

Dilemma on the Kootenai River—The Risk of Extinction or When Does the Hatchery Become the Best Option?

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Abstract.—In 1994, the Kootenai River white sturgeon *Acipenser transmontanus* was listed in the United States as an endangered species. Under provisions of the Endangered Species Act, a recovery plan was prepared and included two main recovery measures: (1) mitigation of spring flows for spawning and early life rearing, and (2) implementation of a conservation aquaculture and breeding plan to prevent extinction and sustain year-classes. The hatchery program was controversial and intended as a short-term measure as the flow mitigation strategy for wild fish developed. It called for the release each year of up to 1,000 white sturgeon from each of 10–12 families. It was believed that the mitigation of spring flows from Libby Dam would rapidly bring about recovery. However, after 8 years of flow mitigation and intensive monitoring and evaluation, it became apparent that recovery needs were more complex. Flow releases were not at the expected magnitude and habitat issues became a significant concern because the spawning location of sturgeon did not appear suitable (silt and sand) for adequate survival of eggs and larvae. Recruitment of wild fish was extremely low, while survival of hatchery sturgeon was higher than expected. Hatchery fish soon became abundant out numbering juvenile wild sturgeon by about 400:1. Assessment of sturgeon demographics, with extinction risk models, provided evidence that the wild population would be extinct within three decades and the population would be comprised almost exclusively of hatchery fish. Population projections described a significant near-term bottleneck in spawner numbers as the wild population diminished but hatchery fish had not yet matured. Managers are faced with a contentious dilemma of elevating the importance of the hatchery program by taking a higher proportion of the remaining wild spawners, escalating the number of hatchery releases, which could result in increasing the risk of inbreeding depression, loss of genetic diversity, genetic swamping, disease magnification, long term domestication, and intraspecific competition with wild recruits, compromising recovery. However, without significant hatchery intervention, the population could become a museum piece with no management options to benefit anglers. There will be disagreements, but risks must be considered, and we propose some compromises that may ease the intrusion of hatchery fish and provide management options.

Introduction

Sturgeon (Acipenseridae) populations worldwide are at risk of extinction or serious population depression (Birstein 1993). In North America, stocking hatchery-reared sturgeon helps sustain wild populations, while angling regulations, habitat improvement or rehabilitation, and augmentation measures are implemented to recover wild populations (St. Pierre 1999;

Smith et al. 2002; Snook et al. 2002). Conservation aquaculture is one fishery management tool that can help facilitate recovery. Such a tool uses wild broodstock with a breeding plan, thus insuring genetic representation of the wild stock (Ireland et al. 2002a). However, stocking resultant hatchery-reared fish does not come without genetic and domestication concerns (Busack and Currens 1995).

In Idaho and Montana, the isolated Kootenai

River white sturgeon *Acipenser transmontanus* population is genetically unique (Setter and Brannon 1992). This population became recruitment-limited after Libby Dam was completed in 1972 (Partridge 1983; Apperson 1991) (Figure 1). The dam substantially modified the flow pattern of the Kootenai River, particularly during spring when white sturgeon spawn (Duke et al. 1999; Paragamian et al. 2002). In the United States, the popu-

lation was formally listed as an endangered species under the U.S. Endangered Species Act on September 6, 1994 (USFWS 1999), and the same transboundary population was "red-listed" in the Kootenay River and Kootenay Lake, British Columbia, Canada in 1999 (Cannings and Ptolemy 1998). An international multi-agency Kootenai River White Sturgeon Recovery Team (KRWSRT) was formed to develop and implement a recovery plan (Duke et al. 1999; USFWS 1999). Two of the main measures of the recovery plan are to (1) monitor and evaluate experimental augmentation flows for spawning and rearing to successfully recruit year-classes of wild white sturgeon, and (2) prevent extinction, preserve genetic representation of the wild stock and establish year-classes through the design and implementation of a conservation aquaculture program (Ireland et al. 2002a, 2002b).

