ENDANGERED SPECIES—MANAGEMENT

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

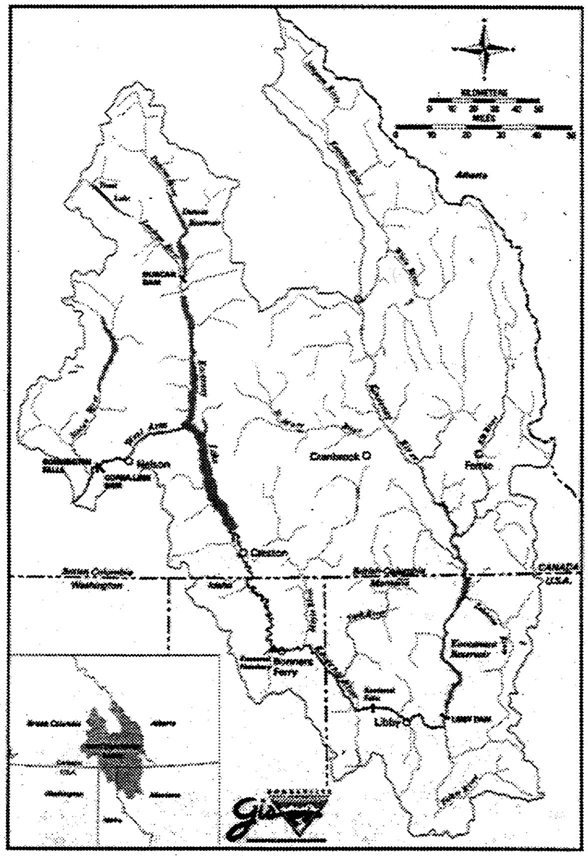

Figure 1 shows the location of the Kootenai River system and the Kootenai Hatchery, where juvenile white sturgeon were propagated for conservation aquaculture.

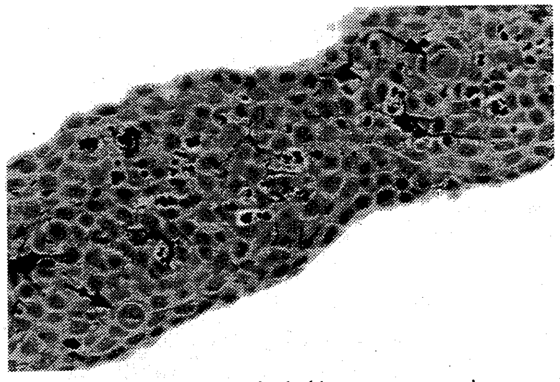

Figure 2. Light photomicrograph of white sturgeon operculum demonstrates that infection of opercular skin cells with WSIV results in cellular hypertrophy (arrows) and increased basophilia of the cytoplasm. Hematoxylin and eosin. x132.

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.

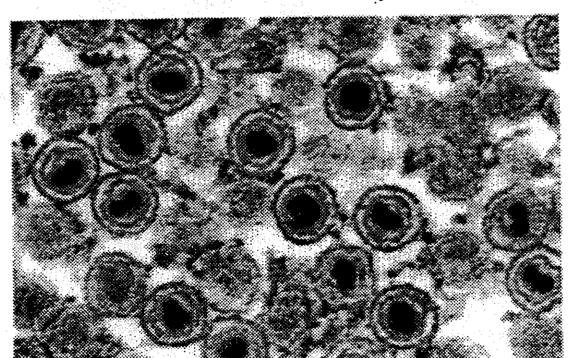

Figure 3. Transmission electron micrograph of white sturgeon gill tissue shows that the infected cells contain multiple iridovirus particles. Lead-citrate and uranyl acetate. x55,000.

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.

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.

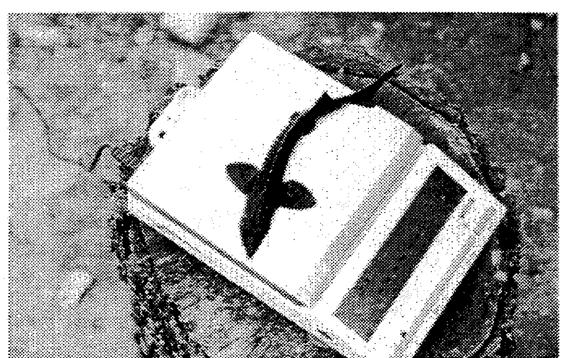

Figure 5. Juvenile Kootenai River white sturgeon were artificially propagated in the conservation aquaculture program. Release of juvenile white sturgeon into the natural environment occurred when identifiable marks or tags could be applied or when the fish were no older than age 2.

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.

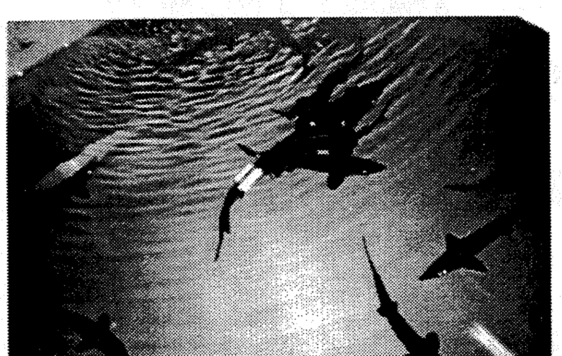

Figure 6. Juvenile Kootenai River white sturgeon were fitted with a sonic tracking device and, after release, were monitored using sonic tracking and gill netting.

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.

Acknowledgments

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Management of lake sturgeon on the Winnebago System – long term impacts of harvest and regulations on populations structure

Summary

The Winnebago System, Wisconsin, supports one of the largest self sustaining stocks of lake sturgeon, Acipenser fulvescens, in North America. Winter spearing harvest of the Winnebago sturgeon population has been actively regulated since 1903 and actively assessed sicken the 1940's. While historic population assessments have shown a steady increase in sturgeon densities in the system, recent surveys indicated overexploitation of adult females. From 1991-97, 13,714 sturgeon were assessed through harvest and spawning surveys to characterize the status of the current population, and historical data from DNR files were reassembled and analyzed to discern population trends over the last 40 years. A summary of management actions since 1903 was completed and reviewed in the context of long term population trends. 1991-97 annual harvests averaged 1337 sturgeon with adult females comprising 46% of the annual harvests from 1991-96 and 34% of the harvest in 1997 following a reduction in the minimum size limit. With the higher size limit, estimated annual exploitation of adult females was 2 to 3 times higher than that of adult males. Historic harvest and population trends showed the benefits of conservative bag limits and harvest season lengths combined with strict law enforcement, and habitat protection, which resulted in an estimated 58% reduction in the annual harvest between 1955 to 1990. The analyses of the historic data reinforced the necessity of standardized long-term harvest and population assessments for effective management of sturgeon populations and fisheries. Public involvement is also identified as an integral component to effective sturgeon management.

