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[Management Brief]

Evaluation of Recovery Goals for Endangered White Sturgeon in the Kootenai River, Idaho

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Abstract.—Our objective was to evaluate recovery goals for endangered white sturgeon *Acipencer transmontanus* in the Kootenai River, Idaho. We used demographic statistics for white sturgeon in the Kootenai River in a stochastic density-dependent population model to estimate recruitment rates needed for population recovery. We simulated future abundance of white sturgeon in the Kootenai River over a 25-year period and a range of hypothetical recruitment rates to estimate the level of recruitment that would lead to population recovery (7,000 fish, the number present before the population suffered recruitment failure). We compared simulations of future abundance at enhanced levels of recruitment with those based on the present status of the population and with the recruitment criterion in the Kootenai River White Sturgeon Recovery Plan. We found that the population would decline to only 57 individuals after 25 years and only 6 individuals after 50 years if recruitment failure continued. The population would reach the target carrying capacity of 7,000 individuals within 25 years only when each adult produced 0.4 age-1 recruits, a recruitment rate equivalent to reaching the target level of recruitment in the recovery plan every year. In contrast, the population would grow to only 1,200 individuals if the target level of recruitment in the recovery plan was produced in only 3 of every 10 years, as specified in the recovery plan. We suggest that recovery goals for white sturgeon in the Kootenai River can be modified as follows: (1) a population goal of 7,000 subadults and adults; (2) population recovery within 25 years; and (3) a minimum recruitment rate of at least 20 age-1 juveniles detected from each year-class in each of 10 years by use of a standardized monitoring protocol.

Sturgeon species (Acipenseridae) are among the most imperiled fish species in the world. Most sturgeon species worldwide are considered endangered or threatened because of overfishing, fragmentation of populations by dams, and habitat degradation (Rieman and Beamesderfer 1990; Birstein 1993; Luk'yanenko et al. 1999). Sturgeon roe is especially valuable as caviar, which has led to excessive exploitation of many species as the availability of caviar from more valuable species (e.g., beluga *Huso huso* and white sturgeon *Acipenser transmontanus*) dwindled through population decline (Cohen 1997; Luk'yanenko et al. 1999; Ivanov et al. 1999). Of the 28 species or subspecies of sturgeon distributed throughout the northern hemisphere, 9 occur in North America (Bemis and Kynard 1997). The North American sturgeon species belong to two genera, of which the six *Acipenser* species or subspecies are generally larger bodied, slower growing, later maturing, and thus less tolerant of exploitation than the three *Scaphirhynchus* species (Brown 1971; Pflieger 1975; Becker 1983; Rieman and Beamesderfer 1990; Findeis 1997). All species of North American sturgeon except the lake sturgeon *A. fulvescens* are listed as extirpated, endangered, threatened, or species of concern in at least part of their range (www.nanfa.org/bccdiversity.shtml).

The white sturgeon is found along the Pacific Coast of North America from Alaska to California, including the vast drainage area of the Columbia River (Scott and Crossman 1998). The species is the largest freshwater fish in North America and is generally anadromous, so construction of dams has led to population fragmentation and reduced abundance of the species throughout its range (Lukens 1981, 1985; North et al. 1993; Parsley and Beckman 1994). Despite this population fragmentation, the species generally exhibits genetic diversity, the range of diversity progressively decreasing upstream within populations (Anders et al. 2001, 2002). The white sturgeon population living in the Kootenai River, Idaho, differs from other populations of the species by being land-locked, less genetically diverse, and more tolerant of cold temperature (Setter and Brannon 1990; Paragamian and Kruse 2001). The white sturgeon population in the Kootenai River, listed as endangered under the U.S. Endangered Species Act on 6 September 1994 (USFWS 1994; Duke et al. 1999), is the only white sturgeon population listed as endangered in the USA (the populations in the upper Columbia, Nechako, upper Fraser, and Kootenay rivers are Red Listed in Canada; UCWSRI 2002).

