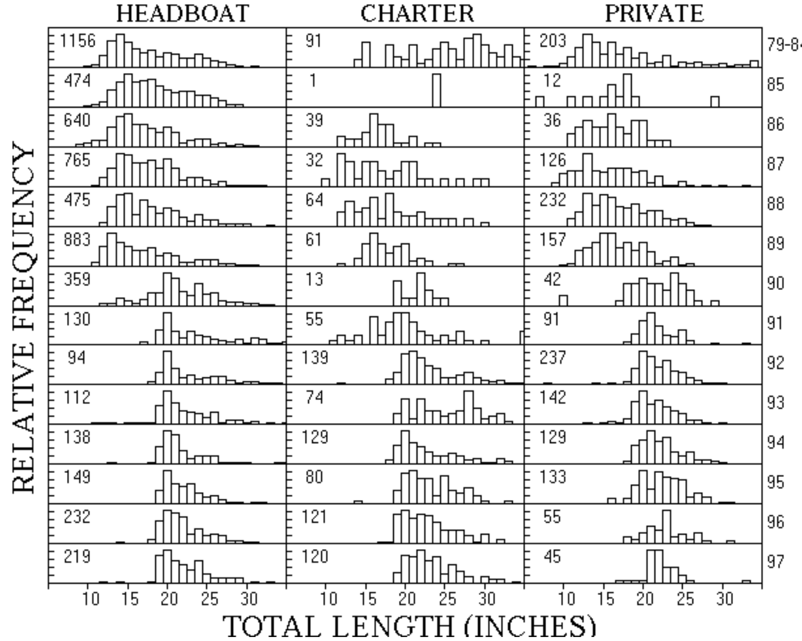

***Figure 40**. Length frequencies of recreational harvest of red grouper by fishing mode, 1979-1997.*

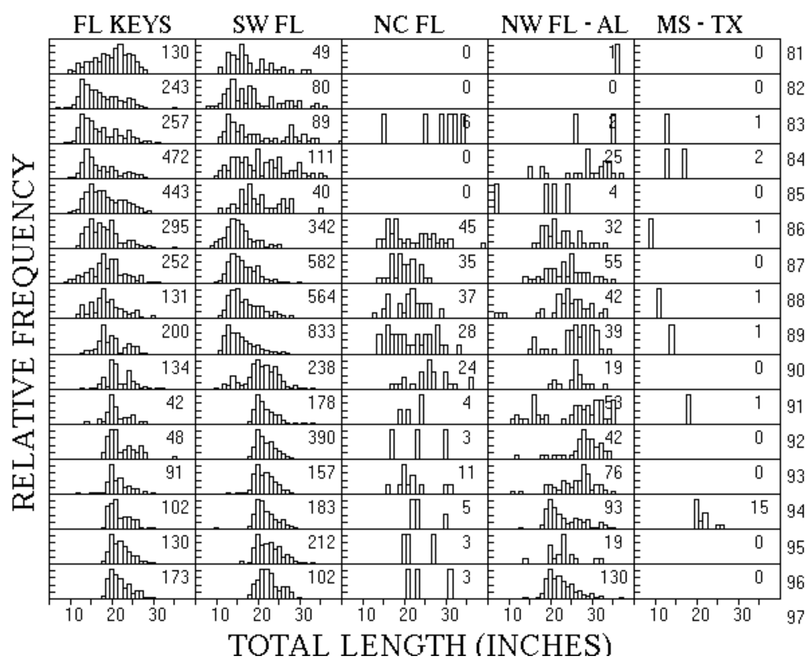

***Figure 41**. Length frequencies of recreational harvest of red grouper by area and year, 1981-1992.*

Recalling the north-south movement pattern (Rivas 1970) and the tendency for larger fish to move further than small fish (Moe 1969), it is reasonable that the harvest of red grouper in the northerly part of their range in the eastern Gulf of Mexico is dependent on emigration from a center of abundance to the south. If this is the case, then one of the more important effects of overfishing would be to greatly reduce the catch north of the Tampa-St. Petersburg area.

As with the samples from the commercial harvest, a primary reason for examining these distributions is to identify the most reasonable way to aggregate the data to estimate the size composition of the harvest. Several constraints are imposed by the headboat and MRFSS catch estimates. First, while the length samples have been collected in specific locations and clearly indicate that there is south-north cline in size, the catch estimates must aggregate samples within strata.

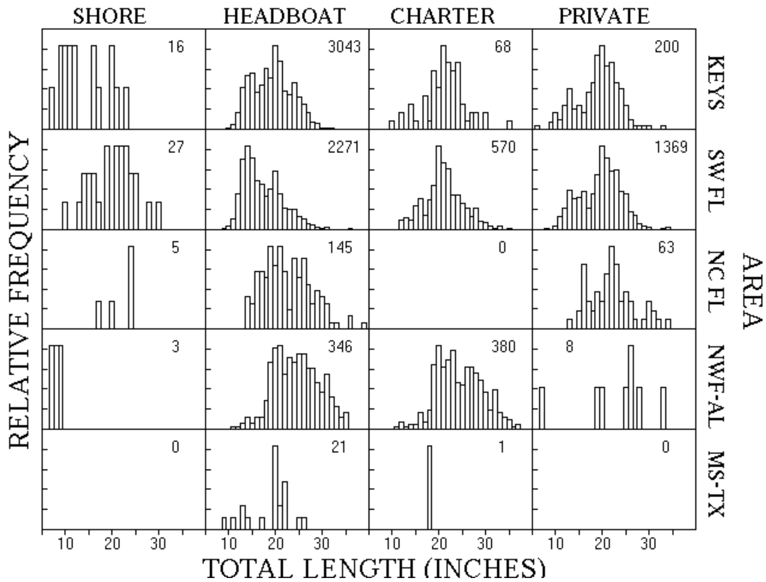

Figure 42. *Length frequencies of the recreational harvest of red grouper by fishing mode and area summed across the year 1979-1997.*

The design of MRFSS provides inshore-offshore resolution within states but is not designed to provide catch estimates along the coastline of a state. Consequently, the finest spatial (along-shore) resolution of the catch estimates from MRFSS are by state. The headboat catch estimates are available by areas that correspond to the regions depicted in Figures 42. After review of the spatial variability of the length-frequency data and the constraints imposed by the catch estimates, we elected not to partition the annual recreational catch any further than those catches from the state of Florida.

TRENDS IN CATCH-PER-UNIT-EFFORT

Commercial Operating Units. The fishery for reef fish in the Gulf of Mexico uses several types of gear including hand lines, power assisted lines (bandit rigs), bottom longlines, buoys, and fish traps. Red grouper are caught by each of these gears although, as discussed later, the total landings of red grouper from fish traps have been small. Red grouper are primarily harvested with bottom longlines, but also with handlines that are operated either manually or with the assistance of electric or hydraulic reels. For the most part, the landings from all of these "handline" gears have been reported under a single gear code. Consequently, they cannot be partitioned into more discrete categories and are referenced herein as "power and hand lines" or simply "handlines." Similarly, bottom longlines and buoys have been combined into a single category termed "bottom longline."

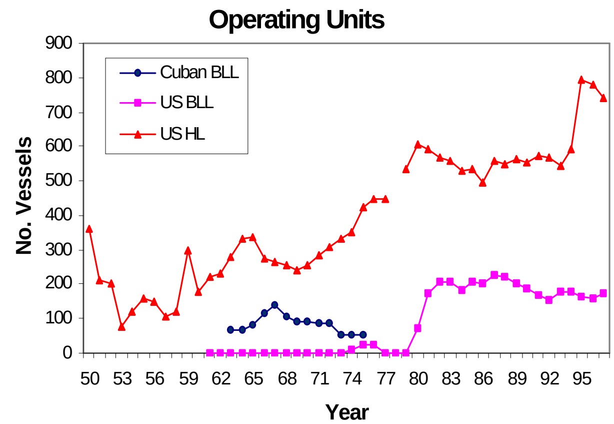

Figure 43. *Number of motorized vessels landing on the west coast of Florida using handlines and bottom longlines, and Cuban vessels, 1950-1997.*

The data from the operating units files on the composition of the fishing vessels categorize them as "documented vessels" or "boats". Documented vessels are those which meet the criteria that require them to have Coast Guard documentation numbers. Boats include all other vessels. They are generally smaller, state registered vessels. The structure of the historical files related to the number of boats in the fishery prohibits separation of those which are used inshore and those that might venture offshore to fish for reef fish. Nearly all the red grouper landings from the Gulf of Mexico are reported from the west coast of Florida. Consequently, this analysis will consider only this state.

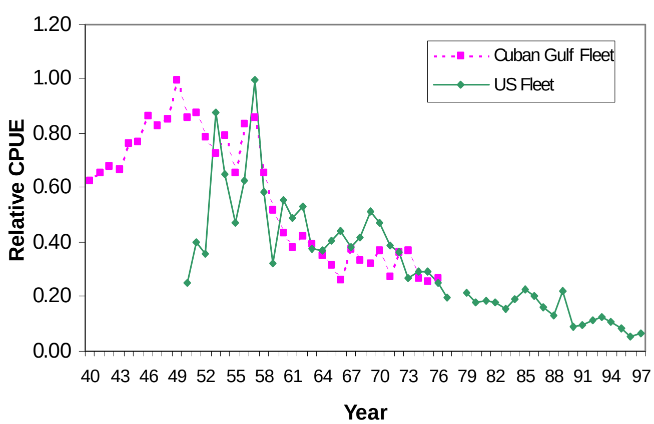

Figure 44. *Relative CPUE for the Cuban Gulf Fleet and U.S. handline fleet for west coast of Florida, 1940-1997.*

The number of documented vessels fishing with handlines on the west coast of Florida has increased almost annually from a low of 79 motorized vessels in 1953 to a peak of 606 vessels in 1980 (Table 54, Figure 43). The number of handline vessels stayed relatively constant from 1980 to 1984 but showed a sharp increase in 1995 to 794 vessels. Given the moratorium placed on federal reef fish permits in 1992, it is possible that this increase in handlines vessels is due at least in part from vessels fishing more off the west coast of Florida and less off the shores of the other states in the Gulf of Mexico. The Cuban Gulf Fleet was using bottom longline gear almost exclusively by 1965. However, bottom longline gear was not used by the U.S. fleet until the early 1980's. The number of vessels employing bottom longlines grew rapidly from none in 1979 to a maximum of about 300 by 1989 (Table 54, Figure 43).

We used operating units to represent an estimate of U.S. fleet effort from 1950 to 1997 because it was the most consistent and continuous time series available. Furthermore, it was the only data set available that would allow us to capture what we felt was the early development of the fishery when catches were considerably higher than they are today. Also available to us were records of the Cuban fleet fishing off the West Coast of Florida. This data included number of days fished and total poundage of harvest each year from 1940-1976. This was predominately a handline fishery from 1940-1964; afer 1964 the fishery used bottom longlines almost exclusively (Tashiro 1977). These two data sets were used to characterize the early development of the red grouper fishery.

