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A Preliminary Analysis of the Effects of Fishing on Shortnose Sturgeon

by

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SUMMARY

Three populations of shortnose sturgeon (Saint John, Hudson, and Pee Dee) were analyzed in order to provide a representation of the effects of fishing on populations with clinal (latitudinal) differences in reproductive strategies. The northernmost population (Saint John) contains the slowest growing and latest maturing individuals. Growth in the younger age groups is faster and fish mature earlier for the more southern populations. The Saint John also has the highest potential lifetime fecundity (197,000 eggs) compared to the Hudson (96,000 eggs) and Pee Dee (111,000 eggs) populations.

The age at first capture that results in the global maximum yield per recruit is highest for the Saint John population (30 years). The Hudson and Pee Dee populations have corresponding values of 17 and 10 years, respectively. Estimates of F0.1 for this age at first capture are approximately equal for all three populations (0.075-0.077).

Harvest estimates (in numbers and weight) were calculated for the Saint John and Hudson populations under two options for fishing mortality (F = F0.1 and F near or at Fmax) and two options for age at first capture (age corresponding to global maximum yield per recruit and age when at least 50% of females are mature). Harvest estimates range from 300 to 500 fish (2,500 kg to 4,200 kg) for the Saint John population and from 600 to 1,300 fish (2,500 kg to 3,000 kg) for the more abundant Hudson population. Fishing the populations at F0.1 rather than at or

near Fmax would increase the percentage of the maximum spawning stock biomass per recruit from 30-50% to 60-80%.

Based on the biological characteristics of the populations examined, and information on other species of sturgeon exploited in the Great Lakes and on the Pacific Coast, a conservative approach to management is recommended. The analysis of the effects of various harvest strategies on the spawning stock biomass per recruit suggests that management of shortnose sturgeon at the F0.1 level may provide enough spawning stock biomass to maintain stock levels. However, even the F0.1 strategy should be approached discretely since losses due to other sources of mortality (incidental catch, pollution, power plant impingement, etc.) are presently not being estimated.

INTRODUCTION

The shortnose sturgeon (*Acipenser brevirostrum*) was placed on the Endangered Species List in 1967 by the U.S. Fish and Wildlife Service (32 FR 4001, 11 March 1967). The endangered status of the species was reconfirmed by the National Marine Fisheries Service (NMFS) in 1974 (39 FR 41367-41377) under the Endangered Species Act of 1973 (as amended), giving the NMFS jurisdiction over the species. Listing the shortnose sturgeon was undertaken in response to a perceived decline in abundance of populations along the Atlantic coast, as evidenced by declines in commercial harvest. General reasons given for the perceived declines were pollution and overexploitation by directed and non-directed fisheries (Anon. 1982).

Since the initial listing, surveys have been conducted on various shortnose sturgeon populations along the Atlantic coast. Populations surveyed include those in the Saint John River in New Brunswick (Dadswell 1979), several Maine rivers (Squiers et al. MS 1981), the Connecticut River (Taubert 1980; Buckley and Kynard MS 1981), the Hudson River (Dovel MS 1981), the Delaware River (Hastings MS 1983), the Pee Dee River in South Carolina (Marchette and Smiley MS 1980), and the Altamaha River in Georgia (Heidt and Gilbert MS 1978). Because of these surveys, data now exist on population sizes, growth rates, maturity, fecundity, and mortality rates, although the information is far from complete and varies in quality and usefulness among the populations surveyed.

Recently, the Northeast Regional Office of the NMFS undertook a re-evaluation the status of the shortnose sturgeon populations. This report presents the results of the NEFC's preliminary analysis of yield per recruit and spawning stock biomass per recruit in response to fishing. Three populations are analyzed (Saint John, Hudson, and Pee Dee) in order to provide a representation of the effects of exploitation on populations with clinal (latitudinal) differences in reproductive strategy. Harvest levels and associated reductions in spawning stock biomass for two populations (Saint John and Hudson) are calculated for combinations of fishing mortality rates and ages-at-capture as derived in the yield-per-recruit analysis.

LIFE HISTORY PARAMETERS

A table of life history parameters was prepared for each of three river systems (Saint John, Hudson, and Pee Dee; tables 1-3) for use in the analyses. Each table contains information on the mean length, mean weight, fraction female, fraction mature female, and average fecundity per fish for each age. Sources of data are noted in the individual tables.

