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Several problems exist with the current Fisheries Management Plan for sharks and proposed changes in the FMP for 1995. Many of these problems were recognized by the Shark Panel of Experts that was convened at the NMFS Workshop in Miami last March. As a member of that Panel, I can note that many of our comments, and much of our data were incorporated into the NMFS Workshop Report. Unfortunately, some important comments were omitted, and more importantly, dissenting conclusions and recommendations were ignored. The Panel members have no way of telling what the consensus recommendations were because such a consensus was not reached at the meeting, but rather we were invited to make comments on a draft workshop report prepared by NMFS Laboratory Director, Joe Powers. Consequently, I offer the following comments.

The FMP Population Model

The current FMP apparently uses a modified maximum likelihood method to estimate parameters of a biomass dynamics model in order to calculate Total Allowable Catch (TAC) and related values. Biomass dynamics models are based on the idea that stock production increases up to some maximum as the "virgin" stock is harvested. These models have been shown to be valid for many species of teleosts and are based on three premises:

1. At or near maximum stock density efficiency of reproduction is reduced and quite commonly, the actual numbers of recruits are less than at smaller stock densities.
2. Growth rates are faster at lower fish densities because there is less competition for prey resources.
3. At smaller stock sizes a higher proportion of faster-growing young individuals are in the population. Thus average population growth is higher.

Let us examine each of these premises in relation to sharks.

1. Teleosts with large numbers of eggs and larvae often show reduced juvenile recruitment at high parent stock densities because of density-dependent mortality of larvae. This is not true in sharks. In K-selected animals there is a close correlation between parent stock and recruitment. In addition, at large stock sizes and low fishing mortality, there is a greater percentage of large females in

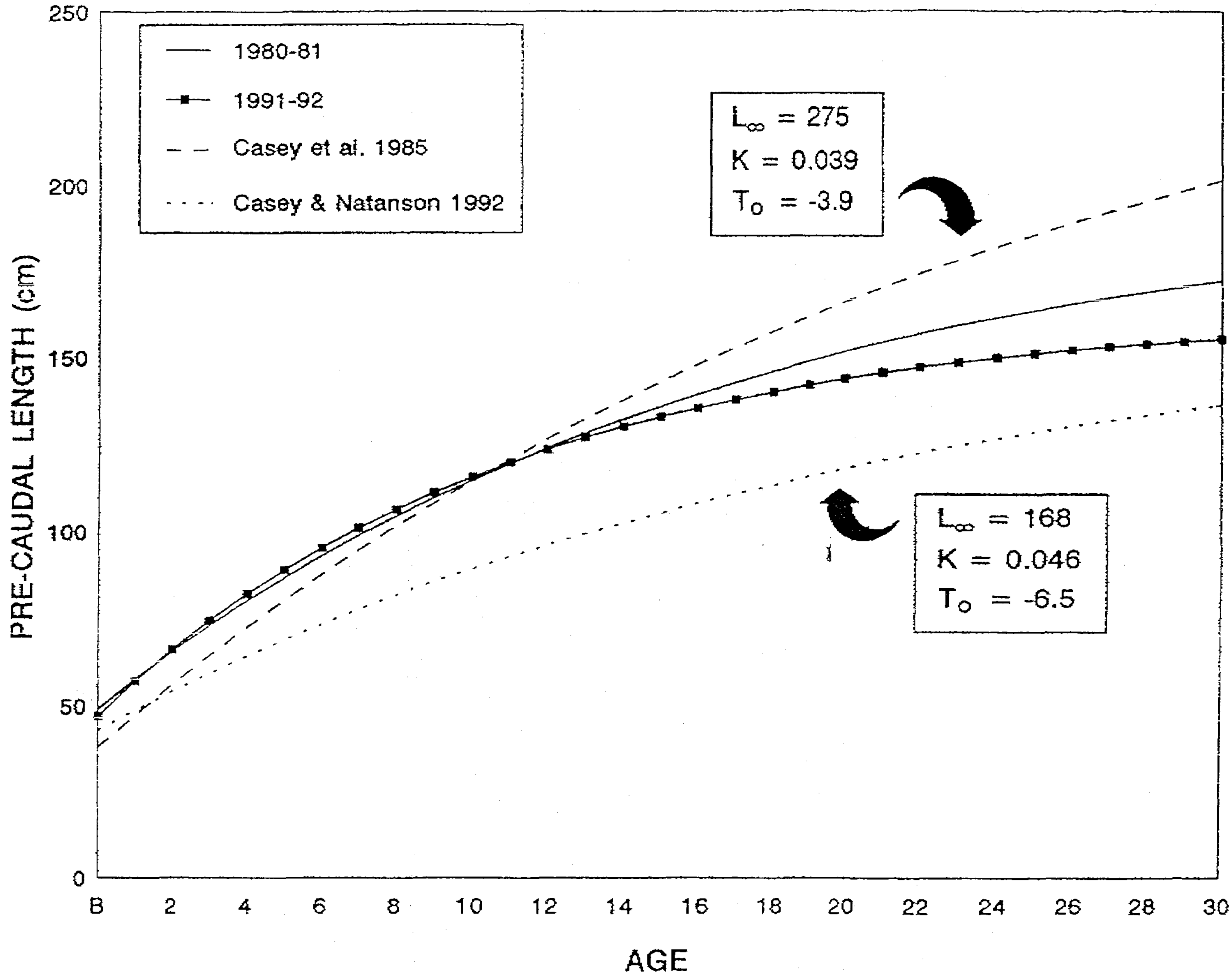
the stock (see Musick et al. 1993). In large carcharhinids like sandbar sharks, there is a correlation between size (age) of a female and litter size (Colvocoresses and Musick 1989; Hoff 1990). Therefore, recruitment is highest at high stock levels containing more large females.

