American Fisheries Society Symposium XX:XXX–XXX, 2002

Can We Study Sturgeons to Extinction? What We Do and Don't Know about the Conservation of North American Sturgeons

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Should we be surprised that none of the eight species of North American sturgeons are yet extinct? Sturgeons co-existed with dinosaurs and have survived the cataclysmic ecological effects of asteroid blasts. Why then should we be concerned? The conundrum of sturgeon is that despite their resiliency through evolutionary time, they are particularly sensitive to harvesting and habitat degradation (Boreman 1997; Gross, this volume; Secor and Niklitschek 2001). If there can be a single generalization about sturgeons, it is that they tend to be poky at life: their heart beats slowly; they respire slowly; they move deliberately, mature slowly, reproduce infrequently, and are slow to die. These conservative life history traits have served sturgeons well over geological time scales. For instance, in naturally-recruiting populations, it does not matter if one year's, or the next year's, reproduction is a wash. In most sturgeon populations, recruitment during subsequent years, or even during subsequent decades, contributes to population persistence.

Given that sturgeon species keep loping along, why are scientists, managers, and others in such a rush to restore them? To paraphrase a famous quote, 'old sturgeon don't die, they just fade away.' First, the species becomes commercially extinct; then, sightings of large adults becomes less frequent, until sightings become so rare that they are written up in the local newspaper. And then, there are none, and the public is prone to forget there were ever sturgeons at all. Such was the experience in Maryland, where no one seemed to notice the disappearance of populations of Atlantic sturgeon in Maryland's portion of the Chesapeake Bay until the 1990s, after nearly a century of slow decline. To be sure, an industrial scale fishery catalyzed the decline of Atlantic sturgeon in Maryland and elsewhere in the late 1800s (Secor, this volume). Still, Atlantic sturgeon populations did not give it up with a large crash; they just faded away over several generations of Chesapeake Bay waterman, scientists, and managers.

Similar stories of sturgeon population extirpation are now common at the turn of the 20th century. Worldwide, many sturgeon populations are in jeopardy of extirpation in the coming decades (Birstein et al. 1997; Rochard et al. 1990). In the Caspian Sea, a ban on most caviar fisheries was imposed in 2001, to protect beluga sturgeon *Huso huso*, Russian sturgeon *Acipenser gueldenstaedti*, and stellate sturgeon *A. stellatus*. In North America, sturgeons were only second to marine *Sebastes* (Scorpaenidae) in the number of species categorized as either threatened or endangered (Musick et al. 2000). Yet, despite dedicated efforts by scientists and managers, sturgeons continue to fade from view. (Albeit, a few notable cases of recovery exist, for example, lake sturgeon *A. fulvescens* in the Winnebago system in Wisconsin and shortnose sturgeon *A. brevirostrum* in the Hudson River in New York). In trying to restore population abundances, we are quickly learning that much more is required than merely protecting the species from further harm. How to promote recovery remains largely illusive—a vexing conundrum in the face of the real likelihood that, during many of our careers, sturgeon populations will continue to become extinct. This leads to the question, "Can scientists and managers study sturgeon to extinction?" In other words, what questions are most relevant in the conservation and recovery of North American sturgeons?

At the Symposium on the Biology, Management, and Protection of Sturgeon, we asked participants (scientists and managers) questions we believed were relevant to sturgeon conservation and restoration. In this symposium synthesis paper, we focus first on what **is** known. Often, in the face of uncertainty, scientists contribute ambiguity to management and policy by focusing on what is unknown, versus what is known. The now widely-accepted precautionary approach in fisheries management (FAO 1996) provides an important and useful framework for conserving species, which requires the advancement of best science (knowledge, perspective), rather than lists of questions, when issues and management actions are uncertain. In other words, uncertainty should no longer entail neglect and inaction due to the need for more science.

So what do we know about sturgeons? In the two days of the symposium, much sturgeon knowledge and "sturgeon sense" was imparted. We learned of strong commonalties among North American sturgeons, regarding population structure, life history attributes, habitat dependencies, sensitivities to degraded habitats and altered watersheds, and exploitation. Because of their life cycles and migrations, most sturgeon populations cross state and international boundaries, presenting important, yet unsolved, management challenges. Key questions relative to sturgeon biology, management and protection and information we do and don't know about each are discussed below.