Maturity data for all three populations indicate that females spawn only once every three years. Therefore, the fraction of females mature in each age class was divided by three to account for this characteristic. It is assumed in the analyses that both spawning and non-spawning fish are equally vulnerable to exploitation once they reach the age of recruitment into the fishery.

The northernmost river, the Saint John, contains the oldest (50 years) and the latest maturing (100% at 25 years) individuals. The southernmost river, the Pee Dee, contains fish only up to 25 years of age. Females in this river are 100% mature by an age of 15 years. Age and maturity parameters for the Hudson River population are, as expected, intermediate to the other two populations.

The Hudson and Pee Dee populations grow faster than the Saint John population in the younger age groups, but slow down in growth much sooner. At age 8 years, the Pee Dee population averages 65 cm in length and 1.8 kg in weight (Table 3), the Hudson population averages 51 cm in length and 1.0 kg in weight (Table 2), and the Saint John population averages 35 cm in length and 0.3 kg in weight (Table 1). However, by age 25 years, the Pee Dee population averages 83 cm in length and 3.8 kg in weight, the Hudson population averages 80 cm in length and 4.2 kg in weight, and the Saint John population averages 88 cm in length and 5.8 kg in weight.

Another striking difference between the Saint John population and the populations farther south is in the expected lifetime fecundity of an age 1 female. Assuming a survival rate of 95% per year with no exploitation (based on Dadswell et al. in press), the expected lifetime fecundity can be calculated using the following equation:

$$L = \sum_{i=1}^{n} N_i M_i F_i \qquad (1)$$

where L is the expected lifetime fecundity of the population, n is the maximum number of ages in the population, N is the number of females remaining at age i, M is the proportion of females in age class i that are mature (divided by 3 to account for tri-annual spawning habits), and F is the average fecundity of females in age class i. Substituting 1 for the number of females at age 1 in Equation (1) gives the expected lifetime fecundity per recruit.

Using the data listed in tables 1-3, the expected lifetime fecundity of an age 1 female recruit in the Saint John population is approximately 197,000 eggs; whereas, an age 1 female recruit in the Hudson population would yield approximately 96,000 eggs and an age 1 female recruit in the Pee Dee population would yield approximately 111,000 eggs. The greater growth rate in the older age classes and the longer life of the Saint John population account for the almost doubling of expected lifetime fecundity with respect to the more southern populations.

YIELD PER RECRUIT

The Thompson-Bell yield-per-recruit model (Thompson and Bell 1934) was used with input data from tables 1-3 to investigate the effects of varying ages of entry into the fishery (tc) and varying levels of fishing mortality (F) on the three populations. Natural mortality was held constant at M = 0.05 (Dadswell et al. in press). The model was also used to estimate a reference level of fishing mortality that is frequently used by managers to avoid overfishing (F0.1, equals the F-level at which the yield-per-recruit slope is equivalent to 10% of the slope at the origin).

The slowest-growing and latest maturing population (Saint John) exhibited the highest tc that corresponds to the global maximum yield per recruit (30 years, Table 4 and Figure 1), hereafter abbreviated as tc(max). The Hudson River and Pee Dee populations had tc(max)´s of 17 years and 10 years, respectively. Estimates of F0.1 (0.075-0.077) were approximately equal for all three populations. The maximum value of F at tc(max), Fmax, is undefined (F is infinitely large at the exact value of tc(max)); however, the F-value at which the slope of the yield-per-recruit curve is 1% of the slope at the origin (Fmax´) gives an indication of the level of F above which yield per recruit increases at a relatively small rate at tc(max). For all three populations this value is approximately 0.3. Values for Fmax can be calculated for tc´s other than tc(max).

SPAWNING STOCK BIOMASS PER RECRUIT

The effect of exploitation on the spawning potential of the three shortnose sturgeon populations can be assessed with an analysis of the spawning stock biomass per recruit (SSB/R). The value of using this method is discussed in Shepard (1982) and is a modification of the Thompson-Bell yield-per-recruit model to accommodate the fraction of mature individuals in each age class. Maximum SSB/R (achieved with no exploitation) serves as a benchmark against which SSB/R estimates with varying F´s and tc´s are compared. Isopleths representing percentages of maximum for SSB/R with varying levels of F and tc for the three shortnose sturgeon populations are shown in Figure 2.