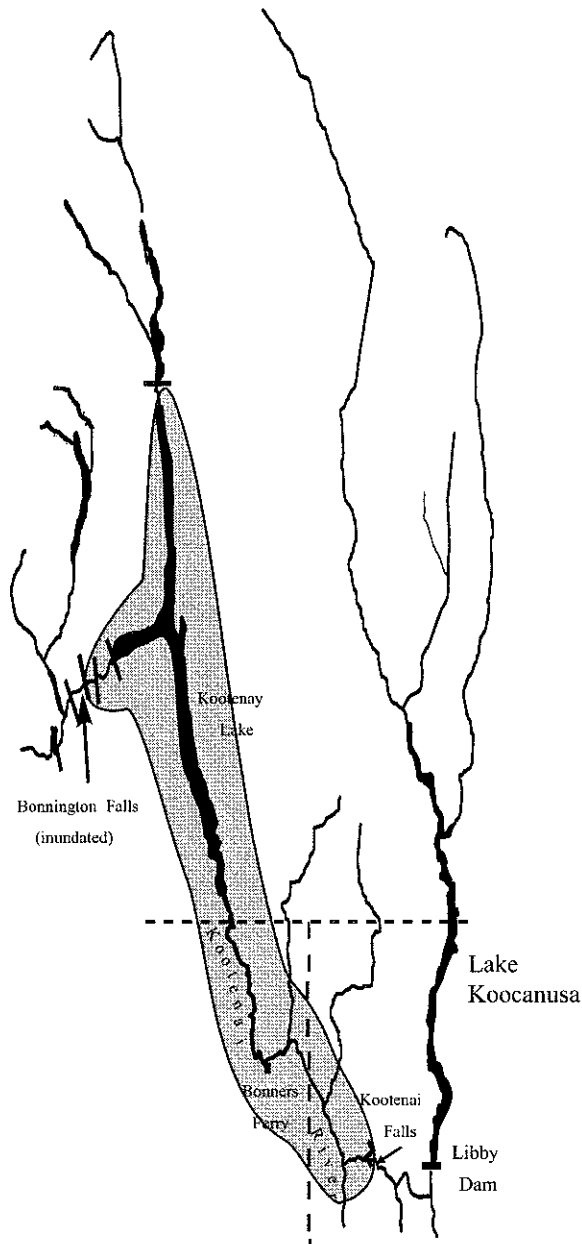


Figure 1. Current range of endangered Kootenai River white sturgeon (shaded), Kootenay Lake, Kootenai River, Libby Dam, Bonners Ferry, and other key locations in British Columbia, Idaho, and Montana.

Conservation Aquaculture

Conservation Aquaculture Program

The Conservation Aquaculture program, which included a breeding component (Kincaid 1993; USFWS 1999), began in 1990 (Apperson and Anders 1990) when sperm and eggs were collected for the white sturgeon hatchery operated by the Kootenai Tribe of Idaho. Risks of stocking hatchery-reared fish were identified early (Apperson and Wakkinen 1992). Initially, primary objectives were to determine whether Kootenai River white sturgeon could produce viable offspring because there were elevated levels of copper in the oocytes (Apperson 1991) and whether these fish could be cultured on river water. By 1995, conservation aquaculture had evolved into a program through which white sturgeon numbers would be increased using progeny from wild broodstock with an eventual goal of a self-sustaining wild population that could be removed from the endangered species list. After wild recruitment was established, hatchery production would be terminated (USFWS 1999).

Initial broodstock collection numbers and juvenile stocking rates under the Conservation Aquaculture program were based on survival, growth, and maturity rates estimated to produce the minimum effective population size (N) necessary to preserve genetic integrity (Kincaid 1993). The breeding plan was designed to use wild fish only once, and hatchery-reared fish were not to be used as broodstock. Each year, it was anticipated that up to 12 adult males and 12 adult females would be collected from the wild stock for the culture program. Removal of adults from

the wild was justified because of the objective of the recovery plan to build year-classes. The breeding plan called for the annual release of a maximum of 1,000 yearlings from each of 10–12 families (up to 12,000 yearlings annually). However, it was soon determined that only older and larger hatchery-reared sturgeon could be released because it was necessary to double mark them for later identification while the target release number remained the same.

