

Assessment of Vermilion Snapper
Resources of the Northern South Atlantic Bight

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May 1984

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INTRODUCTION

Reef fish fisheries represent a valuable resource of the southeastern coast of the United States termed the South Atlantic Bight (SAB). Diverse and complex fish communities are distributed throughout this region. Approximately 112 fish species are known to be associated with these bottom communities (Grimes, 1976) and descriptions of the major exploited ones of these have been published (Huntsman 1976a, b, Huntsman, et al. 1978, Huntsman and Manooch 1978, Grimes, et al. 1982).

Despite a long history of exploitation of reef fish in the SAB, very little is known about the population parameters, structure, and dynamics of these fishes, due mainly to lack of sufficient and reliable fishery data. However, biological and fishery data have been collected by the National Marine Fisheries Service (NMFS) since 1973 which may be used to construct population models for selected species of the SAB.

A yield per recruit approach was used to examine the effect of size limits on snapper and grouper species in the SAB (SAFMC, 1983). As a result, of that analysis several minimum size regulations were promulgated. Specifically a four inch minimum mesh size for trawl fisheries was put into place. A major reason for this regulation was to maintain a minimum size of 30.5 cm (12 in) fork length for vermillion snapper, the species which comprises most of the snapper catch. However, trends in mortality and abundance of vermillion snapper were not addressed in those analyses.

The objective of this report is to quantitatively assess the status of the vermillion snapper resource in the northern South Atlantic Bight (NSAB) in relation to exploitation. The specific objectives are to:

- 1) determine the historical trend in fishing mortality rates;
- 2) determine trends in population abundance and year class strength (recruitment);
- 3) evaluate realized yield-per-recruit levels that have existed in the fishery in relation to the potential yield; and
- 4) examine the relationship between recruitment levels and recent adult female abundance.

DESCRIPTION OF THE FISHERY

Snapper and grouper fisheries have been important recreational and commercial fisheries in the northern South Atlantic Bight area from Cape Hatteras, North Carolina (34°N latitude) to Charleston, South Carolina (31°N latitude: Figure 1). Of these, vermillion snapper comprises the largest proportion of the catch.

Vermilion snapper are caught in three major fisheries: recreational (headboat) hook and line; commercial hook and line; and commercial trawl. The catches of all three of these fisheries are distributed from May until December. However, most of the catches occur in the summer from June through September. The commercial hook and line fishery of the NSAB operated at a low level prior to 1976 with landings peaking in the 1980's (Figure 2). Although there are no accurate and consistent measures of effort for this fishery, the overall number of vessels has increased since 1976.

The commercial trawl fishery for snappers and groupers in the NSAB is a fairly new fishery and is mainly concentrated in the South Carolina region. For the period of 1976 to 1978 there were only 1 or 2 trawlers operating out of South Carolina which caught a small number vermilion snapper (Figure 2). After 1979 the trawler fishing intensity increased rapidly with the increase in the number of trawlers and changes in the mesh size from larger mesh to smaller mesh (shrimp size). Subsequently, the trawler catch increased in 1979 and 1980.

The recreational fishery consists primarily of catches by anglers from headboats (Huntsman et al. 1976a, b). These catches were relatively high in the early 1970's, declining in the period of 1976 to 1979, and increasing again in the 1980's (Figure 2). The number of angler-days aboard headboats during the year has fluctuated but with no apparent trend since the middle 1970's (Table 1).

There are other participants in the recreational fishery including private vessels, charter boats, and recreational divers. Statistics on catch or effort for these sectors are not available. Charter boats fish mostly for pelagic species. The charter boat contribution to the bottom fishing catch is not substantial, approximately 10% of the total recreational catch (Manooch et al. 1981).

The relative contribution of these fisheries has changed over the years (Figure 3). From 1973 to 1976, recreational hook and line (headboat) catches represented approximately 90% of the total catch. After 1976, with the advent of commercial hook and line and trawl fishery development, the proportion is dominated by commercial catches. The net result has been large increases in catch in the 1980's (Figure 4).

DESCRIPTION OF AVAILABLE DATA

Recreational hook and line (headboat) length composition data were collected directly from the headboat catches from 1973 to 1982 in the northern South Atlantic Bight Region. A detailed description of the headboat sampling scheme is discussed by Huntsman (1976a). The number of fish sampled from the headboat catch varied from year to year, from a maximum of 1373 in 1975 to a minimum of 242 in 1980. Although the number of samples per year varied from year to year, length samples were distributed within a seasonal similarly to the catch distribution.

Nominal effort data in the recreational hook and line (headboat) fishery were available in number of angler days. The number of anglers aboard each vessel, the duration of the trip (half-day, one day, or more) and the location of fishing were reported by the captain of each headboat. The duration of the trips varied depending upon the location of fishing. In general one day trips comprise more than 70% of the total trip in the period of 1973 to 1976. This has declined to about 50% in recent years, with more half-day trips being taken. The average number of anglers per trip has not varied greatly with annual means of approximately 30 to 36 per trip.

The commercial hook and line size frequency data from the South Carolina region were provided by the South Carolina Wildlife and Marine Resources Department (Ulrich, pers. comm.). For the period of 1976 to 1982 the length composition data were reported in 5 (cm) total length intervals. The number of length measurements varied from year to year with an average of 1,259 fish per year.

The commercial trawl fishery length composition data in the South Carolina region were available in varying degrees of completeness. Data were provided for years 1977, 1979, 1980 and 1983 by South Carolina Wildlife and Marine Resources Department (Low and Ulrich, 1982 and Ulrich, pers. comm.). In general the number of length measurements from the trawl fishery was low (an average of 200 fish per year). The sampling procedure was not consistent throughout the fishing season for the early years.

STOCK IDENTIFICATION

Vermilion snapper are distributed from Cape Hatteras and Bermuda south the southeastern Brazil, through the West Indies and the Gulf of Mexico (Grimes, 1976). However, it is unclear what (if any) stock structures exist within these areas. Although it is known that factors such as temperature and bottom type regulate the distribution of vermillion snapper, there are no criteria for clear distinction to separate unit stocks. There is little information on genetic characteristics and limited knowledge of migratory patterns. The few studies of the movement of both juvenile and adult fish which have been undertaken have indicated that vermillion snapper of these ages do not migrate long distances. Movement appears to be in the space/time scale of diurnal migration and patch movement (Moe, 1966 and Huntsman, 1980).

The location of the vermillion snapper catch in the South Atlantic Bight indicated that there are major concentrations in the north (north of 32 degrees N lat) and in the south (south of 30 degrees N lat), correlated with regions of live bottom concentrations. Age and size composition data also showed difference between mean size in the north and south regions of the SAB. These differences may be caused by different exploitation strategies in the two regions due to topographic characteristics or the proximity of the shelf edge. However, the hypotheses that these differences have been accentuated by a lack of mixing between the areas cannot be rejected.

The distribution of vermilion snapper recruitment products are not well understood. Larval vermilion snapper like other reef fishes may be regionally affected by oceanographic features such as meanders and eddies of the Gulf Stream. The frequency and magnitude of these are different in the northern area (north of Charleston) and southern region of the SAB (Lee and Atkinson, 1983 and Bane, et al. 1979).

Based upon the above evidence (which is far from conclusive), the working hypothesis used in this analysis is that the vermilion snapper in the northern South Atlantic Bight represent a unit stock which is not significantly affected by net migration of juveniles or adults or by the influx of pre-recruits from outside this region.

Larval influx from outside the NSAB will not affect the estimates of recruitment using virtual population analysis. However, the interpretation of the relationships of recruitment and spawning stock abundance is affected. Migration after recruitment will affect the virtual population analysis. Therefore, this stock assumption can introduce bias into the analyses if in fact there is significant net migration between the southern region of the SAB to the northern area or if recruitment is affected by parent stocks other than in the NSAB.