To decide which are the most desirable levels of F and tc in the absence of adequate information related to the relationship between spawning stock and subsequent recruitment, a subjective decision about the percentage of the maximum SSB/R must be made. Species like silver hake (Merliccius bilinearis), haddock (Melanogrammus aeglifinnus), and Atlantic cod (Gadus morhua) may be fished to 20-40% of the maximum SSB/R and still have enough spawning stock biomass for maintaining stock levels (Gabriel et al. MS 1984). A more conservative range of 50-70% of maximum should be initially chosen for shortnose sturgeon if fishing is re-introduced. Once adequate stock and recruitment information are available from the individual populations, this range may be shifted up or down.

To keep the SSB/R values in the 50-70% of maximum range, either fishing mortality must be held at relatively low levels or tc must be increased as F is increased. For example, if 70% of maximum was the target level of SSB/R for the Saint John population, and an age at first capture of 30 years was chosen, then F would need to be maintained at approximately 0.10. At an age of first capture of 17 years for the Hudson River population, F would need to be near 0.14 to maintain the 70% level. Although F would still need to be maintained at a relatively low value for the faster-growing and earlier-maturing Pee Dee population, the 70% level would be attainable over a much wider range of tc values.

The implication of the series of curves presented in Figure 2 is that relatively low fishing mortality rates must be maintained for all three populations, irrespective of the individual population characteristics, if 50-70% of maximum SSB/R is to be maintained. When information on yield per recruit is combined with the SSB/R analysis, optimal tc values occur at relatively old ages, especially in the Saint John River. This implies that, unless the fish are protected from exploitation for an extended period of time, reproduction could be adversely affected.

ANALYSIS OF HARVEST LEVELS

Population estimates for shortnose sturgeon are available for five river systems (Saint John River: Dadswell 1979; Kennebec River, Maine: Squiers et al. MS 1981; lower Connecticut River: Taubert 1980; Holyoke Pool, Connecticut River: Buckley (cited in Dadswell et al. in press); Hudson River: Dovel MS 1981; and Delaware River: Hastings MS 1983). These estimates are based on tag recapture experiments conducted over a limited number of years between 1976 and 1982. The Saint John and Hudson Rivers were chosen for the analysis of appropriate harvest levels because stock abundance, growth, and maturity data were most complete for these systems.

Values of tc, F0.1, Fmax, and Fmax′ were based on the yield-per-recruit analyses for the Saint John and Hudson populations. It is also assumed that the populations will maintain stable age distributions with a constant level of recruitment from year-to-year under the fishing mortality and tc options. A detailed explanation of the computational technique used to estimate harvest levels for the two populations is provided in the Appendix.

The number of incoming recruits at age 1 for each population was determined from backcalculations using the estimates of population size and a natural mortality rate of 0.05 (Dadswell et al. in press). The total fishable stock was calculated with the estimate of tc(max) and age at first capture equal to the age when at least 50% of the females are mature, hereafter abbreviated as tc(50), for the Saint John (30 years and 17 years, respectively) and Hudson River (17 years and 10 years, respectively) populations.

At tc(max), the estimated stock size available to a fishery in the Saint John River would initially be 7,318 (Table 5 and Appendix). The initial catch from this stock would be 1,829 fish (16,469 kg) at Fmax′ (F=0.3). However, the initial catch is based on fishing a currently unexploited population. Eventually, the catch at Fmax′ would be much less than the initial harvest, equal to a long-term equilibrium catch of 472 fish (4,248 kg) per year. Equilibrium is probably never achieved in nature, but the long-term average catch should approximate the theoretical equilibrium catch. Using F0.1 (F = 0.076) instead of Fmax′, the initial catch from the Saint John population would be about 520 fish (5,267 kg), and would eventually equal 296 fish (2,992 kg) per year.

Subtracting the incidental catch of approximately 200 fish per year (Dadswell 1979) gives a range of initial direct catch between 320 and 1,629 fish, and a range of 96-272 fish for the eventual catch. Dadswell (1975) used a yield-per-recruit model based on an 8-inch gillnet catch curve (representing a tc of approximately 26 years, Dadswell et al. in press) to estimate a sustainable yield for the Saint John population. Their estimate of 350 shortnose sturgeon per year (excluding an incidental catch of 200 fish per year) is quite close to our estimate of an initial catch of 320 fish based on the F0.1 strategy.