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Summary

The Winnebago System, Wisconsin, supports one of the largest self sustaining stocks of lake sturgeon, Acipenser fulvescens, in North America. Winter spearing harvest of the Winnebago sturgeon population has been actively regulated since 1903 and actively assessed since the 1940's. While historic population assessments have shown a steady increase in sturgeon densities in the system, recent surveys indicated overexploitation of adult females. From 1991-97, 13714 sturgeon were assessed through harvest and spawning surveys to characterize the status of the current population, and historical data from DNR files were reassembled and analyzed to discern population trends over the last 40 years. A summary of management actions since 1903 was completed and reviewed in the context of long term population trends. 1991-97 annual harvests averaged 1337 sturgeon with adult females comprising 46% of the annual harvests from 1991-96 and 34% of the harvest in 1997 following a reduction in the minimum size limit. With the higher size limit, estimated annual exploitation of adult females was 2 to 3 times higher than that of adult males. Historic harvest and population trends showed the benefits of conservative bag limits and harvest season lengths combined with strict law enforcement, and habitat protection, which resulted in an estimated 58% reduction in the annual harvest between 1955 and 1965 and a four fold increase in legal stock densities from 1955 to 1990. The analyses of the historic data reinforced the necessity of standardized long term harvest and population assessments for effective management of sturgeon populations and fisheries. Public involvement is also identified as an integral component to effective sturgeon management.

Key words: Lake sturgeon, Acipenser fulvescens, management, regulations, public involvement.

Introduction

The Lake Winnebago System, in east central Wisconsin, is home to one of the largest self sustaining stocks of lake sturgeon, Acipenser fulvescens Rafinesque, in North America. The population supports a popular recreational spear fishery each winter and has been subject to hook and line, and setline fisheries in the past. The fishery has been regulated since 1903 and the sturgeon population and harvest have been consistently monitored and managed since the early 1940's (Schneberger and Woodbury 1946), (Probst and Cooper 1954), (Priegel and Wirth 1975, 1978), (Folz and Meyers 1985). Studies conducted over the years have been primarily concerned with ensuring that exploitation was maintained at a safe level. Information was used to increase the understanding of the population dynamics of the Winnebago system lake sturgeon to identify possible limiting factors and to make necessary adjustments in harvest seasons and bag and size limits.

Since the early 1950's various studies have documented an increase in Winnebago sturgeon stocks from 11500 (>102 cm) in 1959 (Priegel and Wirth 1975) to 25300 (>114 cm) in 1980 (Folz and Meyers 1985) and to 46500 (>114 cm) in 1989 (L.S. Meyers, Wisconsin Department of Natural Resources (DNR), personal communication). Harvest trends though, began to show a steady decline in the relative number of trophy size (>45.4 kg) sturgeon speared each year since the early 1970's. Trophy size sturgeon comprised 1.9% of the harvest between 1955 and 1969, falling through the 1970's and early 1980's to 1.3%, and precipitously over the last 13 years to 0.3% of the harvest. Information from various population assessments conducted in the 1950's, 1970's and 1980's also showed a decline in the relative number of larger, older fish. As the largest fish in the population are typically mature females, interest and concern led to an expansion of population and harvest assessments beginning in 1991 along with a complete evaluation of the long term impacts of harvest regulation changes on the lake sturgeon population structure.

Study Objectives

1) To summarize the history of Winnebago System lake sturgeon regulatory and management actions,

2) To characterize the current (1991-97) Winnebago System lake sturgeon population and fishery,

3) To examine historical population and harvest assessment data for trends that may have been the result of various regulatory, anthropogenic, and/or environmental factors, that may have led to characteristics of the current population.

Study Area

The Winnebago System is a large, eutrophic riverine-lake system in east central Wisconsin Figure 1). Lake Winnebago and the three Upriver Lakes (Butte des Morts, Winneconne and Poygan), collectively known as the Winnebago Pool Lakes, comprise 66845 ha of surface water, situated at the lower end of a 1554026 ha watershed through which flow the Wolf and upper Fox River Systems. The lower 200 km of the Wolf River, along with its major tributaries, and 60 km of the upper Fox River contain the spawning and nursery grounds for the Winnebago Pool sturgeon population. Lake Winnebago has a maximum depth of 6.4 m and a mean depth of 4.7 m. The Upriver Lakes are also relatively shallow with a maximum depth of 5.4 m and a mean depth of 1.8 m. The Winnebago Pool Lakes have a methyl orange alkalinity of 119 to 124 ppm, a pH varying from 7.7 to 8.5., and are characterized by large, open pelagic areas with a soft sediment base and by poor water clarity due to a lack of aquatic macrophytes, nonpoint pollution, resuspension of sediments from wave action and algal blooms. In addition to lake sturgeon, the major species of the

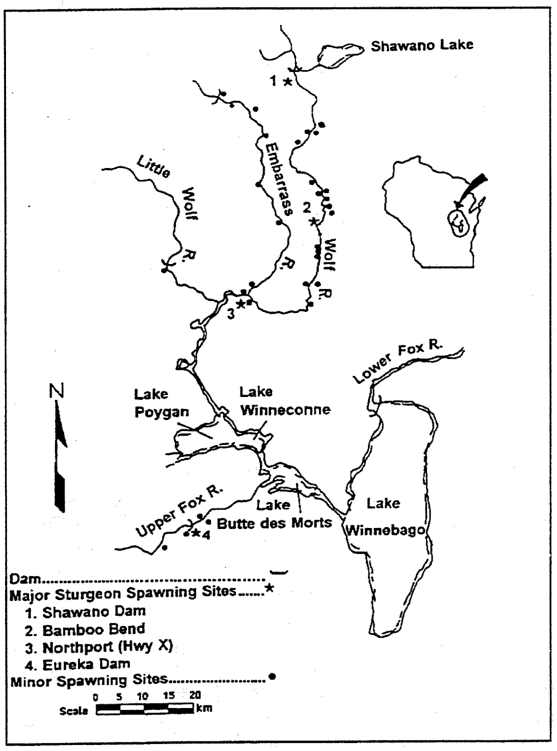

Fig. 1: Winnebago System, with lake sturgeon spawning sites.

Winnebago Pool fisheries community include freshwater drum, walleye, sauger, yellow perch, white bass, trout perch and emerald shiner. Seventy-eight species of fish have been reported from the Winnebago Pool Lakes. The Winnebago system lies within 120 km of two million people and receives heavy use from recreational boaters and anglers (WDNR, Winnebago Comprehensive Management Plan, 1989).

Methods

Historical Review of Winnebago System Lake Sturgeon Regulatory and Management Actions

Historic information on regulatory and management actions initiated to control the Winnebago System lake sturgeon fisheries was found primarily in files housed at the Wisconsin Department of Natural Resources (DNR) Oshkosh Service Center. Information was thoroughly reviewed and discussed, where possible, with individuals who initiated or participated in the various actions.