From 1940 to 1957, CPUE estimates from the Cuban fishery were relatively stable at approximately 900 pounds per day (Table 54). However starting 1958 CPUE and total harvest both began a nine year decline. Some leveling off of this decline was apparent in 1966, however by this time CPUE was only about a third of the previous time period (approximately 300 pounds per day). Despite the decreased CPUE, total effort increased on an almost annual basis from 1964 to 1976, the final year the fishery was allowed to operate in U.S. waters. A remarkable similarity exists between the U.S. fleet and the Cuban catch-per-unit effort (CPUE) from 1950 to 1976 (Figure 44). Peak CPUE occurred for the Cuban Gulf Fleet in 1949 with a secondary peak in 1957, precisely when the U.S. fleet CPUE peaked. Both indices show the same marked decline in 1955 and again from 1957 to 1959. The dome shaped nature of the Cuban and U.S. CPUE trend from 1940 to approximately 1960 makes these two indices quite valuable. This dome shape, coupled with the similarity in the descending limbs of both indices, suggests the possibility that these indices are tracking the development, full utilization, and perhaps over-exploitation of the red grouper stock. If so, these indices become very important in estimating parameters such as maximum potential production of the stock.

Reeffish Logbooks. Additional CPUE data were available from the Reeffish Logbook Program which were used to estimate monthly CPUE for fish traps, handlines, and bottom longlines from August 1990 to December 1997. The Reeffish Logbook Program was program was initiated in 1990, and at this time required that all vessels holding reeffish permits in the states of Alabama, Mississippi, Louisiana, and Texas, and all trap fisherman in the state of Florida, to report on each fishing trip made. For Florida permitted vessels, only those fisherman randomly selected each year (constituting a 20 percent sub-sample of all permitted vessels in Florida) were required to report (note that this 20% sub-sample could be reporting on fishing done anywhere in the Gulf of Mexico, not just Florida). Mandatory reporting for all Florida permitted vessels began in 1993. Because releases are not reported in the Reeffish Logbook Program, these estimates reflect only fish kept. Only those trips reported to have landed red grouper were used. A summary of the components used to calculate the commercial CPUE are given in Tables 48-50.

Mean landings-per-trip using handlines were very similar from 1990 to 1993: approximately 350 pounds-per-trip (Table 48). Thereafter, they declined to 336 in 1994, to 342 in 1995, to 299 in 1996, and to 319 in 1997. The sum of the reported landing peaked in 1994 at approximately 1.5 million pounds. The average duration of the average trip decreased from approximately 6 days in 1990 and 1991 to approximately 4 days in 1993 thru 1997. The mean number of hooks-per-line was lowest in 1990 and 1991 at approximately 2 hooks-per-line. This number increased to almost 9 hooks-per-line in 1994 (incidently, the same year that the sum and mean pounds-per-trip peaked) but decreased again to 3 hooks-per-line in 1997. There is no apparent explanation for this trend.

Mean landings-per-trip using bottom longlines peaked to approximately 3532 pounds-per-trip in 1993 (Table 49). Although the mean landings-per-trip decreased after 1993 there was no apparent declining trend from 1993 to 1997. There was an obvious diversion in the trend in mean hours-per-set, which ranged from a low of 3.66 in 1990 to a high 91 in 1997. This divergence was later explained by differences in the manner in which fishers were requested to report the time in which their lines were in the water.

Estimates of CPUE for handlines were made by individual trip (catch = pounds; effort = (number of lines * number of hooks/line) * (hours fished)). Because of the difference in reporting hours mentioned above, estimates of CPUE for bottom longlines were made by individual trip (catch = pounds; effort = (number of lines * number of hooks/line) * (days fished)). CPUE for traps was calculated as catch = pounds; effort = (number of lines * number of traps/line) * (hours fished)). Trips were then averaged over a year and a mean, median and mode calculated. Mean CPUE for the years were then analyzed using a general linear model (GLM) procedure. Effects considered in the GLM were year, month, and grid. With these effects standardized for, a final index of abundance was calculated.

For handlines, the index, mean, and median values of the annual CPUE were fairly consistent from 1990 to 1997, however a small increase was evident in 1992 (Figure 45). Although significant effects were found for year ($p<0.0001$), month ($p<0.0001$), and grid ($p<0.0001$), the overall fit of the GLM resulted in a low R^2 value ($R^2 = 0.120$).

For bottom longlines, the index, mean, and median values of the annual CPUE were also fairly consistent from 1990 to 1997, however a small increase was evident in 1993 (Figure 46). It is possible that the increase in bottom longline CPUE 1993 corresponds to the increase in handline CPUE the previous year, however length data does not indicate that these two gears catch different size fish. Although significant effects were found for year ($p<0.0001$), month ($p<0.0001$), and grid ($p<0.0001$), the overall fit of the GLM resulted in a low R^2 value ($R^2 = 0.120$).

Trap CPUE showed the same consistent trend as handlines and bottom longlines with the same increase in CPUE in 1993 that was evident in the handline CPUE, and the longline CPUE the following year (Figure 47). Although far from conclusive, the increase seen in 1993 in the CPUE for both handlines and traps suggests perhaps a relatively stronger year

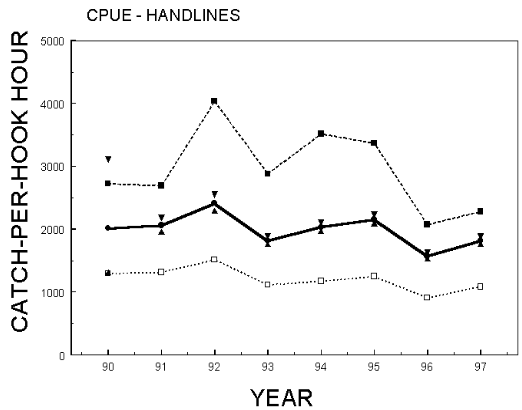

Figure 45*. Catch-per unit effort for commercial handline fishery in the U.S. Gulf of Mexico.*

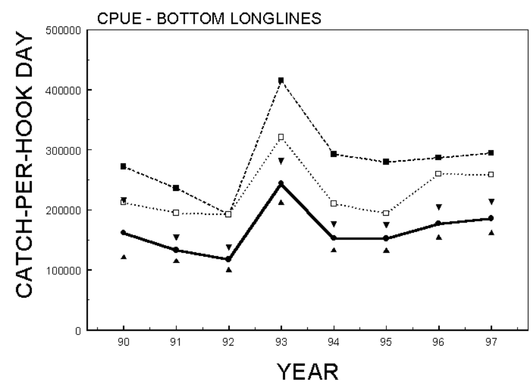

Figure 46*. Catch-per-unit effort for the bottom longline fishery in the U.S. Gulf of Mexico.*

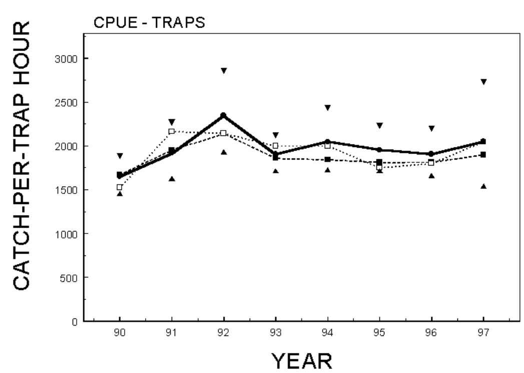

Figure 47*. Catch-per-unit effort for the trap fishery in the U.S. Gulf of Mexico.*

class moving through the fishery that year. Although significant effects were found for year ($p<0.0001$), month ($p<0.0001$), and grid ($p<0.0001$), the overall fit of the GLM resulted in a low R^2 value ($R^2 = 0.120$).

Recreational. Estimates of catch and effort from the headboat fishery were available for analysis, however, the results must be interpreted with caution. Although the traditional use of CPUE has been as an indicator of stock abundance, the estimate is better suited for some fisheries than others. CPUE estimates from the headboat fishery could be influenced by many factors other than stock abundance, the most nebulous of which could be the annual difference in the targeting of the species of interest. Greater or lesser availability of a more desired species, such as red snapper, could lead to a fewer or greater number of headboat trips targeting red grouper, respectively.

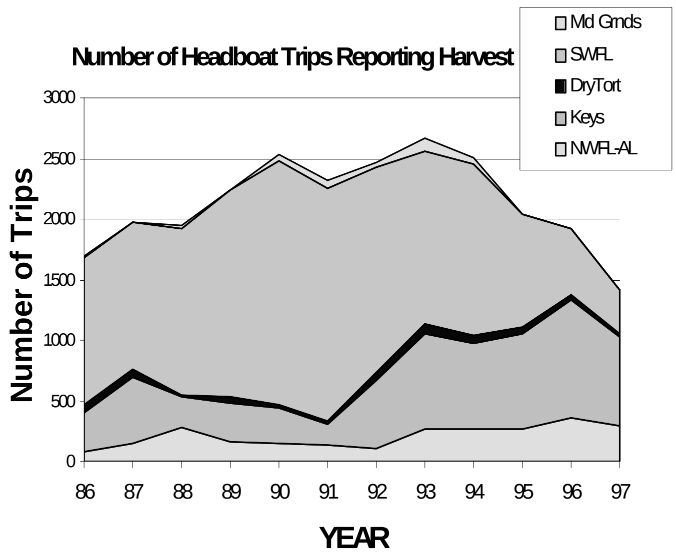

***Figure 48**. Number of headboat trips reporting harvest of red grouper in the U.S. Gulf of Mexico.*

The number of headboat trips reporting having harvested red grouper has shown an annual decline since 1993 (Figure 48). Although this is an overly simple metric of stock abundance, one that could be explained by many factors other than decreasing stock size, it is none the less interesting to note that all areas examined showed the same decline.

Thirty-two percent of the red grouper landed from headboats (number of fish) from 1981 to 1997 was accounted for by the top 5 reporting headboats; fifty-one percent was accounted for by the top 10 headboats (Table 51). Based on these observations the headboat fleet was divided into two groups (top ten harvesting headboats and all others) for further examination. The top ten headboats fished approximately 21% of their trip in July and August (Table 52- A), while all other headboats fished more in January, February, and March (Table 53-A). The top ten headboats fished mostly in south-west Florida (Table 52-B), while all other headboats fished in the Keys, south-west and north-west Florida (Table 53-B). The catch-frequency-per-anglers was also different for the two groups; the top ten headboats had 90% of their trips accounted for at 22 fish/trip (Table 52-C) while all other headboats had 90% accounted for with at only 8 fish/trip (Table 53-C). This same trend was evident in the number landed-per-fisher (Table 52-D and Table 53-D) and number landed-per-day (Table 52-E and Table 53-E). The top ten headboats had 58% of their trip made up of 12 hour trips (Table 52-F) while all other headboats had 57% of their trips made up of trips 9 hours or less (Table 53-F). This is because the top ten headboats were required to make longer trips to get further off-shore to catch red grouper. Table 52-I and 53-I show how the number landed-per-trip for the top ten headboats is considerably larger than that of the other headboats for any given year. Note that the number landed-per-trip in 1995-1997 increased for the top ten headboats, however, this was accompanied by an increase in the number of fishers-per-trip and hours-per- trip for the same years. In order to minimize some of the "noise" associated with CPUE analysis, the top ten vessels from 1986-97 were grouped and examined separately as a "sub-fleet" to represent those vessels targeting red grouper for the analysis given below.