With tc = tc(50) for the Saint John population, a total of 3,539 fish (17,743 kg) would be initially harvested using an Fmax strategy, and a total of 639 fish (3,890 kg) would be initially harvested using an F0.1 strategy. Eventually, the annual harvest with tc = tc(50) would be 510 fish (2,579 kg) using an Fmax strategy and 387 fish (2,364 kg) using an F0.1 strategy.

The catch potential for the Hudson River stock is higher because the projected population size is greater and the fish grow faster in younger age classes (Table 2). At tc = tc(max), the initial size of the exploitable stock would number about 20,318 fish (Table 5). An initial catch of 5,142 fish (15,584 kg) would be possible with Fmax′ (F = 0.3), eventually dropping to 1,296 fish (3,776 kg) per year, and an initial catch of 1,432 fish (4,864 kg) would occur at F0.1 (F = 0.075), eventually dropping to 603 fish (2,044 kg) per year.

With tc = tc(50) for the Hudson population, a total of 3,132 fish (6,685 kg) would initially be harvested using an Fmax strategy, and a total of 1,479 fish (3,609 kg) would be harvested using an F0.1 strategy. After the population has been fished, the harvest would drop to 1,320 fish (2,811 kg) per year using an Fmax strategy and 1,024 fish (2,498 kg)per year using an F0.1 strategy. No information is available on the amount of incidental catch of shortnose sturgeon currently occurring in the Hudson River.

The estimated impact of a fishing strategy of Fmax, Fmax´, or F0.1 on the spawning stock biomass per recruit on each shortnose sturgeon population is shown in Table 5 for tc values equal to tc(50) and tc(max). For both populations, the F0.1 strategy would result in a level of SSB/R approximately within or above the range suggested in the previous section as a conservative choice (50-70% of the maximum SSB/R).

DISCUSSION

Responses of other sturgeon species to exploitation suggest a conservative approach to management. Semakula and Larkin (1968) suggested a "modest" fishery on older female white sturgeon (Acipenser transmontanus) in the Fraser River because of the possibility of recruitment failure, and suggested a sustainable yield of only 25% more than the existing incidental catch (existing tc = 10 years and existing F = 0.13 with M = 0.05). Lake sturgeon (Acipenser fulvescens) was the first species in the Great Lakes that was affected by intensive exploitation and the only one knowlingly depleted by man (Smith 1968). Its slow growth and late maturity were considered as strong influences in its response to the fishing pressure. Priegel (1973) considered exploitation rates of 13-17% too high for lake sturgeon in the Menominee River, Wisconsin, and recommended a rate no higher than 5%.

The analysis of the effects of various harvest strategies on the SSB/R of shortnose sturgeon (Table 5) indicate that management at F0.1 levels may provide enough spawning stock biomass to maintain stock levels. However, even the F0.1 strategy should be approached discretely since other sources of mortality (incidental catch, pollution, and power plant impingement, Dadswell et al. in press) are presently not being estimated.

The estimates of catch (Table 5) can be used to regulate collecting permits and incidental mortalities even if fisheries on the stocks are not resumed. More refined estimates of catch are dependent on the future availability of information on the relationship between stock and recruitment, and on population size. Our analysis points to the immediate need for abundance estimates of recruit-age fish over an adequate number of years. These abundance estimates do not need to be absolute estimates, only indices of relative change in abundance from year-to-year.

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APPENDIX

Example of Calculations to Determine Harvest Levels (Saint John River)

The assumption of a stable age distribution allows back-calculation to a population size for ages 1+, based on the population parameter estimates provided in Dadswell (1979). The population size estimated by Dadswell (1979) is for fish 50 cm and larger.

