Adaptive Disease Management Strategies for the Endangered Population of Kootenai River White Sturgeon

By Scott E. LaPatra, Susan C. Ireland, Joseph M. Groff, Kathy M. Clemens, and John T. Siple

ABSTRACT

For the endangered Kootenai River white sturgeon (*Acipenser transmontanus* Richardson) population, conservation aquaculture was identified as a prudent and necessary recovery tool due to the biological status of the population and the demonstrated uncertainties of other recovery efforts. Conservation aquaculture programs need to address potential impacts on the genetic variability, artificial selection, and effects of disease on the native population prior to development and implementation of the program. Available scientific information should be used to develop management strategies that minimize the transmission of disease from cultured fish to native fish and the potential severity of disease in the native population. The white sturgeon iridovirus (WSIV) is the most prevalent viral pathogen of white sturgeon relative to its distribution and frequency of occurrence, and may be endemic to wild white sturgeon populations throughout the Pacific Northwest. This case study illustrates the importance of conservation aquaculture programs in certain fishery situations. In addition, we discuss how management strategies must remain flexible and must adapt to current available scientific information to provide maximum benefits. Management of the Kootenai River white sturgeon population represents a model cooperative effort of professional fisheries scientists from private industry; academia; Native American tribes; and provincial, state, and federal governmental agencies. This cooperation is an essential prerequisite for successful achievement of the program goals. Cooperation also is necessary for adaptation of management strategies as information is developed.

Background

The white sturgeon (*Acipenser transmontanus* Richardson) population in the Kootenai River was listed as endangered 6 September 1994 (U.S. Fish and Wildlife Service [USFWS] 1994) under the authority of the U.S. Endangered Species Act of 1973. The Kootenai River population is one of several land-locked populations of white sturgeon found in the Pacific Northwest. Its distribution extends from Kootenai Falls, Montana—located 50 river km below Libby Dam—downstream through Kootenay Lake to Corra Linn Dam on the lower West Arm of Kootenay Lake, British Columbia (Figure 1). A natural barrier at Bonnington Falls downstream of Kootenay Lake has isolated the white sturgeon in the Kootenai system from other white sturgeon in the Columbia River basin since the last glacial age approximately 10,000 years ago (Northcote 1973). The population was listed as endangered due to two decades of nearly undetectable recruitment, declining population size, and habitat degradation and destruction (USFWS 1996). The last substantial year-class was naturally produced in 1974.

Construction of Libby Dam impounded the Kootenai River near Libby, Montana, forming Lake Koocanusa. Operation of Libby Dam has drastically altered the hydrograph, thermal regime, and downstream nutrient-loading rates in the Kootenai River (Apperson and Anders 1991). This may have reduced natural recruitment. Research has confirmed natural spawning in six of the past seven years (USFWS 1998). In 1995 the population of adult white sturgeon in the Kootenai River was estimated to be 1,469 individuals (Paragamian et al. 1996). Natural recruitment was estimated to be 1% of the population since 9 years of sampling recovered only 16 white sturgeon less than 22 years of age (Paragamian et al. 1995). Because white sturgeon do not mature until almost age 20, the equivalent of one full generation in the white sturgeon life cycle had been lost.

U.S. and Canadian regional agencies and the Kootenai Tribe formed the Kootenai River White Sturgeon