ASSESSMENT ANALYSES

We evaluated the status of the NSAB vermilion snapper resource by performing a virtual population assessment. Using the results of that analysis we examined the yield per recruit implications and recent recruitment changes. The virtual population assessment (VPA) technique requires an estimate of 1) catch at age for the time period of concern, 2) an estimate of the natural mortality rate (M), and 3) an estimate of the fishing mortality rate (F) of the oldest age in a cohort (referred to as the terminal F estimate). This latter requirement, in turn means that we must have reliable indices of catch per effective effort to calibrate the terminal F estimates. Therefore, the description that follows will present the preliminary analyses that we performed to estimate catch at age, M and effective effort. Then the estimation procedure for the terminal F will be presented, followed by the results of the VPA.

Catch at Age

Generally, catch at age was estimated by converting length frequencies samples to age frequencies using Grimes' (1978) von Bertalanffy growth equation fitted to 1973-75 vermilion snapper length data from the NSAB. This equation was:

$$L_t = 626.5295 (1 - \exp(-0.198167(t - 0.1227))),$$

where t is the age in years and L_t is the total length in mm. The age frequency samples were then matched against the appropriate catches to get

catch at age. Details appropriate to the specific samples are discussed below.

Recreational Hook and Line

The recreational hook and line size data collected from the headboat fishery consisted of individual fish measured in total length. Each one of these individual fish were converted to an age using the transformed growth equation. The relative frequency of these ages categorized into one year increments were then applied to the recreational catch data (also in numbers) to get catch at age (Table 2).

Commercial Hook and Line

The catch at age estimation for the commercial hook and line fisheries required several additional conversions. First, commercial catches are recorded in weight and not in numbers. Therefore, they had to be converted to number. South Carolina catch at age was estimated using the South Carolina Wildlife and Marine Resources Department size frequency data (Ulrich, pers. comm.). The length frequency categories in 5 cm intervals (Low and Ulrich, 1982) were converted to weight intervals using the length-weight relationship of Grimes (1978). The weight frequency was applied to the total catch to get catch in numbers per weight interval. Then the weight intervals were converted back to length intervals. Finally, ages were estimated assuming that all fish in a length interval were of length equal to the interval midpoint. The 1976-82 length frequency data were matched with the appropriate year (Table 3).

The North Carolina commercial hook and line catch at age was estimated using North Carolina recreational hook and line size frequency samples following the same procedures given in the previous paragraph (Table 4).

Commercial Trawl

The only length frequency samples available from commercial trawls were those of the South Carolina Wildlife and Marine Resources Department (Ulrich, pers. comm.) for 1977, 1979-80 (pooled) and 1983. The length frequencies were converted to catch at age using the same procedures as used for the commercial hook and line. The 1977 length frequencies were used for the 1976, 1977 and 1978 catches. Trawl catches were low in these years, so errors introduced by using inappropriate size samples are likely to be small in the overall catch at age table.

The pooled 1979-80 frequency was applied to the 1979, 1980 and 1981 catches. Whereas, the 1983 size frequency was applied to the 1982 catches. In any case, the size frequency distributions were very similar in the two samples (1979-80 versus 1983) indicating little change in the intervening years. The resulting catch at age for the commercial trawl fishery is given in Table 5. The overall catch at age is given in Table 6.

There may be several sources of serious bias in the catch at age data which could affect the results of the virtual population assessment. First, unreported catches from commercial hook and line, commercial trawl, private recreational vessels, charter boats, traps, diving and other fishing activities are occurring to some unknown degree. The magnitude of all of these sources of unrecorded catch may be significant.

Also, transformation of length to age using a growth equation is known to cause some bias in the aging due to the variation of length given age (Bartoo and Parker, 1982). The degree of bias is related to the overlap in length at age and this will change with weak or strong year classes. Witzig and Huntsman (1984) used a stochastic method suggested by Bartoo and Parker for South Atlantic Bight snappers which produces some differences in headboat catch at age than what is estimated here. However, it does not appear that these differences are significant to the analysis.

Finally, the catch at size data have been aggregated by year. Therefore, the time (age) at length cannot be exactly determined. Additionally, vermilion snapper are known to have a protracted spawning period; thus, the birth date cannot be estimated precisely. However, most of the catches, as well as most of the spawning, occur in the summer months. Therefore, the bias effect caused by the aggregation of the data and protracted spawning may not be as large as for more diffuse fisheries. Future data collection efforts should address these sources of bias in the catch age estimates.

Natural Mortality

Various estimates of M have been made for the lutjanidae family (Table 7) ranging from 0.18 to 0.37. We examined these and also employed Pauly's (1980) regression model relating M to the von Bertalanffy growth parameters K and L_{∞} and to the ambient temperature. The K and L_{∞} used were from Grimes' estimates (1976), discussed previously. Temperature was the mean annual temperature (at 75 m depth) off of North and South Carolina over the last 50 years (21°C). The resulting M was 0.23. This was consistent with previous estimates and, thus, we used this value in the virtual population assessments.

Effective Effort

The only detailed effort data available over the recent history of the fishery is that from the recreational headboats (Huntsman et al. 1978). In these data, records are kept for individual headboat trips, the number of anglers on the trip and the catch (numbers) by species. The headboat catch consists primarily of fish three years old and older. Therefore, it was assumed that headboat catch per unit effort was an index of the abundance of fish three years old and older.

Bannerot and Austin (1982) showed that bias might occur when using recreational headboat data to index abundance due to skewness in the catch per unit effort distribution. They suggested several adjustments which

tended to reduce this bias. Powers and Bannerot (in preparation) examined the bias by Monte Carlo simulation and evaluated the adjustments. The most appropriate adjustment (supported by Bannerot and Austin's empirical results) was to use the logarithm of the relative frequency of zero catch in the catch per unit effort distribution. That adjustment was used here.

Relative frequency of zero catches per trip was calculated from the frequency of one day trips in a year and the frequency of these trips in which vermilion snapper were caught (Table 1).

Total standardized effort during year t (f_t) was

$$f_t = C_t / I_t$$

commercial T.E. Harvest + Rec. in private @ FLA MS
spot harvest

NOTE- Effort calculation based on C_t must be different for each target sp.

where C_t is the total catch of fish three years old and older and I_t is the abundance index derived from the headboat catch per unit effort (Table 1).

Terminal F Estimation

An iterative fitting procedure was used to estimate the terminal F (fishing mortality rate during the oldest available age of a year-class) for the virtual population assessment. Essentially, the terminal F for cohorts in 1982 was chosen such that the F 's generated by the VPA for ages 3 through 7 in 1977-81 provided the best match with the effective effort estimated in the previous section.

Specifically, it was assumed that the terminal F for each cohort i which was three years old or older in 1982 (F_{i82}) had a constant fishing mortality rate, F_T . Then the recursive catch equations were applied.

$$(1) N_{it} = C_{it} (F_T + M) / (F_T (1 - \exp(-F_T - M)))$$

$$(2) C_{it} = N_{it+1} (\exp(F_T + M) - 1) / (F_T + M)$$

$$(3) N_{it} = N_{it+1} \exp(F_T + M)$$

where N_{it} is the number of fish of cohort i at the beginning of year t , C_{it} is the catch of that cohort during year t and M is the natural mortality rate. The catch equation was solved numerically for the fishing mortality rate using a direct search method.

The F for age 12 in 1973-81 was obtained by averaging the VPA fishing mortality rates of ages 3 through 11 for each year starting in 1981 and sequentially working backward in time 1973.

The fitting procedure was limited to the recent year's effort data (1977-81) because it is these years' fishing mortality rates we want to estimate most reliably. Therefore, it is assumed that subtle changes in catchability that might have occurred with the development of the commercial fishery would have taken place before 1977.

The fitting procedure was limited also, to the cohorts in 1982 for which the terminal F was being estimated. We want an equal number of ages per year for the 1977-81 years so that all years were weighted equally. Given these two constraints, the largest number of data points for the fitting procedure was obtained by using ages three through seven.