Age at 50 cm = 11 years (from Table 1)

$$N_{t+} = N_{1+} e^{-Zt}$$

where N_{t+} is the population size for ages t+ (11+ years), N_{1+} is the population size for ages 1+, and Z is the total annual instantaneous mortality rate. For ages 1-11, Z = M (the instantaneous natural mortality rate) = 0.05 (Dadswell et al. in press). With this relationship, an initial population size of 31,119 fish is calculated. For tc = tc(max) = 30 years, the fishable stock size that is initially available to harvest would be:

$$N_{30+} = 31{,}119e^{-0.05*29}$$

$$= 7{,}318 \text{ fish}$$

The exploitation rate (u) at Fmax´ (F = 0.3) is calculated as:

$$u = F(1-e^{-Z})/Z$$

where $Z = F+M$ (= 0.3+0.05 = 0.35), and u is the exploitation rate (= 0.25). This exploitation rate implies a catch from the unexploited stock of:

$$0.25 \times 7{,}318 = 1{,}829 \text{ fish.}$$

The total weight of the initial harvest is the catch in numbers multiplied by the average weight of the catch. Since total mortality is assumed equal for all ages available to the fishery, the average weight of the catch can be calculated using the following equation:

$$\text{ave. weight} = \left(\sum_{i=tc}^{n} W_i e^{-Z(i-tc)}\right) / \left(\sum_{i=tc}^{n} e^{-Z(i-tc)}\right)$$

where W_i is the average weight of the fish at age i (from tables 1 or 2), and n is the maximum age of the exploited population.

The number of fish eventually harvested per year under the various tc and F options is the estimated number of recruits to the population at age 1 multiplied by the appropriate yield-per-recruit value. For the Saint John population, the number of recruits at age 1 (R) is calculated as:

$$R = N_{1+} / (1 + e^{-Z} + e^{-2Z} + \ldots + e^{-(n-1)Z})$$

$$= 31{,}119/(1 + e^{-0.05} + e^{-2(0.05)} + \ldots + e^{-49(0.05)})$$

$$= 1{,}653 \text{ fish.}$$

The eventual harvest (in weight) is, therefore, the value of R times the value of yield per recruit for given values of tc and F. The harvest in numbers is obtained by dividing the harvest in weight by the average weight of the catch. The average weight of of the catch is calculated as above.

Table 1. Life History Parameter Values for Shortnose Sturgeon in the Saint John River, New Brunswick, Based on Dadswell (1979)

Age (yrs)	Mean Length (cm)	Mean Weight (kg)	Fraction Female (%)	Fraction* Mature (%)	Fecundity** (000's)
8	35	0.31	-	0	-
9	40	0.48	-	0	-
10	45	0.69	47	0	-
11	51	1.33	47	0	-
12	55	1.32	47	3	15.3
13	59	1.65	47	5	19.0
14	62	1.93	47	7	22.3
15	65	2.25	55	9	26.0
16	68	2.59	55	12	30.0
17	71	2.98	55	17	34.5
18	74	3.33	55	18	38.5
19	76	3.63	55	20	42.0
20	78	3.94	76	23	45.6
21	80	4.28	76	26	49.5
22	82	4.63	76	29	53.6
23	84	5.01	76	31	57.9
24	87	5.40	76	33	62.5
25	88	5.81	81	33	67.2
26	90	6.25	81	33	72.3
27	92	6.71	81	33	77.6
28	94	7.19	81	33	83.2
29	96	7.69	81	33	89.0
30	98	8.22	86	33	95.1
31	99	8.63	86	33	99.8
32	100	8.91	86	33	103.1
33	101	9.20	86	33	106.4
34	102	9.50	86	33	109.8
35	103	9.80	100	33	113.3
36	104	10.10	100	33	116.9
37	105	10.42	100	33	120.5
38	106	10.74	100	33	124.2
39	107	11.07	100	33	128.0
40	108	11.40	100	33	131.9
41	109	11.74	100	33	135.8
42	110	12.09	100	33	139.9
43	111	12.45	100	33	144.0
44	112	12.81	100	33	148.2
45	113	13.18	100	33	152.4
46	114	13.56	100	33	156.8
47	115	13.94	100	33	161.2
48	116	14.33	100	33	165.8
49	117	14.73	100	33	170.3
50	118	15.14	100	33	175.1

*Estimates of fraction mature divided by 3 to reflect tri-annual spawning habits

**Based on estimate of 11,568 eggs/kg

Table 2. Life History Parameter Values for Shortnose Sturgeon in the Hudson River, Based on Dadswell et al. (in press)