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Technical Committee in June 1992 to address the future viability of the species. The Committee was unable to negotiate a Conservation Agreement to implement strategies to prevent the extinction of the Kootenai River white sturgeon. Subsequently, the fish was listed as endangered in 1994. In 1995 the USFWS convened a recovery team to outline strategies needed to recover the species. Because the species range is transboundary, the recovery team included members with technical expertise from the USFWS; Kootenai Tribe of Idaho; Idaho Department of Fish and Game; Montana Fish, Wildlife, and Parks; U.S. Army Corps of Engineers; Bonneville Power Administration; British Columbia Ministry of Environment, Lands, and Parks; and Canadian Department of Fisheries and Oceans. The team concluded that recovering the species depended on reestablishing natural recruitment, minimizing additional loss of genetic variability, and mitigating habitat impacts, primarily those caused by the construction and operation of Libby Dam. Therefore, the recovery strategy addressed these concerns through three priority actions: (1) Augment spring and early summer flows of the Kootenai River to enhance natural reproduction; (2) implement a conservation aquaculture program, i.e., artificial propagation and release to prevent extinction; and (3) reestablish suitable habitat conditions to increase the chances of white sturgeon survival beyond the egg or larval stage (USFWS 1996).

In 1990 the conservation aquaculture program started to address experimental questions but was not fully implemented until 1991. In 1991, 1992, 1993, 1995, and 1998, progeny from wild broodstock were successfully produced and reared in the Kootenai Tribal Hatchery, home of the conservation aquaculture program. While efforts to restore natural reproduction, such as augmented discharge during spawning periods, stimulated natural spawning, these efforts did not appear to restore natural recruitment in the population (Paragamian and Kruse 1996). In the short term, propagation, culture, and release of juvenile white sturgeon appeared to be the most viable option for preventing extinction of this species. The program aimed to address several concerns about the use of supplementation regarding genetic variability and the potential introduction of disease into the wild population.

This case study describes how the issue of introduced disease was addressed. The following sections provide a brief description of white sturgeon iridovirus (WSIV), chronicle a white sturgeon virus epizootic that occurred in 1992, describe the disease management implications of WSIV on the conservation aquaculture program and preservation stocking program, and conclude with a look at future research needs. This case study may be useful for developing other supplementation programs intended to benefit endangered species.

White Sturgeon Iridovirus

The original description of white sturgeon iridovirus disease (Hedrick et al. 1990) resulted from observations of hatchery-raised sturgeon. The source of the virus was not determined at that time, but researchers assumed it originated from captive wild white sturgeon adults collected from the Sacramento River (California) for use as broodstock. The virus also has been detected in cultured white sturgeon from the lower Columbia River in Oregon, Snake River in southern Idaho, and Kootenai River in northern Idaho (LaPatra et al. 1994). Based on its ubiquitous distribution and high frequency of occurrence, WSIV is the most prevalent viral pathogen in this species. This agent has an affinity for epithelial tissue of the skin and gills. High mortality may occur (>90%), presumably from anorexia and disruption of normal respiration and osmoregulation. Secondary infections such as external fungal infections are not uncommon in compromised fish, and the disease caused by WSIV is most severe in juvenile sturgeon younger than age 1.

Numerous observations suggest that WSIV is endemic in wild sturgeon populations throughout the

