

## **Alternatives for the protection and restoration of sturgeons and their habitat**

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### **Synopsis**

This paper reviews the life history and habitat requirements of sturgeons, alternatives for their protection and restoration in North America, and a typical protection and enhancement program in the Columbia River. Sturgeon are uniquely adapted to mainstem river systems which are characterized by their large scale, diverse habitats, and dynamic nature. Adaptations include mobility, opportunistic food habits, delayed maturation, longevity, and high individual fecundity. Unfortunately these life history characteristics are now a handicap for sturgeon because of fragmentation and destruction of their habitat. A variety of habitat-related alternatives for the protection and restoration of sturgeon were identified in a review of the literature and a survey of sturgeon biologists and managers throughout North America. However, harvest restrictions and supplementation using aquaculture are much more likely to be implemented than the system-wide measures needed to affect sturgeon habitat. A program for white sturgeon protection and enhancement in the Columbia River is a typical case where harvest management and supplementation measures are being used to optimize production of existing habitat but significant changes in water use and hydropower operation are needed to restore sturgeon to historic levels of production.

### **Introduction**

Given their singular evolutionary, morphological genetic, and physiological traits (Grande & Bemis 1991, Bemis et al. 1997 this volume, Birstein 1993, Birstein et al. 1997 this volume), it is no surprise that sturgeon are also ecologically unique. However, life history traits which have proven adaptive over the last 100 million years are now a disadvantage in the face of drastic habitat changes and overfishing during the last century. Sturgeon are presently depleted, threatened, or extinct almost everywhere they occur (Smith 1990, Birstein 1993). Biologists throughout North America are grappling with the difficulty of developing protection or recovery pro-

grams for the nine endemic sturgeon species. In this paper, we discuss key characteristics of sturgeon life history which constrain populations, alternatives for protection and restoration of sturgeon and their habitats which have been identified for North American populations, and protection and enhancement efforts for Columbia River white sturgeon which typify the problems faced in many other populations.

### **Life history and habitat requirements**

Critical habitat requirements and effective protection and restoration measures can be inferred from

sturgeon life history. Sturgeon are uniquely adapted to the large mainstem river systems upon which all species rely during all or part of their life cycle (Rochard et al. 1990). Rivers include diverse habitats which are distributed in large scale patterns corresponding to the surrounding topography. Typical transitions include headwaters through tributaries, mainstem, and estuary into an ocean, sea, or large lake. In large basins, rivers may traverse many different regions and climatic zones. Rivers are also extremely dynamic habitats featuring large seasonal and annual variations in physical conditions and resource availability (Sheehan & Rasmussen 1993). Seasonal cycles in weather and runoff drive changes in velocity, morphometry, temperature, substrate, and turbidity. Conditions vary from year to year in unpredictable patterns based on regional weather patterns. Periodic floods and droughts may radically alter the riverine environment. Distribution and abundance of many species of fishes and other organisms vary widely in response to spatial and temporal patterns. For instance, anadromous fishes are seasonally abundant as they move between spawning and feeding areas in portions of many temperate rivers and estuaries.

Sturgeon have evolved life history characteristics which allow them to thrive in these large, diverse, and dynamic river systems. Individuals often range widely to take advantage of scattered and seasonally abundant resources. Regular migrations for spawning and short-term movements for feeding have been observed for many species (Chadwick 1959, Miller 1972a, Haynes et al. 1978, Haynes & Gray 1981, Smith 1985, Wooley & Croteau 1985, Sandilands 1987, Kempinger 1988, Odenkirk 1989, Hall et al. 1991, Mosindy & Rusak<sup>1</sup>, O'Herron et al. 1993). Many species are euryhaline and move freely between freshwater, estuaries, and saltwater (Rochard et al. 1990) to further broaden their resource base. Long-distance movements are facilitated by their large size, shape, and swimming ability which allow them to move through heavy current.

Sturgeon are opportunistic predators that eat a

variety of prey and switch as prey availability changes. These fish can also withstand long periods of starvation during periods of low food availability or spawning migrations (Dadswell 1979, Mason & Clugston 1993). Sturgeon generally feed on invertebrates in the benthic food chain (Held 1969, Dadswell 1979, Carlson et al. 1985, Sandilands 1987, McCabe et al. 1993) where most production occurs in large river systems (Sheehan & Rasmussen 1993). Fish may also be an important diet component of some sturgeon species (Semakula & Larkin 1968). Large sturgeon can consume large prey. Pursuit and capture of active prey belie an image of sturgeon as sluggish bottom scavengers.