Age (yrs)	Mean Length (cm)	Mean Weight (kg)	Fraction Female (%)	Fraction* Mature (%)	Fecundity** (000's)
1	18	0.03	-	0	-
2	26	0.11	-	0	-
3	35	0.29	-	0	-
4	40	0.44	-	0	-
5	43	0.56	-	3	7.4
6	46	0.70	-	5	9.3
7	48	0.80	30	7	10.6
8	51	0.98	30	9	13.0
9	53	1.11	40	12	14.7
10	55	1.25	40	17	16.6
11	58	1.48	40	18	19.7
12	59	1.57	40	20	20.9
13	61	1.75	80	23	23.2
14	63	1.94	80	26	25.8
15	65	2.15	80	29	28.6
16	67	2.37	80	31	31.5
17	69	2.61	80	33	34.7
18	70	2.73	80	33	36.3
19	71	2.86	80	33	38.0
20	72	2.99	80	33	39.7
21	73	3.13	100	33	41.6
22	75	3.42	100	33	45.4
23	77	3.72	100	33	49.4
24	78	3.88	100	33	51.5
25	80	4.22	100	33	56.1
26	81	4.39	100	33	58.3
27	82	4.57	100	33	60.7
28	83	4.66	100	33	61.9
29	83	4.75	100	33	63.1
30	84	4.85	100	33	64.4

*Estimates of fraction mature divided by 3 to reflect tri-annual spawning habits

**Average of Pee Dee and Saint John estimates of number of eggs per kg (= 13,284 eggs/kg)

Table 3. Life History Parameter Values for Shortnose Sturgeon in the Pee Dee River, Based on Dadswell et al. (in press)

Age (yrs)	Mean Length (cm)	Mean Weight (kg)	Fraction Female (%)	Fraction* Mature (%)	Fecundity** (000's)
1	25	0.10	-	0	-
2	39	0.38	-	3	5.7
3	46	0.63	-	5	9.5
4	52	0.91	-	7	13.7
5	56	1.15	31	9	17.3
6	60	1.42	31	12	21.3
7	63	1.64	31	17	24.6
8	65	1.81	40	18	27.2
9	67	1.99	40	20	29.9
10	69	2.17	40	23	32.6
11	70	2.27	79	26	34.1
12	71	2.37	79	29	35.6
13	72	2.47	79	31	37.1
14	73	2.58	80	33	38.7
15	74	2.69	80	33	40.4
16	75	2.80	80	33	42.0
17	76	2.92	80	33	43.8
18	77	3.04	80	33	45.6
19	79	3.29	100	33	49.4
20	80	3.42	100	33	51.3
21	81	3.48	100	33	52.2
22	81	3.55	100	33	53.3
23	82	3.62	100	33	54.3
24	82	3.68	100	33	55.2
25	83	3.75	100	33	56.3

*Estimates of fraction mature divided by 3 to reflect tri-annual spawning habits

**Based on estimate of 15,000 eggs/kg for southern stocks (Marchette and Smiley 1982)

Table 4. Estimates of tc(max) and Corresponding F0.1, Based on the Thompson-Bell Yield-Per-Recruit Model, for Three Populations of Shortnose Sturgeon*

Population	tc(max)	F0.1
Saint John River	30 years	0.076
Hudson River	17 years	0.075
Pee Dee River	10 years	0.077

*tc(max) = age at first capture corresponding to the global maximum yield per recruit, and F0.1 = F level at which the slope of the yield per recruit curve is equal to 10% of the slope at the origin.

Table 5. Estimates of Harvest and Associated Percentage of Maximum Spawning Stock Biomass per Recruit (SSB/R) for the Saint John and Hudson Shortnose Sturgeon Populations*

Population	Yield per Recruit (kg)	Harvest No.	Harvest kg	% max SSB/R
Saint John				
tc(50) = 17				
Fmax = 0.110	1.56	510	2,579	30
		(3,539)	(17,872)	
F0.1 = 0.048	1.43	387	2,364	55
		(639)	(3,904)	
tc(max) = 30				
Fmax´ = 0.3	2.57	472	4,248	51
		(1,829)	(16,461)	
F0.1 = 0.077	1.81	296	2,992	79
		(520)	(5,262)	
Hudson				
tc(50) = 10				
Fmax = 0.118	0.99	1,320	2,811	42
		(3,132)	(6,671)	
F0.1 = 0.054	0.88	1,024	2,498	65
		(1,479)	(3,608)	
tc(max) = 17				
Fmax´ = 0.3	1.33	1,296	3,776	49
		(5,142)	(15,220)	
F0.1 = 0.076	0.72	603	2,044	82
		(1,432)	(4,854)	

*See text for definitions of parameters. Values in parentheses indicate initial harvest estimates, i.e. harvest from a previously unfished population.