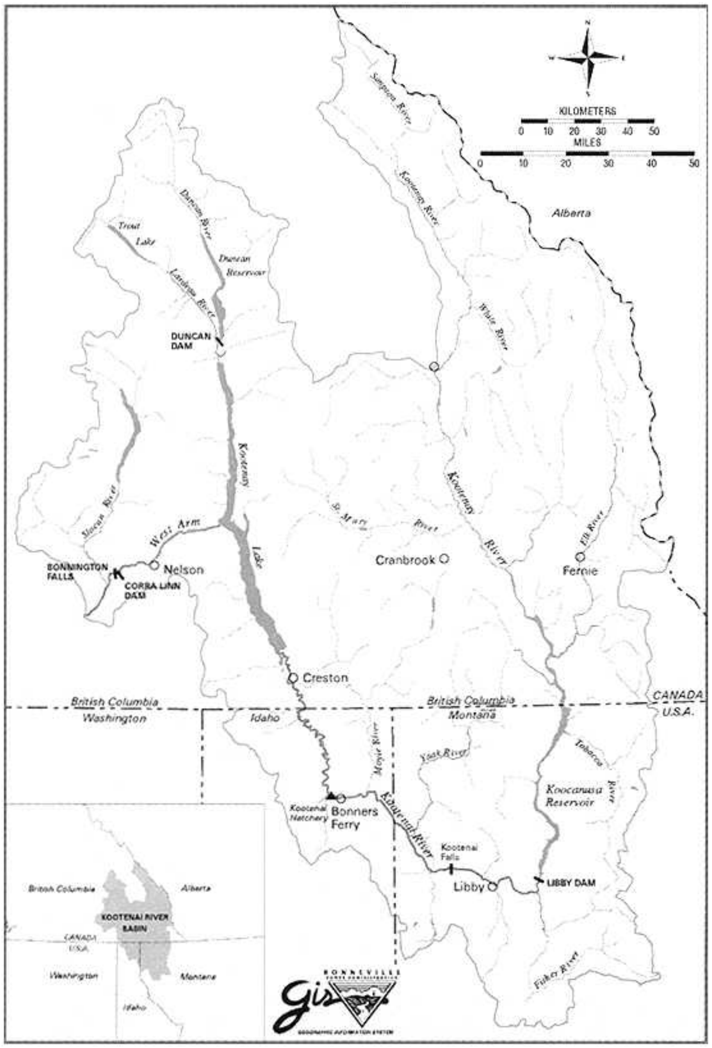

Figure 1 shows the location of the Kootenai River system and the Kootenai Hatchery, where juvenile white sturgeon were propagated for conservation aquaculture.

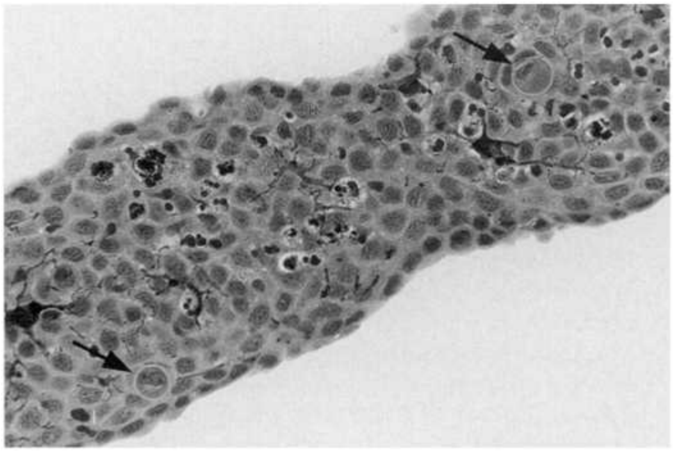

Figure 2. Light photomicrograph of white sturgeon operculum demonstrates that infection of opercular skin cells with WSIV results in cellular hypertrophy (arrows) and increased basophilia of the cytoplasm. Hematoxylin and eosin. x132.

Pacific Northwest (LaPatra et al. 1994), perhaps because of the long life span and highly migratory nature of white sturgeon as well as the continuity of the river systems. Since the disease appears to be related to size (age) and stress, managers have implemented culture management strategies to avoid or minimize WSIV disease. Successful strategies have included fish culture density and loading reduction, use of virus-free water supplies, minimization of adverse environmental conditions, and minimal handling of sturgeon younger than age 1 (LaPatra et al. 1994; LaPatra et al. 1996b).

White Sturgeon Virus Epizootic

During November 1992 increased mortality occurred in 6-month-old juvenile white sturgeon at the Kootenai Hatchery. The mortality was likely due to high fish densities (32–48 kg/m^3) and a temporary loss of water. To decrease the mortality by improving rearing conditions, approximately 800 of the 5,000 affected sturgeon were transferred to an Idaho State Hatchery in Sandpoint. Approximately 75% of the 800 fish transferred to the Sandpoint Hatchery died in comparison to 48% of fish that remained at the Kootenai Hatchery. Therefore, mortality rates may have been exacerbated by the stress of transportation. Scientists initiated an investigation to determine the cause of mortality that included histopathological examination of tissues from fish at both hatcheries. This examination revealed lesions in the gills and skin typical of those manifested in WSIV disease (Figure 2). Samples from fish at the Kootenai Hatchery also were examined by transmission electron microscopy, which confirmed the preliminary diagnosis of WSIV (Figure 3). A total of 2,600 of the 5,000 fish died as a result of the epizootic.

