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CATCH RATES OF SNOWY GROUPER, *EPINEPHELUS NIVEATUS*, ON THE DEEP REEFS OF ONSLOW BAY, SOUTHEASTERN U.S.A.

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ABSTRACT

The decline of a previously unexploited group of snowy grouper, *Epinephelus niveatus*, was monitored from June 1985–April 1986. The study area was located in Onslow Bay, off the central North Carolina coast. Snowy grouper dominated (>90%) the catches from the newly found reef and from other deepwater reefs in Onslow Bay. Catch rates, by weight, and mean size of fish taken from the newly discovered site were initially very high (67 kg·drop^{-1} and 8.4 kg·fish^{-1}, respectively), but rapidly converged to values (7 kg·drop^{-1} and 3.7 kg·fish^{-1}) comparable to other previously exploited reefs. Larger fish had a higher probability of being caught. The newly found site was fished intensively for less than 3 mo, removing 3% of the population daily. The estimates of initial exploitable biomass ranged from 29.2–30.8 t (eviscerated weight), at a density of approximately 11 kg·m^{-2}. By early August, over 60% of the exploitable biomass had been removed, and the site could no longer support exclusive fishing during a trip; within a year over 80% had been removed. The newly discovered site contributed over 30% of the total amount of snowy grouper landed in North Carolina in 1985.

Reef habitat accounts for about 23% of the available habitat on the continental shelf of the southeastern United States (Parker et al., 1983). Generally, the reefs are fossiliferous limestone and sandstone outcroppings (MacIntyre and Milliman, 1970), that along with the many shipwrecks in the region, harbor a diverse assemblage of tropical and subtropical fishes (Struhsaker, 1969; Miller and Richards, 1979). Major commercial and recreational fisheries exist for reef fishes, with the continental shelf off North Carolina representing the northernmost range of those fisheries (Huntsman, 1976; Ulrich et al., 1976; Chester et al., 1984).

The continental shelf has been divided into regions based on faunal assemblages (Miller and Richards, 1979; Chester et al., 1984; Sedberry and Van Dolah, 1984). Generally, the shelf has been divided into inner and outer regions, and an intermediate transitional zone. The deepest region (>100 m) is dominated in the north by snowy grouper, *Epinephelus niveatus*, blueline tilefish, *Caulolatilus microps*, yellowedge grouper, *Epinephelus flavolimbatus*, and warsaw grouper, *Epinephelus nigritis*, and is the least studied region and has received the least fishing effort (Chester et al., 1984). For reasons given herein, this study concentrates on snowy grouper, which are slow to attain maximum size and are long-lived (Matheson and Huntsman, 1984; Moore and Labisky, 1984). Such populations are easily overexploited because they have these life history characteristics (K strategist sensu Adams, 1980).

In April, 1985 an unfished deepwater site was discovered in Onslow Bay, located off the central coast of North Carolina, and was subsequently commercially exploited. The catches from the newly discovered site, and from other deepwater sites in Onslow Bay, were monitored. The objectives of this study were to describe the catches from the deep reefs of Onslow Bay, to describe the response of the unfished community on the newly discovered reef to exploitation, and to compare that site to other exploited sites in Onslow Bay.

METHODS

Deepwater reef catches of two fishing vessels, F/V SHADOW and F/V ALLIGATOR, were monitored June 1985–April 1986. Hook-and-line fishing occurred in water depths of 137–194 m on the outer continental shelf of northern Onslow Bay. Although a few sites were shipwrecks, most sites were hard bottom habitat. The unfished site was in 194 m, and was first fished on 6 June 1985. The site is approximately 48 m × 56 m (2,700 m^2) with a relief of 2–3 m, and may be a natural reef or a shipwreck. Fishermen referred to the site as "Adrian's Mark." With the exception of Adrian's Mark, deepwater sites used in this study represented reefs that were fished but briefly during a trip and were known to many different captains.

Fishing trips were generally 2–3 days long. Two to three lines were fished from hydraulic reels. Each line usually held six gangions ("rally rigs"), each with a number 5 circle hook baited with cut squid. Because of the usually swift current (0.5–1.0 $m \cdot sec^{-1}$), fishing was generally accomplished by motoring the vessel upcurrent of the reef, dropping the lines to the bottom, and drifting for 1–4 min as the baited hooks dragged across the reef at a speed that was dependent on the current. This unit of activity was defined as a "drop"; we assume that the duration of each drop was the same, and use effort units of drop, line-drop and hook-drop.