The headboat survey, unlike the MRFSS survey, does not included released fish. For distinction, I use CPUE to represent those fish that were kept and released, and HPUE (harvest-per unit effort) to represent only those fish that were kept. Harvest (number of fish landed) per unit effort (fishers * hours out) for the headboat fishery was analyzed using a generalized linear model (GLM) procedure. The general components used to calculate HPUE are given in Table 52 G-I. Significant effects were found for all three variables considered: year, month, and specific vessel. These parameters explained 51% of the variability in the model. We also used the MRFSS data to calculate a CPUE and HPUE using a GLM procedure. Significant effects for this model were found for year, month, area, and mode. These parameters explained 20% of the variability in the CPUE and HPUE.

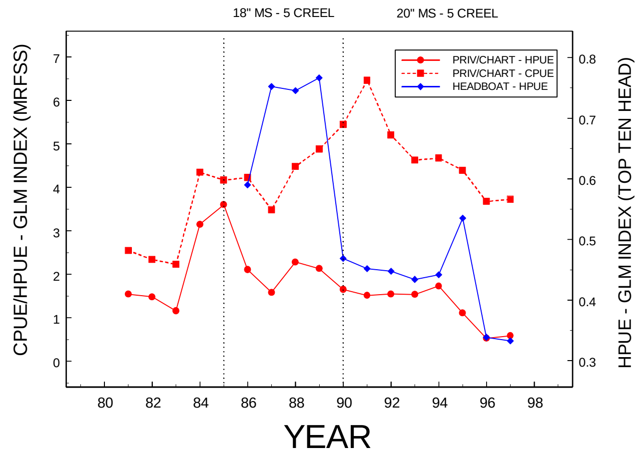

Figure 49*. Harvest and catch-per-unit effort from the top ten headboats and private/charter recreational fishery from the U.S. Gulf of Mexico.*

To examine possible trends in stock abundance we used three of the above mentioned partitions: private/charter HPUE, private/charter CPUE, and top ten headboat HPUE. Examination of the trends of all three of these partitions simultaneously begins to reveal one possible trend in red grouper abundance. The first point of interest is the remarkable similarity between the private/charter and the headboat trend in HPUE (Figure 49). As would be expected, in 1985 and 1986 when the minimum size was increased to 18 inches and the 5 aggregate grouper creel limit enacted the private/charter HPUE decreased. In 1990, when the minimum size was increased to 20 inches, the private/charter declined again, as did headboat HPUE. From 1990 to 1997 the private/charter and headboat HPUE track nearly identical decreasing trends to lows in 1996. The private/charter CPUE trend increased on an almost annual basis from 1982 to 1991. This may have been due, in part, to the above mentioned change in regulations. It is possible that the slight increase in HPUE in 1987 and 1988 is due to the increased number of fish being released in 1985. Similarly, the slight increase in HPUE in 1994 and 1995 cold be due to the increased number of fish being released in 1991. This type of relation might also exist for the slightly increased CPUE in 1995 and slight increase in HPUE in 1997, but keeping in mind the confidence around these estimates, the later relation should be view with great uncertainty. None the less, the CPUE, which includes fish too small (and/or young) to be recruited into the fishery, could possibly be an indicator of the fishable stock size 3 and 4 years later. If this relation is robust, the declining CPUE from 1991 to 1997 may indicate a steady decline in the number of red grouper being recruited to the fishery.

Fishery Independent. Fishery independent data and a summary of methodology were made available courtesy of from C.T. Gledhill of the National Marine Fisheries Service, Pascagoula Laboratory. The relative abundances of fish species found on shelf-edge banks located on the continental shelf of the Gulf of Mexico were estimated from data collected during the annual Southeast Area and Monitoring Program (SEAMAP) offshore reef fish surveys. These surveys were conducted during the months of June, July, and August from 1992-1995. Samples sites were selected in two stages using a list of known coral and hard-bottom features located on the continental shelf and shelf-edge. The first stage or primary sampling units

(PSUs) were blocks 10 minutes of latitude by 10 minutes of longitude, and were selected proportional-to-size where the measure-of-size for each block was the number of reef sites classified within the block. Selected blocks were surveyed at night using the ships echo sounder in 1992-1994, and a Simrad EK500 echo sounder mounted in a towed body in 1995. "Reef" sites were classified based on characteristics of the echo-trace (relief, slope, length of echo-trace foot). The trap or cameras were deployed at sites chosen randomly from the listing of "reef" sites.

The SEAMAP reef fish survey uses stationary Hi-8 video cameras for all censussing. SCUBA diver census techniques are not feasible due to the depth range sampled (maximum depth of 110 m) and the broad extent of the survey. Two types of gear have been used. The first was a trap/video, where a single video camera was mounted at a height of 25 cm on a single-funnel fish trap (2.13 m long by 0.76 m square) and baited with squid. A four-camera rig on which cameras are mounted orthogonal to each other at a height of 25 cm above the bottom was also used. This rig was also baited to be comparable to the camera mounted on the fish trap. The four-camera rig has been the primary gear since 1997. The four-camera rig was developed to mitigate cases where a single camera would face away from any features located on the bottom . One camera is randomly selected for viewing out of all cameras that face "reef" habitat. Video observations are conducted during daylight hours. From 1992 to 1996, the cameras soaked on the bottom for 1 hour before retrieval. Soak time was reduced to 30 minutes in 1997.

Two viewers examined each video tape separately, and identified and enumerated all species for the duration of the tape (maximum time 1 hour). Identifications were made to the lowest taxonomic level practicable, and all fish were counted as they came into view. Discrepancies between viewers were resolved either through discussion among the viewers (e.g. cases where one viewer makes an identification to the generic level and the other viewer's identification is to the species level); or viewing of the tape jointly for cases where counts and identifications differ greatly. In practice, discrepancies were rare, and between experienced viewers and a viewer in training. Since viewing a 1-hour tape was very time consuming, we conducted a study to examine to statistical cost of reducing the view-time. As a result, the time viewed was reduced to 20 minutes.

Three general geographic regions were consider, the lower Florida keys (Area 1), the middle Florida West coast and the Panhandle region (Area 2) and off the Mississippi and Alabama coast (Area 3). There was no specific reason(s) for this division. Frequency plots of depth distribution show two main peaks one at 14-22 fathoms, and a second at 34-42 fathoms. Based on this, two depth zones were specified in the model; Depth 1 from 0 to 32 fathoms, and Depths 2 from 33 and above fathoms. Restricting the data to the east of Mississippi, the video database includes 669 records, from 1992 to 1997. Of these, 189 records contained red grouper. There are observation for 34 of the 36 cells, year/area/depth. However, most of the observations are from area 2 depth 1. An index of CPU was estimated using a Delta lognormal approach. Proportion of zero/positive observations was modeled assuming a binomial error distribution. Deviance analysis indicated that Area and Depth are significant factors in explaining overall variability. The selected model included Year Area and Depth as fixed factors. Positive CPUE were modeled assuming a lognormal distribution. The explanatory variables included Year Area and Depth, however only year was significant. Overall the fit of positive observations was very poor. Annual CPU indexes were estimated from the Least Square means from both the proportion of zero/positive and the positive models. Standardized CPU suggest an increasing trend, however the confidence intervals are large. The CPU show two sets; from 1992 to 1994 similar mean CPU and confidence intervals, and from 1995 to 97, greater CPUE (double and higher) but also greater confidence intervals.

Perceptions of the abundance of the red grouper stock based on the two gears of this study were contradictory (Figure 50). The index of abundance estimated from the trap/video data suggested increasing abundance while the trap observations suggested a decreasing abundance. One possible explanations for this discrepancy is that the trap/video data measured abundance in numbers of fish while the trap data measured in pounds of fish. Another possible artifact may be that, unlike with the trap gear, fish observed from the trap/video gear could theoretically be counted multiple times.

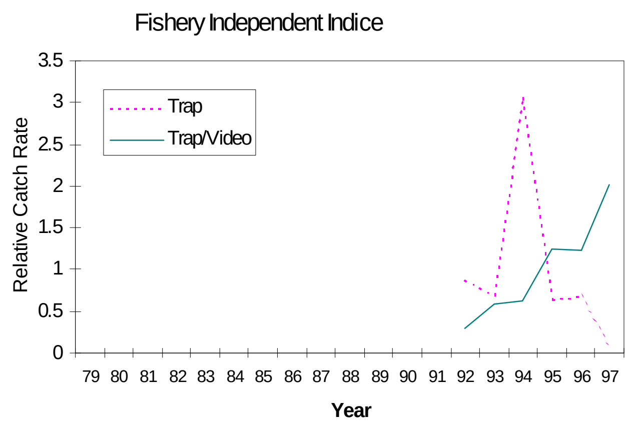

Figure 50. *Trap and trap/video fishery independent indices of abundance from west coast of Florida, 1992-1997.*

Combined Indices of Abundance. Figure 51 shows all six fishery dependent indices of abundance in terms of relative CPUE. From this figure it can be seen that estimates of stock abundance from 1940 to 1980 will be driven primarily by the Cuban and U.S. fleet CPUE, as they are the only indices available at that time. The five "competing" fishery indices are shown in Figure 52. These indices will dictate more the current condition of the stock.

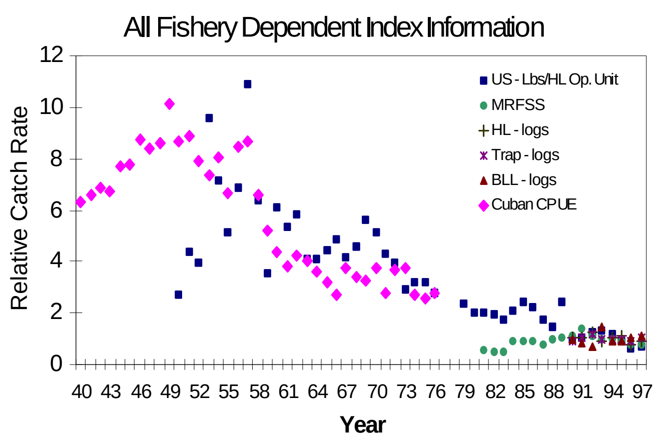

Figure 51. *Relative CPUE for all fishery dependent indices of abundance considered.*

Estimates of fishing mortality were derived from tag/recapture data supplied by the Mote Tagging Program (Legault et al. 1999). These estimates were then converted to CPUE by solving the catch equation for numbers of fish, using estimates of released fish from MRFSS data, and an assumed rate of natural mortality (Figure 53). A summary of all indices examined are given in Table 55.

