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Sensitivity of North American sturgeons and paddlefish to fishing mortality

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Synopsis

Sturgeons and paddlefish exhibit unusual combinations of morphology, habits, and life history characteristics, which make them highly vulnerable to impacts from human activities, particularly fisheries. Five North American sturgeons (shortnose, Gulf, pallid, Alabama, and green sturgeon) are listed as endangered or threatened by management authorities. Managers have instituted fishery closures for the three other species of North American sturgeons (Atlantic, white, and shovelnose) and paddlefish because of low stock abundance at some point in this century. Reproductive potential in four species I examined (Atlantic, white, and shortnose sturgeon, and paddlefish) is more sensitive to fishing mortality than it is for three other intensively-fished coastal species in North America: striped bass, winter flounder, and bluefish. The sturgeons and paddlefish are generally longer-lived than the three other coastal species, and also have an older age at full maturity, lower maximum fecundity values, and older ages at which 50% of the lifetime egg production is realized with no fishing mortality.

Introduction

Of the 25 chondrostean species still living in the Northern Hemisphere, the paddlefish, *Polyodon spathula*, and eight species of sturgeon are found in North American waters (Birstein 1993): Atlantic sturgeon, *Acipenser oxyrinchus*, shortnose sturgeon, *Acipenser brevirostrum*, white sturgeon, *Acipenser transmontanus*, lake sturgeon, *Acipenser fulvescens*, green sturgeon, *Acipenser medirostris*, pallid sturgeon *Scaphirhynchus albus*, shovelnose sturgeon *Scaphirhynchus platorynchus*, and Alabama sturgeon, *Scaphirhynchus suttkusi*. They inhabit fresh, brackish, and sea water systems in North America, and exhibit three types of life history patterns (after Rochard et al. 1990): (1) their entire life history is spent in fresh water (paddlefish, lake sturgeon, white sturgeon, pallid sturgeon, Alabama sturgeon, and shovelnose sturgeon); (2) adults move into brackish water (white sturgeon and shortnose sturgeon); or (3) adults move into the ocean (white sturgeon, green sturgeon, and Atlantic sturgeon). All of the species reproduce in fresh water.

Sturgeons and paddlefish exhibit unusual combinations of morphology, habits, and life history characteristics, which make them highly vulnerable to impacts from human activities, particularly fisheries. In North America, human activities known to impact sturgeons and paddlefish are industrial and municipal pollution, blockage of access to habitats by dikes and dams, channelization and elimination of backwater areas, dewatering of streams, physical destruction of spawning grounds, inundation of habitat by reservoirs, and overfishing (Baker 1980, Carlson & Bonislawsky 1981, Trautman 1981, Becker 1983, Kallemeyn 1983, Cochnauer et al. 1985, Rochard et al. 1990, Moyle et al.[1]).

Five of the North American sturgeons are listed as endangered or threatened by management authorities: shortnose sturgeon (Dadswell et al. 1984), green sturgeon (Moyle et al.[1]), pallid sturgeon (Keenlyne & Jenkins 1993), Alabama sturgeon (Williams et al. 1989), and Gulf sturgeon, *Acipenser oxyrinchus desotoi* (Mason & Clugston 1993), which is a subspecies of Atlantic sturgeon. Although not officially listed as endangered or threatened, three other species of North American sturgeons and paddlefish have been reduced to such low densities at some point in this century that fishery closures were instituted. Harvesting of lake sturgeon in the Lake Winnebago system, Wisconsin, was prohibited from 1915 to 1931 due to a concern over the drop in abundance (Folz & Meyers 1985). Harvest of white sturgeon in the Snake River was terminated after 1983 due to a decline in abundance, and a total fishery closure was recommended for sections of the river (Cochnauer et al. 1985). In Wisconsin and Iowa, non-fishing zones below navigation dams were adopted to protect shovelnose sturgeon from overfishing (Becker 1983). A three-year moratorium on commercial harvest of paddlefish was initiated in Louisiana in 1986 and the recreational creel limit was reduced to one fish per day because of declines in stock levels (Reed et al. 1992).