The number of fish caught of each species, the number of hooks fished, and the depth and approximate time of day were recorded for each line fished and for each drop made while one of the authors (J.W.D.) was aboard either of the two vessels. At the dock, fish were measured to the nearest 5 mm total length (TL). The number of individuals and eviscerated weight landed, by species, were determined. Daily catch records (weight by species) were obtained from the majority of other fishermen fishing the newly discovered site.

For each measure of effort (drop, line, hook), catch-per-unit effort was calculated in two ways for each fishing trip. Trip CPUE is the total number or weight of fish caught during a fishing trip divided by the total units of effort expended during a trip. Trip mean CPUE is the mean of all the individual effort CPUE values (drop, line, hook) during a trip. For example, if a trip consisted of 100 drops, trip mean drop CPUE is the mean of 100 individual drop CPUE values. Trip mean CPUE can be calculated in terms of number of individuals caught only, not weight, because we were not able to record the weight caught for each separate unit of effort. Daily estimates of mortality were calculated from each of the six measures of CPUE for each trip by regressing $\log_e$ CPUE values against time (Ricker, 1975).

Using the Leslie method with Braaten's modification (Braaten, 1969 in Ricker, 1975), catchability coefficients and initial exploitable biomass on Adrian's Mark were estimated for snowy grouper by regressing CPUE values against cumulative catch (Ricker, 1975). The slope of the regression line is the unadjusted catchability coefficient ($\bar{q}$), and the Y-axis intercept (b) is the product of unadjusted estimates of initial biomass (B_0) and $\bar{q}$. CPUE data were available for the F/V SHADOW and F/V ALLIGATOR only. Daily catch data (but not effort) were available for nearly the entire fleet (Table 1); we estimated that an additional 6.4 t was removed in July and August, 1985, by a minority (seven vessels) of the fleet for which no daily landing records were available (personal communication with captains after they consulted their logbooks). The estimates of initial biomass and catchability, obtained from the regression, were adjusted for natural mortality (M = 0.15; Matheson and Huntsman, 1984), outstanding effort associated with the cumulative catch, and catch of the uncensused portion of the fleet (C′) (see Ricker, 1975: Sec. 6.6):

$$B_0 = b/q \qquad q = (\bar{q} - M/f)/(1 + C'/C)$$

where f is the total effort yielding the cumulative catch data (C) represented in the regression data set. When cumulative catch data used for the regression represented more than the catches of F/V SHADOW and F/V ALLIGATOR, the total effort was estimated from the known catch/effort ratio:

$$f = f'(C/C'')$$

where f′ is the effort of the F/V SHADOW and F/V ALLIGATOR and C″ is the catch of the two vessels.

Catchability coefficients and estimates of initial biomass were estimated in two ways. The first method used known catch and effort data for part of the fleet, F/V SHADOW and F/V ALLIGATOR, and parameters were adjusted per above equations (C is the catch of the two vessels, and C′ is the total catch of all other vessels). The second method employed the partial CPUE data of the two vessels, and cumulative catch data of the entire fleet, except for 6.4 t, which could not be attributed to a specific date. The resulting estimates were subsequently adjusted for the remaining 6.4 t, per above equations (C is the catch of all vessels excluding 6.4 t, and C′ = 6.4 t). Catch in weight, not numbers, was used in the analysis because the fishery is valued by weight. Also, analyses using numbers of fish would be sensitive to changes in catchability over time, and estimates of initial population size, N_0, would be biased. Initial biomass estimates would not be biased by such changes.

Table 1. Daily catch of snowy grouper from Adrian's Mark, a previously unexploited reef in Onslow Bay, June 1985–April 1986, and effort for a portion of the fleet. Dates are given for the first day of a trip. Asterisks denote estimates from logbooks. Effort data are represented by line-drops and hook-drops, in addition to the total number of drops made.

	Catch		Effort		
Date	kg	Number	Drops	Lines	Hooks
1985					
Jun 7	737.8				
Jun 15	1,392.9				
Jun 22	363.2*				
Jun 23	1,486.9				
Jun 8–Jun 27	2,270*				
Jun 28	3,225.1	382	48	122	835
Jun 29	45.4*				
Jul 2	601.7	87	21	46	287
Jul 3	1,525.4				
Jul 6	45.4*				
Jul 9	90.8				
Jul 9	747.9	116	32	82	500
Jul 14	735.5	120	34	102	612
Jul 19	90.8				
Jul 19	2,295.8	276	78	149	878
Jul 20	363.2				
Jul 29	1,454.9	201	43	82	492
Aug 5	1,230.7	155	37	105	630
Jul 1–Aug 31	2,724*				
Jul 1–Aug 31	908*				
Jul 1–Aug 31	454*				
Jul 1–Aug 31	454*				
Jul 1–Aug 31	454*				
Jul 1–Aug 31	681*				
Jul 1–Aug 31	681*				
Sep 3	106.3	20	16	32	192
Sep 20	0	0	2	6	36
Sep 30	48.4	13	4	8	48
Oct 19	76.1	22	7	14	84
Nov 19	0	0	2	6	36
1986					
Mar 16	40.9	16	5	15	90
Apr 2	2.3	3	1	2	12