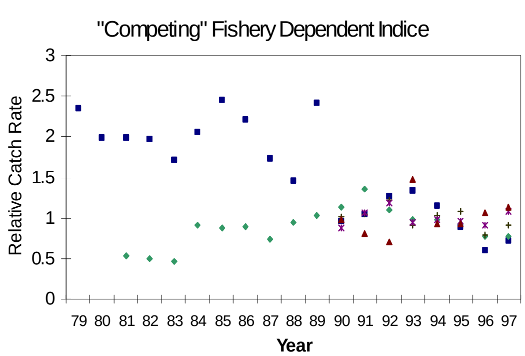

Figure 52. *Relative CPUE for "competing" fishery dependent indices of abundance considered.*

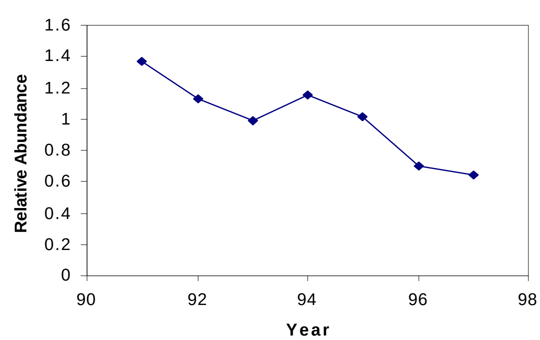

Figure 53. *Relative CPUE from tag/recapture data, 1991-1997.*

POSSIBLE CURRENT CONDITION OF THE STOCK - I

The possible current condition of the red grouper stock was evaluated by using the stock-production model ASPIC (A Stock-Production Model Incorporating Covariates; Prager 1994). The core of this model is based on the simplest surplus-production model, the logistic or Graham-Schaefer model. Surplus production is the algebraic sum of three major population components: recruitment, growth, and natural mortality. One advantage of using such a model is the minimal amount of data required for fitting. However, using such a generalized approach means that sometimes sacrifices must made in terms of how precisely the model fits the actual biology of the species of interest. Nonetheless, fitting the data to the ASPIC model was a useful way to obtain an estimate of the status of the population and to provide estimates for parameters required for management without making a great deal of assumptions.

The two time series required for parameter estimation was a series of observations of catch (yield in biomass) and a corresponding time series of an index of abundance. The 1940-1997 estimated total catch was partitioned into two fisheries. The first fishery included the 1940-1997 recreational, Cuban handline, and U.S. commercial handline catch, where U.S. commercial handline included all commercial gear other than bottom longline (mostly trap and some spear fishing). The index of abundance used for this fishery was developed by taking eight of the indices discussed in the previous chapter (Cuban handline CPUE, U.S. catch-per-operating unit, MRFSS CPUE, the Reeffish Logbook handline and trap indices, the fishery independent trap, trap/video indices, and the Mote tagging index) and standardizing all indices to the relative mean, thus combining them into one index. The second fishery included the 1965-1976 Cuban bottom longline fishery and the 1979-1997 U.S. commercial bottom longline catch. The index of abundance used for this fishery was developed in the same manner as the first using the Cuban bottom longline CPUE, the Reeffish Logbook bottom longline CPUE, and the index of catch-per-operating unit, which considered only vessels using bottom longline gear.

The ASPIC model seeks to maximize the fit between the observed catch and the indices of abundance by estimating essentially three parameters: the maximum population size, or carry capacity (K), the intrinsic rate of population growth (r), and the maximum sustainable yield (MSY). Other parameters estimated include catchability constant of each fishery (q), the ratio of fishing mortality in the last year to the fishing mortality that would produce the estimated MSY (F/Fmsy, or F-ratio), and the ratio of the stock biomass in the last year to the biomass at MSY (B/Bmsy, or B-ratio). Rather than allowing the model to estimate the condition of the stock in the first year of the time series (B1-ratio) we assumed it to be equal to 1.5. A B1-ratio of 2.0 defines the stock as at carry capacity while values below 2.0 define it as below carrying capacity.

The ASPIC model fit of the observed catch to the index of abundance resulted in a relatively high R-squared for both the first fishery (R-squared = 0.615; Figure 54) and the second (R-squared = 0.452; Figure 55). Estimates of the intrinsic rate of population growth (r = 0.3708) fell within the bounds of those estimated for other fish stocks. The estimates of the B-ratio (B-ratio = 0.2077) denotes that the 1997 biomass is estimated to be approximately 20 percent of the biomass the stock would be at if fished at MSY. The estimate of the F-ratio (F-ratio = 2.079) denotes that the 1997 fishing mortality is approximately two times higher than that estimated for Fmsy.

The estimated value for MSY from the ASPIC model was approximately 11.65 million pounds. This is approximately seventy five percent of the estimated peak landings in the 1950's. Landings of red grouper peaked between 1955 and 1960 near 17 million pounds, and the rapid decline from this peak in 1957 to approximately 5 million pounds in 1964 is strong evidence that that rate of removal was not sustainable. It should be kept in mind, however, that historic catches were probably made up of older and larger fish that are evidenced not to exist in the current catch. Consequently, estimates of MSY given the current day selectivity vector may be lower than those that include the historic fishery.

The time series of estimates of the B-ratio and F-ratio from 1940 to 1997 are shown in Figure 56. As stated above, the estimate of B-ratio for 1940 was fixed at an assumed size of 1.5 (75% of carrying capacity). Several values for the B1-ratio were explored between 2.0 and 1.5 but the overall fit to data was found to be extremely robust to the value selected as all trials converged on the value after approximately five years. After 1945 the estimated B-ratio begins a decreasing trend that lasts until 1960. During this same time, estimates of F-ratio increase to values between 2.0 and 2.5. The reason that the estimates of the F-ratio decline between 1955 and 1965 are not obvious. However, the increase in the F-ratio apparent from 1965 to 1975 corresponds with reports of the Cuban fishery switching from handlines to bottom longlines. Similarly, the increase in the F-ratio from 1979 to present corresponds with the years that the U.S. commercial fleet started to use bottom longlines as well.

In an effort characterize the error associated with these estimates, a bootstrap analysis was also conducted using the same model inputs. A total of 600 trials were run to develop distributions around selected parameters. Associated with the ordinary estimates of the various parameters are bias corrected estimates, percent bias, and upper and lower confidence limits around the estimates. These estimates are given in the below. The distribution of estimates of the intrinsic rate of population growth, MSY, the B-ratio, and the F-ratio are shown in Figures 57-60.

The relative lack of bias and small confidence intervals is evidence that the parameters are estimated with a high degree of certainty. While this leads to the conclusion that the data fit the model well, it cannot necessarily be concluded that the estimates depicts the fishery well. The parameters estimated here that should be given the

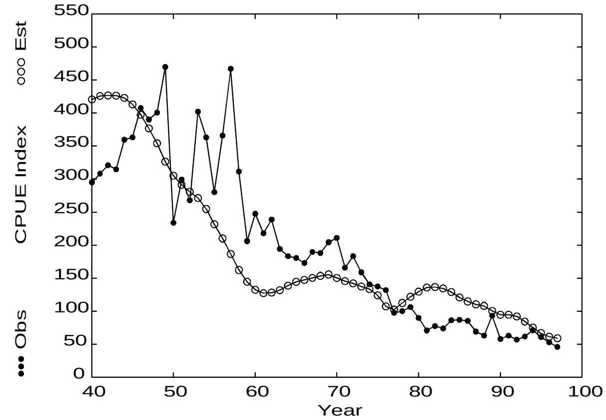

Figure 54*. Time series of observed and estimated CPUE for ASPIC model fishery one, 1940-1997.*

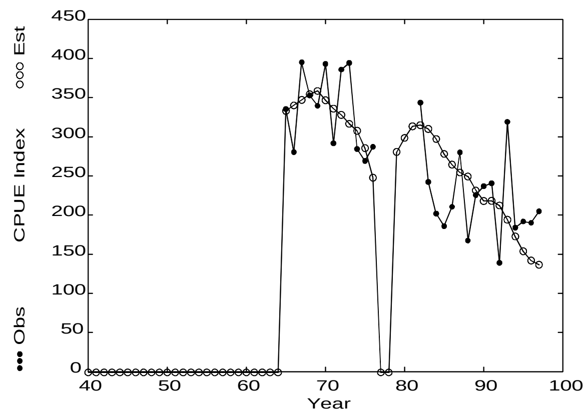

Figure 55*. Time series of observed and estimated CPUE for ASPIC model fishery 2, 1965-1976, and 1979-1997 (note that zero values are years with no data).*

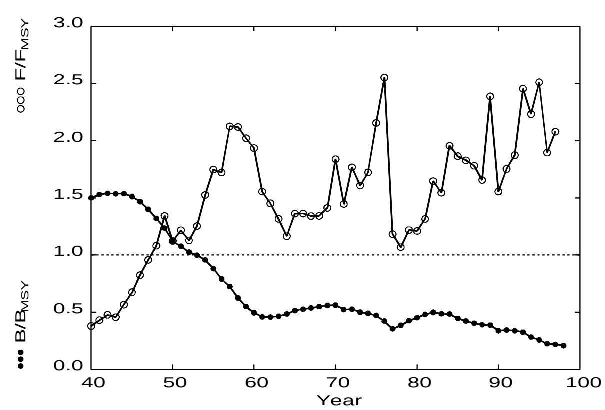

Figure 56*. Time series for estimates of F/Fmsy (F-ratio) and B/Bmsy (B-ratio) from the ASPIC model, 1940-1997.*

most attention are those that estimate the relative statistics: B-ratio, F-ratio, and Y-ratio (the ratio of the last years yield to the yield at MSY). In light of this, we feel with reasonable certainty that the current estimates of stock biomass and yield are below those of MSY, and that the current estimates of fishing mortality are above those that would produce MSY. Consequently, it is likely that the stock is over-fished based on current management benchmarks.

Parameter	Estimate	Bias Corrected	Relative Bias	80% LCL	80% UCL
K	1.26e+08	1.26e+08	0.10%	1.19e+08	1.52e+08
r	3.71e-01	3.71e-01	-0.13%	2.90e-01	3.97e-01
MSY	1.17e+07	1.17e+07	-0.03%	1.10e+07	1.18e+07
Bmsy	6.29e+07	6.28e+07	0.10%	5.97e+07	7.57e+07
Fmsy	1.85e-01	1.86e-01	-0.13%	1.45e-01	1.99e-01
B-ratio	2.08e-01	2.08e-01	-0.22%	1.55e-01	2.78e-01
F-ratio	2.08e+00	2.04e+00	1.87%	1.58e+00	2.57e+00
Y-ratio	3.72e-01	3.73e-01	-0.19%	2.86e-01	4.78e-01

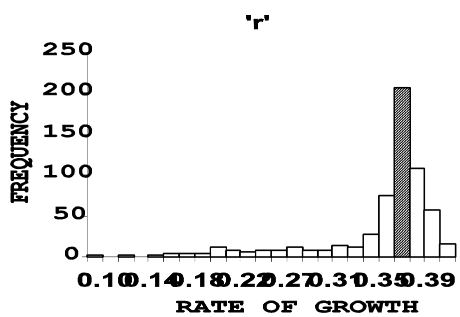

Figure 57. *Distribution of estimates of r from bootstrap analysis. Hashed = point estimate.*

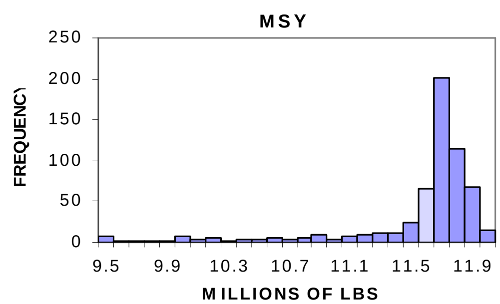

Figure 58. *Distribution of estimates of MSY bootstrap analysis. Hashed = point estimate.*

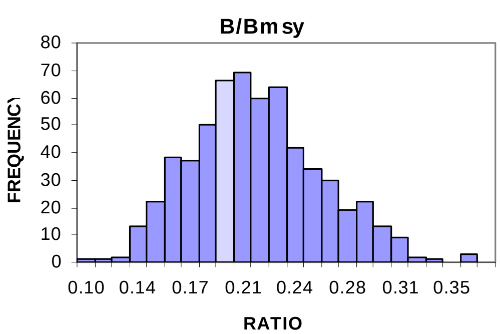

Figure 59. *Distribution of estimates of B-ratio from bootstrap analysis. Hashed = point estimate.*

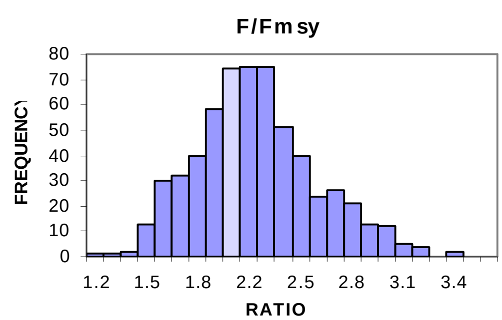

Figure 60. *Distribution of estimates of F-ratio from bootstrap analysis. Hashed = point estimate.*

Projections of the possible future condition of the stock were made utilizing the parameter output from the ASPIC model. Because fishing has continued beyond the time series of available data, and to make projections current with first year available for management (2000), all projections were made assuming that total fishing mortality in 1998 and 1999 was equal to the last year estimated (1997, $F_{BIOMASS} = 0.386$). Eighty percent confidence intervals were approximated by using the confidence intervals calculated for the bias corrected estimates of the parameters that describe the intrinsic rate of population growth (r) and carrying capacity of the stock (K). Based on Sustainable Fisheries Act (SFA) guidelines, if a stock has been determined to bo overfished then the next question is whether or not the stock can be rebuilt (B/Bmsy = 1.0) within a ten year time frame. Consequently, projections were carried out to the years 2000 to 2009.