2. Compensatory growth is well known in teleosts, particularly those with rapid relative growth rates and early age at maturity. Such species are often subjected to "boom and bust" recruitment, with poor parent stock-recruit relationships. There is little evidence that sharks are capable of such compensatory growth within the trophic limits available in the wild. Since most sharks are K-selected species, their evolution has been focused on long life, (high survival), low fecundity, late maturity, and maintaining large numbers of year classes at the carrying capacity of the environment. There has been little natural selection to evolve the genetic capacity to be able to increase growth when additional resources are available. Innate growth rates in sharks may be more closely aligned to those in mammals with little capacity to respond to environmental fluctuations. Accelerated growth for some sharks has been noted in captivity where sharks have to expend little or no energy in capturing prey. In the wild, sharks such as the sandbar or blacktip tend to have a very wide array of

fish and crustacean prey organisms. Thus, even under conditions of high shark density, prey availability may limit growth little. Sminkey (1994) compared the growth rates in sandbar sharks from the western North Atlantic from two time periods: 1980 and 1981, before the recent intensive increase in the commercial shark fishery and 1990 and 1991, when sandbar populations had been reduced to ca. 20% of what they had been in 1980. Also in 1990 and 1991, because of overfishing, the maximum size individuals available for age analysis was smaller than in 1980 and 1981, and L_∞ values were smaller. Consequently there was a small difference in k coefficients for the two periods because k is correlated with L_∞. However, there was little actual difference in the growth curves from the two periods (Fig. 1).

3. Changing the demography of fish populations toward younger, faster-growing individuals may increase average population growth and production in fast-growing teleosts. However, if sharks do not increase recruitment with smaller stock sizes (premise 1), and growth is more or less static, then premise 3 is meaningless. Moreover, the slow growth and very late maturity of many shark species suggest that recruitment overfishing may occur at yields that are below the maxima predicted from classic surplus production parabolas. Also numerous researchers working with

Figure 1



250
200
150
100
50
0
PRE-CAUDAL LENGTH (cm)
1980-81
1991-92
Casey et al. 1985
Casey & Natanson 1992
L∞ = 275
K = 0.039
To = -3.9
L∞ = 168
K = 0.046
To = -6.5
B
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
AGE

other K-selected species have argued that the MSY does not occur at the highest point of the parabola (i.e. at half the virgin biomass), but rather towards the pre-fished condition (i.e. at 60-70% virgin biomass).

In addition to the above discussion Ricker (1958) cautioned against using biomass dynamics type models with fishes like sharks:

> "with long-lived fishes, a big danger lies in the slow reaction of surplus production to stock density".

The application of biomass dynamics models in shark management is difficult at best. Consequently, the existing shark FMP with T.A.C.'s predicated on the classic assumptions made for teleosts, may be on unfirm ground, and the T.A.C.'s themselves may be unfounded.

Alternate Methods of Evaluating the T.A.C.