RESULTS

A total of 17 species was caught in 21 trips made to the deep shelf region of Onslow Bay by the F/V SHADOW and the F/V ALLIGATOR. Snowy grouper dominated the catches from Adrian's Mark, and previously exploited sites in Onslow Bay (Table 2). At shallower sites (137–146 m), blueline tilefish, vermilion snapper (*Rhomboplites aurorubens*), and red porgy (*Pagrus pagrus*) were caught in small numbers (N = 56, 43, 37), but catches of all other species in aggregate were relatively insignificant at Adrian's Mark and the previously exploited areas when compared to the number of snowy grouper caught. Carangids, *Seriola* spp., were a distant second in abundance at Adrian's Mark.

Catch rates were calculated only for snowy grouper because catches of other species were insignificant. The relationship between trip CPUE and trip mean CPUE is linear, and although the two methods do not yield algebraically equivalent results, the two were highly correlated ($r > 0.99$), regardless of the unit of

Table 2. Relative species composition of catches from deep reefs in Onslow Bay (catches less than 0.1% are denoted by an asterisk)

Species	Percent number of individuals	
	Adrian's Mark (N = 1,094)	Previously exploited reefs (N = 2,910)
Epinephelus niveatus	91.7	92.7
Seriola zonata	4.8	0.9
Caulolatilus microps		1.9
Seriola rivioliana	1.6	0.5
Rhomboplites aurorubens		1.5
Pagrus pagrus		1.3
Epinephelus flavolimbatus	*	0.4
Muraena retifera		0.4
Conger oceanicus	0.1	*
Seriola dumerili	*	0.1
Neomerinthe hemingwayi		0.1
Carcharhinus altimus	*	*
Sphyrna lewini	*	
Carcharhinus falciformis	*	*
Epinephelus drummondhayi		*
Epinephelus mystacinus		*
Galeocerdo cuvieri		*

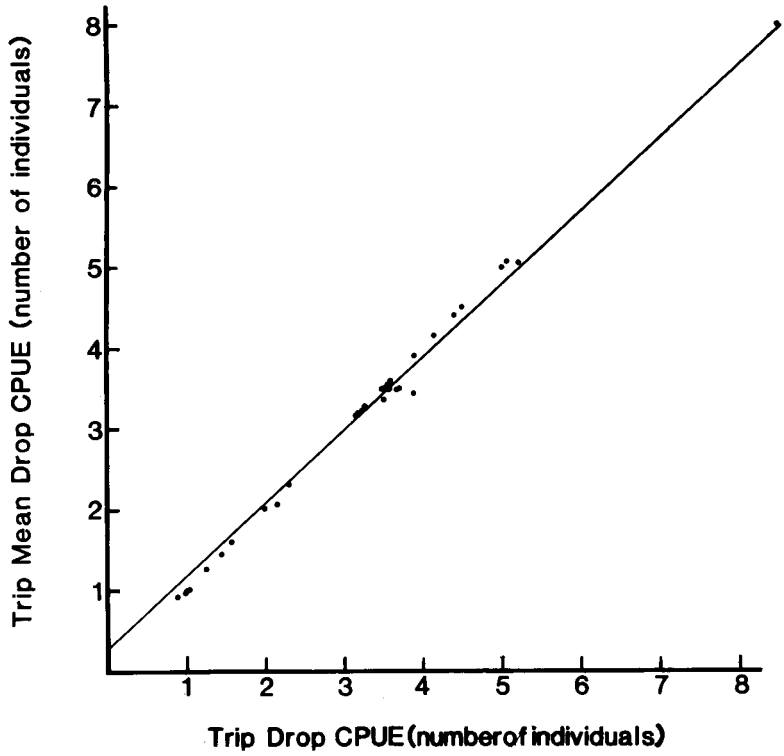

Figure 1. The linear relationship between trip drop CPUE and trip mean drop CPUE, based on number of individuals. Mean Drop CPUE = 0.0017 + 0.9823(Drop CPUE), r = 0.99.