The development of the Conservation Aquaculture program was not problem-free (e.g., an entire brood year was lost in 1996 and 1997 and most of one in 1992 to in-hatchery mortality). However, after several years of experience, upgrading the rearing facility, and adding mechanical redundancies, the program's efficiency improved substantially (measures to improve water flow, dependability, and quality) (Ireland et al. 2002a). In addition, a second rearing facility (Fort Steele, British Columbia, Canada) was added in 1999, which helped protect brood years by splitting families between the two facilities and thus spreading the risk. More than

28,000 age 1 and 2+ juveniles were released from 1992 through 2002 (Sue C. Ireland, Kootenai Tribe of Idaho, unpublished data) (Table 1).

Evaluation of the Conservation Aquaculture Program

Evaluation of the Conservation Aquaculture program began in 1993 when gill nets were deployed from Kootenay Lake, British Columbia to the city of Bonners Ferry, Idaho to capture hatchery-reared and wild juvenile fish (Ireland et al. 2002b). Evaluation was based on comparisons of estimates of survival rates, growth rates, and condition factors between released and recaptured fish (Ireland et al. 2002b). Survival of hatchery-reared sturgeon was higher than expected, and recruitment of wild fish was extremely low (Ireland et al. 2002b). Hatchery-reared fish had a survival of about 60% the first year after being released at age 1 or 2+ (older fish were released in 1990, 1995, and 1998) and about 90% in the following years (up to 8

Table 1. Numbers and recapture rates of hatchery produced white sturgeon juveniles (progeny of wild brood stock) released into the Kootenai River in Idaho between 1990 and 2002.

Year-class	Number released	(mm) at release (SD)	Mean total length (g) at release (SD)	Mean weight Release year	Percent (#) recaptured
1990	14	455	321	Summer 1992	0.5% (8)
1991	200	255.0 (17.2)	65.9 (12.8)	Summer 1992	6.2% (97)
1992	91	482.6 (113.0)	549.3 (482.9)	Fall 1994	6.3% (98)
1995	—	—	—	? ^a	0.1% (2)
1995	1,076	228.5 (27.0)	47.3 (16.6)	Spring 1997	23.1% (362)
1995	891	343.7 (43.7)	147.7 (64.0)	Fall 1997	23.2% (363)
1995	99	410.4 (67.9)	287.4 (137.8)	Summer 1998	3.3% (52)
1995	25	581.5 (40.5)	863.3 (197.9)	Summer 1999	0.7% (11)
1995	—	—	—	? ^a	0.6% (9)
1998	306	261 (42.0)	79.5 (44.4)	Fall 1999	1.9% (29)
1999	—	—	—	? ^a	0.1% (2)
1999	2,186	251.1 (29.6)	70.5 (18.1)	Fall 2000	14.5% (227)
1999	2,074	284.3 (54.4)	107.6 (60.1)	Spring 2001	15.5% (243)
2000	3,940	244.0 (38.9)	64.2 (31.0)	Fall 2001	3.0% (47)
2000	2,209	283.1 (28.7)	99.3 (30.2)	Spring 2002	0.1% (1)
2000	30	365.4 (14.0)	195.3 (19.9)	Summer 2002	— (0)
2000	214	409.4 (53.5)	294.1 (109.8)	Fall 2002	— (0)
2001	7,141	217.2 (32.8)	44.6 (18.6)	Fall 2002	— (0)
2001	1,715	258.2 (52.9)	717.9 (242.1)	Spring 2003	— (0)
2002	5,864	217.7 (37.3)	41.3 (14.2)	Spring 2003	— (0)
2002 ^b	—	—	—	—	0.8% (13)
Total	28,075 ^c	—	—	NA	7.6% (1,564)

^a Year-class determined by scute removal; PIT not matched in database to determine stock year.

^b These juvenile white sturgeon had no PIT; year-class could not be determined by scute removals.

^c Ten additional fish were released below Kootenai Falls, Montana, in 1994.

years) (Ireland et al. 2002b). Growth rates of hatchery-reared fish were acceptable, but slower than growth of wild sturgeon found in other rivers. Hatchery-reared juvenile white sturgeon soon became relatively abundant, outnumbering wild juvenile white sturgeon in the gill-net catch by about 400:1.