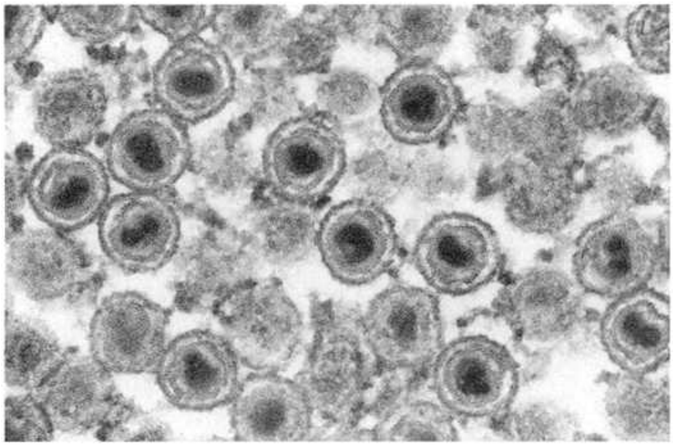

Figure 3. Transmission electron micrograph of white sturgeon gill tissue shows that the infected cells contain multiple iridovirus particles. Lead-citrate and uranyl acetate. x55,000.

A similar epizootic occurred in cultured juvenile sturgeon from southern Idaho. However, reducing densities and increasing water flow decreases the mortality (T. L. Patterson, College of Southern Idaho Aquaculture Program, Twin Falls, pers. comm.). These observations suggested that juvenile white sturgeon infected with WSIV did not exhibit clinical disease until they were subjected to stressful conditions. This has been supported by the absence of mortality in other groups of juvenile white sturgeon originating from the same source and maintained at decreased densities despite decreased water flows at the Kootenai Hatchery. In another example, Sandpoint Hatchery-reared sibling juvenile sturgeon from the fertilized egg stage were not subjected to low water flows and crowded rearing conditions. Despite the apparent presence of WSIV, mortality did not increase. One apparently healthy animal displayed typical WSIV lesions (A. K. Hauck, Utah Department of Agriculture, Salt Lake City, pers. comm.), but scientists did not determine if WSIV was endemic in this group or if the virus was introduced during propagation.

This epizootic represented the first known occurrence of WSIV infection in Kootenai River white sturgeon. Although the source of this virus was not determined, it may have originated from Kootenai River wild sturgeon that were held on site for 2 months and maintained as broodstock. The water did not appear to be a likely source of the virus since, at the time, the culture facilities were using dechlorinated tap water, not Kootenai River water. Kootenai River water may not have been a plausible cause even if it were used in the culture facilities since one group of juvenile sturgeon reared in Kootenai River water did not exhibit mortality due to WSIV.

Kootenai River White Sturgeon Conservation Aquaculture Program

The Kootenai River white sturgeon was listed as an endangered species partially based on the available genetic evidence that the population represented a distinct and unique strain of white sturgeon (Setter and Brannon 1990, 1992). As a condition of the listing, a 10-year conservation program was implemented as part of the USFWS White Sturgeon Recovery Plan (USFWS 1996).