Where in the Life Cycle, and Via What Mechanisms, is Year-Class Strength Established?

What We Do Know

Several papers presented herein emphasize the importance of the first year of life in establishing year-class strength among sturgeon species. Successful spawning is dependent upon flow and temperature conditions (Cooke et al; Jager et al; both this volume). Species are similar regarding the vulnerability of embryo and larval stages to sedimentation, fungal infestation, and pollutants and the dependency by young of the year on bottom substrate as predation refuge (Anders et al; Kruse and Scarnecchia; Parsley; all this volume). Modeling efforts clearly show that the first year of life is most sensitive to environmental change (Gross et al; Jager et al; both this volume). Therefore, recovery rates of sturgeons from depressed levels will most likely occur through increases in vital rates during early life (Gross et al., this volume).

What We Don't Know

Early life history stages of most sturgeons are generally very difficult to sample in the field. Accordingly, more quantitative work is needed relating egg, larval, and juvenile abundance to spawning stock size and environmental factors. Although simulations show the importance of the relationship during the first year of life and environmental factors (Gross et al., this volume), little empirical information exists regarding natural sturgeon vital rates (growth, mortality, and dispersal) to verify these simulations. Symposium participants concurred that highest priority should be placed on developing methods to quantify vital rates, population abundance, and habitat requirements during the first year of life.

What Habitats are Most Critical for Sturgeons?

What We Do Know

North American sturgeons share common habitat requirements. At the regional scale, all sturgeons require large, flowing rivers and estuaries for reproduction and early life growth and survival (Bemis and Kynard 1997). Hard-bottom and structured habitats are critical as spawning substrate and as predation refuge for young (Parsley et al., this volume). In many lower gradient systems, such as Chesapeake Bay, regions of rubble and hard bottom have been buried under meters of sediment due to deforestation, agriculture, and urbanization. In higher-flow systems, access and flow in regions of hard-bottom habitat have been altered in ways detrimental to sturgeon, by dams that support water resource projects such as municipal water supply, irrigation supply, navigation, and hydropower (Parsley et al. 1993; Beamesderfer and Farr 1997). Eutrophication and its common consequence, hypoxia, have disproportionate effects on sturgeons, in comparison to other fauna, because of their limited ability to oxyregulate at low dissolved oxygen levels (Klyashtorin 1976; Secor and Gunderson 1998). Hypoxia effects may be particularly important during the first year of life due to increased sensitivity and lessened abilities to escape inundation from hypoxic waters (Secor and Niklitschek 2001). Although some sturgeon populations can complete their life cycle over small spatial scales (Peterson and Gunderman, this volume), many species of sturgeons are highly migratory, with up to 500-km migrations over their life cycles (DeVore et al. 1999). These migrations can result in substantial gene flow among locations (subpopulations; Anders et al. 2001). Blocked migration corridors have fragmented segments of historical populations and reduced critical ecological and genetic exchange across habitats, contributing to extinction risk (Anders et al. 2001 and 2002, this volume; Jager 2001; Jager et al. 2001; Root et al., this volume).

What We Don't Know

Tagging studies have provided critical insight into sturgeon behaviors, including habitat use and seasonal movement and migration (Cook et al; Fox et al; Savoy and Shake; Snook et al; Welsh et al; all this volume). However, a more fundamental understanding of how habitat is related to sturgeon vital rates (i.e., production) is still lacking. This is a common problem in fisheries ecology: how do we develop more rigorous quantitative frameworks to evaluate fish habitat on absolute or comparative scales? Because abundance of most North American sturgeon populations is depressed compared with historical levels, the problem of restoring sturgeon habitat begs the question - are patterns of sturgeon habitat loss and degradation reversible? Furthermore, are habitat rehabilitation efforts, short of restoration of historical conditions, adequate for long-term viability and persistence of compromised sturgeon populations?

How Do We Restore Demographic and Genetic Vigor to Depressed Populations?