Analysis of the mtDNA of the white sturgeon broodstock used from 1993 to 2002 indicated that the genetic makeup of the hatchery-produced fish was similar to that of wild fish (Paul Anders, S. P. Cramer and Associates, personal communication). However, the N_e of the hatchery broodstock ranged from 2 to 15.5 (Paul Anders, S. P. Cramer and Associates, personal communication), which was substantially less than the minimum desired number of 50.

Flow Augmentation and White Sturgeon Spawning

Augmented Flows and Spawning

Initially, between 1994 and 1997, augmented flows released in the spring from Libby Dam, Montana for white sturgeon spawning were considered sufficient to help recover the population (Paragamian et al. 1997). However, actual flow releases were lower than some KRWSRT members expected. Furthermore, flow augmentation was inconsistent (Paragamian and Wakkinen 2002) (e.g., there was no augmentation in some years [2001]; however, in other years [1994 through 2000 and 2002], daily average flows for spawning ranged from 141 to 1,265 m³/s at Bonners Ferry [Paragamian and Wakkinen 2002]). The desired flows, although technically not achievable (because of perceived threats to flood agricultural fields, the limited number of operational bays [five of eight], and concern that spill would increase N gas over 110%), were to be 991 m³/s from Libby Dam, thus bringing daily average minimum flows at Bonners Ferry to more than 1,132 m³/s for spawning.

After 8 years of flow augmentation and intensive monitoring and evaluation, it became apparent that reproductive needs were not being met (Paragamian and Wakkinen 2002). White sturgeon spawning occurred annually and appeared to improve, but there was little evidence of egg survival (Paragamian et al. 2001). About 1,000 eggs were collected from 1994 through 2002; however, only one yolk sac larva was captured (Paragamian et al. 2001). Thus, after 8 years of flow augmentation, the number of wild juvenile white sturgeon captured was much lower than anticipated (Paragamian et al., in press).

White Sturgeon Spawning Behavior and Anthropogenic Effects on Spawning, Egg Incubation, and Early Rearing

Kootenai River white sturgeon spawn in a 19-km reach of the Kootenai River; spawners use the lower reach first and move upstream as the season progresses (Paragamian et al. 2002). Relevant spawning studies have uncovered a few behavioral characteristics that set Kootenai River white sturgeon aside from other sturgeon populations (Paragamian and Kruse 2001; Paragamian et al. 2001). For example, Kootenai River white sturgeon are active at lower temperatures (Paragamian and Kruse 2001), and they spawn at cooler temperatures (8–12°C). In addition, Kootenai River white sturgeon spawn over sand substrate (Paragamian et al. 2001), which undoubtedly negatively affects survival of eggs and larvae (Paragamian et al. 2001; Paragamian and Wakkinen 2002).

The 19-km reach of the Kootenai River over which the sturgeon spawn is largely made up of moving sandbars (Paragamian et al. 1997; Lipscomb et al. 1998) that are naturally occurring. White sturgeon eggs collected were typically taken near the Thalweg, unattached to gravel or cobble, and frequently coated with fine particles; many white sturgeon eggs are probably buried and suffocate in the moving sand (Paragamian et al. 2002). Additional anthropogenic changes, such as dyking (dikes built along the river corridor) (Anonymous 1996), reduced river productivity because of the nutrient sink effect of Lake Kootenai (Daley et al. 1981; Woods 1982; Snyder and Minshall 1996), and relatively low lake levels during spawning (Paragamian et al. 2002) could also negatively affect recruitment of wild white sturgeon. To date, there has been no evidence that a substantial number of wild eggs are hatching; moreover, for those eggs that do hatch, there has been little evidence that larvae are surviving long enough to absorb yolk, swim up, and forage (Paragamian and Wakkinen 2002). Clearly, there is a survival bottleneck for wild eggs and young fish, while postrelease survival of hatchery-reared white sturgeon of mean total length of 229–455 mm has been high.