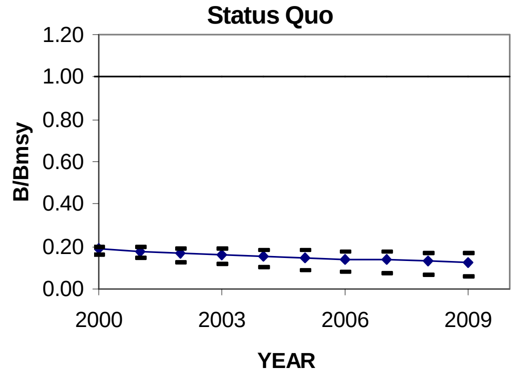

Figure 61. *Projected B/Bmsy with approximate 80% confidence intervals assuming status quo fishing mortality.*

The first projection assumed that the rate of fishing mortality would continue for ten years (from 2000 to 2009). In this projection, estimates of B/Bmsy decreased from an estimate of 0.20 in 1999 to approximately 0.13 in 2009 (Figure 61, Table 57). This is to say that if the fishery continues to operate at the current estimated rate then it is likely that catches could decline and the continued persistence of the stock could be jeopardized.

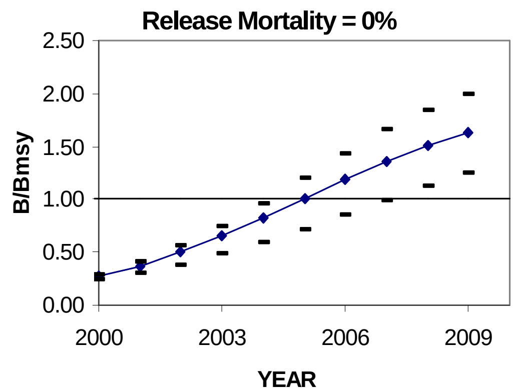

Figure 62. *Projected B/Bmsy with approximate 80% confidence intervals assuming status quo fishing mortality and no release mortality.*

The second projection assumed that all fishing and release mortality would completely cease for ten years. In this projection the stock was estimated to be rebuilt to a level of B/Bmsy = 1.0 in approximately 6 years (2005) (Figure 62, Table 57). However, this assumes that all fishers can totally avoid catching red grouper and that the stock experiences only natural mortality; an unlikely assumption.

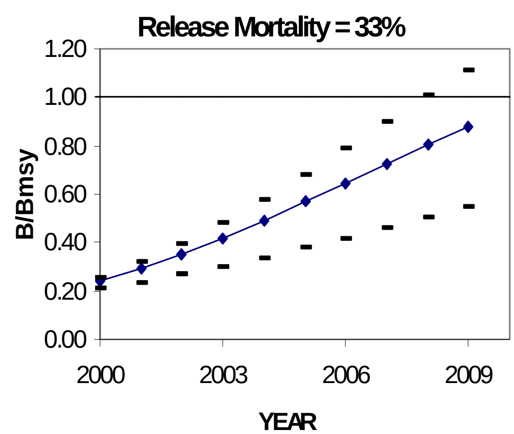

Figure 63. *Projected B/Bmsy with approximate 80% confidence intervals assuming status quo fishing mortality and 33% release mortality.*

The third projection attempts to approximate an average (across all fisheries) release mortality rate of 33 % by setting $F_{BIOMASS} = (0.386 * 0.33)$. Although the relation between $F_{BIOMASS}$ and catch is not exactly linear, we feel this was a satisfactory approximation to incorporate release mortality into the projection. In this projection the estimated mean B/Bmsy in ten years was 0.88, with the lower 80% confidence interval at 0.55 and the upper at 1.11 (Figure 63, Table 57).

POSSIBLE CURRENT CONDITION OF THE STOCK - II

The second approach to evaluate the current condition of the red grouper stock utilized the flexible forward computations assessment model ASAP (Age-Structured Assessment Program; Legault and Restrepo 1998). This model is based on separating fishing effects by different gears into year and age components, as in a separable virtual population analysis. However, the model allows for changes in selectivity and catchability over time and does not require gear specific catch at age for all years. This flexibility requires minimization of the objective function with many, hundreds or thousands, of parameters. The software package AD Model Builder uses automatic differentiation to compute the derivatives used in the minimization algorithm to machine precision and thus allow for these large number of parameters to be estimated. Constraints must be place on how much parameters can vary over time and the relative importance of different parts of the objective function must be input.

Conversion of Gear Specific Catch Distributions from Length to Age

The Goodyear (1997) probabilistic method was used to convert annual catch at length to catch at age. A recruitment index for red grouper was not available and so a constant recruitment pattern was assumed for the conversions. Since no cohort strength information was available it was decided to use a constant F (=M=0.2) at age by year matrix as well and not iterate the process such that the length to age conversion is essentially a probabilistic form of age slicing. This means that the catch at age cannot provide as much information to ASAP regarding cohort strengths compared to an ageing algorithm which incorporates auxiliary year class strength information. Three gears were chosen for the conversion: commercial longline, commercial other (consisting mainly of handline catches), and recreational. The recreational fishery converted length to age separately for the four modes (shore, charterboat, headboat, and private/rental), with the yearly overall values used when sample sizes were not sufficient (n<50) for any particular mode in a given year. The recreational catch and discards at age were then summed over all modes to produce the single gear "Recreational" for use in the assessment. The date of capture was available for all fish and a single birth date was assumed for all fish such that the fraction of a year for each fish could be computed when assigning the probabilities of each age for a given fish. Ages 1-30 were assigned and afterwards the catch for ages 20-30 was summed to produce a 20+ group.

One advantage of this approach over straight age-slicing is the ability to estimate total discards for the commercial fisheries. This is done by assuming selectivity is age based and the number of fish at age landed reflects the total number at age caught. The fraction of fish at each age below the minimum size for that year can then be used to estimate the total releases and a release mortality rate used to determine how many of those die. The selectivity of age 1 fish was set to 0.0 for periods when minimum size regulations were in place to prevent unrealistically large numbers of discards from being estimated. Large numbers of age 1 fish would be estimated for age 1 because the distribution of length at age was almost entirely below the minimum size. Thus, a single age 1 fish landed would be expanded to a very large number of discards.

This probabilistic length to age method also generates the age distribution of the recreational discards. The total recreational discards come directly from MRFSS estimates. The program only partitions the annual totals by age according to an input selectivity function.

Release mortality rates used to derive the discards for the three gear strata are: commercial longline 0.90, commercial other 0.33, and recreational 0.10. These values were derived by combining the catch at depth distributions by the three gears with the reported release mortality rates at depth in Burns and Wilson (1996).

Catches and discards at age by gear are given in Table 58.

Stock Assessment and Projections

Methods

A complete description of the program ASAP is not repeated here, rather the modifications to the program for use in the red grouper assessment are described. Modifications were made to both allow for more realism and to improve the estimation properties. Discards are now included in the program, selectivity is estimated for only some ages while the remainder are fixed, and the process of estimating recruits is modified. The inclusion of discards requires a matrix of the fraction of fish caught that are released by year and age. This matrix is then used to determine which fish caught by the total selectivity pattern will be landed and which released, with some of the released fish suffering release mortality.

The selectivity at age for each gear is estimated only for a range of ages, but these values can be either below or above 1.0. Thus, the selectivity over all ages can become dome shaped even if older ages are fixed at 1.0. The ages which are fixed can be set at any values, but the pattern will remain the same. Deviations in selectivity over time only occur for the estimated ages, but since the estimated ages can be either below or above 1.0, the total selectivity pattern can change from flat-topped to dome shaped or vice versa.

The method used to estimate annual recruitments now is based on deviations from an estimated stock-recruitment relationship (SRR). Previously, the recruitment values were estimated and then a SRR was fit to the observations. This forced a good match between the estimated SRR and the annual stock and recruitment values, but caused problems for the minimization routine because given stock-recruitment data could be fit equally well by quite different SRRs. The new approach has better estimation properties but forces dependence upon the estimated SRR.

Some additional penalties were added to the program to prevent unreasonable solutions. If a gear specific F multiplier was greater than 3.0 for any year, a penalty was added to the objective function of ?$(F\text{-}3.0)^2$, where lambda is a weight for the penalty. Similarly, if an estimated selectivity value was greater than 100, ?$(sel\text{-}100.0)^2$ was added to the objective function.

Projections are done by combining the F at age in the last year from all gears into a single one to form directed and discard selectivity patterns. These patterns are used to project different F multipliers, such as Fmsy or Fcurrent, or to solve for the F multiplier needed to generate a given amount of landings in weight, for example a 5 million pound catch. Thus, if allocations amongst the gears change from the final year, the projections will not be correct.

The AD Model Builder software package only allows a single function to be minimized during one run. The estimates of Fmsy or the F to achieve a given catch were solved through a bisection algorithm carried out 30 times which gives precision in F to approximately 2.0E-07. The Fmsy estimate was computed by calculating the spawning stock per recruit (SPR) and yield per recruit (YPR) under a given F. The stock recruitment relationship was rearranged such that spawning stock is a function of SPR to derive the spawning stock for that F value. Plugging this spawning stock back into the stock recruitment relationship generates an estimate of the expected recruitment in equilibrium at that F value. Multiplying this equilibrium recruitment by the yield per recruit gives an estimate of the yield in equilibrium for that F value. The F value is then changed until the equilibrium yield is maximized.

Red Grouper Application

Two sets of analyses were conducted for the red grouper fishery: a long time series (1940-1997) and a short time series (1986-1997). The short time series used only data where catch was known to be red grouper and could be aged for all gears while the long time series used all the available data.