The plan specifically includes the collection of wild adult Kootenai River white sturgeon by rod and reel, and setline each spring. Fish are used as broodstock at the

Kootenai Hatchery for the artificial propagation and captive rearing of juvenile white sturgeon (Figure 4). The conservation aquaculture program strategy outlined in the recovery plan was designed to (1) maintain the genetic variability within the wild population, (2) reduce the risk of disease to the wild spawning population, and (3) reduce selection of artificial characteristics during the selection and mating of broodstock and/or the juvenile sturgeon cultivation (USFWS 1996). A breeding plan, the "Kincaid Plan" (Kincaid 1993), designated that wild adults representing both the temporal and geographic natural spawning run would be collected for use as broodstock. The Kincaid Plan aims to maximize the number of different adults contributing gametes and progeny to the population over time while minimizing the contribution of any one sibling group. Release of juvenile white sturgeon into the natural environment was recommended either as soon as suitable identifiable marks or tags could be applied to the fish or when the fish are no older than age 2 (Figure 5). Since the fish reaches sexual maturity at approximately age 20, natural selection should counteract any potential impact of domestication in the cultivated juvenile white sturgeon.

A concern of professionals involved in the conservation aquaculture program also was the potential for introduction of disease into the native population (USFWS 1996). In response, scientists developed a strategy to prevent or reduce the transmission of disease from cultured fish to the wild population. This included implementing fish culture practices, policies, and procedures developed for the anadromous salmonid hatcheries (Integrated Hatchery Operations Team 1995). A disease-testing protocol was specifically developed for this program. It was implemented prior to the release of any hatchery-reared Kootenai River white sturgeon into the Kootenai River. The plan included virological and bacteriological testing of 30 fish along with examination for parasites in skin and gill wet mounts from 10 fish. Additionally, histological examination of all major organs of 20 fish was required. A qualified fish health professional supervised this disease-testing protocol.

Kootenai River White Sturgeon Preservation Stocking Program

From 1990 to 1993, progeny from wild Kootenai River white sturgeon broodstock were successfully produced and reared at the Kootenai Hatchery. During this period, five females were mated with 10 males, resulting in five families of progeny. Two experimental releases totaling 305 hatchery-reared 1- and 2-year-old fish were released into the Kootenai River in 1992 and 1994. Included in the total were 91 survivors of the 1992 WSIV epizootic. They were tagged, marked by scute removal, and released in three locations on the Kootenai River from July to September 1994 (Siple and Anders 1994). The survivors did not exhibit evidence of a WSIV infection at the time of release, which was consistent with the conservation aquaculture program directives (Bonneville Power Administration 1997). During 1995 and 1996, fisheries professionals used gill nets to capture 70 hatchery-reared white sturgeon (Paragamian et al. 1995, 1996), indicating that released sturgeon were surviving in the Kootenai River.

Figure 4. Larval white sturgeon were artificially propagated at the Kootenai Hatchery. These fish were progeny of wild Kootenai River white sturgeon that were captured and used as broodstock in the conservation aquaculture program.

In 1995, two wild Kootenai River adult white sturgeon females were mated with four males that resulted in four families or two pairs of half-sibling families, each with a shared female parent. This mating scheme was used to maximize genetic diversity in the progeny fish by maintaining genetically different broodstock. Prior to the 1997 release of the sturgeon (mean age, 2 years), a disease-testing protocol was implemented specifically developed by agreement among the cooperating parties. Although no pathogens were detected, histological examination of the skin revealed a 40% prevalence of cellular changes indicative of WSIV. However, these findings were not associated with morbidity or clinical signs of infection; i.e., infection occurred in the absence of disease (asymptomatic infection). Two of the families did not exhibit signs of WSIV infection or had a low prevalence and intensity of infection.

Figure 5. Juvenile Kootenai River white sturgeon were artificially propagated in the conservation aquaculture program. Release of juvenile white sturgeon into the natural environment occurred when identifiable marks or tags could be applied or when the fish were no older than age 2.

Table 1. Monthly prevalence of WSIV infection was determined by histological examination of skin specimens obtained from two groups of 1995 brood year 2-year-old Kootenai River white sturgeon.