The Dilemma

Conservation Aquaculture

The Conservation Aquaculture program was expected to be a short-term measure; however, it has become an extinction-prevention system that may last decades. Consequently, there has been a paradigm shift within

the KRWSRT, and team members face the dilemma of relying almost entirely on the Conservation Aquaculture program to produce the next generation of sturgeon. Such a strategy will likely require increasing the number of wild fish taken for spawning and increasing the number of hatchery-reared fish released.

The cumulative effects of domestication and habitat degradation threaten the long-term viability of the recovery plan. Expanding (or not expanding) the Conservation Aquaculture program will affect the risks and uncertainties of inbreeding depression, loss of genetic diversity, genetic swamping, family effects and degree of relatedness, disease magnification, and long-term domestication (Busack and Currrens 1995). The implications of these issues are currently unknown because of the long maturation process of Kootenai River white sturgeon (Paragamian et al., in press).

White Sturgeon Demographic Analysis

Demographic analysis of the white sturgeon population (Paragamian and Beamesderfer 2003; Paragamian et al., in press) revealed that present recovery measures are inadequate, thus amplifying the dilemma of relying almost entirely on the Conservation Aquaculture program. The demographic analysis, based on data collected from 1978 through 2002 (Paragamian et al., in press), predicted that the wild white sturgeon population would be nearly extinct within 30 years (Figure 2) and that what remained would be a sturgeon population comprised almost exclusively of hatchery-reared fish (Paragamian et al., in press) (Figure 3). More specifically, given the "critically low" wild white

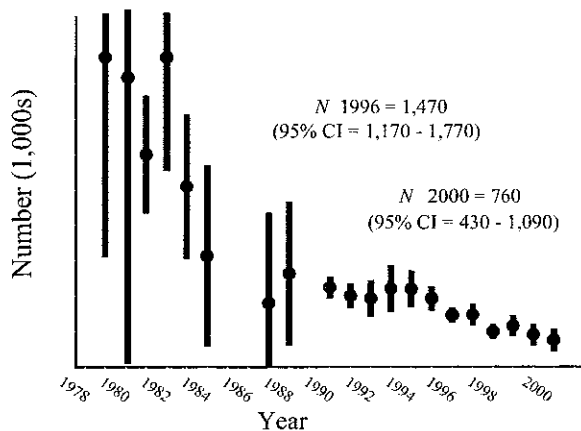


Figure 2. Seber-Jolly population estimates of wild Kootenai River white sturgeon from 1979 through 2002 (from Paragamian et al., unpublished).

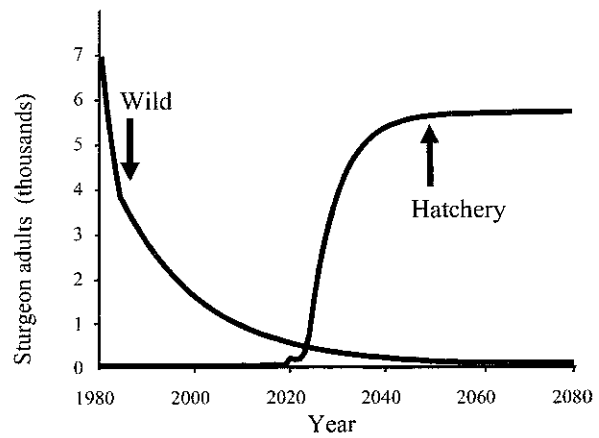


Figure 3. Simulated future population numbers of wild fish and hatchery Kootenai River white sturgeon showing extinction rate of wild fish and expanding numbers of hatchery fish till the year 2080 (from Paragamian et al., unpublished).

sturgeon population of 630 adults in 2002, the analysis predicted that the wild population is declining by half about every 8 years, that fewer than 500 adult wild fish will remain by year 2005, and that fewer than 50 adults will remain by year 2030. Moreover, if recommended habitat restoration actions (see the December 2000; Jeopardy Biological Opinion on the Federal Columbia River Power System, including Libby Dam) are not fully implemented, then restoration of wild spawning fish with adequate survival of young is unlikely.