One method that might be useful in evaluating whether the T.A.C.'s in the management plan are reasonable is to use the fishery independent CPUE trend data from the VIMS long-line monitoring program begun in 1973 (Musick et al. 1993, Musick et al. 1994). The analysis of the VIMS data shows a steady decline in sandbar and other large coastal sharks from the mid-1970's and early 1980's to the early 1990's. This same trend is reflected well in Heuter's Florida Recreational Fishing Tournament data (Heuter 1994) and in the data from the Large Pelagic Logbook Program and Japanese Long-line Bycatch

Program (Cramer 1994). In addition, both the VIMS data and the Heuter data show a drastic decrease in the CPUE of large size classes of large coastal sharks. If we analyze the VIMS CPUE for large coastals (Musick et al. 1994) and the recreational and commercial landings (provided in the FMP) from 1980 to 1985 an estimate may be made of the standing stocks of sharks along the Atlantic coast in 1980.

From 1980 to 1985 the VIMS index declined from 8.26 to 3.67. Thus, the stock had declined about 56% over six years, or an average of 9.3% per year. During the same period the average annual combined landings of sharks were about 4773 mt = 9.3% of the standing stock in 1980. Therefore, the standing stock was $\simeq$ 51,323 mt.

If one follows this logic further to try to estimate what stock was left in 1990, a comparison of the VIMS CPUE in 1980 (8.26) with that in 1990 (1.69) suggests that the stock in 1990 was only 0.20 of that in 1980; or 0.20 X 51,323 = 10,265 mt.

The shortcomings of the method are that the catch statistics for 1980-85 include pelagics and small coastals as well as large coastals, whereas the VIMS data are based on large coastals alone. However, during the period 1980-85 recreational landings probably were comprised of mostly large coastal species and some pelagics, with relatively little contribution from small coastals by weight. Furthermore, the Japanese Long-Line Bycatch data and Pelagic Logbook data (Cramer 1994) show a large decline in CPUE for pelagic sharks during the same time period, and the overall trends are similar to those in the VIMS data.

Parrack's (1990) estimate of standing stock of large coastal sharks in 1990 was 678,208 sharks which had an average wt of 26.92 lbs. This is equal to a standing stock weight of about 8281 mt, a value not too different from the 10,265 mt derived from the VIMS CPUE data and average landings in the early 1980's. (The VIMS estimate would be expected to be higher because it is predicated on all groups of sharks landed from 1980-85). However, the annual rate of replacement determined by Parrack's method, 26% per year, is much higher than that calculated for both fast-growing and slow-growing carcharhinids using accepted demographic models (Bonfil-Sanders, 1993; Cailliet 1993; Cortes, 1994; Hoenig and Gruber 1990; Hoff 1990). Recent modeling in our laboratory (Table 1) suggests that for sandbar sharks the annual population increase rate can vary from 6% to 12.2% with an age at maturity of 15 years. If a more conservative age of first maturity of 29 years is used (based on tagging data) then the annual population increase rate may vary from 2.9% to 5.3%. These low rates of intrinsic increase are probably close to the real situation and reflect the K-selected life history parameters typical of virtually all sharks. The reasons for the discrepancy might lie in the use of the number of fishing vessels in the Parrack model as an estimate of fishing effort. Long-line vessels might increase the number of sets, or the number of hooks set, etc. to increase their effort. In addition, major components of the fishery such as the winter long-line fishery off North

Table 1

LIFE HISTORY TABLE FOR SANDBAR SHARKS

Max. Age	Annual Survival Age 0	Annual Survival Age 1	Annual Survival Age 2+	# Female Offspring	R	T	r	Population Increase Rate (%/yr)
				Age of Maturity = 15				
30	0.95	0.95	0.95	2.25	11.67	21.42	0.115	12.2
40	0.95	0.95	0.95	2.25	15.35	24.70	0.111	11.7
50	0.95	0.95	0.95	2.25	17.56	27.26	0.105	11.1
30	0.50	0.70	0.95	2.25	4.53	21.42	0.070	7.3
40	0.50	0.70	0.95	2.25	5.95	24.70	0.072	7.5
50	0.50	0.70	0.95	2.25	6.81	27.26	0.070	7.3
30	0.75	0.95	0.95	2.25	9.21	21.42	0.104	10.9
40	0.75	0.95	0.95	2.25	12.12	24.70	0.101	10.6
30	0.75	0.90	0.90	2.25	3.15	20.36	0.056	5.8
40	0.75	0.90	0.90	2.25	3.61	22.20	0.058	6.0
				Age of Maturity = 29				
50	0.95	0.95	0.95	2.25	6.88	37.48	0.051	5.3
60	0.95	0.95	0.95	2.25	8.20	40.31	0.052	5.4
50	0.75	0.95	0.95	2.25	5.43	37.48	0.045	4.6
60	0.75	0.95	0.95	2.25	6.47	40.31	0.046	4.7
50	0.50	0.70	0.95	2.25	2.67	37.48	0.026	2.7
60	0.50	0.70	0.95	2.25	3.18	40.31	0.029	2.9
50	0.75	0.90	0.90	2.25	0.80	35.60	**-0.006**	**-0.6**

Carolina can provide catch-per-effort trends that are misleadingly high. In the winter, large vulnerable concentrations of sharks occur in a relatively narrow geographic band at the edge of the Gulf Stream sandwiched by cold coastal water to the west and the edge of the continental shelf to the east. In summer, these sharks disperse inshore off the Carolinas and north into the mid-Atlantic Bight.