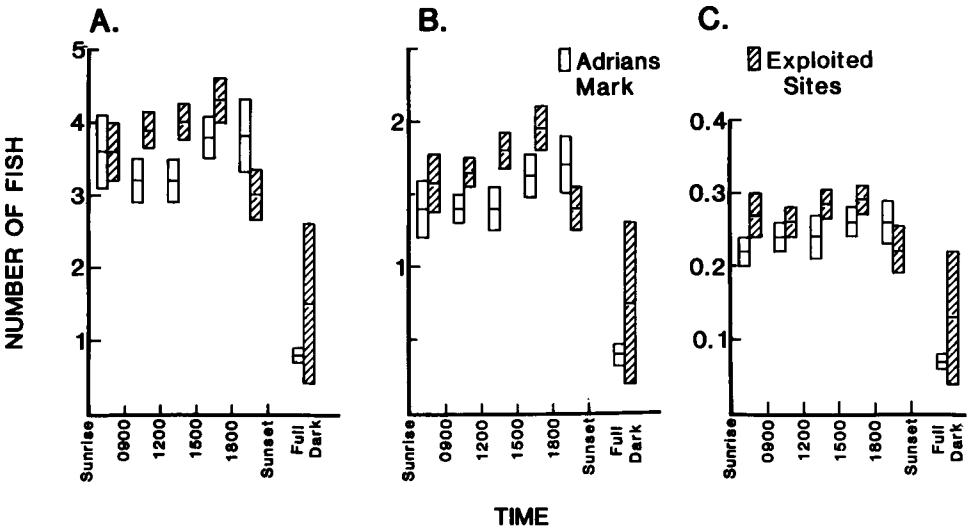

Figure 2. Catch-per-unit effort by time of day for Adrian's Mark and previously exploited sites in Onslow Bay. The duration of the "full dark" interval varied according to the seasonal changes in sunrise and sunset. Mean catch-per-unit effort and one standard error of those means are illustrated. A) Catch-per-drop, B) Catch-per-line and C) Catch-per-hook.

effort chosen (Fig. 1). Hereafter, trip mean CPUE data are used as measures of relative abundance, as these are considered replicates drawn from the total population. Comparable mean CPUE data are not available for biomass comparisons, and trip CPUE data are used for those analyses.

Fewer snowy grouper were caught at night. There was a general trend for increased catches as the day progressed and the fish moved higher over the reefs, as indicated by fathometer recordings, but there were no overall statistically significant differences in number of snowy grouper caught in daylight from one time interval to another, or between the sites (ANOVA, $P > 0.05$) (Fig. 2). Catches did drop significantly after sunset at the newly discovered site (Tukey's Studentized Range (HSD) test, $P < 0.05$).

Catch rates of snowy grouper on Adrian's Mark were initially very high (Fig. 3), even though 7 t had been removed from the site prior to acquiring the first measure of CPUE on June 28 (Table 1). Catch rates declined from the high of 8.10 snowy grouper (68.8 kg) per drop in June to 1.25 (6.6 kg) in September. Fish caught on Adrian's Mark initially averaged 700–800 mm TL (Fig. 4A), but mean size began to decline by September. During the same time period, the number of snowy grouper caught per unit effort on previously exploited sites varied greatly, and frequently exceeded that of Adrian's Mark (Fig. 3). Fish caught on the previously exploited sites averaged 500–550 mm TL (Fig. 4B), only slightly smaller than the mean size caught on Adrian's Mark after intensive exploitation (Fig. 4A).

The period of 28 June through 7 August 1985 was used to estimate the rate of decline in number of individuals on Adrian's Mark. We assumed that recruitment and emigration either were zero or balanced and that M was negligible during the 40 d period. We found that approximately 3% of the population was removed daily by fishing (Table 3).