The recovery plan for white sturgeon in the Kootenai

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River (Duke et al. 1999; USFWS 1999) specified three management actions to facilitate population recovery and downlisting. First (short term), conservation aquaculture would prevent extinction, establish year-classes, and preserve genetic integrity (Ireland et al. 2002a, b). Second, increased spring discharge from Libby Dam, an upstream hydropower and flood control dam, would facilitate spawning and recruitment (Duke et al. 1999; Paragamian et al. 2001; Paragamian and Wakkinen 2002). Last (long term), spawning habitat enhancement would increase reproductive success. Wild recruitment is still largely lacking, however, despite conservation aquaculture, begun in 1990, which added thousands of hatchery fish to the population since 1992. Hatchery fish will begin recruiting to the adult population in 2020 (Paragamian et al. 2005). Under current levels of hatchery production, the population is expected to stabilize at about 3,000 adults (Paragamian et al. 2005); accordingly, the next generation of white sturgeon will be mostly hatchery-produced progeny of wild adults. Discharge mitigation was used nearly every year since listing of the species as endangered, and spawning and egg deposition was observed in most years, but poor egg and larval survival precluded measurable natural recruitment (Paragamian et al. 2001, 2005; Paragamian and Wakkinen 2002). Consequently, population surveys confirmed that the wild population would be extinct within a few decades if wild recruitment continued to fail (Paragamian et al. 2005). Similarly, the white sturgeon population in the upper Columbia River, composed of only 1,400 adults in 2002, will be functionally extinct by 2044 without remedial actions (UCWSRI 2002).

Our objective was to evaluate recovery criteria for white sturgeon in the Kootenai River and to recommend revisions to the Recovery Plan, based on our findings. To achieve our objective, we used demographic statistics (Paragamian et al. 2005) and a stochastic simulation model to estimate population growth and time to recovery in relation to a simulated range of recruitment rates. The recovery plan specifies that population recovery would be indicated if a naturally produced year-class of white sturgeon, measured by capture of 20 juveniles age 1 or older per year-class, occurred in 3 different years during a 10-year period (USFWS 1999). Specific delisting recovery criteria would be developed as new population data became available (Duke et al. 1999; USFWS 1999). To evaluate feasibility of the recruitment recovery criterion for achieving population recovery, we used demographic statistics in a stochastic population model. Population models have widely been used to estimate the future status of animal populations and to evaluate effects of potential management actions on progress toward population recovery goals (Beissinger and McCullough 2002; White et al. 2002). Our study differed from a previous study that quantified population demographics, the decline in numbers of wild fish, and expected recruitment of hatchery-origin juveniles to the adult population (Paragamian et al. 2005), by focusing only on the fate of wild-origin fish. We justified a focus on wild fish because: down-listing or de-listing of the population must be based on the status of wild-origin fish (Duke et al. 1999). The genetic contribution of hatchery-origin fish is not clear and cannot be known until fish mature (Paragamian and Beamesderfer 2004), and reproductive ability of hatchery-origin fish is uncertain (Smith et al. 2002).

Methods

We used vital statistics from Paragamian et al. (2005), along with a stochastic population model, to evaluate recovery goals for white sturgeon in the Kootenai River, Idaho, over a range of hypothetical recruitment rates. We used a density-dependent logistic (Ricker-type) model to simulate future population abundance:

$$N_{t+1} = N_t e^{r[1-(N_t/K)]} e^{\varepsilon}.$$

In the simulation model, N_{t+1} = the population number at time $t+1$; N_t = the population number at time t; r = the intrinsic rate of population change; K = the carrying capacity of the population, and ε = stochastic error. In the model, we used demographic parameters derived by Paragamian et al. (2005), who estimated population numbers annually during 1977–2001, a period of little or no natural recruitment, by using a Jolly–Seber open-population deaths-only mark–recapture model (Seber 1982; Arnason et al. 1998a, b). We began with a starting population (N_0) of 500 fish, the estimated number present in the Kootenai River in 2005. We used a carrying capacity (K) of 7,000 individuals as the number in the population when recovery would be complete because that many were estimated to be present in the population in the late 1970s shortly after closure of Libby Dam. We included random error (ε) in the model by treating r as a normally distributed random variable with a standard error (SE) = 0.01 the standard error of the annual mortality rate during 1989–2001 (A = 0.087; SE = 0.01; Paragamian et al. 2005) estimated by using program MARK (White and Burnham 1999; Cooch and White 2001). We then simulated population growth over a 50-year period and a range of population growth rates r to quantify: (1) the number of white sturgeon present after 25 years; (2) the likelihood of reaching threshold numbers of 1,000–