What We Do Know

Because genetic vigor or integrity is positively related to population size (demographic vigor), the intuitive but overly simplistic answer to this question involves increasing the size of depressed sturgeon populations via recruitment by fish representing all genetic components of the population. However, many sturgeon species and populations are plagued by limited or failed recruitment, often due to several interacting and often unquantified factors. This confounds restoration efforts in real time. Thus, a crucial initial approach to addressing rehabilitation of demographic and genetic vigor of depressed sturgeon populations involves determining and understanding the causes of genetic depression at population-specific levels.

Regardless of specific causes of individual sturgeon population depression, all such populations require at least periodic recruitment for short-term sustainability and persistence. Reliable recruitment over the longer term is also important for long-term population viability and persistence, from demographic and genetic perspectives (Jager 2001; Jager et al. 2001). Therefore, maintenance or reestablishment of sturgeon recruitment is critical (Gross et al., this volume) because genetic vigor or viability is positively related with population size and demographic vigor, which are both recruitment-dependent. Sturgeon recruitment can result from natural or artificial production or perhaps some planned alternating combination of both. Regardless, all approaches to maximize the numbers of contributing breeders should be strictly mandated, consistent with the goal of maintaining the proportional contributions of population genetic characteristics for subsequent generations.

Sturgeon populations can be grouped into two demographic categories: those that retain reliable or at least periodic natural recruitment, and those that do not. This distinction is important because it provides and precludes particular suites of possible restoration activities. For example, Cochnauer (this volume) reported the beneficial response over several decades of a naturally recruiting white sturgeon *A. transmontanus* population in the Snake River (Idaho, Oregon, and Washington) to cessation of recreational harvesting. In this case, given adequate time, this population appears to be responding favorably, demonstrating increased demographic and presumably genetic vigor, as reproducing fish representing available genetic components of the population may be contributing through natural recruitment. Alternatively, Ireland et al. (this volume) discussed the use of conservation aquaculture to provide short-term recruitment for a white sturgeon population in the Kootenai River, in Idaho, which was characterized by prolonged natural-recruitment failure. In this program, particular attention was given to representing population-level genetic characteristics in the broodstock, taken from the source population, to restore both demographic and genetic vigor of this first endangered white sturgeon population in North America.

What We Don't Know

The field of theoretical population genetics provides insight into requirements and useable management targets for demographic and genetic vigor. All progress aside, the question of how to restore demographic and genetic vigor to depressed populations remains central to the success of most sturgeon management programs. It appears that an approach encompassing both theoretical population genetic modeling and risk-averse empirical experimentation holds promise for addressing this paramount question (e.g., see Jager 2001 and Jager et al. 2001). Multidisciplinary approaches appear necessary for the solution of multivariate problems, such as the rehabilitation of imperiled sturgeon populations, which are usually due to multivariate problems at ecosystem scales. Furthermore, because sturgeons are late maturing, slow growing, and iteroparous, these traits should be accounted for in recovery programs. In summary, using a combination of scientifically defensible approaches and criteria, complementary habitat and ecosystem improvement programs and population safeguards may be a reasonable approach to protect and enhance demographic and genetic vigor of imperiled sturgeon populations.

What are the Effects of Dams on Sturgeon Populations?

What We Do Know

The social and economic benefits of dams are frequently attained at the expense of physical and biological processes that detrimentally effect ecosystems and specific organisms in various ways (Ligon et al. 1995; Gup 1994). Relative to sturgeon, dams simultaneously affect all phases of their life cycle (Cooke et al; Jager et al; Anders; Kruse and Scarnecchia; Parsley; all this volume). Perhaps the most important effect is that fragmentation of a river system by dams transforms a sturgeon population into a series of relatively isolated subpopulations (Anders et al. 2001 and 2002, this volume; Anders et al. 2001; Jager 2001; Jager et al. 2001). Sturgeon behavior does not necessarily favor voluntary upstream passage via facilities that are effective for other species (Cooke et al., this volume). As a result, alternative methods of maintaining connectivity between river segments have been evaluated, such as transplanting sturgeon upstream (Rien and North, this volume). Downstream passage at a dam via spillways or through turbines (entrainment) may occur at any life stage, although not without some risk of injury and mortality. To minimize this mortality risk, studies are evaluating the ability of bar racks and louvers to safely guide sturgeon to a downstream bypass (Amaral et al., this volume; Kynard and Horgan 2001).