An exhaustive search over F_T was done (to an accuracy of 0.01) such that the criteria RES^2 was minimized:

$$RES^2 = \sum_{t=1977}^{1981} \sum_{j=\text{age } 3}^{\text{age } 7} (\hat{f}_{it} - f_t)^2 \quad (1)$$

where f_t is the observed effort on three year olds and older in year t , and $\hat{f}_{it}$ is the estimated effort on age " i ". The estimate $\hat{f}_{it}$ was found by the regression model

$$F_{it} = \hat{q}_t f_t \quad (2)$$

where the F_{it} are the age specific F's from the VPA. Thus,

$$\hat{f}_{it} = F_{it}/q_t. \quad (3)$$

Finally, the terminal F of fish one and two years old in 1982 was estimated by assuming that the 1982 F values were equal to the age specific averages in 1979-81. Using this assumption means that 1982 and 1981 recruitment estimates are very imprecise. Although on average we expect fishing mortality to be close to these estimates, we do not really know if 1982 was near to the average or not. Therefore much confidence cannot be put in the estimates of recruitment of one year olds in these years.

The terminal F chosen by the minimization procedure for ages 3-12 in 1982 was 0.40. The response surface (Table 8) was well-behaved, albeit relatively flat in the region of the minimum. However, terminal F's ranging from 0.35 to 0.5 did not qualitatively change the conclusions of this study. The minimization criteria (1) implies that the F versus f relationship (equation (2)) with the best R^2 is being chosen. A plot of that relationship is given in Figure 5.

Virtual Population Assessment

The detailed VPA results are presented in Table 9 (age specific fishing mortality rates), Table 10 (age specific abundance), Figure 6 (stock abundance of 2 to 12 years olds), and Figure 7 (recruitment of one year olds).

Fishing mortality rates were low from 1973 to 1978, then increasing through 1982. Stock abundance reached a low in the middle 1970's, peaking in 1980, with some decline, thereafter. The 1982 stock size of fish 2 years old and older was approximately 40-50 percent higher than in 1977 and 15-20 percent higher than in 1973.

Recruitment reached a peak in the late 1970's and then declined. However, 1980-82 levels were still higher than those of 1973-75 when fishing effort was low. Note again that 1981-82 recruitment estimates are very imprecise.

Yield Per Recruit

Realized yield per recruit was examined by two methods. Both required that Grimes' (1978) growth and length-weight equations be used to calculate yield in weight. First the yield per recruit by cohort was computed and compared to the yield per recruit with present (1982) fishing patterns. It was also compared to the potential yield with the present (1982) fishing mortality rate, but with age of first capture increased (Table 11).

The fishing mortality rates were low in the early to middle 1970's, therefore the cohorts recruiting in 1973 through 1977 were able to build fairly strong yields per recruit (YPR). These cohorts (which are still present in the fishery) have achieved YPR's which are close to that which will be achieved with present fishing practices (Table 11). However, the YPR's are considerably less than the potential if the age of first capture were increased (Table 11). At the present fishing mortality rate of $F = 0.4$, YPR would be increased by approximately 30 percent by increasing the age of first capture from 2 years to four years old.

The second method used age-specific average fishing mortality rates (1979-81 average) to examine YPR (Table 12). With these mortality rates, the equilibrium YPR is 185 g. Substantial gains in YPR would be achieved if the fishing mortality rate on one, two and three year olds were reduced to zero. The increase would be approximately 20 percent. Therefore, delaying capture of young fish would improve the overall yield of fishery. However, since the commercial fishery catches most of the fish less than three years old, they would not realize these overall gains.

Stock and Recruitment

Female stock abundance was estimated using the VPA results and Grimes' (1976) study on the reproductive biology of the vermilion snapper. He found that the sex ratio of vermilion snapper varied significantly from 1:1. From 874 individuals sampled, 63% were females and 37% were males. The sex ratio was higher in older ages (after 8 years) with virtually no males in the population (Figure 8). Grimes also indicated that female vermilion snapper mature at approximately the end of the fourth year of life. These data were used to estimate abundance of the mature female stock. Sex

ratio changes with size occur because: (1) there is differential mortality between sexes; (2) there is differential growth, (3) sex reversal occurs, or (4) the sexes separate in space or time such that sampling is biased. Grimes' (1978) results reject the hypothesis of sex-differential growth. Also, there is no evidence of sex reversal in vermilion snappers, the other two scenarios cannot be rejected. In any case assuming a 1:1 sex ratio does not change the trend in adult female abundance estimate from the VPA. Despite having information available on age-specific fecundity, it is not known how many times and when vermilion snapper spawn. Therefore, egg biomass could not be estimated as a spawning stock index.

The number of mature females declined somewhat since 1973 (Figure 9). As the future population becomes dominated by younger age classes (1978-81 recruitment: Figure 7) and the older age classes diminish in size, then the number of mature females will continue to decrease. If mortality rates are maintained at high levels, survival of fish to the mature female ages will be reduced. The spawning stock will increase with the maturation of the strong 1978-80 year classes; however, the survival to maturation is not large, the spawning stock abundance subsequently decline again.

No demonstrable relationship between spawning stock size and recruitment is apparent (Figure 10), other than that expected as a result of the developing fishery. With the advent of the fishery, stock size and the number of mature females declined. As a consequence, recruitment increased and became more variable. However, it is likely that the mature female stock size will continue to decline somewhat in the near future. Therefore, mature females and recruitment levels should be closely monitored.

CONCLUSION

The vermilion snapper resource of the northern South Atlantic Bight was assessed using virtual population analysis techniques. Results showed that catches have gone up in recent years after being fairly stable through 1979. Stock abundance declined slightly in the middle 1970's, rose in the late 1970's with several strong year-classes and has declined slightly in 1981 and 1982.

The distribution and intensity of fishing effort by age indicates that there is potential for increasing the yield per recruit. This potential of 20-30 percent may be achieved by reducing effort on one to three year olds. Some decline in the mature female stock have occurred, and because of present age structure of the population, further declines will likely occur. Therefore, any reduction in recruitment caused by low spawning stocks is likely to be rapid. Therefore, both females and recruitment abundance should be monitored closely.

Recent recruitment levels have been relatively high, but highly variable. Both these characteristics are expected compensations of a population stressed by a fishery. Further research should be directed at defining the causes of the variation in recruitment and in developing models of prediction based upon these investigations.

Finally, further data collection is needed to improve these assessments. First landings, catches and size samples should be obtained from each fishery disaggregated by month. This will allow ageing to be more precise. Secondly, detailed effort data from all fisheries should be collected and evaluated for its potential for indexing stock abundance for individual age groups.

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Table 1. Nominal headboat effort (angler days) and standardized total effort on vermilion snapper ages 3.12 in the northern South Atlantic Bight.

	No. Headboat angler days (x 10000)	No. Headboat Trips (one day trips)	No. Headboat Trips in which no vermilion snapper were caught	-ln (relative frequency of zero catch trips)	Total Catch in numbers (ages 3-12)	Total Standardized Angler Trips (x10000)
1973	5.95	737	166	1.4906	86963	5.83
1974	8.56	1084	214	1.6224	103356	6.37
1975	9.18	1376	425	1.1748	145085	12.35
1976	9.26	1473	580	0.9320	115806	12.43
1977	9.26	1451	949	0.4246	62866	14.81
1978	9.35	1648	1029	0.4246	96720	20.54
1979	8.34	1176	787	0.4016	124631	31.03
1980	8.80	1143	651	0.5629	303279	53.88
1981	7.81	786	461	0.5336	361236	67.70

Table 2. Catch at age (numbers of fish) of vermilion snapper by recreational hook and line (headboats) in the northern South Atlantic Bight Region, 1973-1982.

Age	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
1	365	122	173	-	-	366	816	-	-	100
2	2288	11430	18019	5245	1309	1008	454	2053	912	1483
3	14419	39112	43739	21558	4000	5200	2665	5798	8517	48608
4	19160	20500	31223	16478	7444	12179	2164	9165	16270	52368
5	11221	12206	20190	13681	4498	7503	1027	4107	11374	26414
6	11007	9663	15117	7370	3104	2564	1854	5766	8175	14696
7	7035	4524	6607	4789	3214	1993	2716	4474	7459	8906
8	6266	3715	6078	2971	2483	2923	3123	5346	6578	6495
9	4440	3093	2761	1491	2018	2013	2317	3064	1449	4754
10	3342	1788	4880	1440	1453	2802	1529	3061	2079	2103
11	2973	1309	3119	1454	1019	1647	855	1499	270	2928
12	715	1003	3028	1867	749	1517	559	948	1582	462

Table 3. Catch at age (numbers of fish) of vermilion snapper by the commercial hook and line fishery in the South Carolina Region, 1973-1982.