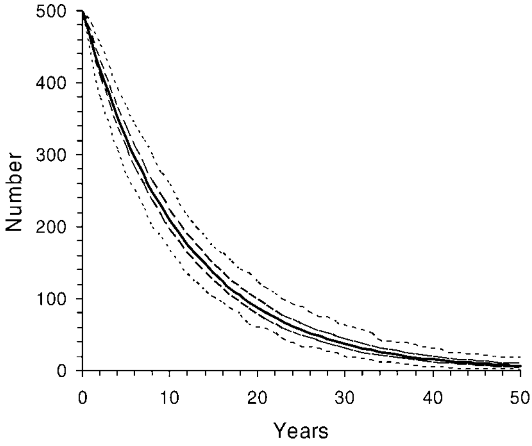

FIGURE 1.—Simulated abundance of white sturgeon in the Kootenai River over 50 years if recruitment failure continues and the population continues to survive at a rate of $S = 0.913$. Curves depict the average, ±SD, and ± range (minimum and maximum) of 1,000 simulations for a stochastic population model, based on demographic parameters estimated by Paragamian et al. (2005).

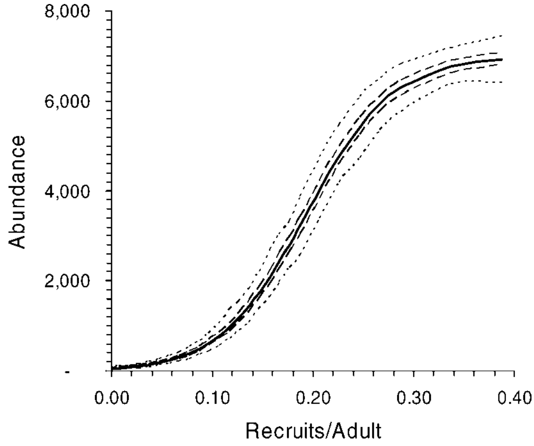

FIGURE 2.—Simulated abundance of white sturgeon in the Kootenai River after 25 years of population recovery versus the recruitment rate (number of recruits produced per adult in the population). Curves depict the average, ±SD , and ± range (minimum and maximum) of 1,000 simulations for a stochastic population model, based on demographic parameters estimated by Paragamian et al. (2005).

7,000 individuals (in increments of 1,000 individuals) after 25 years; and (3) the number of years necessary to reach 1,000–7,000 individuals (in increments of 1,000 individuals). We transformed r into an annual recruitment rate F based on the relationship $e^r = \lambda = F + S$, where $S = 1 - A$ ($A = 0.913$; Paragamian et al. 2005), to express the results in relation to recruitment rate F.

We estimated the number of wild recruits observed during routine white sturgeon population surveys in the Kootenai River, as a basis for comparing a simulated range of recruitment rates against the recruitment goal in the recovery plan. The recovery criterion for natural reproduction in the recovery plan is the natural reproduction of white sturgeon in at least three different years by the year 2006, where a naturally reproduced year-class must be demonstrated through detection of at least 20 juveniles from that year-class reaching 1 year of age (Duke et al. 1999). We reformulated the recovery criteria in terms of an annual recruitment rate, to facilitate its evaluation in a simulation model. First, because the recovery plan specified no sampling period during which to observe the recruitment goal, we assumed that a 10-year period applied from 1996, when the plan began, to 2006, the end date for the recruitment criterion. Second, we assumed that wild-origin recruits would be observed during routine gill-netting assessments at the same rate that hatchery-origin fish released during 1992–1999 would be recaptured in routine gill-netting surveys (9.7% per year; Ireland et al. 2002b). Third, we assumed that routine surveys with experimental gill nets (29.4-m-long panels of 1.5–2.0-cm bar mesh; Ireland et al. 2002b) would continue at similar levels of effort in the future. Fourth, we estimated that 3 year-classes of 20 age-1 juveniles per year-class observed during a 10-year sampling period was equivalent to an average of 6 age-1 wild juveniles observed per year, that is, a total year-class contribution of 62 age-1 fish produced (6 fish observed/9.7% capture rate) and an annual recruitment rate of 12% (62 recruits/500 adults). Last, we compared this estimate of 12% recruitment to a simulated range of recruitment rates, to test of the feasibility of the recovery plan for rebuilding the white sturgeon population in the Kootenai River.