Although draconian fishing restrictions have been instituted for many of the North American chondrosteans, demand for the species has not diminished. Since the middle 1800s, North American sturgeons have been the target of intensive fisheries, primarily for caviar and also for their meat (fresh, smoked, or tinned); angling for sport is also growing more popular, especially for white and lake sturgeons (Rochard et al. 1990). When sturgeons became unavailable for the lucrative caviar market, some fisheries switched to paddlefish (Carlson & Bonislawsky 1981, Reed et al. 1992).

[1] Moyle, P.B., R.M. Yoshiyama, J.E. Williams & E.D. Wikramanayake. 1996. Fish species of special concern in California (second edition). Prepared for the State of California, The Resources Agency, Dept. Fish and Game, Inl. Fish. Div., Rancho Cordova, California (in press).

In this paper, I examine the sensitivity of North American sturgeons and paddlefish to fishing and early life mortality. Specifically, I present the impact of fishing mortality on reproductive potential for several representative sturgeon and paddlefish populations, and examine whether adjustments to fishing mortality could be used to offset reductions in reproductive potential caused by other sources of mortality due to human activities. I also compare the chondrosteans to other fish species currently supporting intensive fisheries in North America (striped bass in the Hudson River, New York, winter flounder in Cape Cod Bay, Massachusetts, and bluefish along the Atlantic coast of North America) to demonstrate how life history characteristics make the chondrosteans more sensitive to fishing mortality.

Methods

Effects of fishing mortality on reproductive potential

For purposes of this paper, I define reproductive potential as the potential lifetime egg production of an age 1 female (eggs-per-recruit, *EPR*). This measure is the sum of the number of eggs she is likely to produce at each age times the probability that she will survive to that age (Boreman et al. 1993):

$$EPR = \sum_{i=2}^{n} \rho_i \varphi_i \prod_{j=1}^{i-1} e^{-(F_j+M_j)}, \qquad (1)$$

where ρ_i is the proportion of females mature at age i, φ_i is the average fecundity of an age-i female, F_j is the instantaneous rate of fishing mortality during period j, M_j is the instantaneous rate of natural mortality during period j, and n is the oldest spawning age. The maximum value for potential lifetime egg production (EPR_{max}) is achieved when no fishing mortality occurs ($F_j = 0$ for all j). As F is increased, *EPR* will decline due to the lessened probability that an age *1* female will survive to the next age, given the increased risk of fishing mortality along with the risk of natural mortality she also must endure. Relative sensitivity of reproductive potential to a specific rate of fishing mortality is the ratio of the *EPR*-value calculated for that rate to EPR_{max}.

Restricting fishing mortality to offset losses from other sources

Fishery managers have the option of regulating fishing mortality to offset impacts of mortality from unknown or largely uncontrollable sources, such as changes in river flows and contaminant toxicity, which usually occur in fish stocks during the first year of life. To maintain stationary population abundance, i.e., population abundance that is neither increasing nor declining over generations, the survival rate of a female egg to age *1* (S_0) must be equal to two times the reciprocal of the *EPR*-value (assuming the sex ratio of deposited eggs is 50:50), so that:

$$EPR \cdot S_0 = 2. \quad (2)$$

If survival rate during age *0* declines, the population abundance can be maintained if *EPR* is increased to a level that keeps the product of age *0* survival and *EPR* equal to two, assuming that the population has sufficient compensatory capabilities to maintain stationarity under all mortality conditions.

Data sources

Sufficient information exists in available publications to estimate *EPR* values for three sturgeon populations and one paddlefish population in North America: white sturgeon in the Columbia River below Bonneville Dam (Tracy & Wall 1993, DeVore et al. 1996); Atlantic sturgeon in the Hudson River (Kahnle et al. 1992, Kahnle unpublished data); paddlefish in Lake Ponchartrain, Louisiana (Reed et al. 1992); and shortnose sturgeon in the lower Connecticut River (Boreman[2]). The fishery for white sturgeon in the lower Columbia River currently has minimum size limit of 112 cm and a maximum size limit of 168 cm (DeVore personal communication), and the fishery for Atlantic sturgeon in the Hudson River has a minimum size limit of 152 cm (Kahnle et al.[3]). I did not attempt to divide fishing mortality into sport or commercial. For shortnose sturgeon and paddlefish, I assumed that all ages 1 and older would be equally vulnerable to any increase in mortality beyond that already incorporated into the natural mortality rates.