Age	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
1	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-
3	217	165	104	1115	430	2399	1667	5164	8164	14563
4	1193	905	575	7248	3323	10795	5370	15837	36368	45534
5	2007	1522	967	8921	5372	9595	4259	8607	20782	30394
6	868	658	418	3345	3438	4398	1481	1377	4453	11604
7	488	370	235	1951	2149	2799	926	689	1484	5765
8	271	205	131	1951	1934	2399	741	344	742	4351
9	271	246	131	1394	1719	1599	1111	344	742	869
10	108	82	52	1394	1719	1599	1111	344	742	857
11	54	41	26	557	1074	1599	926	344	742	851
12	54	41	26	279	645	2399	1296	1377	742	1724

Table 4. Catch at age (numbers of fish) of vermilion snapper by the commercial hook and line fishery in the North Carolina region, 1973-1982.

Age	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
1	-	-	-	-	-	-	-	-	-	-
2	19	217	732	70	46	156	166	-	1573	257
3	160	772	1572	236	19	233	1318	664	1640	2271
4	208	535	1368	264	128	179	1874	2738	6678	13268
5	101	316	886	276	56	327	1234	6733	13781	20643
6	104	223	665	150	243	1108	5846	11054	12655	15406
7	74	95	280	90	529	1278	5621	8687	11538	10491
8	71	86	276	77	547	2659	8787	11483	9875	6785
9	51	74	185	57	378	2494	6064	7141	2179	7106
10	42	43	169	51	397	2921	5207	8312	2755	1841
11	27	32	152	54	208	1972	1653	3962	550	3097
12	16	32	170	41	113	1374	2294	1578	1658	624

Table 5. Catch at age (numbers of fish) of vermilion snapper by the commercial trawl fishery in the South Carolina region, 1976-1982.

	1976	1977	1978	1979	1980	1981	1982
1	-	-	-	8524	29598	28863	15114
2	5271	3424	901	48819	169518	165306	162930
3	8472	5503	1448	30943	107446	104777	63149
4	2048	1330	350	6500	22571	22011	50019
5	1757	1141	300	3089	10726	10459	26346
6	761	494	130	2406	8355	8147	2646
7	169	95	25	1369	4754	4636	2610
8	-	-	-	1024	3557	3468	54
9	-	-	-	678	2354	2295	-
10	-	-	-	378	1173	1144	-
11	-	-	-	332	1151	1123	-
12	-	-	-	341	1185	1155	-

Table 6. Total catch at age (numbers of fish) for vermillion snapper in the northern South Atlantic Bight.

Age	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
1	365	122	173	100	100	366	9340	29598	28863	15114
2	2307	11647	18751	10686	4579	2065	49439	171571	167791	164670
3	14796	40049	45415	31381	9952	9280	36593	119072	123098	128591
4	20561	21940	33166	26036	12125	23503	15881	50311	81327	161189
5	13329	14044	22043	24635	11067	17725	9609	30173	56396	103797
6	11979	10544	16200	11626	7279	8070	11587	26552	33430	44352
7	7597	4989	7122	6999	5987	6200	10632	18604	25117	27772
8	6608	4006	6485	4999	4964	8006	13675	20730	20663	17685
9	4762	3413	3032	2942	4115	6106	10170	12903	6665	12770
10	3492	1913	5101	2936	3569	7322	8225	12890	6720	4801
11	3054	1382	3297	2065	2301	5218	3796	6956	2685	6876
12	785	1076	3224	2187	1507	5290	4490	5088	5135	2810

Table 7. Estimated rates instantaneous natural mortality (M) of selected Lutjanidae species estimated by various authors for different regions.

	Species/ Region	M
Nelson and Manooch (1982)	Red Snapper/ Gulf of Mexico and southeast region	0.18 - 0.20
Huntsman (1982)	* Vermilion Snapper/ Carolinas	0.25 - 0.37
	Red Snapper/ Carolinas	0.30
	Lane Snapper/ Carolinas	0.20
	Yellowtail Snapper/ Carolinas	0.20
Morgan (1983)	Snapper/ Persian Gulf	0.3

Table 8. Sum of squared residuals of observed and predicted effort (RES^2) for alternative values of the terminal fishing mortality rate of fish three years old and older in 1982 (F_T). Effort is measured in 10^5 standard angler trips.

F_T	RES^2	F_T	RES^2
0.10	40.5808	0.41	25.6513
0.20	30.0483	0.42	25.6542
0.30	26.5182	0.43	25.6639
0.35	25.8763	0.44	25.6789
0.36	25.7998	0.45	25.7050
0.37	25.7420	0.50	25.9873
0.38	25.6902	0.60	26.8101
0.39	25.6352	0.70	27.8800
0.40 <u>1/</u>	25.6311 <u>1/</u>	0.80	29.0531
		0.90	30.1984

1/ Minimum

Table 9. Instantaneous fishing mortality rate at age estimated by VPA for vermillion snapper in the northern South Atlantic Bight, 1973 -1982 (assumes $M = 0.23$).

Age	73	74	75	76	77	78	79	80	81	82
1	.0007	.0002	.0003	.0002	.0001	.0003	.0068	.0353	.0219	.02
2	.0045	.0302	.0403	.0248	.0103	.0036	.0534	.1700	.2945	.17
3	.0460	.1030	.1626	.0905	.0299	.0266	.0838	.1813	.1830	.40
4	.0672	.0920	.1199	.1364	.0472	.0943	.0598	.1636	.1874	.40
5	.0682	.0616	.1298	.1268	.0815	.0931	.0522	.1592	.2880	.40
6	.0596	.0729	.0968	.0966	.0517	.0811	.0837	.2058	.2746	.40
7	.0360	.0327	.0664	.0569	.0680	.0585	.1508	.1937	.3164	.40
8	.0720	.0246	.0559	.0626	.0537	.1259	.1826	.5052	.3536	.40
9	.0685	.0489	.0240	.0334	.0693	.0892	.2410	.2712	.3106	.40
11	.1157	.0298	.0840	.0556	.0306	.1060	.1332	.2224	.2240	.40
12	.0656	.0559	.0933	.0765	.0539	.0944	.1288	.2742	.2629	.40

Table 10. Population size at age of vermillion snapper in the northern South Atlantic Bight, 1973-82, estimated by VPA (assumes $M = 0.23$).

Age	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
1	55162	668070	614916	632452	509273	1338904	1551796	954571	1487860	819197
2	578033	437960	530696	488417	302415	642905	1063479	1224648	732132	1156495
3	367665	457215	337621	404991	378564	395114	508973	801043	820923	433306
4	353494	278974	327723	227984	293917	291936	305682	371903	530119	543150
5	225949	262599	202175	230957	158045	222753	211087	228766	250882	349759
6	231560	167685	196168	141078	161645	115744	161248	159178	155008	149451
7	240599	173340	123866	141480	101770	121965	84796	117828	102949	93582
8	106271	184412	133290	92090	106193	75542	91397	57945	77133	59592
9	89450	78567	142960	100142	68728	79963	52917	60498	27778	43030
10	70111	59691	59391	110891	76951	50951	58112	33041	36651	16178
11	31217	52603	45726	42657	85497	57969	33992	38881	14910	23170
12	13946	22093	40566	33403	32058	65885	41427	23640	24731	9469

Table 11. Realized yield per recruit by cohort of vermillion snapper in the northern South Atlantic Bight.

<u>Year of Cohort's Recruitment as One Year Old</u>	<u>Number of Years in Fishery</u>	<u>Realized Yield Per Recruit(g)</u>	<u>Percent of ^{1/} Present Yield Per Recruit</u>	<u>Percent of ^{2/} Maximum Yield Per Recruit</u>
1973	10	192	110	85
1974	9	173	99	77
1975	8	169	97	75
1976	7	158	90	70
1977	6	146	83	65
1978	5	111	63	49
1979	4	80	46	36
1980	3	51	29	23

^{1/} Present yield per recruit assuming age of first capture equals 2 years old and the fishing mortality rate equals 0.4 for all ages.