Many effects of dams on sturgeon are directly related to the altered seasonal patterns in flow and temperature regimes, created by a dam (Cooke et al; Jager et al; both this volume). These effects are particularly pronounced when the dams are associated with hydroelectric facilities that operate in a peaking power mode. In such cases, downstream daily flow and temperature regimes can vary substantially, in association with generating patterns designed to match the daily pattern of electricity usage (Auer 1996). Secondary, yet important, effects of altered flow and temperature regimes include decreases in water quality, particularly in the reservoir part of river segments, and changes in physical habitat suitability, particularly in the free-flowing part of river segments. While the papers presented indicate that the suitability of habitat critical for spawning, incubation, and growth and survival of sturgeon larvae and early juveniles generally decreases as a result of these altered physical processes (Anders et al;

Kruse and Scarnecchia; Cooke et al; Jager et al; Parsley et al; all this volume), more detailed information is needed on the relationship between them and sturgeon life history.

What We Don't Know

Identifying potential effects of dams may be relatively easy; however, our understanding of the relative importance of these effects remains incomplete. Resulting negative and positive effects clearly vary, depending on how a dam is operated and the characteristics of the reservoir and free-flowing reach of the river (if any), both upriver and downriver from dams (Jager 2001; Jager et al. 2001 and 2002, this volume; Root, this volume). In general, research on fishways that facilitate voluntary upstream passage of sturgeon has been limited. Given the continued stock declines and habitat fragmentation issues, more focused research is needed. In particular, fish elevators have demonstrated some success for passing sturgeon in the United States and Russia (Warren and Beckman 1993). Research on the factors that attract sturgeon to elevator entrances would be particularly helpful towards improving their effectiveness and use at dams for their passage. Relative to protecting downstream migrants from hazardous spillway passage and turbine entrainment, research on the effectiveness of behavioral guidance technologies (e.g., infrasound, light) for directing sturgeon to safe passage facilities, or precluding spillway and turbine entrainment, is also needed. Therefore, a major challenge for sturgeon researchers and managers is to provide currently lacking biological data, to be used in objective benefit/risk analyses, regarding ways to minimize negative effects and maximize potential for hydropower and sturgeon production.

Is There a Role for Hatcheries in Sturgeon Restoration?

What We Do Know

Hatcheries have long been proposed as a means to sustain and restore sturgeon populations. Hatcheries have been quite successful in developing methods for artificial propagation of sturgeons (Doroshov 1985; Deng et al., this volume). Evaluations of released sturgeon in several systems indicate that hatchery-produced sturgeons can survive to adulthood and contribute to fisheries and spawning populations, particularly in depressed populations (Smith et al., this volume, Secor et al. 2000). Demographic modeling suggests that hatcheries might be an effective means to restore populations because survival rates at critical early life stages can be increased manyfold over current empirical survival rates (Gross et al., this volume). Also, abundances can be more rapidly recovered because degraded and lost spawning and nursery habitats can be "circumvented" by rearing early stages in artificial environments (Ireland et al., this volume).

What We Don't Know

Although hatchery programs may prove to be a particularly effective mechanism to restore juvenile and adult abundance, there is no guarantee that such efforts will always catalyze natural recovery. Indeed, to expect so may be naive. The number of females available for use in hatchery programs is often limited by the depressed abundance of natural stocks, and it would be undesirable to deplete natural breeding populations that remain (Ireland et al., this volume). We should, at all costs, minimize the risk of inbreeding and the potential for selecting maladaptive traits in released sturgeons. Initial genetic evaluation of a conservation aquaculture program with an endangered population of white sturgeon suggests that underrepresentation or overrepresentation of a portion of a wild population's genetic makeup can be avoided to minimize these risks (Ireland et al., this volume). Evaluation of hatchery programs for sturgeons, and most other fishes, is nascent, with an inadequate understanding of the influence of artificial rearing on postrelease behaviors. Adaptation to artificial hatchery environments may entail maladaptive natural behaviors affecting predation risk, foraging, migration, homing, and spawning. Also, individuals from a single release of a moderate number of juvenile sturgeons (10^5 to 10^6) could stray into adjacent populations, resulting in genetic (i.e., gene flow) or ecological (i.e., competition) interactions.