Characterization of the Current (1991-97) Winnebago System Lake Sturgeon Population and Fishery

The current Winnebago System lake sturgeon population and fishery was examined through harvest and population assessments conducted from 1991-97. The 1991-97 assessments were designed to provide data comparable to historic assessments and to also provide estimated densities and age structure of males and females in the spawning stock and the sex and maturity of harvested fish. Previous assessments conducted since the early 1950's, have provided relatively consistent data on estimated densities of the stock of legal sized fish, the size structure of the spawning stock, and spearing harvest - numbers harvested and effort, size and age distribution of harvested fish and estimated exploitation rates.

Historically, density estimates were derived for all legal size sturgeon in Lake Winnebago. In certain years, sturgeon (unsexed) captured in DNR "sheepshead", Aplodinotus grunniens, removal trawling operations, were tagged and released, and recapture data were collected the following winter in the spear fishery. After these operations ceased in 1990, sturgeon tagged in the spring on the Wolf and upper Fox Rivers during their spawning period were used as the marked portion of the population for deriving density estimates, with the recapture data collected the following winter during the spear fishery. Therefore density estimates attempted after 1990 were for adult males and females in the spawning stock only.

Density estimates were derived using Chapman's modification of the Petersen estimate according to Ricker (1975), with an adjustment to account for spawning migration patterns.

During the spawning periods of 1991-97, sturgeon were captured at upriver spawning sites on the Wolf and upper Fox River using handheld dip nets as the fish spawned along current swept, rocky, river shorelines. All captured fish were measured in total length to the nearest half inch, sexed, tagged with a monel metal tag (size 49) and released. All males were sampled for age in 1992 and 1993 and all females were sampled for age in 1992-95.

Harvest data were collected at registration stations as successful spearers brought in their fish. During the 1991-95 spearing seasons, fish were registered by local taverns and restaurants, with DNR fisheries staff sampling fish at stations every Saturday, Sunday, Wednesday, Thursday and Friday of the season. Beginning in 1996, DNR fisheries staff assumed responsibility for all registration operations which allowed every fish registered to be examined. In each year of the study all fish examined by DNR staff were measured in total length to the nearest one half inch, and weighed to the nearest half pound, checked for tag returns, and sexed and staged. The sex and stage of maturation of harvested fish was determined using techniques and criteria developed by Bruch, Dick and Choudhury (1997, in press). In the 1991-94 seasons all fish examined were sampled for age by removing the anterior ray of a pectoral fin. In 1995 and 1996, fish were randomly subsampled by sex for age.

All fin bones were cross sectioned using an Isomet Low Speed Saw and examined under a binocular scope to determine the number of annuli present.

Harvest effort was estimated via aerial counts of spearing shanties on the ice on the opening day of each spearing season.

Minimal exploitation rates of the mature spawning stock were developed from tag recapture data from marks applied in the spring tagging efforts in 1991-96, and recovered in the subsequent winter spear fishery. Dorsal fin scarring data collected during spring assessments were used to develop a one year tag retention rate, which in turn was used to adjust the expected number of marks available in the harvestable population.

Total annual mortality rates (A) were derived from catch curves according to Ricker (1975).

Historical Population and Harvest Assessment Data Review and Analysis

All historic data from harvest and spawning assessments conducted between 1941 and 1990 were also gathered from data files housed at the DNR Oshkosh Service Center. Data were tabulated and analyzed to discern long term trends and changes in population size and age structure. No data exist on any set line or hook and line harvests.

Historic trends on the following parameters were examined: estimated population densities, size distribution of males and females in the spawning stock, annual harvest and harvest effort, minimal exploitation rates, size and age distribution and condition of harvested fish and total annual mortality rates.

Density estimates for the Winnebago harvestable lake sturgeon stock were calculated over the years by various researchers - Priegel and Wirth (1975) for the period 1955-59, Folz and Meyers (1985) for the period 1976-83, and Meyers for 1990 (DNR, personal communication).

Size distributions of males and females in the spawning stock were determined using total length data collected during spring spawning assessments for the years 1954-64, and 1975-90.

Annual spear harvests from 1941-54 were estimated via creel surveys, except for 1943-45 when no censuses were conducted. Since 1955, mandatory registration has provided records of annual harvests.

Harvest effort has been measured on Lake Winnebago since 1956, and on the Upriver Lakes since 1952 via ice shanty counts taken from the air on the first day of the spearing season. Spearing license sales data also exist since the inception of the license in 1960, but were not used as a measure of effort due to substantial inconsistencies in license sales distribution and use patterns.

Estimated historic exploitation rates of adult sturgeon were developed from tagging studies conducted during spawning periods from 1954-64 and 1975-90, with recapture data collected in subsequent winter spear fisheries.

Size distributions of harvested fish were calculated using total length and weight data collected from harvested fish. Age distributions were calculated from age data collected during the harvest assessments in 1953-1969, 1975-76, 1981 and 1986.

Condition factors were calculated according to Carlander (1969) using the formula:

$$K' = (10^5 * W)/L^b$$

where:

W = weight
L = total length
b = slope of the LogW on LogL regression.

Total annual mortality rates were calculated as described earlier.

All historical data were reviewed in the context of regulatory changes and unusual environmental conditions to determine coincidences and/or relationships between events and population parameters.

Results

Summary of Winnebago System Lake Sturgeon Regulatory and Management Actions

The sturgeon fishery of the Winnebago System appears to have always been maintained through natural reproduction. No records were found to indicate sturgeon have ever been stocked into the system. Sturgeon have been regularly harvested from the Winnebago System waters via spearing, hook and line, as well as other methods since pre-European settlement (Probst & Cooper 1954). Harvest regulation began in 1903 with the enactment of a statewide minimum size limit for lake sturgeon of 8 lbs (3.6 kg), with no bag limit on the number of fish an individual could harvest. All sturgeon harvest on the Winnebago System was banned from 1915 through 1931. While no records were found explaining the specific justification for the closure, it can be safely assumed the closure was enacted out of concern for preserving the sturgeon stock. The initial "modern day" spearing season for sturgeon on Lake Winnebago took place in the winter of 1931-32. Setline, as well as hook and line seasons, were also established for certain time periods on parts of the Winnebago System, but neither have been legal since the 1950's. The first spearing season on the Upriver Lakes took place in 1952 as an annual season to replace the abolished setline fishery. At the time, the Upriver Lakes sturgeon population was considered to be separate from the Lake Winnebago population (Priegel and Wirth 1978) and was managed as thus.

Over the years, the lengths of the Lake Winnebago and Upriver Lakes spearing seasons and seasonal bag limits have been reduced several times, and the minimum size limit was increased twice in efforts to control harvest and maintain average annual exploitation at or below 5% (Priegel and Wirth 1975). The minimum size limit was increased also as a means to protect young fish to allow them to reach the size of sexual maturity before entering the legal stock. Recommendations to increase the minimum size limit over the years were based on the assumption that harvests would be reduced proportional to the percentage of fish, for example, under 102 cm from a harvest with a 76 cm size limit, and reduced even further if the minimum size limit would be increased to 114 cm. In other words, it was felt that if 20% of the fish from a harvest with a 76 cm minimum size limit were less than 102 cm, raising the size limit to 102 cm would reduce the harvest by 20% (R. Probst, DNR, personal communication), (Priegel and Wirth 1975).