Using similar population models based on known demographic parameters, Sminkey (1994) showed that if the F (0.25) recommended in the FMP to achieve MSY was applied to sandbar sharks (the most important species in the Atlantic fishery) the population would decrease by >7%/yr (using 15 yr at the age at maturity and 8 yr as the age at first capture). Fishing mortality (F) would have to be reduced to 0.10 in order to achieve any population growth and that would be minimal (1.15%/yr). Sandbar sharks may not mature until 29 years of age and in addition, recent trends in the fishery suggest that the age at first capture may be 4 or 5 years of age. Under these conditions, it is virtually impossible to maintain an economically viable fishery and achieve any population growth.

Other Problems

I agree with the workshop recommendation to close shark pupping and nursery grounds to fishing. However, the workshop report seems only to recognize the summer inshore pupping areas. In winter, young sharks move south and/or offshore to winter nursery areas. For instance, juvenile sandbar sharks from the Middle-Atlantic apparently overwinter south of Cape Hatteras in large concentrations over the outer contintental shelf, between the Gulf Stream to the east and cold coastal water to the west. These concentrations are particularly vulnerable to fishing. Winter offshore nurseries should be protected as well as summer inshore nurseries.

Another major problem is that the catch of "small coastal sharks" probably includes substantial numbers of juvenile sharks managed as "large coastal" species. VIMS monitoring in the sandbar nursery in lower Cheseapeake Bay shows that the number of year classes using the summer nursery have declined from 4-5 in 1980-81 to 3-4 in 1989 to 2 in 1993. We believe this reduction in older year classes of juveniles has occurred probably because of winter fisheries off North Carolina, which land young sandbars as "small coastal sharks" or "dogfish". The species composition in these fisheries should be closely monitored, and appropriate action taken by NMFS.

Conclusions

In light of the above discussions the following conclusions are apparent:

1. The basic biomass dynamics model used in the FMP to estimate T.A.C. is probably inappropriate for long-lived K-selected animals like sharks.
2. When compared to another method using fishery independent data to estimate stock size in 1990, the standing stock of large coastals estimated in the FMP seems reasonable.

3. However, comparison of the annual rate of increase estimated in the FMP to rates derived from direct demographic analyses for several shark species suggests that the rate used in the FMP was from 2 to >10 times too high.
4. Because the annual rate of increase is an important element in calculating surplus production and T.A.C.'s, as well as in estimating the time it will take for the stock to recover, the estimates of these parameters in the FMP are highly questionable. Therefore, the T.A.C.'s in the FMP for large coastal sharks are risk prone not risk adverse.
5. If landings of ca. 4000-5000 mt per year were leading to a 10% annual decline in the stock in the early 1980's, how can T.A.C.'s of similar magnitude be used to rebuild the stock in 1995 when it has been reduced by 80-90%?
6. The demographic analyses suggest that even if the directed fishery were closed, the stocks of large coastal sharks will take decades to recover to levels of the late 1970's and early 1980's. Even so the stocks at that time were not virgin, because data provided in the FMP suggest that the recreational fishery harvested large numbers of sharks throughout the 1970's, and Anderson (1980) suggested that sharks in the Atlantic were probably already "excessively exploited" by 1980.

7. Using NMFS own criteria for other groups of animals (marine mammals, sea turtles) with life history traits and population declines similar to those shown for large sharks in the Atlantic, many large shark species such as sandbar, dusky, tiger, and sand tiger could be classified as "depleted" or even "threatened" under the U.S. Endangered Species Act (ESA).
8. Given the above information, it is obvious that maintaining shark catch quotas at 1994 levels is risk prone and will not allow the stocks to rebuild, but rather will contribute further to their decline. Further reduction in quotas (i.e. to 50% 1994 levels) as I suggested earlier this year probably will not lead to stock recovery (based on Sminkey, 1994). Therefore, the most prudent action NMFS could take to protect the shark resource, and to provide stock recovery would be to close the directed fishery and seriously evaluate whether species such as dusky and sandbar sharks should be classified as "depleted" or even listed as "threatened".

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