Month (1997)	Water Temperature (range)	Family Number 30	Family Number 33
May	8.7°C (6.3–11.1)	100% (10/10)	100% (10/10)
June	10.6°C (7.2–14.0)	50% (5/10)	20% (2/10)
July	15.1°C (12.8–17.3)	11% (2/19)	10% (2/20)
October	11.3°C (9.8–12.8)	0 (0/10)	20% (2/10)

These families were individually tagged and released as approved by the oversight committee. The rationale for this decision was based on (1) the absence of disease in the infected group and (2) the circumstantial evidence suggesting that WSIV was endemic in the population and had evolved with the wild white sturgeon throughout their range. Furthermore, wild sturgeon used for broodstock were considered the most likely source of WSIV infection in the progeny. In the final analysis, the release of sturgeon infected with WSIV was considered the most prudent strategy in the face of a progressive decline of the Kootenai River white sturgeon population with little improved natural recruitment.

The fish that remained in captivity at the Kootenai Hatchery were composed of two families. These fish were maintained at low densities and monitored monthly for WSIV infection using a nonlethal sampling method. The maintenance of reduced densities was considered the most prudent strategy to minimize infection and prevent disease. An additional prudent strategy was prolonged holding and monitoring of the infected groups as the water temperature increased, thus enhancing the immunological capabilities of the animals.

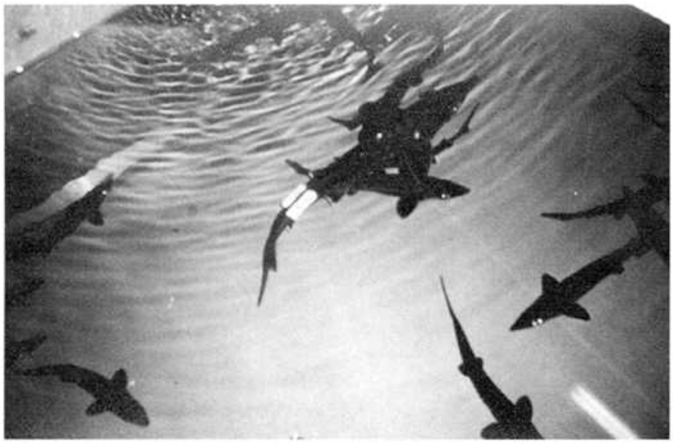

Figure 6. Juvenile Kootenai River white sturgeon were fitted with a sonic tracking device and, after release, were monitored using sonic tracking and gill netting.

The initial sampling of these two remaining families in May 1997 indicated that 100% of the animals were asymptomatically infected. The intensity of infection was mild. Ten individuals from each family were subsequently tagged and nonlethally sampled at monthly intervals. From May through August, as water temperature progressively increased to 15.6°C, the individual sturgeon that had tested positive for WSIV exhibited no evidence of the virus. Apparently, the prevalence of WSIV decreased to negligible levels without evidence of clinical disease (Table 1). Therefore, all of the remaining sturgeon were tagged and released into the Kootenai River in October 1997. In summary, 2,283 white sturgeon juveniles representing four family groups from the 1995 year class were released (Ireland 1997). Currently, researchers are monitoring the fish using sonic tracking (Figure 6) and gill netting.

Discussion

Conservation aquaculture was identified as a prudent and necessary tool for recovery of endangered Kootenai River white sturgeon. The biological status of the species and the demonstrated uncertainties of other recovery efforts justified the use of conservation aquaculture. Conservation aquaculture programs need to address the potential impacts on the genetic variability, artificial selection, and effects of disease on the native population prior to developing and implementing the program. Management strategies should be based on available scientific information to minimize (1) transmission of disease from cultured fish to native fish and (2) the potential severity of disease in the native population. It is essential that these strategies be flexible and are designed to continually incorporate new scientific information.