Numerous fisheries biologists and conservation wardens have worked on the lake sturgeon of the Winnebago System since the early 1940's with some level of work occurring regularly to this day. As different biologists came and went, various and sometimes differing aspects of sturgeon management were emphasized by each. The public, especially the spearing public, has always been interested in the sturgeon regulation and management programs and has become increasingly involved in providing input into management decisions.

The chronology of Winnebago System sturgeon regulatory and management actions is listed in Table 1.

Table 1.
Sturgeon regulatory changes and significant management actions on the Winnebago System from 1903 to 1997.

Pre 1903	No Regulations.
1903	8 lb (3.6 kg) minimum size limit.
1913	14 May to 31 April open season, 20 lb round weight minimum size limit.
1915	All sturgeon harvest on the Winnebago System is prohibited.
1931	First regulated spearing season on Lake Winnebago, open throughout the winter, 30 " (76.2 cm) minimum size limit, 5 bag limit per person per season, tags $.05 each, fishing license required.
1932	Set line fishery opened on the Upriver Lakes, September 5 to October 31, 30" (76.2 cm) size limit, 5 bag limit per person per season (spear and set line fisheries combined), tags $.05 each, set line license required.
1935	Wolf River hook and line season opened (Waupaca and Winnebago Counties), September 5 to October 31, no minimum size limit, 5 bag limit per person per season (spear, set line and hook & line combined), tags $.05 each, fishing license required.
1937	Wolf River hook and line season expanded to include Shawano County.
1939	Hook and line season on Wolf River shortened by two weeks, September 5 to October 15
1940	Hook and line 30" (76.2 cm) minimum size limit initiated, and bag limit modified to allow only 1 fish per day. (maintaining 5 per season limit),
1941	Hook and line season closed on Wolf River.
	First spear harvest creel census on Lake Winnebago.
	Lake Winnebago spearing season reduced to one month, February 1 through March 1.
1942	First significant biological assessment conducted on the sturgeon population and spearing harvest.
1944	Hook and Line season reopened on Wolf River but in Winnebago County only.
1946	Hook and line season opened on all portions of Wolf River (now including Outagamie County), retaining previous season length of September 5 to October 15, 30" (76.2 cm) size limit, bag limit of 5 per season, and $.05 tags.
1950	Hook and line, and spearing sturgeon tag fees increased to $1.00 each.
1952	Set line season on Upriver Lakes closed.
	"Experimental" spearing season conducted on the Upriver Lakes, 16 days February 15 through March 1, 30" (76.2 cm) minimum size limit, seasonal bag limit of three, $.05 tags (Lake Winnebago retained the Feb 1 -March 1 season and the bag limit of 5).
1953	Hook and line seasonal bag limit on Wolf River reduced to 3.
	Upriver Lakes spearing season reduced to 14 days .
1954	Spearing seasonal bag limit on Lake Winnebago reduced to 3.
	First biological assessment conducted on the sturgeon spawning stock (conducted annually until 1964).
1955	Minimum size limit for spear fishery (Lake Winnebago and Upriver Lakes) increased to 40" (101.6 cm).
	Mandatory registration of all sturgeon harvested in spear fishery (Lake Winnebago and Upriver Lakes); fish must be registered on same day speared by 6:00 pm.
1956	Spearing, and hook and line seasonal bag limit reduced to 2 fish.
	Upriver Lakes spearing season reduced to 9 days.
	Lake Winnebago spearing season reduced to 2nd Saturday in February through March 1.
1957	Spearing seasonal bag limit on the Upriver Lakes reduced to 1 fish (2 fish limit retained on Lake Winnebago).
	Upriver Lakes season length reduced to 5 days.
1958	Spearing seasonal bag limit on Lake Winnebago reduced to 1 fish .
	Spear fishery closed on Upriver Lakes.
1959	Upriver Lakes spearing season reopened for one year for three days (On both Lake Winnebago and the Upriver Lakes at this point there was a 40" (101.6 cm) minimum size limit and a seasonal bag limit of 1).
	Hook and Line season on the Wolf River closed.
1960	Separate sturgeon spearing license is required at a cost of $2.50; only persons age 14 and over could buy a spearing license, and persons age 16 and over were also required to possess a fishing license; a license could be purchased before, or at anytime during the spearing season.
1962	Upriver Lakes new spearing season format implemented: 2 day season once every three years.
1968	All transported sturgeon must be "openly exposed", i.e they must visible in the transporting vehicle, to a person in a passing vehicle.

1971 Upriver Lakes spearing season format reconfigured again to a 2 day season once every five years.

1974 Minimum size limit increased to 45" (114.3 cm).

1975 Annual spawning stock assessments re-established.

1977 Sturgeon for Tomorrow, a private sturgeon conservation organization, formed by local sturgeon spearers to provide financial and political support for sturgeon aquaculture and other management activities.

"Sturgeon Patrol" initiated in the spring using volunteers (citizens, students, DNR staff, etc) to guard sturgeon spawning sites on the Wolf River 24 hours a day during the spawning period; funded by Sturgeon for Tomorrow.

1980 Spearing license fee increased to $5.50; license has to be purchased prior to season.

1985 $1,500 minimum fine established for possession of illegal sturgeon.

1986 Sturgeon registration hours extended to 7:00 pm during the spearing season.

1991 Expanded harvest and population assessments initiated on Lake Winnebago, the Upriver Lakes and the Wolf and upper Fox Rivers.

1992 Winnebago Citizens Sturgeon Advisory Committee, comprised of representatives of 30 sturgeon spearing and conservation organizations from the Winnebago region, established to work with DNR fisheries and law enforcement staff in the development and implementation of regulations and management actions.

1993 Angling through a sturgeon spearing ice hole prohibited (due to serious illegal hooking problems during the 1992 spearing season).

1996 Emergency rule reduces Lake Winnebago spearing season to nine days with the possibility of extension if the average water clarity on the 3rd day of the season is less than 10 feet (Average water clarity was >12 ft, therefore the season ran only nine days).

1997 Series of new rules went into effect as the 1st phase of the developing Safe Harvest Management System for Winnebago sturgeon:

The Lake Winnebago spearing season length is reduced to 16 days, beginning the second Saturday in February (no change in the Upriver Lakes season format);

The minimum size limit is reduced to 36" (91.4 cm);

Successful spearers are required to accompany their fish to a registration station, and to stay within a specific road boundary around the lake until their fish is registered;

The covering of large ice holes (spearing holes) with shanties is prohibited during periods other than 48 hours before and continuing through the open spearing season;

Hours of sturgeon spear harvest registration are reduced by one hour to close at 6:00 pm.

Status of the Current (1991-97) Winnebago System Lake Sturgeon Population and Fishery

To assess the status of the 1991-97 Winnebago System lake sturgeon population and spear fishery 13,714 sturgeon were captured and/or handled through various assessments (Table 2).