Populations of sturgeon are buffered from annual variation in environmental conditions by delayed maturation, longevity, and high individual fecundity. Delayed maturation (Roussow 1957, Sunde 1961, Dadswell 1979, Conte et al.<sup>2</sup>, Chapman 1989, Guenette et al. 1992, Keenlyne & Jenkins 1993) speeds growth to large sizes as energy is devoted to somatic rather than gonadal development. Large size helps reduce predation, lowering natural mortality rate and increasing longevity. A long lifespan (Pycha 1956, Wilson 1987, Rien & Beamesderfer 1994) allows fish numerous opportunities to spawn and reduces the need to spawn in years when conditions are not suitable. Many species have been observed to resorb eggs under these conditions (Artyukhin et al. 1979, Chapman 1989). High fecundity associated with large size improves spawning success in years when suitable conditions are encountered.

Many sturgeon species depend on free-flowing rivers and seasonal floods to provide suitable spawning conditions. Adhesive eggs are typically broadcast over rocky substrates in turbulent, high-velocity areas during high spring runoff (Magnin 1966, Buckley & Kynard 1985, Smith 1985, Kempinger 1988, Hall et al. 1991, Mosindy & Rusak<sup>1</sup>, La-Haye et al. 1992, Parsley et al. 1993). Recruitment

<sup>1</sup> Mosindy, T. & J. Rusak. 1991. An assessment of lake sturgeon populations in Lake of the Woods and the Rainy River 1987-90. Ontario Ministry of Natural Resources. 66 pp.

<sup>2</sup> Conte, F.S., S.I. Doroshov & P.B. Lutes. 1988. Hatchery manual for the white sturgeon *Acipenser transmontanus* Richardson with application to other North American Acipenseridae. University of California Cooperative Extension Publication 3322. 104 pp.

has been widely correlated with spring and summer discharge (Stevens & Miller 1970, Khoroshko 1972, Votinov & Kasyanov 1979, Kohlhorst et al. 1991, Veshchev 1991). Flowing water provides oxygen, disperses eggs, and excludes egg predators. Seasonal floods scour substrates free of sand and silt which might suffocate eggs. Seasonal floods and corresponding changes in temperature, velocity, and turbidity may also provide spawning cues (Kempinger 1988, Kohlhorst et al. 1991, LaHaye et al. 1992).

Unfortunately, many of these adaptations to large river systems are now detrimental to sturgeon. Availability of food and critical spawning areas are limited where construction of dams blocks movements among scattered areas and creates homogeneous reservoirs which reduce habitat diversity. Dam and reservoir operation for hydropower generation, flood control, irrigation, and navigation reduce seasonal and annual variability in flow which provide suitable spawning and rearing conditions for sturgeon and many of their prey. Altered systems favor development of a new array of prey, predators, and competitors. Benthic feeding and delayed maturation increase vulnerability to bioaccumulation of toxic pollutants (Ruelle & Keenlyne 1993). Longevity and delayed maturation make populations extremely susceptible to overexploitation. Large size and high fecundity increase the value of individual fish and provide incentives for excessive or illegal harvest.

Because of the unique features of their large river habitats and adaptive life history characteristics, sturgeon require a much broader definition of habitat than is typically applied to fishes when alternatives for habitat improvement are considered. Fish habitats are often defined in terms of site-specific conditions like depth, velocity, substrate, and cover. Sturgeon habitat must be defined in terms of system-wide conditions including large areas of diverse habitat; natural variation in flow, velocity, temperature, and turbidity; high water quality; a broad prey base; and free-flowing sections which provide suitable spawning sites (Carlson et al. 1985,

Crance<sup>3</sup>, Mosindy 1987, Payne 1987, Curtis 1990, Taub<sup>4</sup>, Lane 1991, Pitman<sup>5</sup>, Beamesderfer 1993, Dryer & Sandoval<sup>6</sup>, USFWS & GSMFC<sup>7</sup>).