One of the primary concerns of any artificial propagation program is the potential introduction and transmission of pathogens in both cultured and native populations. Generally, predictions of potential disease impacts in natural populations have been extrapolated from observations of disease conditions in cultured fish. However, these predictions may not be directly applicable to wild populations since conditions associated with aquaculture (e.g., increased densities, suboptimal water quality) often promote clinical manifestation of infection. High-density conditions that can occur in culture facilities also can promote progressive and relatively rapid disease transmission among captive populations.

Conceptually, infection and disease are separate phenomena, although these events are often mistakenly considered in the same context. Simply put, *infection*—defined as invasion of a host by a pathogenic agent—is a more common event, although both infection and disease depend on the interaction of various factors, including (1) the health and immunological status of the host, (2) the dose and virulence of the pathogen, and (3) the environmental conditions that affect the host and pathogen (LaPatra 1998). In contrast, *disease* is defined as the condition that results in morbidity and, possibly, mortality in the individual host or population as a consequence of infection.

The extent and severity of disease also is a function of these various factors. Adverse environmental factors include temperature and conditions that may increase stress in fish populations such as inadequate water flows and increased densities. Conditions that promote or exacerbate disease are generally more prevalent and pronounced in aquaculture facilities than in wild populations. Increased densities are not only conducive to disease but also promote the rapid and progressive transmission of infection throughout the population. However, increased incidence and severity of disease in aquaculture for any pathogen is generally due to adaptation of pathogens over time that can become endemic to a species (LaPatra 1997). This is important for viral pathogens that have a restricted host specificity such as WSIV. For example, experimental exposures of WSIV to chinook salmon (*Oncorhynchus tshawytscha*), channel catfish (*Ictalurus punctatus*), and striped bass (*Morone saxatilis*) indicated their resistance to infection, but lake sturgeon (*Acipenser fulvescens*) suffered a mild form of the disease (Hedrick et al. 1992). In wild populations an increased incidence of morbidity and mortality would result in extinction of the host species and its endemic pathogen. Therefore, asymptomatic infection may be widely distributed throughout wild populations without clinical manifestation of disease that may subsequently occur due to aquaculture-specific stressors.

Clinical disease that results in sickness and/or death is more easily diagnosed than asymptomatic infections or subclinical disease that may require more sophisticated diagnostic tests or procedures. Regardless, the isolation or presence of a pathogen does not indicate a disease event. However, identifying a pathogen in otherwise healthy fish populations should be followed by review and appropriate alteration of husbandry and management practices to prevent possible future disease events. Changes in these practices may simply be the alteration or management of specific environmental conditions such as the maintenance of decreased culture densities or increased water flows necessary to minimize or prevent potential future disease events in the population (LaPatra 1997). These preventative measures also may apply to wild populations and are underscored by the recent decline in the Kootenai River white sturgeon population as a result of changes in the physical and biological parameters of the river ecosystem after construction of Libby Dam.

As mentioned, WSIV is the most prevalent viral pathogen of white sturgeon relative to its distribution and frequency of occurrence, and may be endemic to wild white sturgeon populations throughout the Pacific Northwest. The latter assumption is based on observations that wild sturgeon used as broodstock were the source of WSIV in progeny of these broodstock and that clinical manifestation of disease in these progeny was due to adverse environmental conditions (LaPatra et al. 1994; LaPatra et al. 1996). In 1992 juvenile Kootenai River white sturgeon were destroyed, and movement of surviving fish was severely restricted following diagnosis of WSIV in this group of fish. These juvenile fish were invaluable due to the progressive decline in the natural population and the failure to reestablish natural recruitment in the population with augmentation of water flows in the Kootenai River. This response was probably not necessary based on the available scientific information that infection may be a natural phenomenon within the wild population.

Conclusions

Intervention to stabilize the population and the continual adaptation of management strategies to achieve this

Table 2 lists individuals involved in the Kootenai River white sturgeon cooperative effort and their professional affiliations.