Catchability coefficients and initial exploitable biomass of snowy grouper on

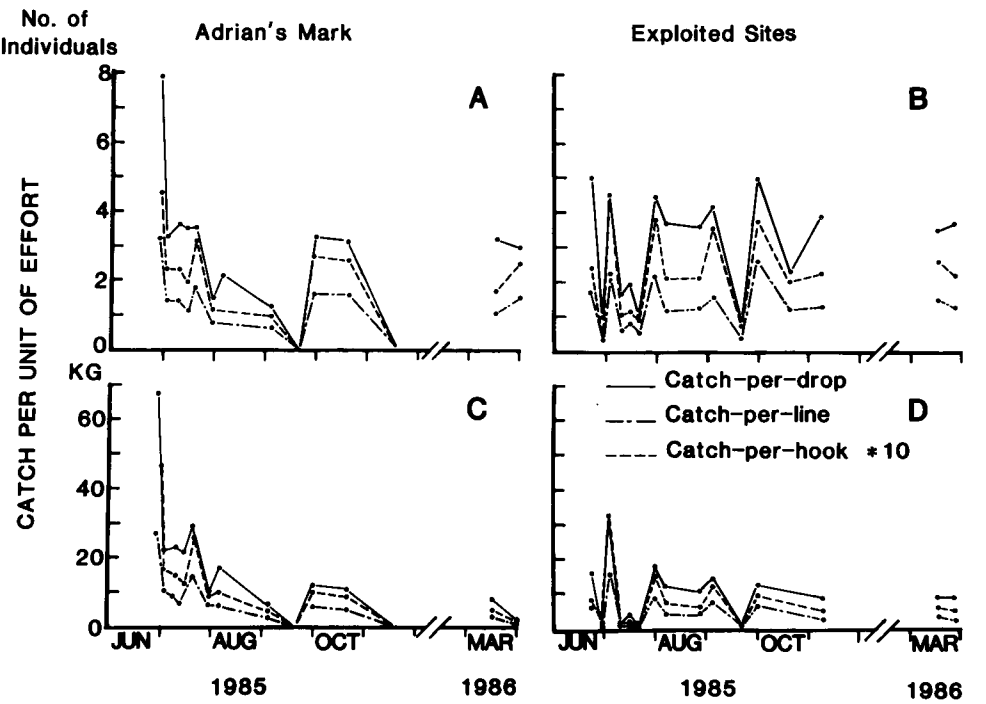

Figure 3. Catch-per-unit effort of snowy grouper over time on Adrian's Mark and previously exploited sites in Onslow Bay. A) CPUE of individuals on Adrian's Mark, B) CPUE of individuals on previously exploited sites, C) CPUE of weight on Adrian's Mark and D) CPUE of weight on previously exploited sites.

the site were estimated (Table 4) based on linear relationships between CPUE and cumulative catch (Fig. 5). Estimates of initial exploitable biomass (eviscerated weight), ranged from 29.2–30.8 t. Our best estimate of cumulative catch by March 1986 was 25 t, with nearly 19 t removed before late August 1985. Given the reef's area, the initial density of exploitable snowy grouper on the virgin reef was approximately 11 $kg \cdot m^{-2}$.

Discussion

Several important points relevant to the management of deep reef fishery resources were evident as a result of this study. In less than 3 mo, the small area of Adrian's Mark (2,700 m^2) yielded an astounding quantity (19 t) of commercially exploitable snowy grouper, but fishing caused rapid and marked changes in the size structure and catch-per-unit effort of the newly discovered population of snowy grouper. In less than 3 mo, CPUE and the average size were depressed to levels comparable to other exploited sites in Onslow Bay. Although fish are still being caught on the site, our data provides some insight into the high level of exploitation that the deepwater reefs off the southeastern U.S. coast have received in the recent past, and the ease and rapidity of their overexploitation.

Estimates of initial exploitable biomass on Adrian's Mark ranged from 29.2–30.8 t (eviscerated weight), at a density of approximately 11 $kg \cdot m^{-2}$. Catch rates were initially high (68.8 $kg \cdot drop^{-1}$), and individuals caught soon after exploitation began averaged 8.5 kg. Catch rates in numbers of fish never differed much from