Values for life history parameters of female striped bass in the Hudson River are from Goodyear (1988). The values are for the population prior to closure of the fishery in the river in 1976 due to chemical contamination, and represent a period when coastal landings of striped bass from the Hudson River and elsewhere along the Atlantic coast of North America were at their peak (Boreman & Austin 1985). Boreman et al. (1993) list parameter values for female winter flounder in Cape Cod Bay, and parameter values for female bluefish along the Atlantic coast are given in MAFMC[4].

Results and discussion

Effects of fishing mortality on reproductive potential

To prevent harvesting of spawners below the replacement level of their progeny, Goodyear (1993) recommends maintaining levels of spawning stock biomass per recruit that are at least 20% of the maximum (when $F = 0$), unless evidence exists for exceptionally strong density-dependence in the population. Boreman et al. (1984) used a higher level of 50% of maximum spawning stock biomass per recruit as a target for rebuilding (rather than maintaining) populations of shortnose sturgeon along the Atlantic coast. If spawning stock biomass and egg production are linearly related (fecundity is typically a linear function of female body weight), then the same 20% and 50% target levels should

[2] Boreman, J. 1992. Impact of added mortality on the reproductive success of shortnose sturgeon in the lower Connecticut River. Report prepared for the Northeast Regional Office, National Marine Fisheries Service. 14 pp.

[3] Kahnle, A., K. Hattala & K. McKown. 1992. Proposed New York State Atlantic sturgeon regulations. Prepared for the Atlantic States Marine Fisheries Commission, Atlantic Sturgeon Plan Review Team. 14 pp.

[4] MAFMC (Mid-Atlantic Fishery Management Council). 1990. Fishery management plan for the bluefish fishery. Mid-Atlantic Fishery Management Council, Dover, Delaware. 79 pp.

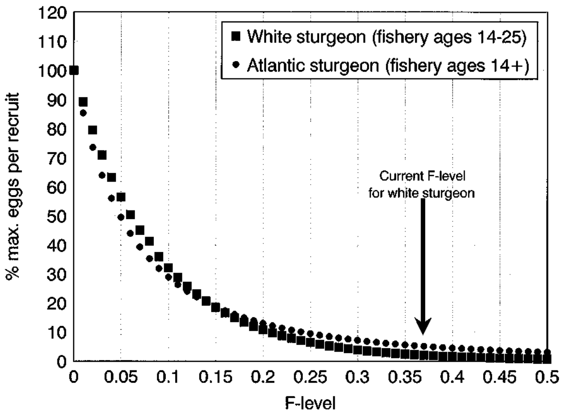

Figure 1. Relationship between fishing mortality rate (F) and corresponding percentage of the maximum lifetime egg production of an age 1 female when F = 0 for white sturgeon in the Columbia River below Bonneville Dam and Atlantic sturgeon in the Hudson River.

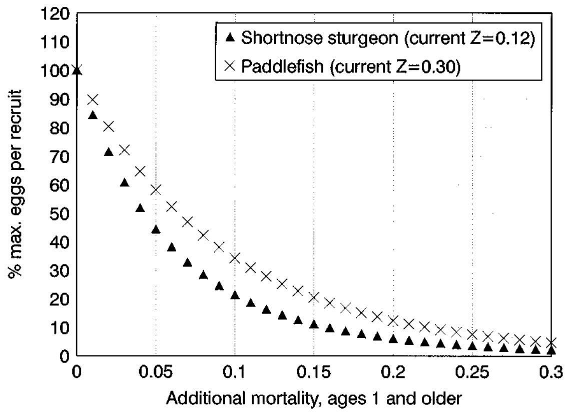

Figure 2. Effects of an increase in the current mortality rate (Z) of age 1 and older females on the corresponding percentage of the maximum lifetime egg production of an age 1 female for shortnose sturgeon in the lower Connecticut River and paddlefish in Lake Ponchartrain.

apply to potential lifetime egg production per recruit (*EPR*).