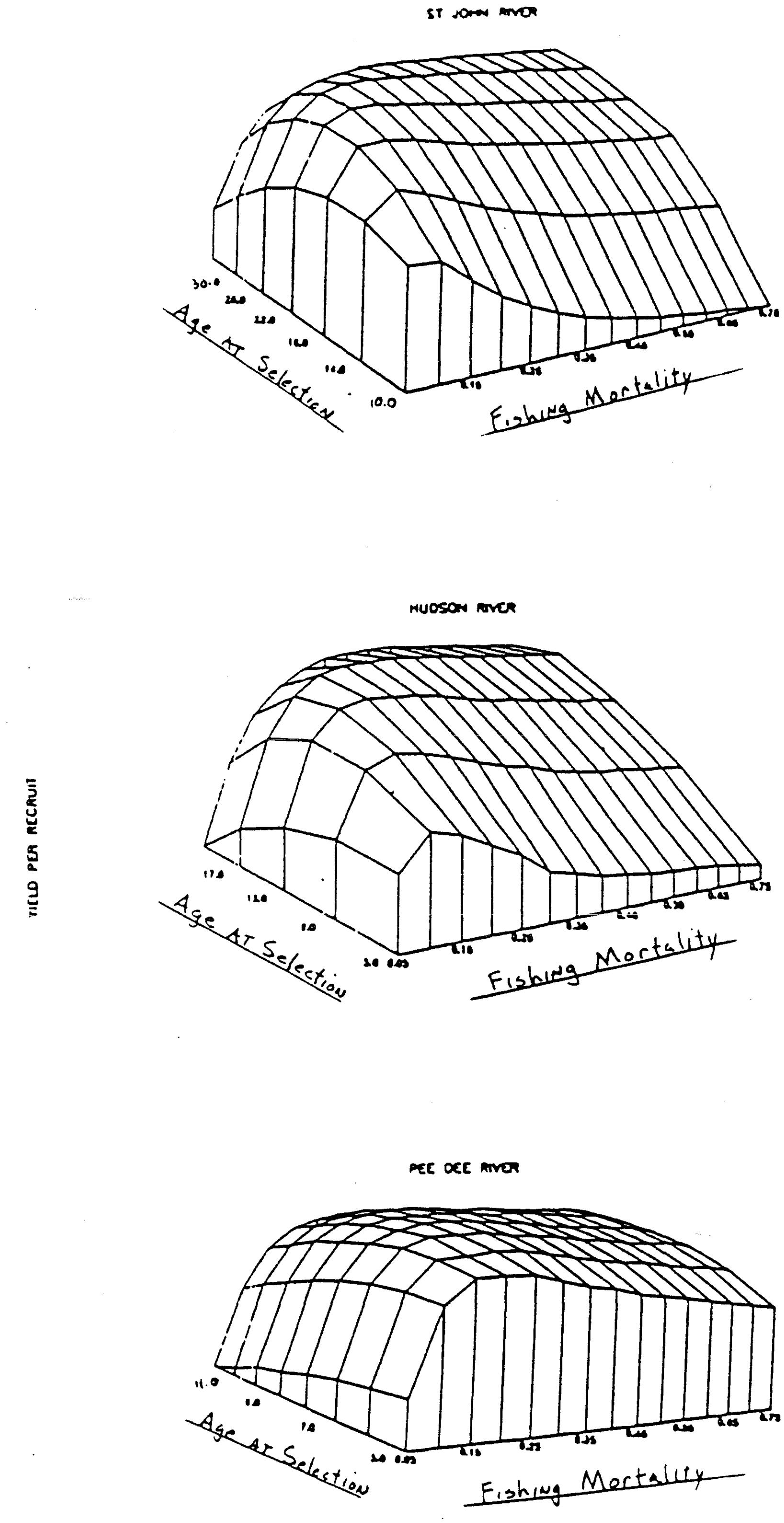

Figure 1. Yield per recruit for three shortnose sturgeon populations. Optimal t_c's are 30, 17, and 10 years for the Saint John, Hudson, and Pee Dee populations, respectively.