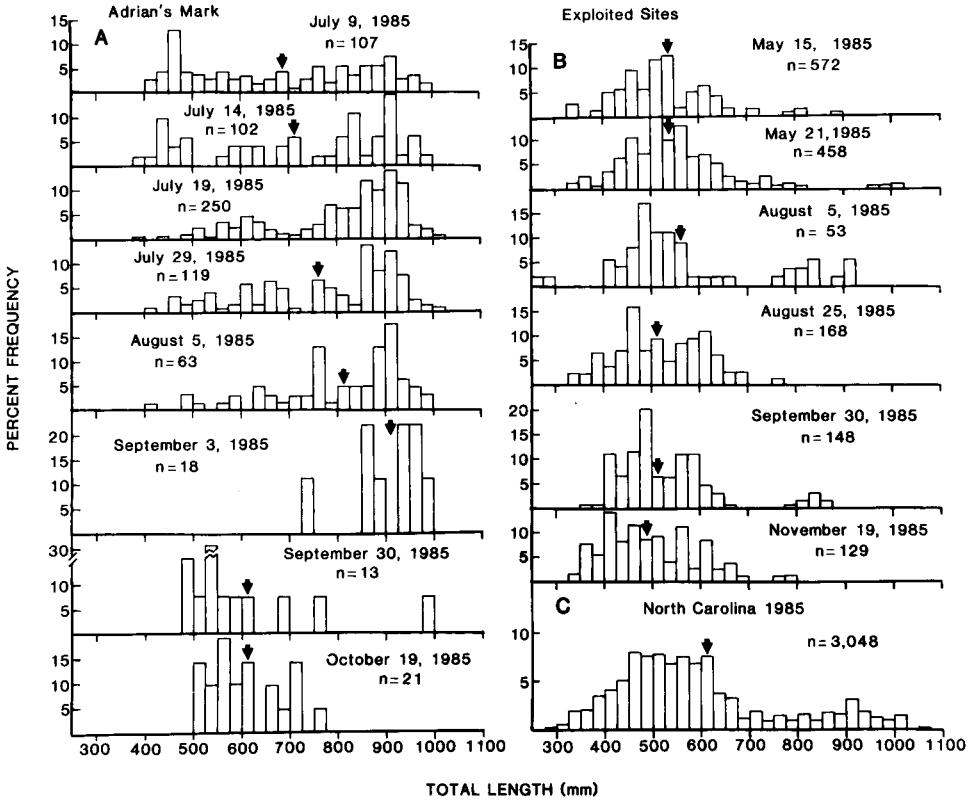

Figure 4. Monthly size frequencies of snowy grouper caught in 1985 by hook and line. Mean sizes are denoted by arrows. A) snowy grouper caught on Adrian's Mark, a previously unexploited reef, July–October; B) snowy grouper caught on previously exploited deepwater sites in Onslow Bay, May–November and C) snowy grouper landed in North Carolina, January–December.[1]

those of previously exploited reefs, but catch rates by weight remained higher than on other deepwater reefs until September. At that time, the new site was no longer productive enough (weight removed per unit effort) for the vessels to remain on site continuously. Thereafter, Adrian's Mark became one of many possible sites to be fished during a single trip. When fishermen downgraded the site to one for browsing, 19 t of snowy grouper had been removed.

Fishermen get paid for weight landed, not number of individuals. Hence, catch

Table 3. Daily instantaneous mortality (Z) and survival rates (S) of snowy grouper on Adrian's Mark, a previously unexploited reef in Onslow Bay

Estimate based on:	Z	Std. error of Z	S	r^2
Catch-per-drop	0.0306	0.0098	0.9699	0.66
Catch-per-line	0.0297	0.0093	0.9707	0.68
Catch-per-hook	0.0271	0.0087	0.9732	0.66
Mean catch-per-drop	0.0319	0.0096	0.9686	0.69
Mean catch-per-line	0.0269	0.0075	0.9735	0.72
Mean catch-per-hook	0.0229	0.0070	0.9773	0.68

Table 4. Estimates of catchability (q) and initial population biomass (B_0) for snowy grouper on Adrian's Mark, a previously unexploited reef in Onslow Bay (see text for a description of the two methods)

	Original parameters		Adjusted parameters		
Estimate based on:	$\bar{q}$	y-intercept	q	B_0	r^2
Method 1					
Catch-per-drop	0.00451	52.6285	0.00180	29,225	0.70
Std. error	0.00085	7.2643			
Catch-per-line	0.00179	21.3365	0.00071	30,013	0.67
Std. error	0.00036	3.1102			
Catch-per-hook	0.00269	3.2862	0.00011	30,790	0.67
Std. error	0.00005	0.4696			
Method 2					
Catch-per-drop	0.00376	76.7945	0.00263	29,221	0.71
Std. error	0.00069	11.2870			
Catch-per-line	0.00149	30.9414	0.00104	29,850	0.68
Std. error	0.00029	4.8339			
Catch-per-hook	0.00022	4.7142	0.00015	30,549	0.67
Std. error	0.00004	0.7383			