Table 2
Number of lake sturgeon sampled for size, sex and age, 1991-97.

Year	Survey Type	Number sampled for size	Number sampled for sex	Number sampled for age
1991	Harvest	806	245	233
1991	Spawning	200	200	0
1992	Harvest	525	247	247
1992	Spawning	426	426	131
1993	Harvest	1643	428	428
1993	Spawning	442	442	372
1994	Harvest	700	374	374
1994	Spawning	720	720	96
1995	Harvest	3173	1225	622
1995	Spawning	1401	1401	120
1996	Harvest	1221	1198	912
1996	Spawning	819	819	0
1997	Harvest	1290	1288	292
1997	spawning	348	348	0
TOTAL		13714	9361	3827

Population Characteristics, 1991-97

Estimated Densities of Adult Stock

The 1995 lake sturgeon population within the Winnebago System was estimated at 43841 adult males (26867 to 87682 95%CI), 7850 adult females (4194 to 24979 95% CI) and an unknown number of juvenile fish. In attempting to collect the necessary data to develop density estimates for the adult sturgeon stock in the Winnebago System, a number of difficulties were encountered during the study: 1) marking an adequate number of females during the spring spawning run; 2) unreported recaptures during the 1991-1995 spearing seasons; and 3) discovering, during the 1996 Upriver lakes season, that all the fish marked in the spring may not make it back to Lake Winnebago by the February spearing season. Tag return data showed that in some years adult fish remain in the Upriver Lakes on their post spawn migration back towards Lake Winnebago, especially if there is a good food supply such as the high gizzard shad populations during the winters of 1990-91 and 1995-96, which the sturgeon foraged heavily on. Measures were taken to address these difficulties - increasing marking effort in the spring, having fisheries staff register all harvested fish to ensure tag recaptures are noted, and realizing the best and maybe the only reliable estimates may come from the years with an Upriver Lakes season.

Size and Age Structure, Mean Length at Age of Adult Males and Females

The mean total lengths of adult males and females captured in spawning assessments from 1991-97 were 137 cm and 159 cm, respectively. Mean age in the spawning stock was 21 for males with a range of 12 to 44 years. Mean age of adult females was 29 with a range of 20 to 59 years.

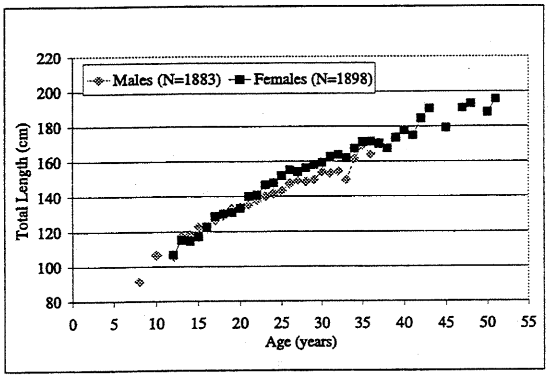

Fig. 2: Lake sturgeon mean total length at age, Winnebago System 1991-97.

Mean length at age of each sex (mature and immature stock combined) shows males and females exhibiting similar growth rates up to age 20, after which the growth rate of males decreases (Figure 2). Males apparently have a substantially shorter life span with very few fish reaching 40 years of age. While females from the Winnebago System have been found to reach an age of 80+ years (D.J. Folz, DNR, personal communication), during the course of the current study, few were found in excess of age 50.

Mortality Rates of Adult Stock

Estimated total annual mortality rates of the adult stock were 16.7% for males age 17 to 28, and 17.3% for females age 26 to 36. Out of 407 males from the spawning stock sampled for age, only 4 were older than age 30. Out of 312 adult females sampled for age, only 11 were older than age 40.

Characteristics of the Spear Fishery, 1991-97

Harvest and Effort

Total harvests for each year, 1991-97 are listed in Table 2. Annual harvests averaged 1337 fish (25725 kg) with a total for the period 1991-97 of 9358 (180078 kg). The 1995 harvest of 3,173 fish was the highest since mandatory registration began in 1955 (Figure 8). Spearing effort on Lake Winnebago ranged from 2238 shanties in 1992 to a record number of 3779 in 1997 (Figure 9). Lake Winnebago shanty counts for the remaining study years were: 1991 - 3131; 1993 - 3615; 1994 - 3400; 1995 - 3760; and 1996 - 3708. Opening day ice shanty counts for the two Upriver Lakes spearing seasons held in 1991 and 1996 were 629 and 1656, respectively. The 1656 shanty count of 1996 was surpassed only once in the history of the Upriver Lakes spear fishery with a count of 1,789 in 1986.

Estimated Minimal Exploitation of Adult Stock

Estimated minimal exploitation through the 1992-97 period averaged 3.2% for adult male sturgeon and 6.0% for adult female sturgeon for the period 1993-97. Tag retention rates were 0.912 for males and .800 for females. Based on observations each spring of the condition of tags on previously marked fish it was felt that most of the tag loss occurs within the first year, after which the tags become "in-grown" on the dorsal fin. Tag retention was highest in fish in which tags were inserted well into the fleshy area at the base of the dorsal.

Low numbers of females tagged in 1991 prevented an exploitation estimate to be calculated for adult females using the 1992 harvest data. Rates for both sexes were obviously higher in high harvest seasons. Exploitation was lower for both sexes, especially for adult females, in 1996 and 1997. Estimated exploitation rates for adult males during the 1996 and 1997 seasons were 1.8% and 1.7%, while the rates for adult females in the same seasons were 5.1% and 5.3%. The rates developed prior to 1996 were likely underestimates due to registration stations missing tags on harvested fish, despite a $10.00 reward offered by Sturgeon for Tomorrow. Following the 1991-95 harvest assessments, when local tavern and restaurant owners were responsible for registering fish, and fisheries staff subsampled the harvested fish at stations for sex and age, a number of tags returns would be sent in to the DNR office, sometimes months after the harvest. These tags had been missed by the registration stations. A comparison of the 1995 daily tag return rates for DNR staffed vs unstaffed stations revealed that, indeed, stations registering fish without DNR staff present missed an average of 14.4% of the tag returns. Therefore, rates developed from tag return data from the 1996 and 1997 seasons would be the most accurate, as DNR fisheries staff registered all harvested fish in those years.

Sex Ratios of 1991-97 Harvests

Male sturgeon comprised an average of 38% of the harvests from 1991-96 and were primarily adult fish (Figure 3). Both adult females (> 140 cm) and juvenile females made up substantial portions of the harvests from 1991-96, comprising 46% and 16%, respectively. In 1997 the proportion of adult females in the harvest dropped to 34% with juvenile females comprising 25% and males comprising 42%. Overall harvest sex ratios in 1991 and 1996 were more balanced males to females as more males were harvested in the Upriver Lakes fisheries than in the Lake Winnebago fisheries.