^{2/} Maximum yield per recruit assuming the fishing mortality rate equals 0.4 for all ages and age of first capture equals 4 years old.

Table 12. Yield per recruit of one year old vermillion snapper in the northern South Atlantic Bight assuming 1979-81 average fishing mortality rates.

<u>Age</u>	<u>F (1979-81 Ave)</u>	<u>Yield (g)</u>	<u>Percent Yield</u>	<u>Cumulative Percent Yield</u>
2	0.172	10.7	5.8	5.8
3	0.149	16.8	9.1	14.9
4	0.137	19.7	10.7	25.6
5	0.166	25.1	13.6	39.1
6	0.188	25.7	13.9	53.1
7	0.220	24.6	13.3	66.4
8	0.347	27.9	15.1	81.5
9	0.274	14.7	8.0	89.5
10	0.322	11.3	6.1	95.6
11	0.193	4.6	2.5	98.1
12	0.222	3.6	1.9	100.0

Total Yield Per Recruit 184.7 g

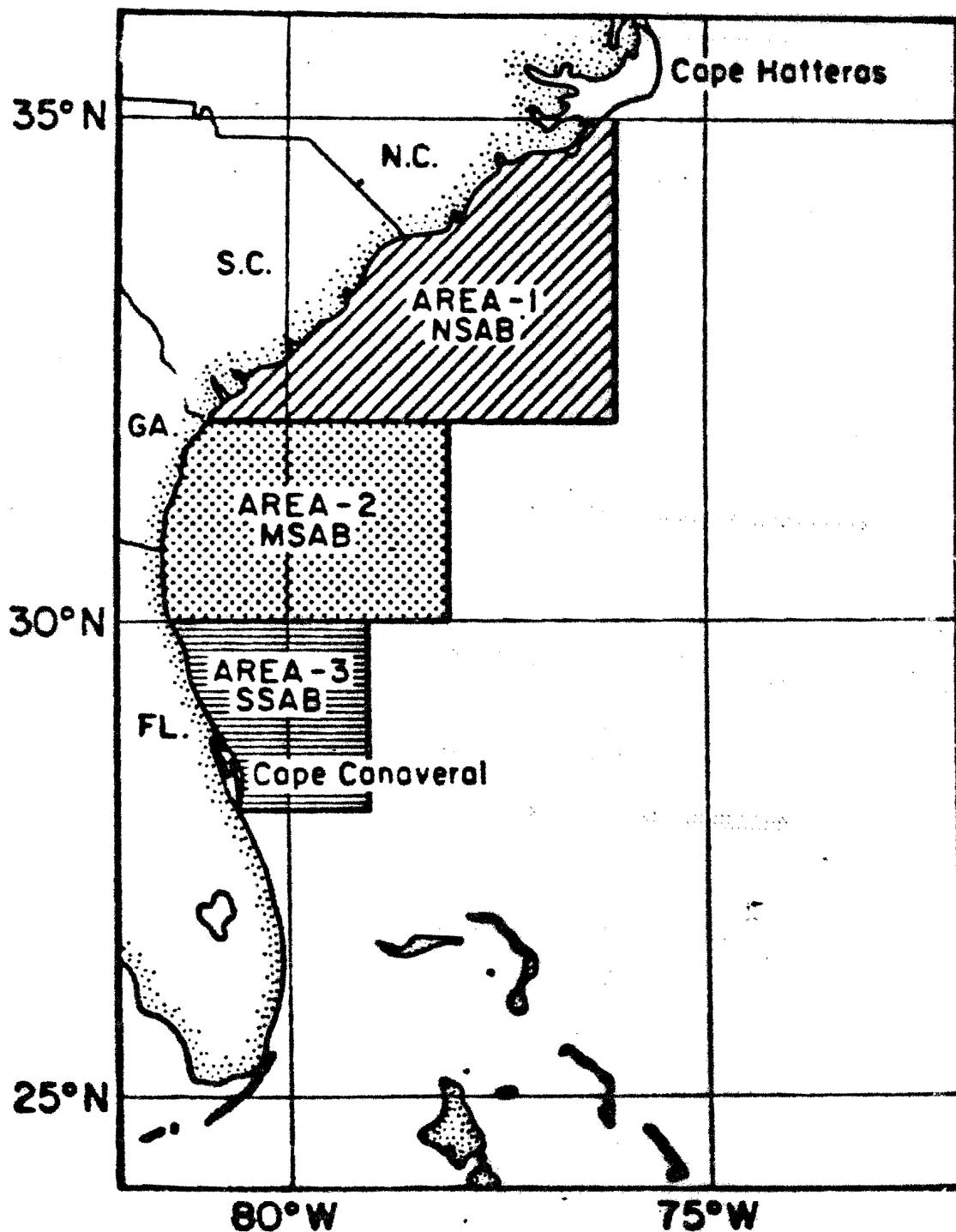


Figure 1. Diagram of South Atlantic Bight including northern region (NSAB), middle region (MSAB), and southern region (SSAB). The resource examined in this study are the vermilion snapper of the NSAB.

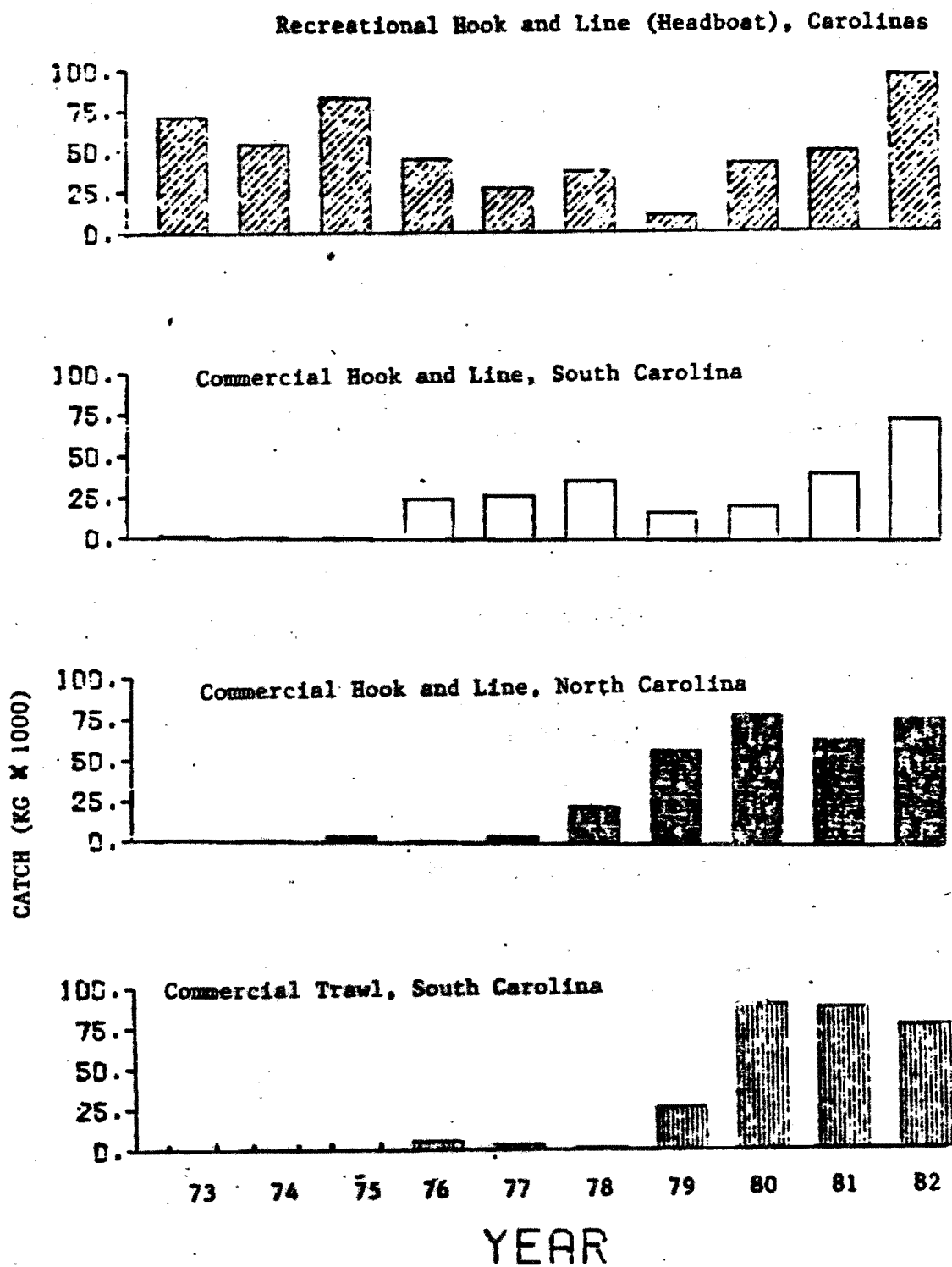


Figure 2. Catch trends (thousands of fish) of vermilion snapper in the northern South Atlantic Bight by gear type.