rates by weight best reflect the fishing success of the fleet. Typically, most commercial reef fishing trips off the Carolinas, and much of the South Atlantic Bight, consist of brief stops at a number of sites during any given trip. As a result of this roving or browsing pattern, a reef is fished hard repetitively by a number of vessels, and not abandoned long enough to allow the discrete stock to recover. Even though a reef may be known to, and fished by many fishermen, it can be productive briefly because, during each visit, the more aggressive (usually the largest fish) are removed first (Thompson and Munro, 1974). Size dominance influenced the outcome of intraspecific competition for the baited hook on the deep reefs of Onslow Bay. Typically, when any reef was fished initially during a trip, large snowy grouper were caught (pers. obs.). Only when the weight taken per drop was high enough to warrant continued fishing were smaller snowy grouper, and hence the expanded size range present on the reef caught (pers. obs., Fig. 4A). While the new site was fished intensively, there was a broad range of sizes caught. In early September, as a result of reduced effort, the range of sizes caught contracted. Thereafter, even though mean size was declining, the length frequencies were biased towards the larger fish remaining on the reefs, as the fishermen did not stay on site long enough to catch the expanded range of sizes. Thus, catchability of small snowy grouper was a function of the number of larger, more aggressive individuals in the area. Intraspecific competition in reef fish populations implies that assumptions of knife-edge recruitment used in the Beverton and Holt models of yield per recruit are invalid (Huntsman et al., 1983). Behavior and the presence of more aggressive animals may be just as important a consideration in evaluating vulnerability as is absolute size or age. Further, interspecific competition has been documented for other deep dwelling reef species (Polovina, 1986; Matlock et al., 1991). Application of constant catchability models to populations with variable catchabilities usually leads to underestimates of initial biomass (Polovina, 1986). However, a constant catchability model fit the snowy grouper data from Adrian's Mark relatively well (r = 0.82–0.85; Fig. 5), indicating that the probability that it was a snowy grouper hooked, rather than another species, appeared unchanged.