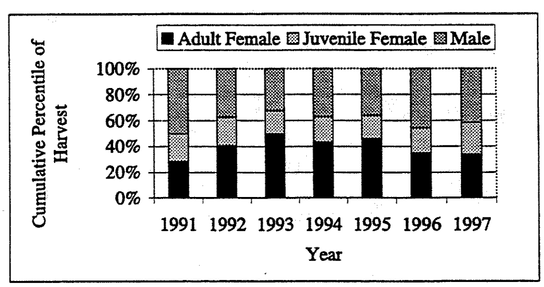

Fig. 3: Lake sturgeon sex ratios, Winnebago System spear harvest 1991-97.

The average sex ratio for the 1991 and 1996 Upriver Lakes seasons was 54.3% male and 45.7% female, while the average sex ratio for the 1991-97 Lake Winnebago harvests was 38.5% male and 61.5% female.

Maturity data from the 1991-97 Lake Winnebago harvests revealed that most of the males with fully developed testes (M2 stage) and nearly all of the females with fully developed ovaries (F4 stage) migrate out of Lake Winnebago prior to the spearing season. This pre-spawn movement begins in the fall with fish moving out of Lake Winnebago through the Upriver Lakes and into the Wolf and upper Fox Rivers to stage in deep holes (3 to 9 m) for the winter (D.J. Folz, DNR, personal communication). Maturity data from the Upriver Lakes harvests of 1991 and 1996 revealed that a substantial portion of these fish remained in the Upriver Lakes during those winters feeding on an unusual abundance of gizzard shad. In the 1991 and 1996 Upriver Lakes harvests an average of 60.2% of all males were stage M2, and 33.5% of all females were F4 stage. Of all fish examined from the 1991-97 Lake Winnebago harvests an average of only 12.9% of all males were stage M2 and 2.3% of all females were stage F4.

Size and Age Distribution of Harvested Fish

The mean size of males in the harvest was 135 cm and 15.6 kg from 1991-96, and 133 cm and 13.4 kg in 1997. Females averaged 148 cm and 22.3 kg in 1991-96, and 142 cm and 18.3 kg in the 1997 harvest. Figure 4 illustrates the length frequency distribution of males and females harvested from 1991-96. Analysis of variance

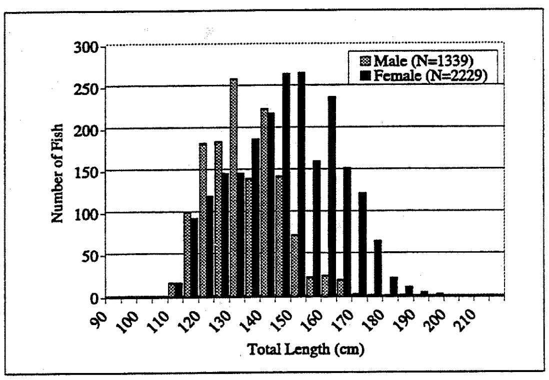

Fig. 4: Lake sturgeon total length frequency, Winnebago System spear harvest 1991-96.

and subsequent least significant difference pairwise comparisons of means found the mean lengths and weights of both males and females harvested in 1997 were significantly less (.05) than those of males and females harvested during the previous six seasons. Males harvested from 1991-96 had a mean age of 21 years, ranging from 10 to 39 years, while harvested females had a mean age of 25 years, ranging from 12 to 51 years.

Historic Population and Harvest Trends

Sturgeon Population Characteristics, 1954-90

Estimated Densities of Legal Sized Stock

Figure 5 illustrates estimated changes in densities of legal stock (all fish larger than 102 or 114 cm) from 1956 through 1990, and the estimated size of the adult stock in 1995. Estimates throughout the 35 year period indicate at least a fourfold increase in densities of legal fish.

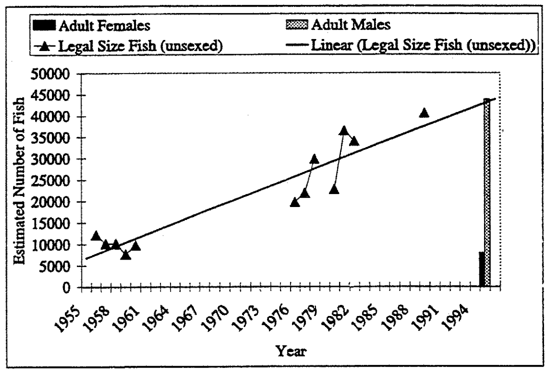

Fig. 5: Lake sturgeon estimated population densities, Winnebago System 1956-95.

Size Structure of the Spawning Stock

Mean total length of males and females in the spawning stock has changed substantially over the last 40 years. Adult males were found to average 137 cm in total length in 1954-64, 132 in 1975-84, 135 in 1985-94, and 138 in 1995-97 (Figure 6). Adult females were

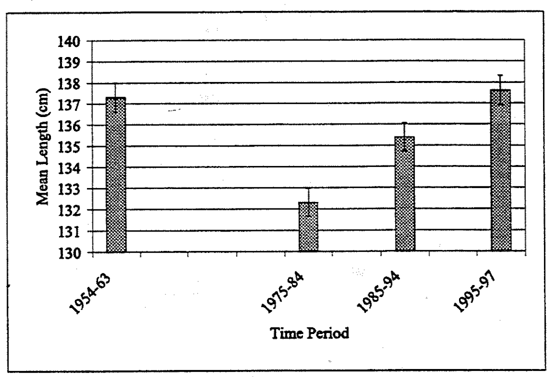

Fig. 6: Adult male lake sturgeon mean total length. Winnebago System 1954-97.

found to average 164 cm in 1954-63, and 160 cm in all periods 1975-97 (Figure 7). Both sexes exhibited a relatively large mean total length in the mid 1950's when spawning assessments first began, as well as a pronounced decrease in mean size over the 20 year period from 1954-74.

Since 1974 though, the mean length of males has been steadily increasing, while the mean length of females has remained static. Analysis of variance and pairwise comparisons of means via the Tukey (HSD) test found no significant difference (.05) between mean total length of males captured in 1954-63, to males captures in 1995-97, but did find significant increases in length (.05) from 1975 to 1995. Females also experienced a significant decrease (.05) in

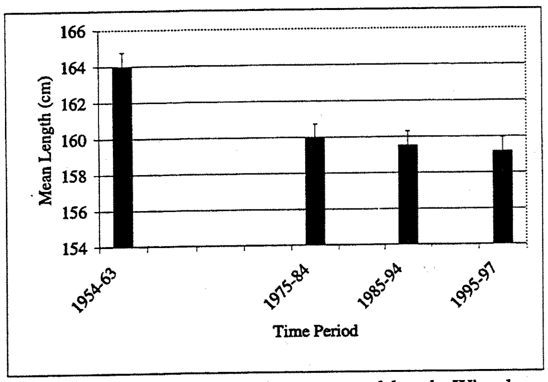

Fig. 7: Adult female lake sturgeon mean total length, Winnebago System, 1954-97

total length from 1954 to 1975, but did not experience the increase in mean total length enjoyed by the males from 1975 to 1995. No significant differences were found between mean total lengths of females captured from 1975 to 1995.