### Alternatives for protection and restoration

To help identify and assess the potential feasibility of alternatives for protecting and restoring sturgeons and their habitat, we recently conducted a mail survey of 268 sturgeon and paddlefish biologists and managers from throughout North America. One page questionnaires including a return address and postage were sent to each person identified in a 'Summary of sturgeon and paddlefish researchers and managers' developed by the United States Fish and Wildlife Service. While survey results from this sample cannot be construed as an unbiased indication of which measures are appropriate, results should be useful in identifying the range of alternatives available.

Survey questions included 'please list measures you believe to be potentially beneficial to the conservation, productivity, or diversity of sturgeon or paddlefish populations with which you are familiar' and 'which of the above alternatives have been implemented and proven beneficial to the targeted sturgeon or paddlefish species?' In addition, each person was asked to (1) identify their experience with sturgeon or paddlefish (basic research, applied research, stock assessment/monitoring, habitat protection, fishery regulation, or aquaculture); (2)

<sup>3</sup> Crance, J.H. 1986. Habitat suitability index models and in-stream flow suitability curves: shortnose sturgeon. U.S. Fish and Wildlife Service Biological Report 82 (10.129).

<sup>4</sup> Taub, S.H. 1990. Fishery management plan for Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*). Atlantic States Marine Fisheries Commission Fisheries Management Report 17. 73 pp.

<sup>5</sup> Pitman, V.M. 1992. Texas paddlefish recovery plan. Texas Parks and Wildlife Department, Austin. 30 pp.

<sup>6</sup> Dryer, M.P. & A.J. Sandoval. 1993. Recovery plan for the pallid sturgeon (*Scaphirhynchus albus*). U.S. Fish and Wildlife Service, Denver. 55 pp.

<sup>7</sup> USFWS & GSMFC (United States Fish and Wildlife Service & Gulf States Marine Fisheries Commission). 1995. Gulf sturgeon recovery plan. Atlanta. 170 pp.

Table 1. Specific alternatives identified as potentially beneficial to the conservation, productivity, or diversity of sturgeon or paddlefish populations in a survey of sturgeon and paddlefish biologists throughout North America. Each biologist developed a list of alternatives and ranked them according to potential benefit.

Category Specific response	Number responses	Number implemented	Mean rank
<b>Habitats</b>			
General (e.g. protect or restore critical habitat)	59	18	1.9
Flow (e.g. restore hydrograph)	30	6	1.8
Spawning habitat (e.g. protect)	15	10	2.9
Dredging or channelization	9	4	2.4
Control predators	3	0	5.7
Dams	3	0	3.0
Rearing habitat	2	1	3.0
Construct spawning habitat	1	1	5.0
<b>Harvest</b>			
Partial size specific (e.g. protect broodstock)	37	31	2.2
General (e.g. control harvest)	32	25	2.6
Complete closure	17	11	1.8
Enforcement (e.g. poaching and caviar sales)	14	7	3.0
Commercial closure	10	5	1.8
Bycatch control	2	0	3.5
<b>Research</b>			
Stock assessment	20	6	2.9
Aquaculture	18	5	2.4
Genetics	17	6	3.1
Life history	15	6	2.4
Habitat requirements	14	5	2.6
General	9	4	3.6
Reproduction	9	4	2.2
Monitoring	3	2	2.3
Pollution	3	0	2.3
Passage	1	0	3.0
<b>Culture stocking</b>			
General	29	16	2.5
To historic ranges	17	7	2.3
Fingerlings	5	5	2.2
Establish cryogenic stock reservoirs	4	3	2.5
Young of the year	1	1	2.0
Use as reservoir for genetic stock	1	1	2.0
<b>Passage</b>			
Improve passage at dams	16	4	3.0
Eliminate dams	12	1	1.7
Run of the river operations	6	6	1.8
General	2	1	2.5
<b>Pollution</b>			
General	19	5	3.1
Contaminants	8	1	4.1
Sediments	5	2	2.8
Nutrient (e.g. feedlot runoff)	2	2	3.5
<b>Planning</b>			
General (e.g. coordinate interstate efforts)	13	8	2.1
Listing/legal protection	9	7	2.0
Recovery plan	4	4	3.0
Management plan	4	3	3.7
<b>Information and education</b>			
Public outreach	15	5	3.1
General	7	2	4.0

name the sturgeon or paddlefish species with which familiar; and (3) provide related articles or reports.