Finally, although hatcheries can improve sturgeon population abundance, hatcheries cannot be expected to stimulate natural recovery when more fundamental changes such as restoring habitats and reducing bycatch are also required. Hatcheries remain an important tool in the conservation of sturgeons, but hatchery releases must be treated experimentally, with emphasis on understanding postrelease behaviors and demographic attributes, rather than the typical emphasis on hatchery production rates. Development of conservation aquaculture practices, rather than a specific set of culture techniques, represents an adaptive, creative approach that prioritizes preservation of wild populations, along with their locally adapted gene pools, phenotypes, and behaviors (Anders 1998). Application of this approach holds promise for sturgeon conservation.

Can Sturgeons be Harvested on a Sustainable Basis?

What We Do Know

Caviar continues to be a highly sought and valuable commodity. In addition, demand for sturgeon flesh has increased during the past decade in North America. High domestic demand for caviar and flesh and declining harvests of sturgeons elsewhere in the world will result in increased pressure on North American sturgeon and paddlefish stocks. Sturgeon populations can be exploited on a sustainable level, but only if sufficient spawner escapement is guaranteed (Boreman 1997; Secor et al. 2000). Typically, sturgeon populations cannot tolerate more than 5% fishing mortality rates on a given spawning run. Due to their late maturation rates, sturgeons are extremely vulnerable to declines and extirpation if juveniles are harvested (Gross et al., this volume). Because sturgeons can only sustain harvest rates of single digit percentages, even low levels of bycatch in other fisheries and poaching can result in further decline following closures of directed fisheries.

Nearly all sturgeon populations migrate across state or international borders, creating difficulties if resource agencies are not coordinated and consistent in their management and protection of sturgeon populations. Furthermore, harvesting restrictions designed to protect species are difficult to enforce, due to species-specific identification problems (Birstein et al. 2000; Wills et al., this volume).

What We Don't Know

Because even low rates of incidental take and poaching can curtail recovery of protected sturgeon populations, it is critical to evaluate and reduce such mortality. With increased efforts to regulate trade and harvests, there is a clear need to develop forensic methods that allow determination of sturgeon products by species and population. Significant hurdles remain in development of coordinated sturgeon science management, among midwestern and western states and between the United States and Canada. The management of Atlantic sturgeon *A. oxyrhynchus* by the Atlantic States Marine Fisheries Commission provides a model of coordinated state management and a possible alternative to federal listing of depressed and declining sturgeon stocks (NMFS 1998). It remains unknown whether policy makers will be willing to pursue inter-jurisdictional solutions to sturgeon conservation.

The Ultimate Question—Does the Public Care?

What We Do Know

The public is generally unaware of endangerment of North American sturgeons. This appears to be related more to lack of attention by media and policy makers, than by lack of interest by the public. The key here is, obviously, to effectively provide society, over time, with an understanding that sturgeons are more important than simply being synonymous with caviar. Aquarium, museum, and other efforts to educate the public about sturgeons have generated substantial interest. Public exhibits are now providing school kids an opportunity to learn about sturgeons. The unique behaviors and appearance of sturgeons seem to be a real crowd-pleaser. Also, there seems to be a general interest in the natural and fisheries heritage of sturgeons. For some sturgeons, particularly white sturgeon, there is considerable interest by the angling community in maintaining and restoring sturgeons (e.g., Cochnauer, this volume).

What We Don't Know

It would be somewhat disingenuous to suggest that we are now restoring sturgeon stocks to support future commercial fishing. Sturgeons require decades to centuries to recover, and following their recovery, low production rates would only permit small fisheries. Scientists, managers, and policy makers have poorly articulated the goals of sturgeon recovery in terms of benefits to society. Sturgeon recovery is a multi-decadal affair. Will public and resource user groups be patient enough to support recovery plans for species that currently can only be captured by our imagination? Will fisheries professionals and numerous additional stakeholder groups provide the insights, initiatives, and cooperation needed to enable an improved future desired condition for sturgeons? Deliberate and focused effort toward this end, perhaps in the form of inclusive scientific, public relations, and educational programs, can help provide an affirmative response to these important questions.

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