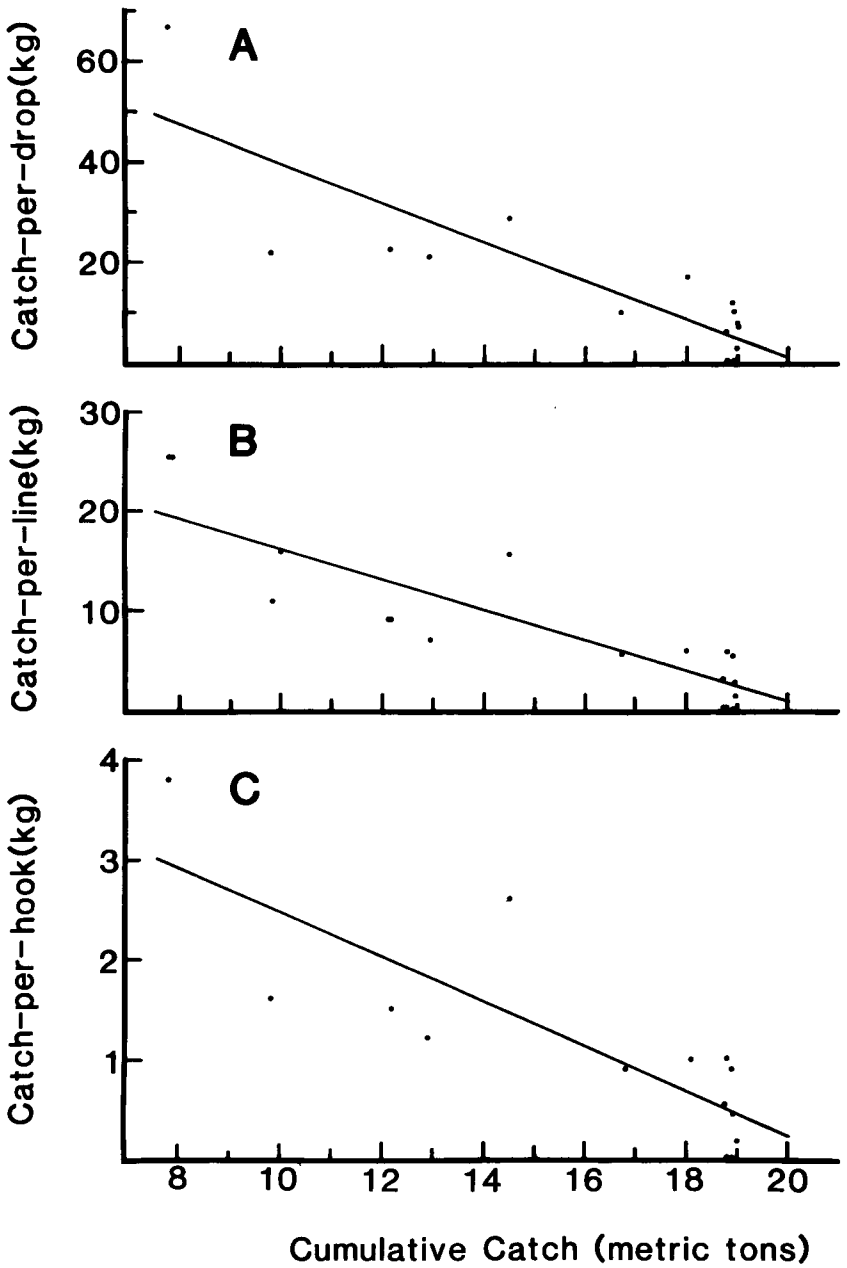

Figure 5. Relationship between CPUE and cumulative catch data for snowy grouper taken from Adrian's Mark, a previously unexploited reef in Onslow Bay, North Carolina. CPUE data are from the records of two commercial vessels. Cumulative catch data represent the catch of the entire fleet, except for a residual 6.4 t. See text for details of Method 2. A) catch-per-drop vs. cumulative catch; B) catch-per-line vs. cumulative catch and C) catch-per-hook vs. cumulative catch.

Several lines of evidence suggest that Adrian's Mark contained a resident population of snowy grouper, and that it was not populated with spawning snowy grouper recruited from other reefs. We do not believe the large concentration of snowy grouper on the newly discovered reef was a spawning aggregation, which have been described for shallow water Epinepheline species such as nassau grouper, *Epinephelus striatus,* and red hind, *E. guttatus* (Smith, 1972; Olsen and LaPlace, 1978; Colin et al., 1987), but not for snowy grouper. Snowy grouper in the Florida Keys have a protracted spawning season, likely spring–summer (Moore and Labisky, 1984). The period of intense fishing on Adrian's Mark overlapped the spawning period reported for the Keys. Furthermore, locality-specific fishing success at other deepwater reefs of Onslow Bay did not indicate that fish were moving to, or off, the reefs, and adult snowy grouper are thought to be sedentary (Smith, 1971). In addition, a fish that had been hooked but not boated was caught over a month later on the same previously exploited reef (the old hook in its mouth was unique to the monitored fishermen).

Snowy grouper represented approximately 25% of the grouper landed in North Carolina during 1985,[1] and Adrian's Mark contributed over 30% of the snowy grouper, despite being fished intensively for a very short period. At the time it was downgraded to a browsable site, over 60% of the exploitable biomass had been removed, and within a year over 80% had been removed. Matheson and Huntsman (1984) reported annual mortalities of 21–22% for the commercially fished snowy grouper stocks off the Carolinas in the late 1970's, and Moore and Labisky (1984) reported an annual mortality of 16% in 1978–1981 for a relatively unexploited stock of snowy grouper in the Florida Keys. Even today, 1993, the commercial fishery for the deep-reef community continues to operate, although mean size of snowy grouper landed is declining, and the spawning stock per recruit ratio (SPR) for snowy grouper (0.15) is less than 0.3, the overfishing criterion set by the South Atlantic Fishery Management Council (SAFMC) (Huntsman et al., in press).

Fishing pressure has been increasing in the U.S. southern Atlantic region, and many reef species, including snowy grouper, are illustrating symptoms of decline (Huntsman et al., 1983; Low et al., 1985; Plan Development Team, 1990; Vaughan et al., 1992; Huntsman et al., in press). Matheson and Huntsman (1984) estimated that the headboat and commercial fisheries were harvesting 60–80% of the maximum available yield per recruit of snowy grouper in the late 1970's. A fishery assessment in 1992 indicated that 42% reduction in current effort is needed to attain the SAFMC goal of 30% SPR (Huntsman et al., in press). Monitoring of catches from a previously unexploited group of snowy grouper afforded insight into the impact of fishing on these deepwater reef communities, and underscored how vulnerable these stocks are to overexploitation. It also provided a comparative baseline for evaluating the degree of exploitation experienced on other deepwater reefs in Onslow Bay, and possibly other areas in the South Atlantic Bight. These results support the need for drastic conservation measures. Traditional management measures, such as the minimum size limits that already exist for shallow water reef species, are not a viable option to manage the harvest of this species, because snowy grouper live at great depth and embolize when brought to the surface (Matheson and Huntsman, 1984). Marine reserves (Plan Development Team, 1990) and individual transferable quotas that are being discussed by the

[1] Mercer, L. P., F. C. Rohde and S. P. Epperly. 1986. Study II. North Carolina commercial fisheries stock assessment, July 1983–March 1986. Pages 55–192 *in* North Carolina/National Marine Fisheries Service regional cooperative statistical program. Completion report for cooperative agreement project SF-20, N.C. Dep. Nat. Resour. Community Devel., Div. Mar. Fish., Morehead City.

SAFMC specifically for deepwater reef species (single and multispecies quotas), represent the best options to restore snowy grouper populations.

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