Specific alternatives identified in 151 responses were classified into 8 general categories (Table 1), including general problem areas identified in the 'Framework for the management and conservation of paddlefish and sturgeon species' prepared by a national steering committee of biologists for the U.S. Fish and Wildlife Service. The most frequently identified categories included habitat, harvest, and research (Figure 1). Average ranks based on order of listing were similar for habitat, harvest, passage, culture/stocking, and planning (Table 1).

Habitat-related alternatives most often involved protection of critical habitat, especially for spawning. Effects of the natural hydrograph, dredging or channelization, dams, and predators were also recognized (Table 1). Pollution- and passage-related measures were tabulated separately although they might also be considered as habitat-related measures. Pollution-related alternatives mentioned contaminants, nutrients, and sediments. Passage-related alternatives recognize the widespread construction of dams which are barriers to migration. Harvest-related alternatives involved complete fishery closures, partial restrictions, and more intensive enforcement of restrictions especially with respect to caviar. Specific alternatives to culture-stocking most frequently involved stocking juveniles to supplement or reestablish populations within historic ranges. Research needs on all aspects of biology and management were noted. Frequent references to planning efforts recognize the widespread distribution of sturgeons across several jurisdictional boundaries. Several responses also reiterated a need for public outreach programs.

The most likely measures to be implemented involved planning (73%), harvest restrictions (70%), and aquaculture (58%). Although habitat protection and enhancement measures were the most frequently recognized as potentially beneficial, they appeared least likely to be implemented in cases where identified. Planning efforts were frequently identified as beneficial, perhaps reflecting the relatively low cost of such efforts. A generally poor understanding of sturgeon biology is implied by the frequent mention of a need for additional research

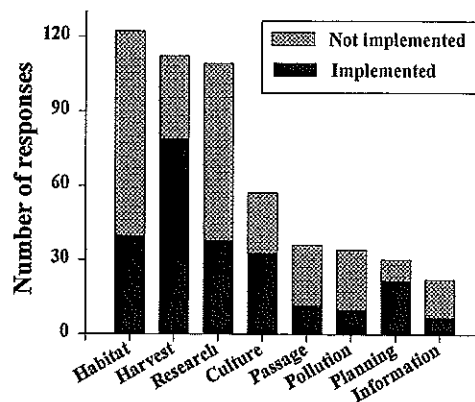


Figure 1. Potentially beneficial alternatives identified and implemented for the conservation, productivity, or diversity of sturgeon or paddlefish populations in a survey of sturgeon and paddlefish managers throughout North America.

but the low incidence where programs had been implemented (35%).

The capture and harvest of sturgeon are restricted almost everywhere they occur in North America. Annual harvest rates greater than 5–10% are almost universally believed to exceed sustainable levels because of resulting low survival to large reproductive sizes (Semakula & Larkin 1968, Miller 1972, Huff<sup>8</sup>, Threader & Brousseau 1986, Nowak & Jesup 1987, Young et al. 1988, Rieman & Beamesderfer 1990, Kohlhorst et al. 1991). Closed reasons, protected areas, size limits, bag limits, gear restrictions, and catch-release regulations have all been used for sturgeon and paddlefish (Cochner 1983, Cochner et al. 1985, Foltz & Meyers 1985, Galbreath 1985, Smith 1985, Hart 1987, Debrot et al.<sup>9</sup>, Scarnecchia et al. 1989, Taub<sup>4</sup>, PSMFC<sup>10</sup>). Significant fisheries still occur for white sturgeon, *Acipenser transmontanus*, and paddlefish, *Polyodon spathula*,

<sup>8</sup> Huff, J.A. 1975. Life history of gulf of Mexico sturgeon, *Acipenser oxyrinchus desotoi*, in Suwannee River, Florida. Florida Marine Research Publication No. 16. 32 pp.

<sup>9</sup> Debrot, A.O., H.A. Schaller & M.A. Matylewich. 1989. Estimates of sustainable exploitation rates for Columbia River landlocked white sturgeon: evaluating the importance of a maximum size limit. Columbia River Inter-Tribal fish Commission Technical Report 88-4. 41 pp.

<sup>10</sup> PSMFC (Pacific States Marine Fisheries Commission). 1992. White sturgeon management framework plan. Portland. 201 pp.