Name	Agency	Specialty
Susan Ireland	Kootenai Tribe of Idaho, Bonners Ferry	Fisheries biologist/manager
Scott LaPatra	Clear Springs Foods, Inc., Buhl, Idaho	Fish health specialist
Joseph Groff	University of California, School of Veterinary Medicine, Davis	Fish health specialist/ veterinarian
Robert Hallock	USFWS, Spokane, Washington	Fisheries manager
Stephen Duke	USFWS, Boise, Idaho	Recovery team leader
John Morrison	USFWS, Olympia, Washington	Fish health specialist
Kathy Clemens	USFWS, Ahsahka, Idaho	Fish health specialist
Larry Lockard	USFWS, Kalispell, Montana	Fisheries biologist
Jay Hammond	BC Ministry of Environment, Land, and Parks, Nelson	Fisheries manager
Sally Goldes	BC Ministry of Environment, Land, and Parks, Nanaimo	Fish health specialist
Gordon Ennis	CDFO, Vancouver, British Columbia	Fisheries manager
Dorothy Keiser	CDFO, Nanaimo, British Columbia	Fish health specialist
Ned Horner	Idaho Department of Fish and Game, Coeur d'Alene	Regional fisheries manager
Keith Johnson	Idaho Department of Fish and Game, Eagle	Fish health specialist
Vaughn Paragamian	Idaho Department of Fish and Game, Coeur d'Alene	Fisheries research biologist
Jim Peterson	Montana Fish, Wildlife and Parks, Helena	Fish health specialist
Brian Marotz	Montana Fish, Wildlife and Parks, Kalispell	Fisheries research biologist
Paul Anders	University of Idaho, Aquaculture Research Institute, Moscow	Fisheries research biologist
Rick Westerhof	National Marine Fisheries Service; formerly of Bonneville Power Administration, Portland, Oregon	Fisheries biologist
Scott Bettin	Bonneville Power Administration, Portland, Oregon	Fisheries biologist
Jeff Laufle	U.S. Army Corps of Engineers, Seattle, Washington	Fisheries biologist

USFWS = U.S. Fish and Wildlife Service
CDFO = Canada Department of Fisheries and Oceans

objective were partially the result of the uncertain status of the wild Kootenai River white sturgeon population. However, development of management strategies also was influenced by relevant scientific information that became available during implementation of the Kootenai River white sturgeon conservation aquaculture program. This case study illustrates the importance of conservation aquaculture programs in certain situations and the necessity that management strategies remain flexible and adapt to the current available scientific information for maximum benefits. Fisheries professionals are continuing efforts to understand the ecology and natural history of WSIV in white sturgeon to ensure the best possible management of the species. Successful development and use of nonlethal sampling procedures for detecting WSIV infection will permit the future examination of tagged fish released from the Kootenai Hatchery and wild-caught sturgeon broodstock. Hatchery renovations also have begun to minimize the adverse conditions associated with artificial rearing and to prevent or minimize infectious disease. Finally, surveillance strategies that are more sensitive and specific to detection of these pathogens need to be developed and used in conservation aquaculture programs and management of the population.

Restoration of an entire population that has been severely altered for decades and that inhabits a large floodplain ecosystem such as the Kootenai River system requires long-term, multiagency cooperation and commitment. Management of the Kootenai River white sturgeon population represents a model cooperative effort of professional fisheries scientists of various disciplines from private industry; academia; Native American tribes; and provincial, state, and federal agencies (Table 2). This cooperation is a necessary prerequisite for the successful achievement of the program goals and continual modification and adaptation of management strategies. Furthermore, such a cooperative effort illustrates that effective management of entire populations is best achieved through interdisciplinary cooperation of various fisheries professionals. This interdisciplinary cooperation reflects a current trend in the fisheries profession that replaces the more traditional approach of various professionals working in isolation on separate aspects of the same problem. Obviously, the latter approach is less effective and, therefore, less desirable for managing threatened or endangered populations such as the Kootenai River white sturgeon.

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