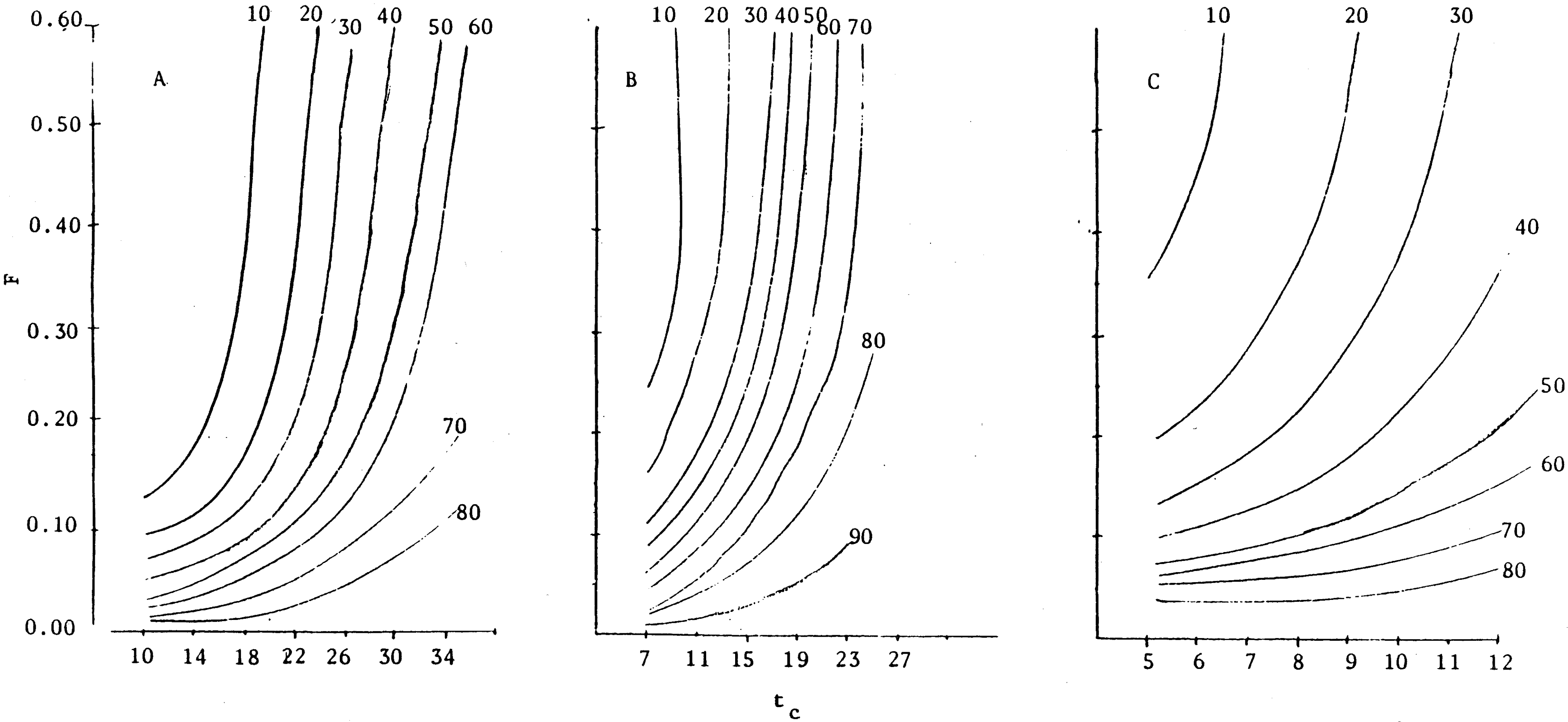

Figure 2. Percent of maximum spawning stock biomass per recruit attainable in three shortnose sturgeon populations: (A) Saint John, (B) Hudson, and (C) Pee Dee, under different options of fishing mortality (F) and age at selection (t_c).