(Galbreath 1985, Pitman<sup>11</sup>, Graham 1996). Small fisheries remain for lake *Acipenser fulvescens*, green *Acipenser medirostris*, Atlantic *Acipenser oxyrinchus oxyrinchus*, and shovelnose *Scaphirhynchus platyrhynchus* sturgeons (Smith et al. 1984, Foltz & Meyers 1985, Thuemler 1985, Olver 1987, Smith 1990, Michalenko et al. 1991). Fishing for shortnose *Acipenser brevirostrum*, pallid *Scaphirhynchus albus*, and gulf *Acipenser oxyrinchus desotoi* sturgeons has been curtailed by their federally-recognized status as endangered or threatened species. Alabama sturgeon *Scaphirhynchus suttkusi* are rare and not subject to harvest.

Culture of North America sturgeon currently relies on the capture of wild broodstock which are stimulated to spawn using hormones, although captive broodstock are being developed for several species (Smith 1990). Artificial spawning has been documented for Atlantic, shortnose, pallid, lake, and white sturgeons, and for paddlefish (Conte et al.<sup>2</sup>, Smith 1990). Success of several experimental releases of lake sturgeon, shortnose sturgeon, and paddlefish is currently being evaluated (Graham<sup>12</sup>, Anderson 1987, Pitman<sup>11</sup>, Smith & Jenkins 1991, LaPan et al.<sup>13</sup>, Graham 1996). Stocking programs for white sturgeon have been restricted to release of small numbers of juveniles in the Sacramento, Snake, and Willamette rivers as partial mitigation from private hatchery operators for use of wild broodstock. An experimental hatchery program is also being developed to supplement white sturgeon in the Kootenai River which flows through British Columbia, Idaho, and Montana (Apperson & Wakinen 1992, Kincaid<sup>14</sup>).

<sup>11</sup> Pitman, V.M. 1991. Synopsis of paddlefish biology and their utilization and management in Texas. Texas Parks and Wildlife Department, Austin. 70 pp.

<sup>12</sup> Graham, L.K. 1986. Reintroduction of lake sturgeon in Missouri. Final Rep., D.J. Proj. F-1-R-35, Study S-25. Missouri Dep. Conserv., Columbia. 11 pp.

<sup>13</sup> LaPan, S.R., A. Schiavone, R.M. Klindt, W.F. Krise, M.N. Di-Lauro & K. Fynn-Aikins. 1994. Re-establishment of lake sturgeon in tributaries of the St. Lawrence River, 1993. Report to the Lake Ontario Committee, Great Lakes Fishery Commission. 10 pp.

<sup>14</sup> Kincaid, H.L. 1993. Breeding plan to preserve the genetic variability of the Kootenai River white sturgeon. Bonneville Power Admin., Portland. 18 pp.

Habitat modifications to benefit sturgeon have rarely been implemented. The elimination of daily discharge fluctuation for hydroelectric power generation at a dam in Michigan has increased spawning activity of lake sturgeon (Auer 1996). Effects of experimental releases of water from a Montana reservoir on spawning success of white sturgeon are currently being tested (Marcuson<sup>15</sup>). Dredge and fill operations have been modified or curtailed in spawning areas of lake sturgeon in the St. Lawrence River (Dumont et al. 1987). Successful site-specific habitat alterations have improved spawning by lake sturgeon in several areas where rock substrate was limiting and introduced to stabilize shoreline (Folz & Meyers 1985) or to increase current velocity (Rochard et al. 1990, LaHaye et al. 1992). A fish elevator was operated sporadically from 1938-1969 to lift white sturgeon past Bonneville Dam on the Columbia River (Warren & Beckman<sup>16</sup>).

The broad habitat needs of sturgeon suggest that only large-scale, system-wide habitat protection and improvement programs can be expected to provide significant benefits for those populations that are depleted or threatened by habitat alteration. Except in rare cases, site specific changes can be expected to have little effect. Options for producing system-wide changes to benefit sturgeon are limited because they involve complex issues of water diversion, land use, and hydropower system development or operation whose implementation is constrained by economic and social considerations.

Our survey demonstrated that while several alternatives may be identified, effective options are limited. Managers have had to rely on harvest management and aquaculture because system-wide habitat protection and enhancement measures have been extremely difficult to implement. These measures have effectively maintained populations and provided fishery benefits where habitat degradation is not severe. However, efforts which do not address habitat degradation have generally failed

<sup>15</sup> Marcuson, P. 1994. Kootenai River white sturgeon investigations annual report. Bonneville Power Admin., Portland. 67 pp.