CATCH DISTRIBUTION OF VERMILION SNAPPER

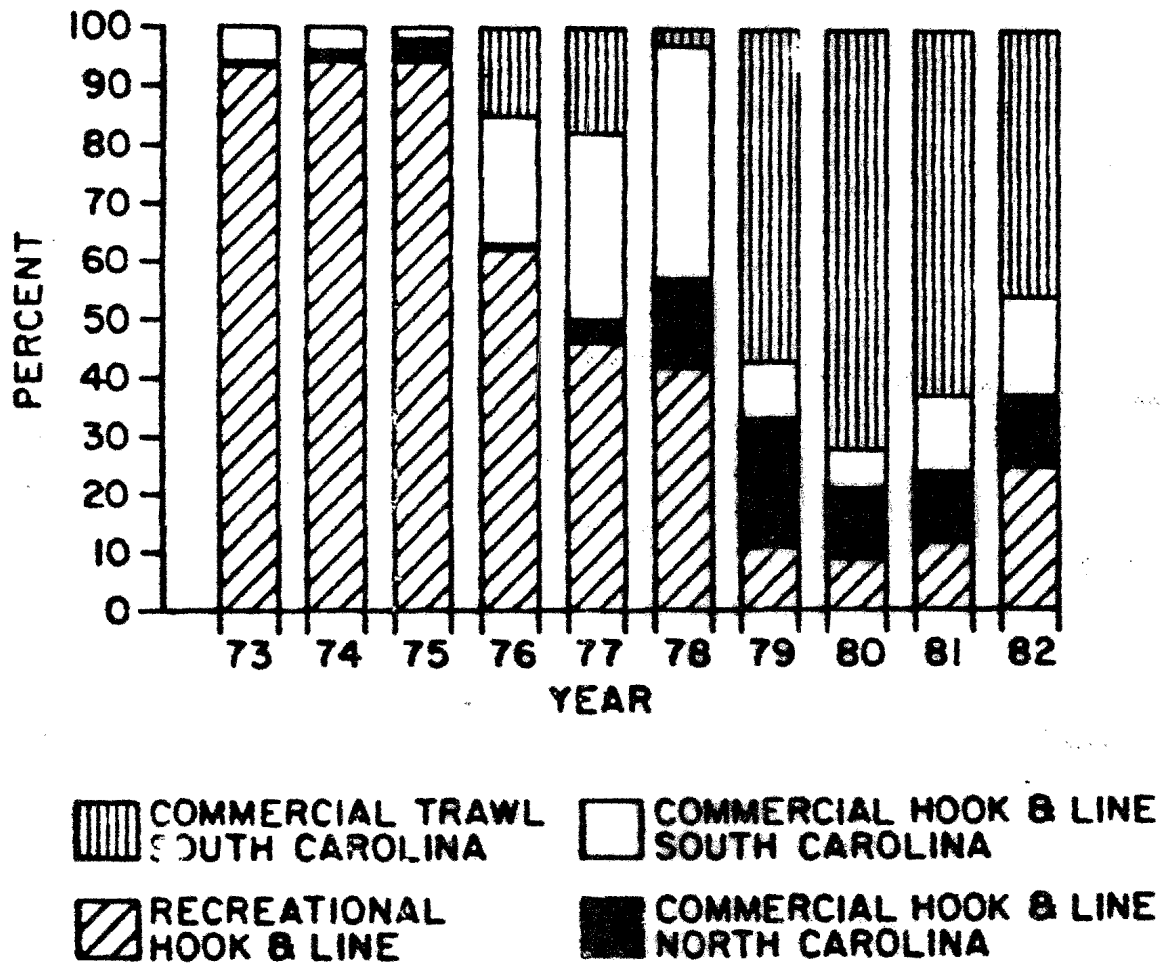


Figure 3. Percent (numbers) catch of vermilion snapper in the northern South Atlantic Bight by gear.

TOTAL CATCH

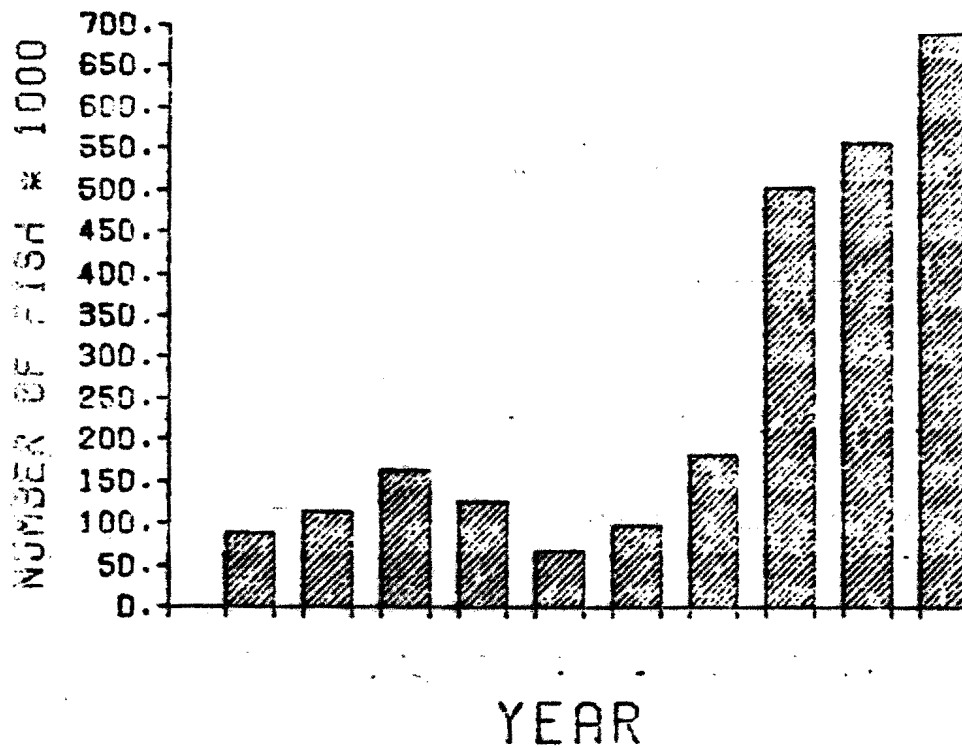


Figure 4. Total catch in numbers (1000's) of vermilion snapper in the northern South Atlantic Bight.