Demographic issues

Considerable genetic and demographic risks and uncertainties are also associated with the impending disappearance of the current generations of wild Kootenai River white sturgeon. Genetic risks include the potential loss of rare alleles, drift in gene frequencies, increased genetic load from inbreeding, and a small population founder effect in the next generation. Demographic risks include too few spawners in any year to ensure synchronous maturation by sufficient numbers of males and females to take advantage of suitable habitat conditions, if they occur.

Such genetic and demographic risks are exacerbated by a female maturation cycle that does not involve spawning in every year. Small spawner numbers may also confound our ability to recognize suitable recruitment conditions if they occur and require difficult decisions on whether to leave limited numbers of potential spawners in the river to spawn naturally or

move mature fish from the river to the hatchery. Finally, every decrease in spawner numbers increases the difficulty and costs of collecting ripe broodstock for the Conservation Aquaculture program.

Kootenai River white sturgeon may have 28–40 years between generations, high survival, and have shown no signs of reproductive senility (Paragamian et al., in press). On one hand, white sturgeon are octoploidy and also have more than 200 chromosomes, attributes that may provide a short-term reprieve because long generation times and genetic diversity may stave off inbreeding depression and genetic drift (Allendorf and Ryman 2002). On the other hand, without recruitment of the wild stock, genetic and demographic risks can soon become much more significant because the effective breeding population size (N_e) will decline to lower levels with the lower numbers of breeding adults (Soule 1980; Lande and Barrowclough 1987; Rieman and Allendorf 2001). Loss of diversity and inbreeding depression associated with small effective population sizes may substantially reduce population fitness and productivity (McElhany et al. 2000). Small population sizes can also result in compensatory population processes (also known as Allee effects) that increase the decline to extinction (Courchamp et al. 1999; Musick 1999).

Conservation Aquaculture Issues

Extinction of the wild white sturgeon population will occur without an effective Conservation Aquaculture program. Hatchery-reared fish, having been released since 1992 (Apperson and Wakkinen 1992), should begin recruiting to the adult population after year 2020 (Figure 3). The adult white sturgeon population comprised almost exclusively of hatchery-reared fish will rapidly increase from 2,020 to 2,030, after which it is projected to stabilize at about 3,000 fish (five times the current adult population and just less than half the total population estimated in 1980).

The unexpected high survival of hatchery-reared white sturgeon and unexpected high (up to 12,000 sturgeon annually) release numbers led to concerns for some recovery team members because of the potential of intraspecific competition with wild fish (larger and older fish of the same cohort). There has been no evidence that carrying capacity is being exceeded (Ireland et al. 2002b) with the present stocking numbers; however, continuation of the Conservation Aquaculture program and stocking at high levels will further increase the density of juvenile hatchery sturgeon. Since carrying capacity is unknown, stocking in excess of

the carrying capacity could impact both wild and hatchery-reared fish and compromise management goals and objectives. Furthermore, stocking of hatchery-reared fish that are larger at the same age than wild white sturgeon could further compromise recovery by depressing condition, growth, and survival of wild juveniles, especially if food resources are limited by low system productivity.

Because many of the hatchery-reared families released from 1992 through 2002 were of unequal numbers (Ireland et al. 2002b: Table 1), the increased risk of inbreeding depression and loss of heterozygosity is another major concern of the KRWSRT. Furthermore, many KRWSRT members are in support of the release of surplus white sturgeon (fish produced in excess of the recommended stocking numbers in the breeding plan) that have been produced at the Fort Steele facility. Proponents of releasing the surplus fish contend that it is not known how many progeny were produced by the wild stock. With fecundity of up to 200,000 eggs in a single spawning event, group spawning, multiple spawning events in one season by individual females, and the point females may or may not always be synchronized with best survival conditions for rearing suggests there was likely huge variability in annual recruitment. And historically, it is known that some year classes failed; thus, what level of stocking really represents a serious risk? Yet with the wild stock continuing to decrease, low N_e could also result in inbreeding depression, compensatory population processes, and loss of diversity (Soule 1980; Lande and Barrowclough 1987; Rieman and Allendorf 2001).