Three separate gears were employed in both time series: commercial longline, commercial other and recreational. These gears had total catch in weight for every year and catch at age in numbers for years 1984-1997, commercial, and 1981-1997 recreational. If catch at age was not available for a given year, gear combination, it did not contribute to the objective function. Nine (eight) tuning indices were available for the long (short) time series, although the video and trap tuning indices were given less weight than the remaining indices. For the short time series, the estimates of uncertainty for each point within an index were used, with CV=1.0 assigned to the US historical time series. For the long time series, equal weighting of all points within indices was employed due to lack of fit when input variances were used. Natural mortality was constant over all years and ages at 0.2 for both time series.

Spawning stock was measured as the product of female gonad weight, proportion female at age, and the number of fish at age, summed over all ages. The 20+ group values for fecundity (female gonad weight times proportion female) and weight were calculated as a weighted average of the values for ages 20 to 30 with the weights set at the expected relative number of fish alive under a survivorship of e^{-2M}.

Selectivities for each gear were estimated for ages 1-10 and allowed to change each year from 1986-1996, or from 1981-1996 for the recreational gear in the long time series. The selectivities for ages 11-20+ were set to 1.0 for all gears in both time series, but because the selectivity for ages 1-10 could be greater than 1.0 the older age classes could be rescaled to lower values.

Preliminary analyses determined that the stock-recruitment relationship could not be well estimated for the short time series, most likely due to lack of regression range. To prevent this from occurring, the steepness parameter of the reparameterized Beverton and Holt stock-recruitment relationship was fixed at five different levels (0.4, 0.5, 0.6, 0.7, and 0.8) and only the virgin spawning stock size estimated. These fixed values for steepness were selected based on work done for the Pacific whiting 1998 stock assessment (Dorn et al. 1998) which estimated steepness for all Merluccid species in the Myers et al. (1995) database. The steepness parameter is bounded by 0.2, a straight line relationship between stock and recruitment, and 1.0, essentially constant recruitment. The long time series provided enough contrast in data to allow estimation of both steepness and the virgin spawning stock size.

Results and Discussion

Components of the likelihood functions for the six analyses (five values of steepness for the short time series and one long time series) are presented in Table 59. The large number of components in the objective function presented a problem for the minimization routine because conflicting pieces of information were present. The lambdas given in the table were derived based on considerations of the uncertainty associated with each component in the objective function. For log normally distributed errors about a given observation, the lambda (?) can be derived from the coefficient of variation (CV) as $?=1/\ln(CV^2+1)$. The CV's were chosen based on past experience and knowledge of the data associated with the particular component of the objective function. For example, total catch in weight by any gear is known much better than the total discards while selectivity is assumed to vary over time more than catchability.

Results were found to be sensitive to the choices for the ? values, with unrealistic results for many other choices examined, especially for the long time series, the short time series was more robust. The results were deemed unrealistic when a single cohort essentially accounted for the entire fishery. This occurred when either a cohort from the first year or from the early part of the time series (prior to 1950) was more than an order of magnitude larger than neighboring values. This unrealistically strong cohort would be fished out, or mined, causing the decline in catches from the early part of the time series. These results are most likely due to difficulty of estimating the initial population age structure when catch at age is not available for more than four generation times later. The classification of the recent stock status as overfished or undergoing overfishing was not impacted by the choice of lambda's however.

The tuning indices could not all be fit well due to different trends exhibited by indices that were measuring the same relative abundance. The compromises reached by the model seem reasonable (Figure 64). As seen in Table 59, the five values of steepness for the short time series produced quite similar fits and thus only one series of predicted values is shown for the short time series (steepness of 0.6). In general, the short time series model fit the indices better than the long time model.

The changes over time in selectivity were more pronounced for the short time series commercial gears than the long time series commercial gears, while the recreational gear showed larger changes in selectivity for the long time series than the short time series (Figure 65). In both time series, the two commercial gears have full selectivity on the oldest fish while the recreational sector has full selectivity on younger fish. Some of the younger fish selected by each are discarded as the figure shows the full selectivity patterns. The large percentage

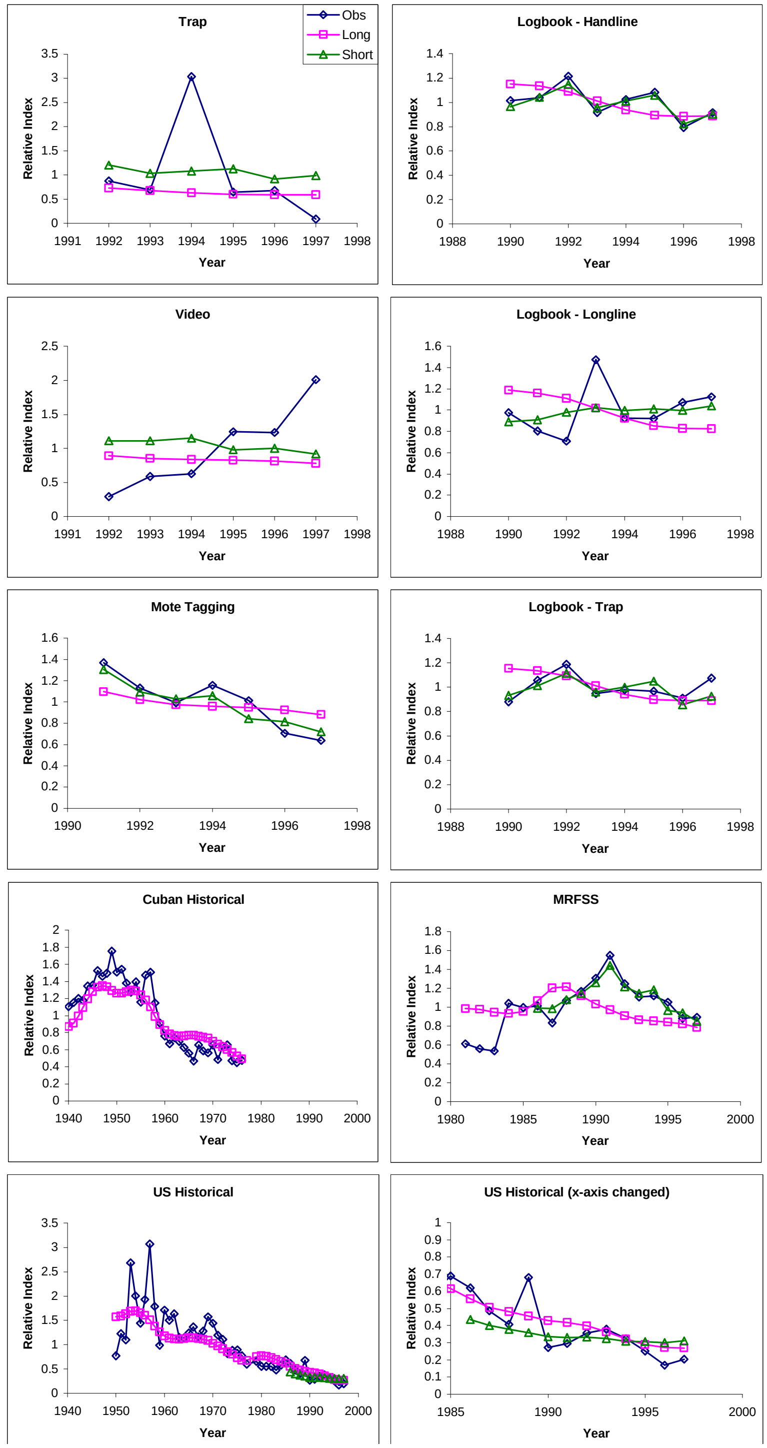

Figure 64. *Fits to the tuning indices from the long (1940-1997) and short (1986-1997) time series ASAP analyses.*

of releases by the recreational fishery causes the selectivity to be highest at young ages, but the low release mortality rate for this gear (10%) means that the fishing mortality rate will not be as high at these young ages as would be assumed just considering the selectivity pattern. The commercial selectivity patterns have a decrease in the age 1 selectivity when the minimum size regulations were enacted. This decrease in selectivity was fixed in the model to prevent unrealistically large numbers of age 1 fish being caught in the commercial fisheries and to match the process used in the length to age conversion.

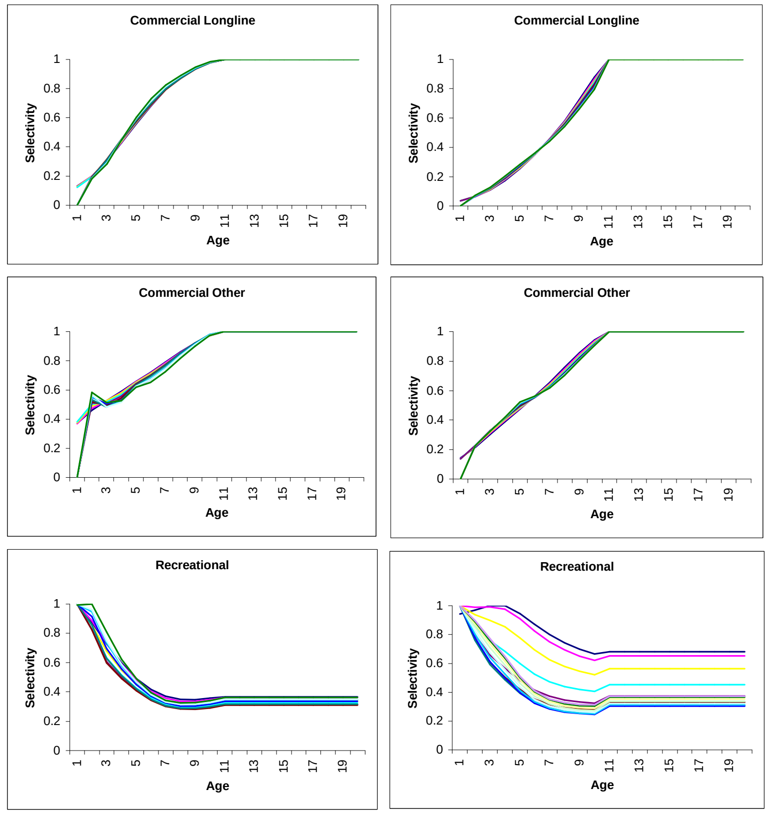

Figure 65. *Selectivity at age for the short time series (left panels) and long time series (right panels) ASAP analyses. Each line is a different year.*

Both the short and long time series ASAP analyses show an increase in total fishing mortality (due to both landings and dead discards) in the most recent years (Figure 66). Although the recreational fishery is fully selected at age 1 or 2 and has similar, but lower, catches to the commercial fisheries, the total F is not great for young ages due to the low release mortality rate (10%) for the recreational fishery. The commercial longline and commercial other fisheres have high release mortality rates, 90% and 33% respectively (Burns and Wilson 1996), but have low selectivity for young fish, which also causes total F for young ages to be low. Thus, the total F pattern is largely a function of the commercial fisheries in terms of the age structure. The increase in F for the recent years while catches have remained the same or decreased is attributed to a decreasing stock size (see below). The long time series estimated a larger total F in the recent period than do the short time series analyses and estimates a smaller population in recent years, which is a result of accounting for the large catches before the short times series began.