<sup>16</sup> Warren, J.J. & L.G. Beckman. 1993. Fishway use by white sturgeon to bypass mainstem Columbia River Dams. U.S. Fish Wildl. Sea Grant Extension Proj., Col. R. Series WSG-AG 93-02. 12 pp.

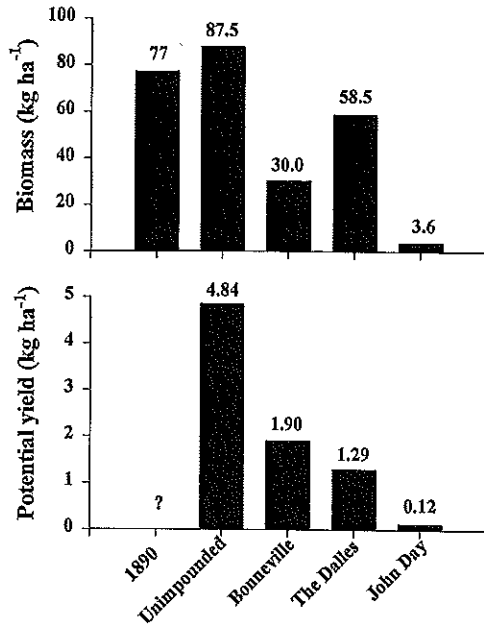


Figure 2. Abundance and productivity of the pristine (1890) and present impounded and unimpounded white sturgeon stocks in the lower Columbia River (Beamesderfer et al. 1995, DeVore et al. 1995).

to restore sturgeon populations to historic levels of productivity.

### A Columbia River example

The Columbia River white sturgeon populations represent a typical situation where habitat changes have drastically affected the stock, harvest has been regulated, supplementation stocking is being considered, but only habitat changes can be expected to restore sturgeon productivity to historic levels. Only an accident of engineering prevented the Columbia River population of white sturgeon from joining the other threatened and endangered sturgeon and paddlefish populations throughout the world. In 1983 Bonneville Dam was completed in the gorge where the river cuts through the Cascade mountain range. If this dam had been built at the bottom of the gorge just 5 miles downstream, it would have flooded or blocked access to critical spawning habitat and destroyed productive commercial and sport sturgeon fisheries in the lower river which annually produce 45 000 fish, yield

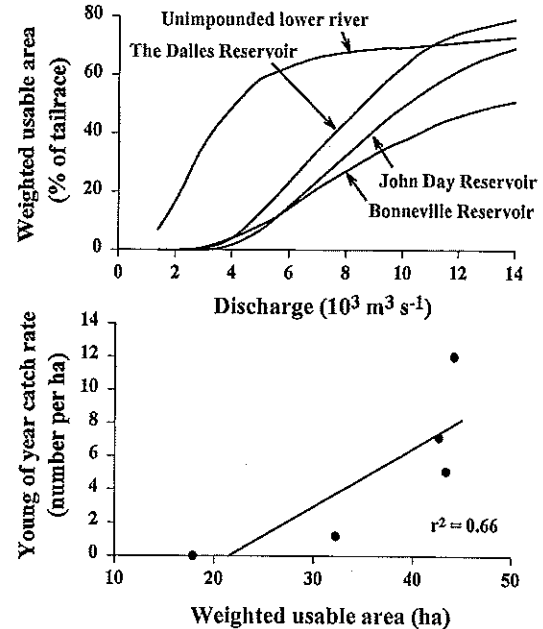


Figure 3. Relations between river discharge, availability of spawning habitat, and annual recruitment (Bonneville Reservoir only) for white sturgeon in the lower Columbia River (adapted from Parsley & Beckman 1994).

350 000 kg, and support 145 000 angler trips (DeVore et al. 1995).

Current sturgeon biomass in the unimpounded 234 km of the lower Columbia River appears similar to levels during pristine conditions prior to significant exploitation in the late 1800s (Figure 2). Upstream from Bonneville Dam, a series of main-stem dams have trapped stocks of white sturgeon in a series of reservoirs. Individual white sturgeon range extensively throughout each reservoir but rarely pass upstream or downstream dams (North et al. 1993). All reservoirs are similar in that hydrologic retention times are short, littoral zone is limited, and current is measurable most of the year. However, reservoirs vary in size, depth, substrate, and length of the free-flowing portion in the tailwater of the upstream dam.