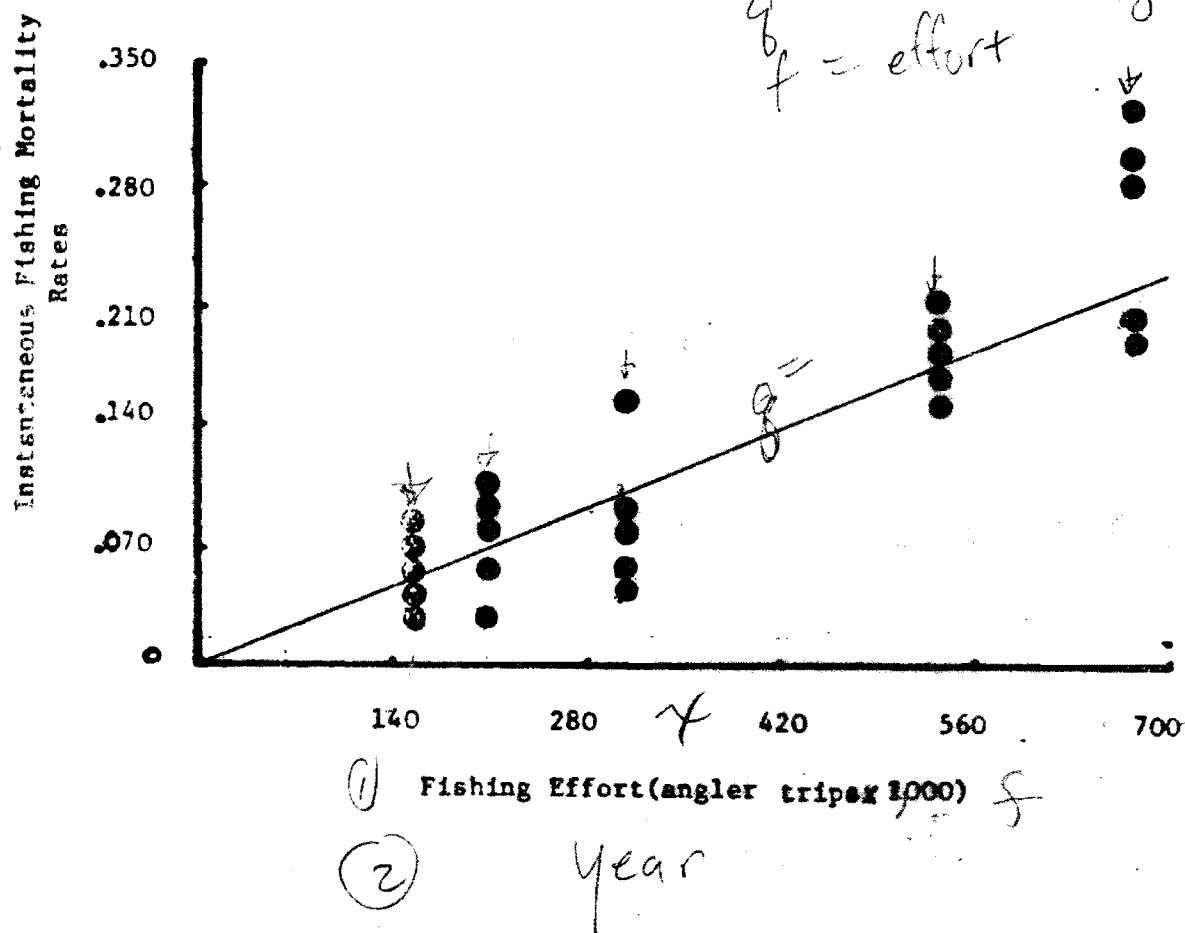


Figure 5. Best fitting relationship of age specific fishing mortality rates and effective effort found by iteration of the virtual population analysis (VPA).

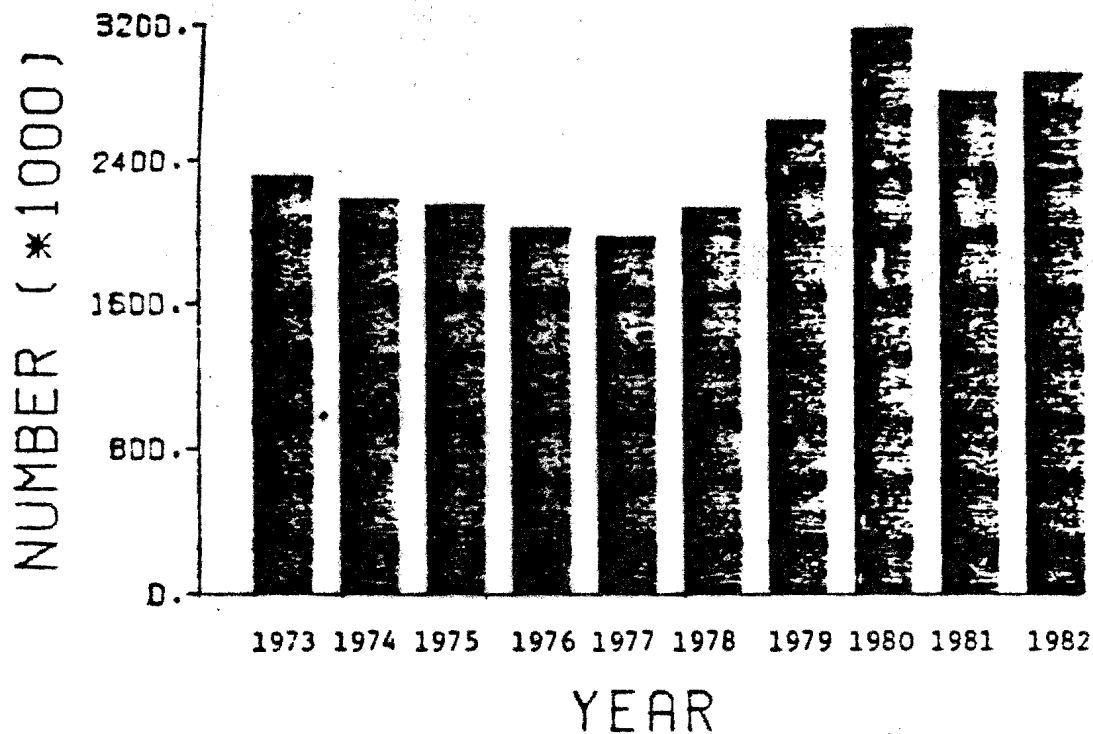


Figure 6. Number of 2 through 12 year old vermilion snapper in the population estimate by VPA.

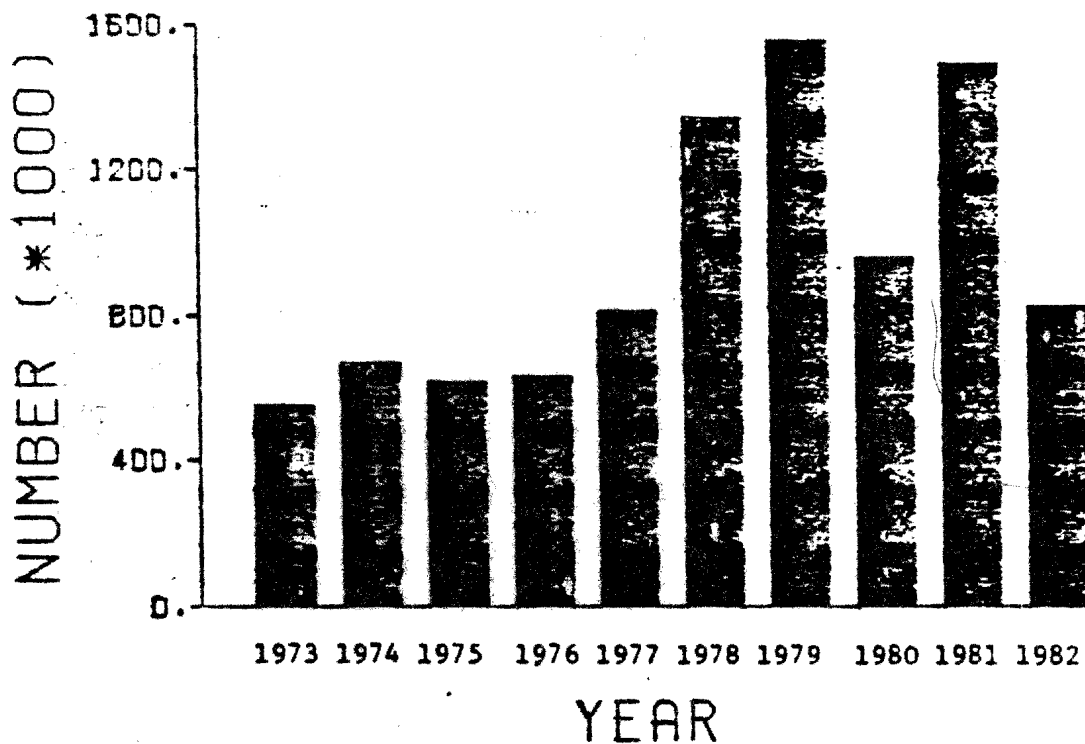


Figure 7. Number of one year old vermilion snapper (recruits) estimated by VPA.