Within 20 years, hatchery-reared white sturgeon will reach maturity and (in theory) recruit to the adult stock (Paragamian et al., in press). The hatchery environment in which they were reared might affect their behavior and survival (Busack and Currens 1995), with potential selection consequences before and after release. How hatchery-reared fish will “perform and contribute” to natural recruitment is unknown.

Long-term studies of the assimilation of hatchery-reared sturgeon with wild fish are sparse. Smith et al. (2002) evaluated the contribution of hatchery-reared shortnose sturgeon *A. brevirostrum* to the wild stock in the Savannah River, South Carolina. They found that hatchery-reared fish accounted for about 39% of the adult stock but that the contribution did not result in improved capture rates of wild juvenile fish, suggesting that a survival bottleneck still occurred at one or more of the early life history stages. Lack of genetic diversity was another concern cited by Smith et al. (2002) and was thought to result from lack of

control in the numbers of individuals per family that were stocked.

Options to Consider

Based on our assessment, there is an urgent need to update and revise the recovery plan for the Kootenai River white sturgeon (USFWS 1999). All KRWSRT members agree that extinction is the most serious risk, and there are no alternatives at present but to expand the Conservation Aquaculture program. We expect disagreements during the revision process, and demographic risks (removing adults from the wild) and genetic risks (stocking more hatchery-reared fish) will be considered.

We propose management options that may moderate demographic and genetic risks and capitalize on the benefits of hatchery-reared fish. First, the captive breeding program could be revised to take into consideration the new information on survival rates and N_e . Second, sources causing differences in the number of fish per "hatchery" family could be researched to minimize family-release differences. Third, the number of wild adult male sturgeon spawned each year could be increased to maximize the breeding plan and increase family diversity; the Kootenai Tribe of Idaho hatchery can hold only seven females, while sperm is collected in the field and transported to the hatchery. Fourth and fifth cryopreservation of sperm could extend the use of broodstock males to future generations (Cloud et al. 2000), and outbreeding males from the upper Columbia River, a closely related stock, could help reduce inbreeding depression. Sixth, disease concerns could be reduced by continued disease monitoring monthly for white sturgeon iridovirus and other diseases (Lapatra et al. 1999; Ireland et al. 2002a). Seventh, wild spawned and fertilized eggs could be taken into the hatchery to rear for later release.

Without the Conservation Aquaculture program and the stocking of hatchery-reared fish, the Kootenai River white sturgeon population could not eventually provide a sport fishery, but would remain on the Endangered Species list and likely become extinct within 30 years (Paragamian et al., in press). Increased stocking could benefit anglers via experimental catch-and-release or limited-harvest fisheries; however, such sport fisheries would require, for example, substantial angler education, a permit system, and adequate law enforcement to protect wild fish. Increased stocking would also increase the relative abundance of hatchery-reared white sturgeon in the river, and this and

other potential stocking effects on wild fish could be modeled with available data.

Risks associated with intraspecific competition and exceeding carrying capacity can be reduced by expanding stocking locations. Excess hatchery-reared fish could be stocked in new locations (e.g., the Kootenai River in British Columbia and Montana and Kootenay Lake in British Columbia). However, it is not known if these fish would demonstrate the same migration and spawning patterns as those observed in other wild white sturgeon (see Paragamian and Kruse 2001). Monitoring distribution, growth, and condition of hatchery-reared and wild white sturgeon should continue (Ireland et al. 2002b) because accurate records of change are needed for adaptive management decisions about stocking numbers and location of hatchery-reared fish.

Because of the widespread development in the Kootenai valley floodplain (Anders et al. 2002), it is not known whether the required flows or physical modifications for spawning and rearing of white sturgeon are feasible. However, current physical habitat surveys will provide a systematic basis for evaluation of habitat alternatives. Monitoring and evaluation of white sturgeon spawning and rearing under experimental flows should continue (Paragamian and Wakkinen 2002). More rigorous habitat enhancement and restoration feasibility studies should be implemented and directed at early life history survival. But the dilemma of the recovery of Kootenai River white sturgeon will probably continue until cohorts can be consistently recruited to the population and until the population is removed from the endangered species list.

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