The fishing mortality rate corresponding to 20% of EPR_{max} for white sturgeon in the lower Columbia River and for Atlantic sturgeon in the Hudson River is $F = 0.14$ (Figure 1). A 50% level of EPR_{max} would be achieved if the fishing mortality is $F = 0.06$ for white sturgeon, and $F = 0.05$ for Atlantic sturgeon. At the 1986–1990 average fishing mortality rate of $F = 0.37$, lifetime egg production of age *1* females in the white sturgeon population is approximately 2% of EPR_{max} – far below the recommended minimum level of 20%. An estimate of the current fishing mortality rate for Atlantic sturgeon in the Hudson River is unavailable.

Mortality due to incidental capture in indirect fisheries is probably incorporated in the current estimates of total mortality (Z) for both the shortnose sturgeon population in the lower Connecticut River and the paddlefish population in Lake Ponchartrain. Increasing the total mortality rate on age 1 and older shortnose sturgeon from $Z = 0.12$ (current) to $Z = 0.16$ will reduce potential lifetime egg production of a female recruit to 50% of EPR_{max},

Table 1. Female life history characteristics for white sturgeon in the lower Columbia River, Atlantic sturgeon in the Hudson River, shortnose sturgeon in the lower Connecticut River, paddlefish in Lake Ponchartrain, striped bass in the Hudson River, winter flounder in Cape Cod Bay, and bluefish along the Atlantic coast.

Characteristic	White sturgeon	Atlantic sturgeon	Shortnose sturgeon	Paddlefish	Striped bass	Winter flounder	Bluefish
Maximum age (years)	104	60	30	20	18	12	8
Natural mortality (M)	0.09	0.07	0.12	0.30	0.15	0.35	0.25
Length (cm) at oldest age	309	343	91	120	105	45	89
Fecundity at oldest age	1 500 000	1 800 000	66 000	200 000	3 100 000	2 200 000	5 300 000
Age at first maturity (years)	16	11	5	9	3	2	2
Age at full maturity (years)	35	21	17	10	9	6	3
Years between successive spawnings	3	3	3	2	1	1	1
Age at 50+% EPR_{max} (years)	37	29	17	11	11	6	3
Fishing mortality (F)	0.37	?	0	0	0.39	1.07	0.80
Ages in fishery	14–25	14+	–	–	2+	2+	0+

and increasing total mortality to $Z = 0.23$ will reduce the EPR value to 20% of EPR_{max} (Figure 2). For paddlefish, increasing the total mortality rate from $Z = 0.30$ (current) to $Z = 0.36$ will reduce the EPR value to 50% of EPR_{max}, and increasing the rate to $Z = 0.45$ will reduce the value to 20% of EPR_{max} (Figure 2).

As a group, chondrostean populations are more sensitive to loss in reproductive potential caused by increases in the mortality rate of age *1* and older females than are striped bass, winter flounder, and bluefish populations (Figure 3). The higher sensitivity of the chondrosteans to mortality in age *1* and older fish is due to a combination of characteristics that determine their population dynamics (Table 1). The chondrosteans are generally longer lived, are later maturing, and have lower natural mortality rates than striped bass, winter flounder, and bluefish. The chondrosteans do not spawn every year once they reach sexual maturity and, except for Atlantic sturgeon and white sturgeon, have substantially lower fecundity than the other three species I examined. A life history characteristic that integrates individual fecundity, natural mortality, age at maturity, and years between successive spawnings is the age at which at least 50% of the maximum lifetime egg production of an age *1* female is achieved when no fishing mortality occurs (EPR_{max}). For white and Atlantic sturgeons, this age is 3–10 times greater than the equivalent age for striped bass, winter flounder, and bluefish (Table 1); therefore, the probability of surviving from age *1* to the age of 50% of maximum lifetime egg production is reduced by a power of 3–10 for the sturgeons.