The six ASAP analyses estimated similar recruitment trends, with the short time series having more variability than the long time series (Figure 67). The five short time series recruitment estimates were nearly identical. The variability in the short time series recruitment estimates is a result of fits to the tuning indices because the catch at age was created with little information about cohort strength. The long time series has a smoother trend in estimated recruitment in the recent years because it is more influenced by the total catch estimates, which were much higher in the past, before the short time series began. The 1940 recruitment estimate is quite low relative to other estimates in the early part of the time series. This is due to difficulty in estimating the population age structure when the catch at age information is not available until much later and the fact that the first recruitment does not enter into the stock recruitment deviations in the objective function. In the long time series model fit, this small cohort was deemed more realistic than the exceedingly large cohorts that were estimated under different choices for the lambdas, but this cohort estimate did not affect the classification of current stock status as overfished or undergoing overfishing.

The short times series estimated a different pattern for the population abundance in the plus group relative to the long time series (Figure 68). The 1997 estimates from all six ASAP analyses are similar, but the level in the mid eighties and early nineties are quite different. Both time series show a large depletion of the plus group occurs rapidly, in about ten years, but differ as to when this depletion occurred. This rapid depletion is caused by the high selectivity estimated for older fish in the commercial fisheries.

However, this difference in plus group abundance estimates does not carry over into the estimates of spawning stock from the six ASAP estimates, which are all similar (Figure 69). The long time series spawning stock (total female gonad weight in the population) is lower than the short time series estimates, but follows the same pattern during the period 1986-1997. The contrast between the plus group abundance and spawning stock patterns is due to the plus group not being the largest portion of the spawning stock estimate, as it usually is, due to the protogynous hermaphrodism exhibited by this species. Since females become males at older ages, the relative abundance of the plus group does not contribute as much to the spawning stock estimates as it would in non sex changing species.

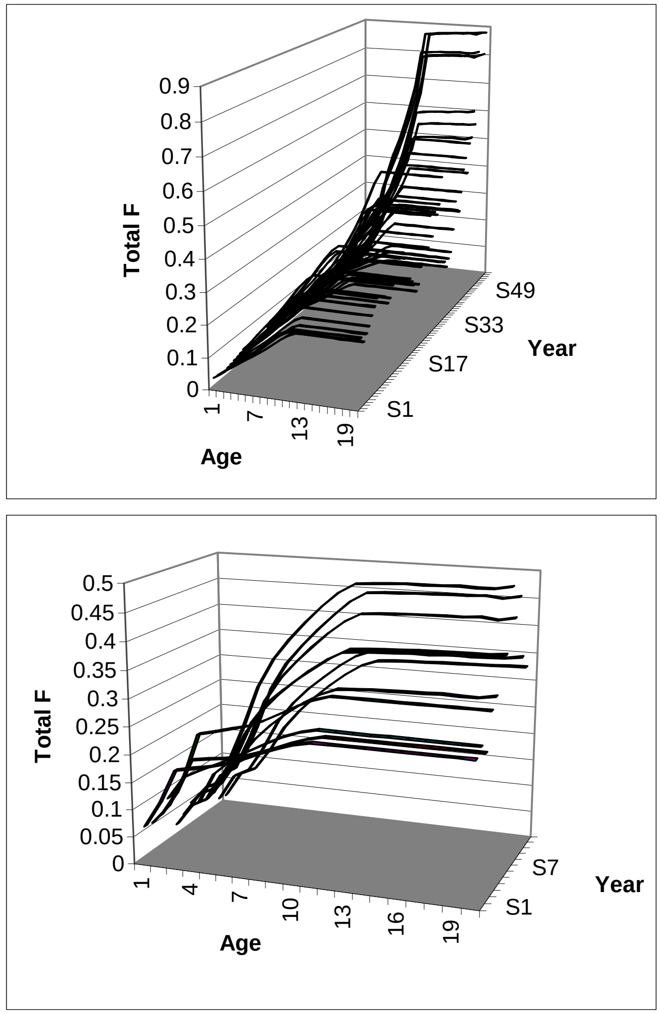

Figure 66. *Total fishing mortality rates by age and year from the long time series (top panel) and short time series with steepness fixed at 0.6 (bottom panel) ASAP analyses. Highest F values are the most recent ones.*

The fits of the stock recruitment relationships are all reasonable, although the short time series fits suffer from lack of regression range as discussed above (Figure 70). The recruitment estimates for the five short times series are all nearly identical, as seen in Figure 67; changes in scale that make them appear different in Figure 70. The five short time series fits cannot be distinguished statistically, but they have a major impact on calculations of maximum sustainable yield (see discussion below). This inability to estimate a stock recruitment relationship using data from only a few recent years is common to many stocks in the southeast U.S. The long time series, however, contains enough contrast in spawning stock and recruitment estimates to produce an estimable relationship. It should be noted

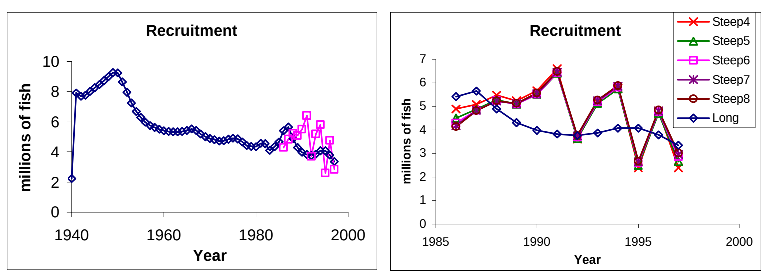

Figure 67. *Recruitment of age 1 fish in numbers for the six ASAP analyses.*

that the model is estimating deviations from the Beverton and Holt form and thus a reasonable fit is guaranteed because the stock recruitment points are not independent of the fit curve. Even given this caveat, the fit is quite strong, with the large positive residuals from the early part of the time series. Other stock recruitment relationships could be fit to these points with similar residual sum of squares and would create differences in the maximum sustainable yield estimates in the same way as the short time series. This feature should be examined in future assessments. The stock recruitment curves from the six ASAP analyses are plotted on the same scale in Figure 71 to demonstrate their similarities. Note the inverse relationship between steepness and virgin spawning stock size exhibited, which produces curves with similar fits in the range where the data is present.

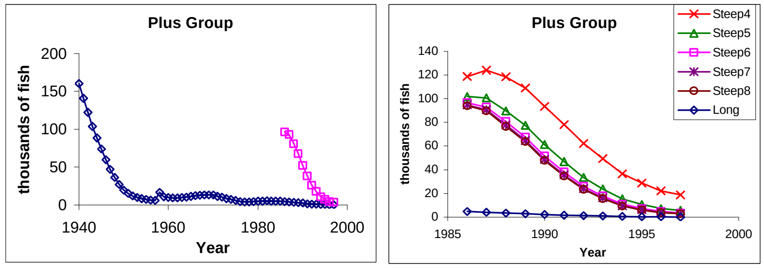

Figure 68*. Number of fish in the 20+ age category for the six ASAP analyses.*

The catchability coefficients did not change much for any of the short time series analyses (the changes cannot be seen graphically if the y-axis minimum is set to zero). Only the two historical time series from the long time series ASAP analysis produced changes in the catchability coefficients that can be seen graphically (Figure 72). Both indices have a decreasing trend in catchability, a counter-intuitive result. It should be noted that the Cuban Historical index had no catch at age information and the U.S. Historical index had catch at age information only for the years 1984-1997. This means that selectivity could notchange over all or most of the time series. Thus, these changes in catchability are a function of trying to fit the total catch in weight while not changing selectivity pattern and should not be interpreted as the fishers decreasing their ability to catch fish.

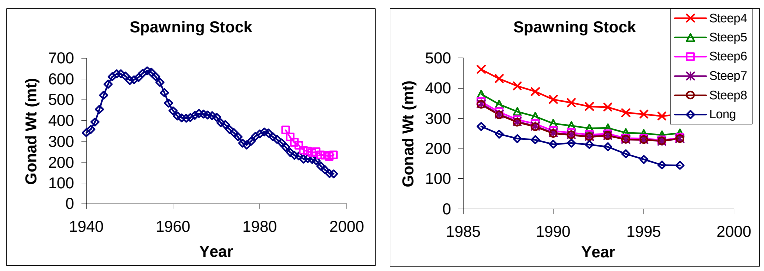

Figure 69*. Spawning stock, as measured by total female gonad weight in the population, for the six ASAP analyses.*

For the projections, a single selectivty pattern was formed for the total directed fishery and another single pattern for the total discarded dead fish. These patterns were formed by summing the directed and discard F at age from 1997 and rescaling by the maximum directed F at age. Thus, the discarded dead selectivity pattern is a function of the directed fishing mortality rate. The resulting selectivities were similar for all six ASAP analyses (Figure 73). The long time series had lower directed (harvest) selectivity for ages 4 through 10 relative to the short time series analyses and an associated lower discard selectivity pattern. The short time series with steepness fixed at 0.4 had slightly higher directed and discard selectivity patterns relative to the other short time series, which were nearly indistinguishable. These patterns all correspond with the total F shown in Figure 66 where old fish are fully selected and harvested while young fish are selected but discarded dead.

Current conditions relative to MSY parameters given these selectivity patterns are given in Table 60 for the six ASAP analyses. All analyses show the red grouper stock is both overfished (SS97/SSmsy<1.0-M) and undergoing overfishing (F97/Fmsy>1.0) and differ only in magnitude (Figure 74). As stated above, this result of the stock being overfished and undergoing overfishing was found for all choices of lambda values tried.

The MSY estimates range from 6.5 to 11.1 million pounds and are inversely related to the steepness parameter. This inverse relationship is caused by higher steepness values not allowing for as large of population sizes as lower steepness values, given that the curves pass through similar stock and recruitment values. The higher MSY values have lower Fmsy values with the exception of the long time series ASAP results. These F values are dependent upon the selectivity patterns however, and should not be compared unless the selectivity patterns are nearly identical. The Fmsy values can be compared to the 1997 F for each ASAP analysis because the same selectivity is used within an anlysis. The ratio F97/Fmsy ranges from 1.38 to 3.21 for the six ASAP analyses, which all correspond to values larger than the maximum fishing mortality threshold (MFMT) of Fmsy. Likewise, the ratio SS97/SSmsy ranges from 0.19 to 0.60 for the six ASAP analyses, which are all below a value of 1-M as recommended in the National Technical Guidelines document (Restrepo et al. 1998) as a default minimum stock size threshold (MSST). The inverse relationship between F97/Fmsy and SS97/SSmsy is expected, the higher the fishing mortality rate the lower the spawning stock. For the short time series analyses, the higher steepness causes the current conditions to be estimated as worse than the low steepness values, meaning lower spawning stock and higher F in 1997. These high steepness values are classified as closer to recovery however because future recruitment cannot get much larger than current levels as F is reduced to Fmsy, which itself is higher than the Fmsy for low steepness values. Thus, the form of the stock recruitment relationship determines to a large degree the MSY and related benchmarks used to classify the stock as overfished or undergoing overfishing. Using only the short time series would not allow for estimation of stock recruitment relationship and thus management would be more uncertain. Use of the long time series allows for better estimation of the stock recruitment relationship, although it should be considered in light of the difficulties encountered selecting lambdas and the poor quality of the catch at age information.