Spear Harvest and Fishery, 1941-90

Harvest and Spearing Effort

Sturgeon harvest estimates for 1941-54 and registrations for 1955-90 for the Winnebago Pool Lakes are illustrated in Figure 8. Since mandatory registration began in 1955, annual harvests ranged from 8 fish in 1969 and 1973 to 3173 fish in 1995. Annual harvests averaged 1249 fish for the period 1955-59 dropping to a mean

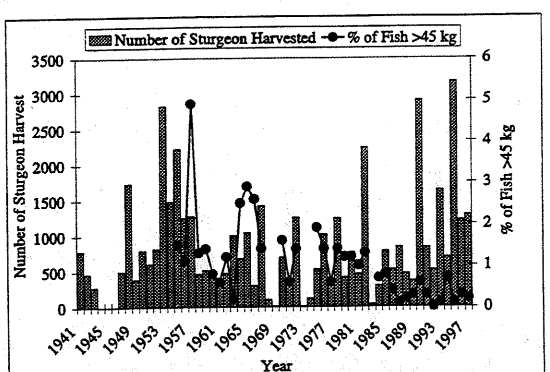

Fig. 8: Winnebago System lake sturgeon harvest, winter spear fishery 1941-97

annual harvest of 501 fish from 1960-64. Mean annual harvest within five year periods 1965-69 through 1985-89 remained between 510 fish per year and 761 fish per year. From 1990 through 1997 however, mean annual harvest increased to 1209 sturgeon registered per year.

Since aerial spearing shanty counts were first made on Lake Winnebago in 1956, the number of shanties has increased nearly 2.5 times from an average of 1602 or one shanty per 34.8 ha for the first four years of counts, 1956-59, to an average of 3661 or one shanty per 15.2 ha for the last four years, 1994-97 (Figure 9). Shanty counts in some years on Lake Winnebago are quite low due to poor ice condition, adverse weather, and/or poor travel condition on the ice. Shanty counts on the Upriver Lakes during the 16 seasons held there since 1952, show much higher densities than Lake Winnebago, with an average of 888 or one shanty per 12.5 ha from 1956-59 (three seasons), to a count of 1656, or one shanty per 6.7 ha during the last season held in 1996.

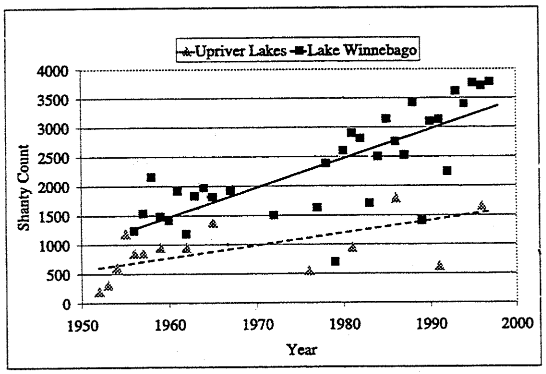

Fig. 9: Sturgeon harvest effort measured through ice shanty counts, Winnebago Pool Lakes 1952-97.

Estimated Exploitation

Exploitation of the spawning stock calculated for year periods from 1952-56 to 1992-96 showed a dramatic decrease in the estimated exploitation rate, from relatively high levels, for both sexes from the mid 1950' to the early 1960's, with a subsequent rise beginning in the mid 1980's (Figure 10). The increase in estimated exploitation in the mid 1980's was especially acute for mature females, peaking in the early 1990's. Since 1995 estimated exploitation rates for both sexes have decreased.

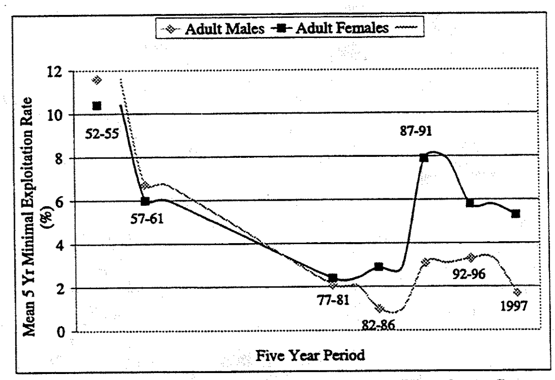

Fig. 10: Estimated minimal exploitation rates, Winnebago System lake sturgeon 1955-97.

Size and Age Distribution, and Condition of Harvested Sturgeon

Mean total length of harvested sturgeon has been steadily increasing since 1951 from 125 cm in 1951-54 to 136 cm in 1955-64, and then again to 140 cm in 1974 (Figure 11). The increases coincide with increases in the minimum size limit from 76 cm to 102 cm in 1955, and from 102 cm to 114 cm in 1974-84. The increases in mean size from the period 1985 to 1995 coincides with the 1985 implementation and strict enforcement of the $1,500 fine for possession of an undersize sturgeon. Analysis of variance and subsequent pairwise comparison of means (HSD) found the increases in mean size of harvested fish resulting from the increases in the minimum length limit to be significant at the .05 level.

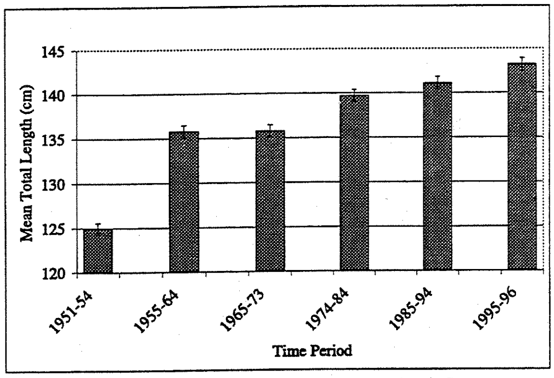

Fig. 11: Lake sturgeon mean total length, Winnebago System spear harvest 1951-96.

Length frequency distributions of fish harvested from the periods of the three different minimum length limits illustrate the changes in mean size and the shift in the mode of the distribution towards larger fish while the upper end of the frequency range remained static (Figure 12).

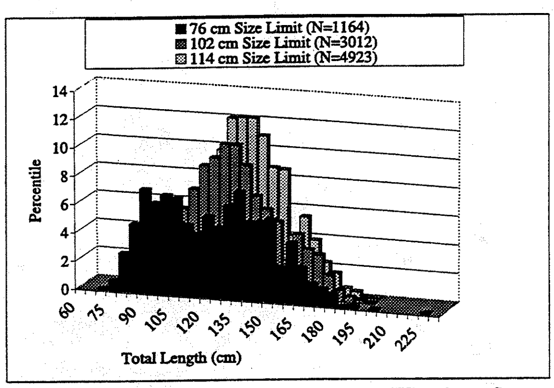

Fig. 12: Lake sturgeon total length frequency, Winnebago System spear harvest 1951-94.