Results

If recruitment failure continues for white sturgeon in the Kootenai River, the population will decline to very low numbers within 25 years (Figure 1). Numbers in the population probably would be only 57 individuals after 25 years (±SD = 49–65; range = 33–89) and only 6 individuals after 50 years (±SD = 4–9; range = 0–17). Although the probability of extinction after 50 years was only 0.001, the number of fish in the population by then would probably be too low to sustain the population beyond 50 years.

Simulated abundance of white sturgeon in the Kootenai River after 25 years was positively related to the average number of age-1 recruits produced by each adult (Figure 2). The population reached the target carrying capacity of 7,000 individuals (± SD = 6,787–7,067; range = 6,415–7,430) only when each adult

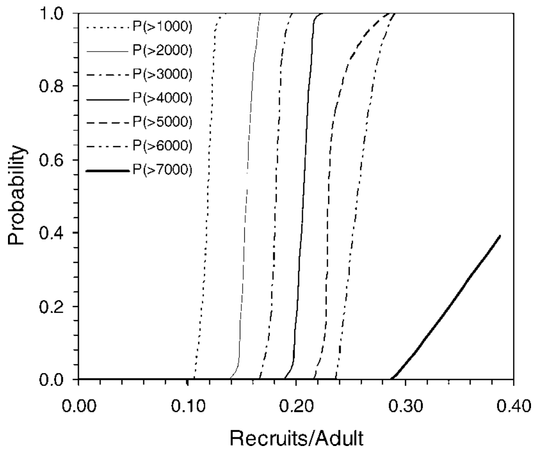

FIGURE 3.—Simulated probability of the white sturgeon population in the Kootenai River reaching a range of population thresholds after 25 years of population recovery versus the recruitment rate (number of recruits produced per adult in the population). Curves depict the number of 1,000 simulations that reached each target threshold at each recruitment rate for a stochastic population model, based on demographic parameters estimated by Paragamian et al. (2005).

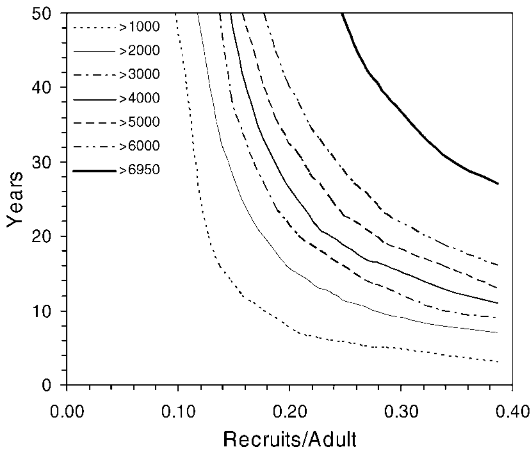

FIGURE 4.—Years to reach a range of population thresholds for the white sturgeon population in the Kootenai River versus the recruitment rate (number of recruits produced per adult in the population). Curves depict the number of 1,000 simulations that reached each target threshold at each recruitment rate for a stochastic population model, based on demographic parameters estimated by Paragamian et al. (2005).

produced 0.4 age-1 recruits, a recruitment rate equivalent to reaching the target level of recruitment in the recovery plan every year. The population grew to only 4,000 individuals (±SD = 3,834–4,249; range = 3,390–4,747) in 25 years if the target level of recruitment in the recovery plan were produced every other year (0.2 age-1 recruits per year). The population grew to only 1,200 individuals (±SD = 1,087–1,297; range = 900–1,531) if the target level of recruitment in the recovery plan were produced in only 3 of every 10 years (0.12 age-1 recruits per year), the target level specified in the recovery plan.