Table 2. Reduction in fishing mortality rate (F) necessary to achieve equivalent lifetime egg production of an age 1 female white sturgeon in the Columbia River below Bonneville Dam when the fraction of females surviving from egg to age 1 (S_0) is reduced.

Reduction in S_0 (%)	F needed to maintain equivalent lifetime egg production	Reduction in F (%)
0	0.370	0
5	0.364	2
10	0.358	3
15	0.352	5
20	0.345	7
25	0.339	8
30	0.331	11

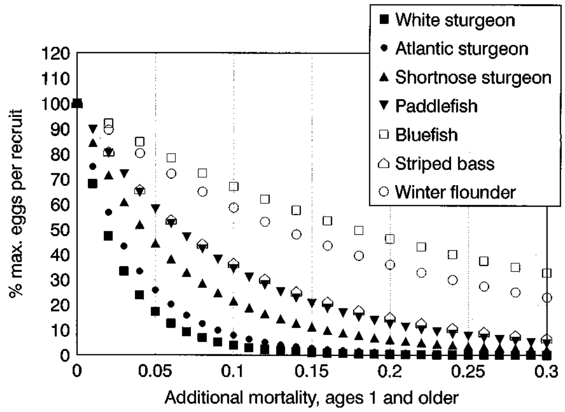

Figure 3. Effects of increasing the total mortality rate (Z) of age 1 and older females above the level when F = 0, on the corresponding percentage of the maximum lifetime egg production of an age 1 female for white sturgeon in the Columbia River below the Bonneville Dam, Atlantic sturgeon in the Hudson River, shortnose sturgeon in the lower Connecticut River, paddlefish in Lake Ponchartrain, striped bass in the Hudson River, winter flounder in Cape Cod Bay, and bluefish along the Atlantic coast.

Restricting fishing mortality to offset losses from other sources

For relatively long-lived species such as sturgeons and paddlefish, a small reduction in fishing mortality on the age groups vulnerable to harvest can offset the effects of a relatively large reduction in age *0* survival. This relationship is possible because the age *0* fish are exposed to the risk of reduced survival during only one year in their life; whereas, exposure to the risk of fishing spans many years. As an example, suppose the number of age *0* white sturgeon in the lower Columbia River is reduced by 20% due to contaminant toxicity. A 20% reduction in age *0* survival implies that for every age *1* female that would have survived her first year of life, only 0.8 females are now surviving under the altered conditions. The value for potential lifetime egg production from 0.8 age *1* females with the baseline fishing mortality rate of $F = 0.37$ is equal to the lifetime egg production of one age *1* female and a fishing mortality rate that is reduced by 7%, from $F = 0.37$ to $F = 0.345$ (Table 2).

Even though fishing may not be the reason for an observed decline in abundance of sturgeon and paddlefish populations, reducing fishing mortality is an effective means of offsetting the effects on reproductive potential caused by other, often uncontrollable mortality sources. Restricting fishing mortality may be the only tool available to managers for restoring depleted populations. At a minimum, reducing fishing pressure on long-lived species allows managers time to detect and correct the true causes of population decline. This strategy is currently being employed to rebuild the population of white sturgeon in the lower Columbia River (Columbia River Management Joint Staff[5]). The strategy was also adopted by the Atlantic States Marine Fisheries Commission in the early 1980s to restore the depleted coastal migratory stock of striped bass (ASMFC[6]), which is now producing year classes at record levels (Donald Cosden personal communication).

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[5] Columbia River Management Joint Staff. 1993. Status report: Columbia River fish runs and fisheries 1938–1992. Prepared for Oregon Department of Fish and Wildlife and Washington Department of Fisheries. 257 pp.

[6] ASMFC (Atlantic States Marine Fisheries Commission). 1989. Amendment 4 to the Atlantic States Marine Fisheries Commission interstate striped bass management plan. ASMFC, Washington, DC. 60 pp.

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