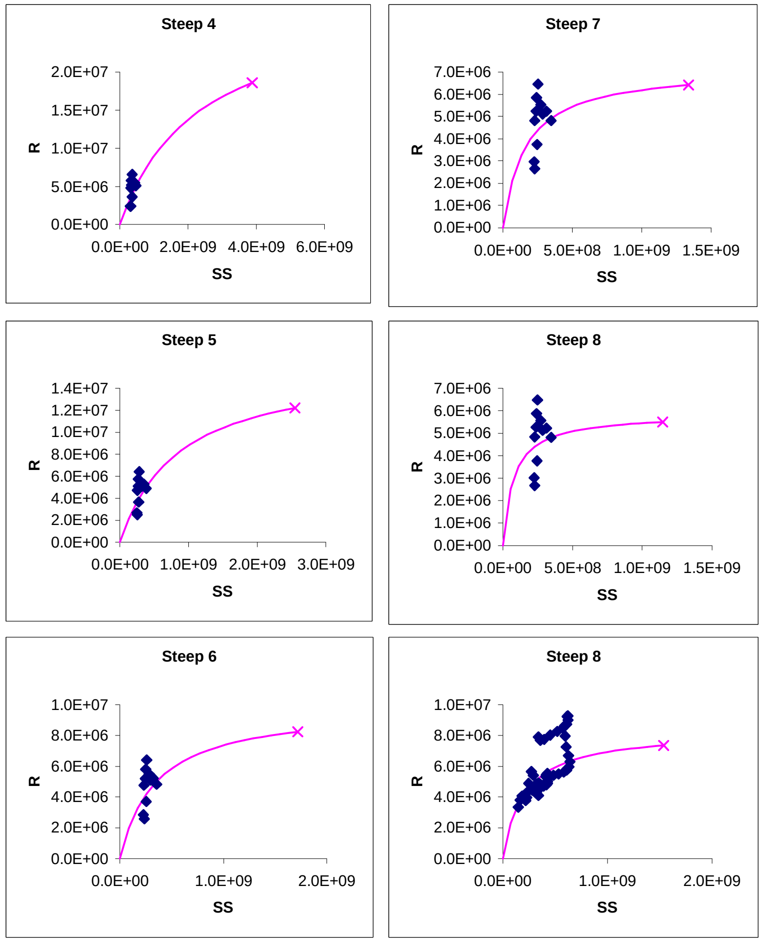

Figure 70. *Stock recruitment relationships for the six ASAP analyses. Filled diamonds denote the estimates of stock and recruitment, the solid lines denote the predicted Beverton and Holt curves, the curves end at the estimate of virgin spawning stock size.*

The ability to recover the stock from the overfished condition within ten years under no fishing was examined by setting F98 and F99 equal to F97 and then setting F to zero for years 2000 through 2009 for all six ASAP analyses. In some, but not all, cases the stock can recover from the overfished condition (SS/SSmsy>1.0) within ten years if no fishing mortality occurs (Figure 75). The short time series with steepness values of 0.4 and 0.5 recovered in the years 2022 and 2013, respectively. Given a generation time of nine years, the short time series with steepness values of 0.4 and 0.5 have recovery dates of 2031 and 2022, respectively, while the other ASAP analyses all have recovery dates of 2009 because they can recover within ten years. This discontinuity in recovery date based on whether or not the fishery can recover within ten years causes a discontinuity in the maximum constant catch that can be taken for recovery for the six ASAP analyses (Table 61). As steepness increases for the short time series from 0.4 to 0.5, the maximum constant catch for recovery increases from 2.20 to 3.20 million pounds. However, as steepness for the short time series continues to increase to 0.6, the maximum constant catch decreases to 1.65 million pound because the recovery date is now 10 years instead of the recovery time under F=0 plus one generation time. The maximum constant catch then continues to increase for the short time series as steepness increases to 0.7 and 0.8 while the recovery date remains the same. The long ASAP analysis demonstrates this discontinuity as well. Because it can recover within ten years, but just barely, the maximum constant catch must be set low to allow for recovery within the ten years. The extreme example of this discontinuity would be if the recovery under no fishing occured just one day before the ten years elapsed. The maximum constant catch would then be unmeasurable.

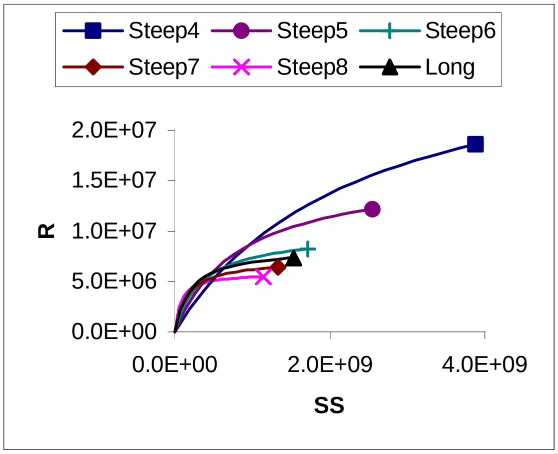

Figure 71. *Predicted stock recruitment curves from the six ASAP analyses. Curves end at the estimate of virgin spawning stock size.*

All of these recovery projections are deterministic. Inclusion of uncertainty would almost certainly allow for some probability of recovery taking longer than ten years under no fishing, with the possible exceptions of the short time series with steepness fixed at 0.7 or 0.8. Additionally, these projections of no fishing assume that no fish are caught and discarded dead. If in fact fishing continued, but landings were prohibited, the recovery times for all six ASAP analyses would be longer, in some cases probably enough to make recovery take more than ten years.

For these reasons, projections were conducted to either the recovery date (short time series with steepness of 0.4 or 0.5) or to the year 2020 (all other ASAP analyses). Two constant F strategies were considered, the 1997 F and Fmsy, and five constant catch strategies were considered, catches of 1, 2, 3, 4, and 5 million pounds. Yields from the constant F strategies and the ratio of SS/SSmsy for all strategies for the six ASAP analyses are given in Tables 62-67. In all ASAP analyses, the current F is too high for recovery to occur by 2020, even though catch can increase in some cases. Application of Fmsy results in an immediate decrease in landings, but the landings then increase over time, often to produce larger total landings than the F97 strategy by the year 2020. The constant catch strategies allow for recovery by the year 2020 at different values for the six ASAP analyses. It should be noted that a constant catch that allows recovery for one ASAP analysis could cause the stock to crash for a different ASAP analysis.

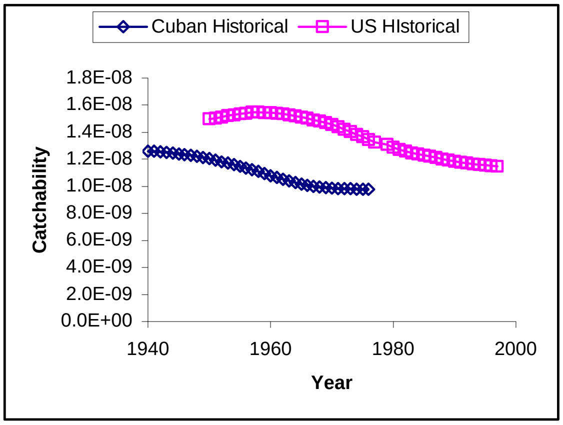

Figure 72. *Catchability over time for two indices from the long time series ASAP analyses. All other catchability changes over time were too small to detect graphicallly.*

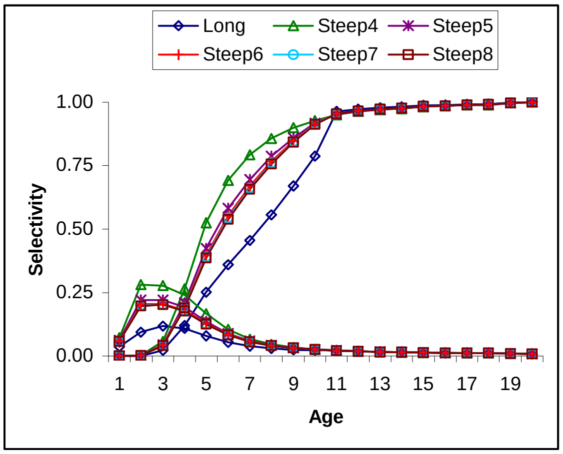

Figure 73. *Selectivity at age for projections of the six ASAP analyses. There are two curves for each analysis: the curve with a maximum around 0.2 is the discard selectivity while the curve with a maximum at 1.0 is the harvest selectivity.*

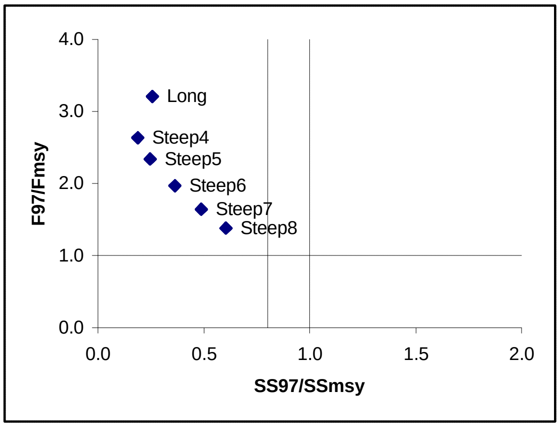

Figure 74. *Fishing mortality rate and spawning stock ratios of current to maximum sustainable yield values. Points above the horizontal line are undergoing overfishing, while points to the left of the left vertical line are overfished.*

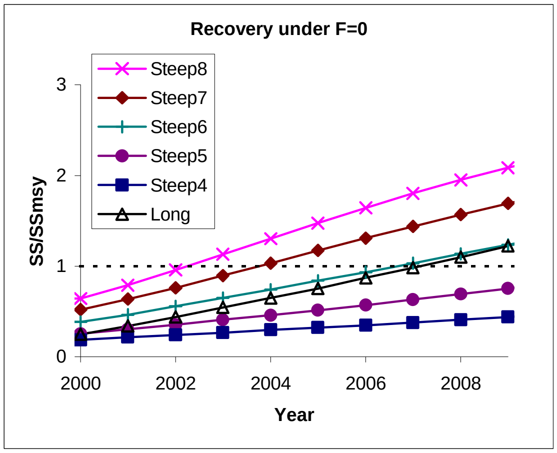

Figure 75. *Recovery under F=0 starting in the year 2000 for the six ASAP analyses.*

Estimates of age-based fishing mortality from the ASAP model relative to the previous assessment are shown in Figure 76. A distinct similarity exists between the previous estimates and those estimated in the current assessment. Both assessments estimated the average rate of fishing mortality for ages 5-11 to be approximately F = 0.30 for the years in which they overlap (1986-1992).

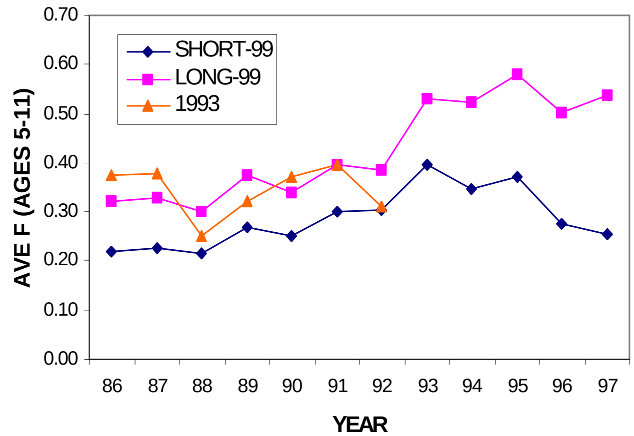

Figure 76. *Estimates of average fishing mortality for ages 5-11 from previous assessment (1993), the ASAP model using the short time series (short-99), and the long time series (long-99).*

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