Abundance thresholds for white sturgeon in the Kootenai River after 25 years were positively related to the average number of age-1 recruits produced by each adult (Figure 3). After 25 years, 1,000 individuals would nearly certainly be present (likelihood = 1.0) if a recruitment rate of 0.137 age-1 recruits were produced by each adult. Similarly, 2,000 individuals would be present at a recruitment rate of 0.177; 3,000 individuals would be present when recruitment was 0.207; 4,000 individuals would be present when recruitment was 0.227; 5,000 individuals would be present when recruitment was 0.287; and 6,000 individuals would be present when recruitment was 0.387. Recruitment would need to be higher than specified in the plan (and to occur every year) to guarantee the presence of 7,000 individuals in the population after 25 years, the number probably present before the population experienced recruitment failure.

Time to recovery was inversely related to the average number of age-1 recruits produced by each adult white sturgeon in the Kootenai River (Figure 4). Time to recovery first fell below 50 years at a recruitment rate greater than 0.097 for a threshold of 1,000 individuals, greater than 0.117 for 2,000 individuals, greater than 0.137 for 3,000 individuals, greater than 0.147 for 4,000 individuals, greater than 0.157 for 5,000 individuals, greater than 0.177 for 6,000 individuals, and greater than 0.247 for 6,950 individuals. Time to recovery first fell below 25 years at a recruitment rate greater than 0.117 for a threshold of 1,000 individuals, greater than 0.157 for 2,000 individuals, greater than 0.177 for 3,000 individuals, greater than 0.207 for 4,000 individuals, greater than 0.237 for 5,000 individuals, and greater than 0.277 for 6,000 individuals. Recruitment would need to be higher than specified in the plan (and occur every year) for the population to reach 7,000 individuals within 25 years, though the population would probably reach 6,950 individuals within 27 years at a recruitment rate of 0.387 age-1 recruits per adult.

Discussion

Our modeling confirmed that the white sturgeon population in the Kootenai River will continue to decline in the future if wild recruitment continues to fail. Paragamian et al. (2005) also modeled the white sturgeon population in the Kootenai River and found that with consistent failure of natural recruitment, numbers of wild-origin fish declined by almost 90% from about 6,800 fish in 1980 to 640 fish in 2002, such that the population was composed of mostly hatchery-origin fish by 2030. Our modeling further into the future confirmed that the population of wild-origin fish will be virtually extinct within 50 years and will probably fall below biologically viable levels much earlier. Because a female white sturgeon spawns only once every 5–6 years (Paragamian et al. 2005), the number of adults in the population would need to be 10–12 times higher than the minimum viable number of spawning females (assuming a 1:1 sex ratio). We propose development of such a criterion for minimum viable population size, below which recovery has failed. Further, although hatchery-origin fish have recruited to the population, uncertain genetic issues (Paragamian and Beamesderfer 2004) and unknown spawning ability of hatchery-origin fish (Smith et al. 2002) render the role of the conservation hatchery program doubtful. These issues underscore the urgency of effective recovery measures for the wild population.

Our modeling suggests that the target recruitment rate in the recovery plan for white sturgeon in the Kootenai River would only slowly rebuild the population, a result not yet established. For example, if year-classes of target size are produced in only 3 of 10 years (annual recruitment = 0.12), as stipulated in the recovery plan (Duke et al. 1999), the population would consist of only about 1,200 individuals after 25 years, only 2.4 times more individuals than were present in 2005. In contrast, if year-classes of target size are produced every other year (annual recruitment = 0.20), the population would consist of about 4,000 individuals after 25 years, an eightfold increase. Better still, if year-classes of target size are produced every year (annual recruitment = 0.41), the population would consist of nearly 7,000 individuals after 25 years, the number that were present before the population suffered recruitment failure. Therefore, we suggest increasing the recruitment target in the recovery plan to 0.41 age-1 recruits per adult, to reduce the time for population rebuilding. We also suggest setting the timeline for recovery at 25 years to permit progeny from wild-origin parents to mature and spawn.

Under present recruitment limitations, recovery of white sturgeon in the Kootenai River will depend primarily on improving first-year survival, as has been shown for other sturgeon populations (Gross et al. 2002; Parsley et al. 2002). For example, for three sturgeon species (white sturgeon, shortnose sturgeon *A. brevirostrum*, and Atlantic sturgeon *A. oxyrhinchus*), population growth rate was most strongly influenced by first-year survival, based on elasticity analysis, even after accounting for the effects of hatchery supplementation, harvest regulation, and habitat restoration (Gross et al. 2002). We conclude that future improvement in recruitment and first-year survival of white sturgeon in the Kootenai River must rely on habitat enhancement to improve incubation and rearing conditions (Duke et al. 1999; Paragamian et al. 2005).