Columbia River reservoirs provide a laboratory for examining limiting factors for white sturgeon. Each stock is presented with a different array of habitat conditions which affect reproduction, growth, and survival and in turn regulate population size and productivity. Fish that historically moved throughout this area to use scattered resources are now trapped in a reservoir which no

longer furnishes optimal conditions for different intervals of the life cycle. In some areas recruitment is high but rearing habitat is limited. Elsewhere rearing habitat is abundant but spawning habitat is not. The net result is that biomass and potential yield are less in impounded stocks than in the unimpounded stock (Figure 2).

Productivity of some impounded stocks is especially limited by poor recruitment resulting from lack of suitable spawning habitat. Columbia River white sturgeon spawn in areas of high velocity ( $> 0.8 \text{ ms}^{-1}$ ) over large rocky substrate now available only in riverine areas downstream from dams (Parsley et al. 1993). Availability of usable habitat increases with river discharge and recruitment is correlated with habitat availability (Figure 3). Discharge effects vary among areas as a result of differences in channel morphology, and some areas provide little habitat except at very high flows. Discharge regulation in isolated areas of the upstream Kootenai and Snake rivers has resulted in complete reproductive failure (Apperson & Wakkinen 1992, Marcuson<sup>15</sup>).

Harvest levels which could be supported by the productive unimpounded stock cannot be sustained by the impounded stocks (Beamesderfer et al. 1995). As a result, fisheries for several impounded stocks collapsed in the late 1980s after a period of intense exploitation as sport and commercial fisheries switched to sturgeon following declines of salmon fisheries. Hydropower system managers are now cooperating with government agencies and Indian tribes responsible for managing these fish to protect and enhance these impounded stocks.

One element of this program is intensive harvest management. Before 1988 sturgeon stocks throughout the lower Columbia River were managed with similar regulations and only a few key stocks were monitored. Fisheries are now being regulated with stock-specific regulations tailored to the unique attributes of each stock in an attempt to optimize fishery benefits. A more intensive monitoring program has also been undertaken to regulate harvest at optimum levels.

A second program element is evaluating transplants of juveniles from the large and productive unimpounded stock into reservoirs where poor

recruitment appears to have understocked the available rearing habitat. We believe that production of sturgeon by the system will ultimately be limited by the carrying capacity of the rearing habitat and that peak production will result from full stocking of all areas. Survival, growth, and condition of transplanted fish will be monitored to determine the costs and benefits of this alternative. Transplants also provide a low-cost means of evaluating the potential for enhancement of reservoir stocks without capital costs, genetic risks, or disease problems of a hatchery operation. Hatchery supplementation will be considered in more detail if transplants are not feasible or effective.

A third program element is developing and supporting recommendations for hydropower system operation to optimize river discharge and velocity during spring periods when water temperature is suitable for spawning. However, the large social and economic costs of modifications in hydropower system operation are likely to preclude changes in water allocation for the sole benefit of sturgeon. Program cooperators are therefore implementing intensive sampling designs for eggs, embryos and larvae in an attempt to identify effects of within-year differences in flow and to develop recommendations for using available water to optimize spawning conditions within each year.

Flow management is the only element in the lower Columbia River program which attempts to enhance sturgeon by directly modifying habitat. Intensive harvest management for each stock and supplementation recognize habitat limitations but maximize productivity of the existing habitat rather than producing habitat improvements.

## Conclusions

The flexible and opportunistic life history style of sturgeons may help explain their persistence and success over the last 100 million years. However, system-wide changes in the large river systems they inhabit now pose serious risks to these remarkable creatures. The large scale of detrimental habitat changes make them extremely difficult to control for the sole benefit of sturgeon and so sturgeon

managers and biologists have been forced to rely on harvest restrictions and aquaculture programs with limited success.

Sturgeon provide obvious economic and scientific benefits. We believe that sturgeon also serve as very large canaries in the coal mine of riverine ecosystems. These fish are universally threatened because their large riverine habitats are on the verge of ceasing to function at the ecosystem level. Only a combination of alternatives integrating habitat protection and recovery with harvest restrictions and supplementation can be expected to sustain sturgeon populations that are anything more than museum pieces. The challenge of all who recognize these problems will be to push for fundamental changes in how we use these large riverine systems rather than settling solely for alternatives in the constrained sphere of our immediate influence.

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