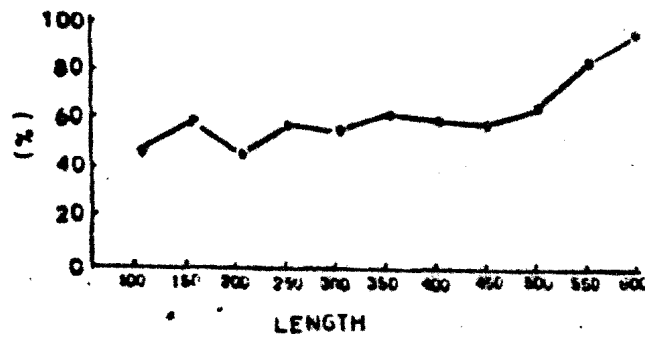


Figure 8. Vermilion sex ratio (percent female) versus total length from Grimes (1976).

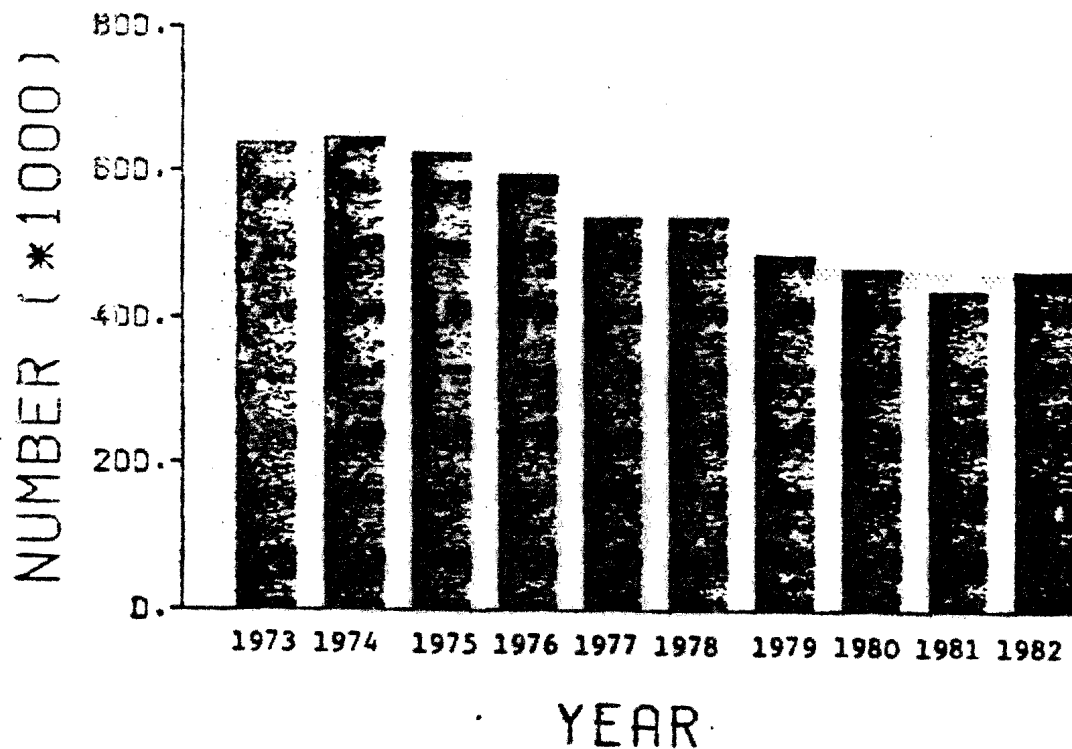


Figure 9. Number of mature female vermilion snapper estimated by VPA and sex ratio data of Grimes (1976).

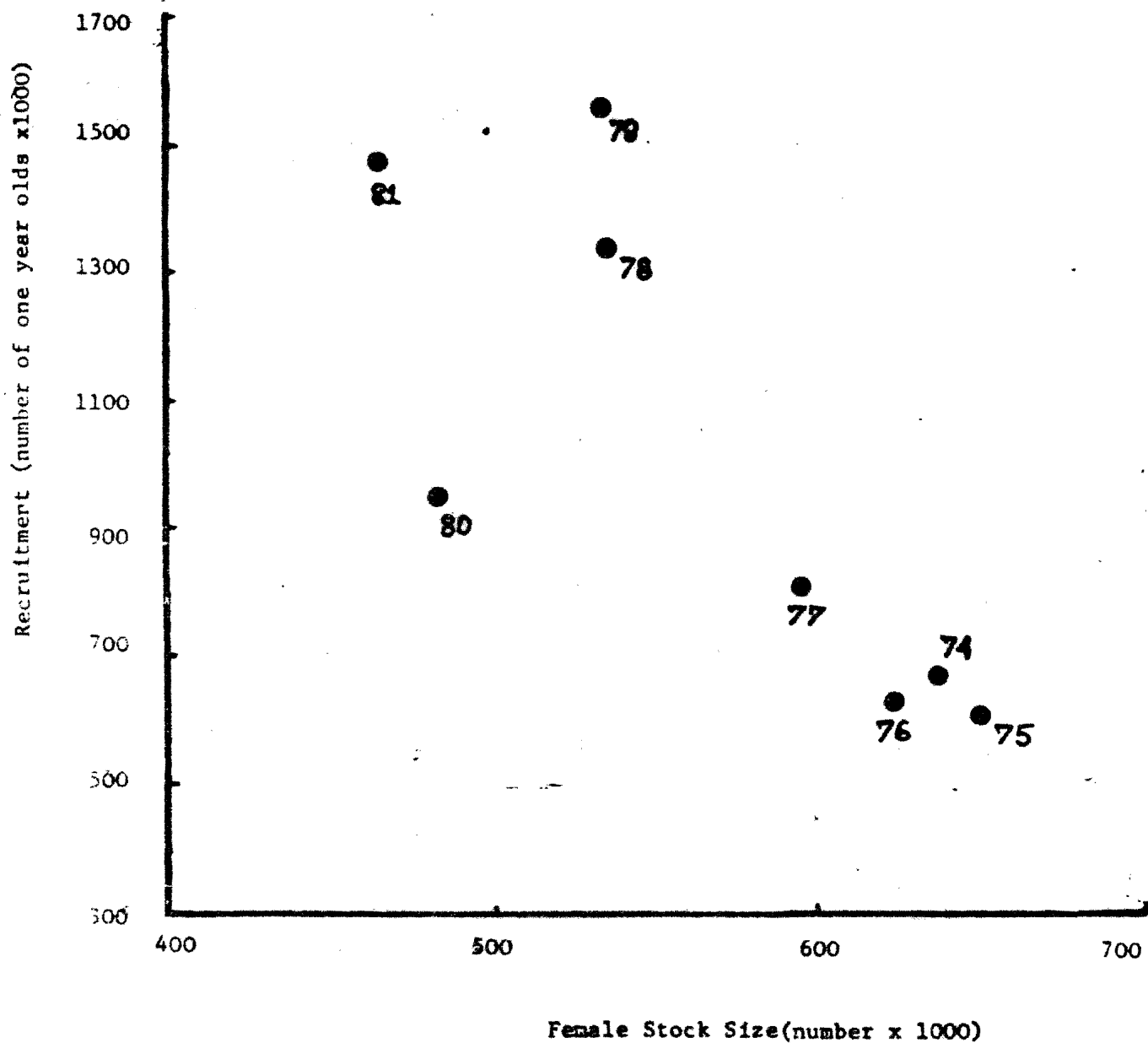


Figure 10. Number of recruits versus spawning stock abundance (number mature females) estimated by VPA.- Data points are labeled by the year in which the recruits became one years old.