Population growth could be increased by reducing mortality of subadult and adult individuals, because the white sturgeon is highly vulnerable to exploitation (Beamesderfer et al. 1995; DeVore et al. 1995). Total mortality (natural mortality) for subadult and adult white sturgeon in the Kootenai River is already low (8.7%), because of bans on fishing for sturgeon in the Kootenai River (Duke et al. 1999; Paragamian et al. 2005). Natural mortality rates of other white sturgeon populations are similar: 12% in the upper Columbia River (RLL 1994), 6–16% in the middle Snake River (Cochnauer 1983; Lukens 1985; Lepla and Chandler 1995, 1997), 4.2–9.0% in the lower Columbia River (Beamesderfer et al. 1995), and 5.0–16% in the Sacramento River (Kohlhorst et al. 1980). Mortality rates of hatchery-origin juvenile white sturgeon in the Kootenai River were 40% in the first year and 9% for subadults (Ireland et al. 2002b). Nonetheless, small reductions in mortality translate into large increases in numbers over the extended periods over which white sturgeon live (75+ years; Paragamian et al. 2005).

Our analysis of recruitment targets was relatively simple because the life history of white sturgeon in the Kootenai River is simpler than those of other sturgeon populations (Duke et al. 1999; Paragamian and Kruse 2001). In contrast to the population in the Kootenai River, white sturgeon in the Snake and Columbia rivers are fragmented by dams, and some populations support fisheries (RLL 1994; Beamesderfer et al. 1995; Lepla and Chandler 1997; Lepla et al. 2001). In addition, some sturgeon populations have more complex life histories—including straying, migration, and differences in survival between freshwater and saltwater (Nickelson and Lawson 1998; Hilderbrand 2002; Legault 2005). Last, stock (Paragamian et al. 2005) or genetic limitations (Paragamian and Beamesderfer 2004) could influence white sturgeon in the Kootenai River. For example, numbers of female spawners declined from 270 in 1980 to about 77 in 2002 (Paragamian et al. 2005). Because fewer than 30 females will spawn annually after 2015 (females spawn every 5–6 years), the conservation aquaculture program, which requires production of at least 10 families from the wild stock each year (Ireland et al. 2002a), will eventually be in jeopardy.

Our results suggest that the recruitment goal for white sturgeon in the Kootenai River is too low. When the recovery plan was developed, the population was larger (more than 1,000 fish) and only limited demographic data were available. Spawning habitat and ecosystem needs were much more complex than originally anticipated (KTOI 2005) and discharge mitigation was expected to increase natural recruitment. However, after more than 10 years of mitigation, natural recruitment was estimated at only 10 fish per year-class, and recovery has not occurred (Paragamian et al. 2005).

We suggest the following modifications to recovery criteria for white sturgeon in the Kootenai River. First, we suggest a recovery goal of 7,000 subadult and adult wild-origin individuals in the white sturgeon population, the number that were present before the population suffered persistent recruitment failure. Second, we suggest a 25-year timeline for achieving the population goal, a period that would permit wild-origin recruits to mature and spawn. Third, we suggest increasing the minimum recruitment rate to detection of at least 20 wild-origin juveniles from each year-class reaching 1 year of age in each of 10 years (total annual recruitment of at least 206 fish), the recruitment rate that would rebuild the population to nearly 7,000 individuals within 25 years.

Time is running out on the white sturgeon population in the Kootenai River, as well as other sturgeon populations in the world (UCWSRI 2002). No one knows if or when hatchery fish may contribute to population recovery through successful spawning, or if habitat remediation will successfully enhance wild recruitment enough to stave off extinction. In any case, other sturgeon recovery programs may benefit from evaluation of recovery targets through simulation (Dryer and Sandvol 1993; Quist et al. 2004; Webb et al. 2005; Jager 2006), as in our study, if a sampling program is in place to monitor population demographics and recruitment (e.g., Rust and Wakkinen 2004).

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