Mean age of sturgeon harvested ranged from 23.3 years for the period 1991-96 to 19.8 years for the period 1965-69. The pattern of mean ages generally followed the pattern of mean total length of harvested fish - increasing as the size limit was increased. Mean ages of harvested fish along with minimum and maximum ages for seven sample periods from 1953 to 1996 are listed in Table 3. Analysis of variance and pairwise comparisons of means (LSD) found the mean age of sturgeon harvested in 1991-96 to be significantly higher (.05) than in any other period sampled. From 1953 to 1996 minimum ages of harvested fish increased from 6 to 10 while maximum ages, after initially rising from 49 to 75 (in 1960) consistently decreased to 51.

Table 3
Mean age, minimum and maximum age, sample size, and standard deviation of the mean for sturgeon harvested via the Winnebago System spear fishery 1953-96.

Time Period	Mean Age	Min-Max Age	N	SD
1953-54	20.6	6-49	738	8.5
1955-59	22.9	8-68	3981	7.5
1960-64	21.2	7-75	2522	8.8
1965-69	19.8	6-56	2745	8.8
1975-81	20.2	9-55	706	6.9
1982-90	22.2	11-55	239	7.3
1991-96	23.3	10-51	2828	5.2

Mean condition of harvested sturgeon remained relatively stable for the period from 1951-79 (Figure 13). Since 1980 condition has generally decreased, although also becoming slightly more variable. Condition has been calculated separately for harvested males and females since 1991, and while there are differences between the sexes with females generally having a higher mean condition, the mean condition of both sexes followed the same trend.

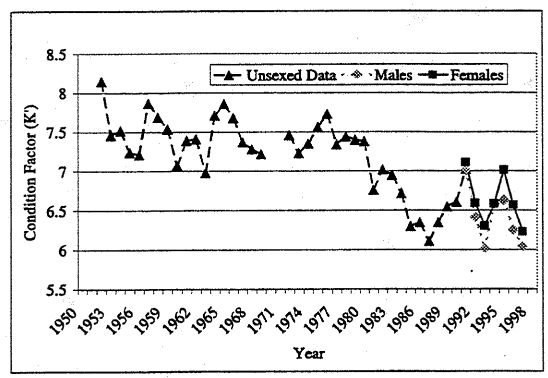

Fig. 13: Lake sturgeon mean condition factor (K), Lake Winnebago 1951-94.

Sturgeon Length at Age

Sturgeon length at age, using unsexed or combined sex samples, shows similar patterns from harvest aging data collected in 1954-56 and in 1993-94. Generally a 20 year old sturgeon from both periods would be approximately 134 cm, with a 35 year old fish being approximately 164 cm. The 1993-94 data did show greater lengths at age for fish between 20 and 35 years of age compared to fish of the same ages in 1954-56.

Estimated Total Annual Mortality Rates

Total annual mortality rates (A) calculated from catch curves developed on unsexed harvest aging data over the last 40 years, shows a sharp rise in estimated total annual mortality rates from 1953-54 (A=0.143) to 1955-59 (A=0.221), followed by a substantial decline in the rate, as measured in 1975-81 (0.098). Since 1981 though, the total annual mortality rate has risen sharply again to an estimated A of 0.186 for the 1991-96 time period (Figure 14).

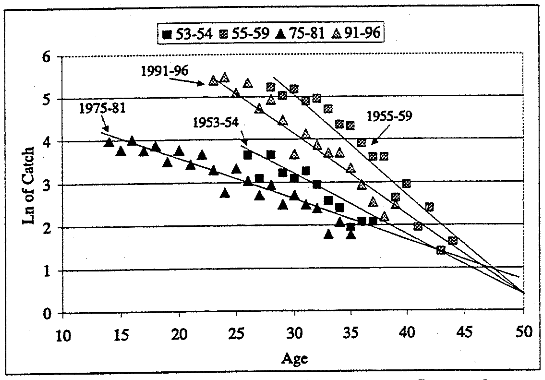

Fig. 14: Lake sturgeon catch curves; Winnebago System harvest data 1953-96.

Discussion

Status of the 1997 Winnebago System Lake Sturgeon Population and Fishery

The 1997 lake sturgeon population finds itself in the interesting dilemma of being at the crest of a four decade rise in densities, while at the same time experiencing apparent overexploitation of adult females exhibited by a nearly complete lack of large, old fish (>50 years of age) in the population. Males, on the otherhand, appear to be responsible for a large share of the density increases over the last 15-20 years, and have every opportunity to live to an old age, but do not as apparently their relatively high natural mortality rate results in few living past the age of 40. Recruitment (which is not measured) has obviously been good over the last forty years to allow for the buildup of the sturgeon stock - it has likely been enhanced by the spring Sturgeon Patrol and the 4 to 5 fold increase in Wolf River sturgeon spawning sites resulting from the placement of riprap shore protection. As a result of consistent recruitment, densities have increased but sturgeon biomass may have reached a level to effect a decrease in overall condition of sturgeon in the population. The decrease in condition though, does not seem to have impacted growth in terms of unsexed length at age. Fish that historically were consistently found to have the lowest condition were many (but not all) of those harvested during the Upriver Lakes spearing seasons, which led early biologists to believe that the Upriver Lakes population was distinct from the Lake Winnebago sturgeon population. Tag return data over the past 15 years (DNR files, Oshkosh) and recent Wolf River surveys (Bruch, Wolf River sturgeon assessments, 1994-96) strongly indicate that the Upriver Lakes sturgeon population is not a separate stock as previously thought, but instead a nursery stock of juveniles that are gradually working their way down to Lake Winnebago over a 10 year period. These new data suggests that the most appropriate strategy for management of the Winnebago sturgeon population and fishery is from a system-wide perspective.

The spear fishery on both Lake Winnebago and the Upriver Lakes has grown in popularity and annual harvests have risen since 1990 to the point of concern, especially regarding the harvest of adult females. Improvements in water quality, likely the result of a number of water quality improvement actions over the last two decades, such as sanitary sewers, urban stormwater management, and implementation of agricultural erosion and waste controls, have resulted in more seasons with good winter water clarity. As water clarity has improved the average annual harvest has increased. Newly documented pre-spawn migration patterns strongly suggest that females (adults and juveniles) have likely always made up a substantial portion of the spearing harvest from Lake Winnebago. Sex and maturity data collected on the harvest since 1991 has provided key insights into the actual impact of the spear fishery on the sturgeon population, with the realization that with a 114 cm size limit, adult females have been making up nearly half of the harvest while only comprising a relatively small portion of the harvestable population. Record shanty counts have been set in three of the last five years and shanty occupancy rate has likely also increased with an observed increase in immediate family members, children and grandchildren, entering the fishery in the last 10 years. The current estimated total annual mortality rate for females, 17.3%, and relatively high recent mature female exploitation rate are further evidence that the harvest patterns are affecting the female stock.

Long Term Impact of Harvest Regulations

Reviewing the history of regulations enacted to control or shape the sturgeon harvest on the Winnebago System is vital to understanding how we arrived at the sturgeon population we have today, as well as to understanding which regulations result in the desired impact and which ones do not. Of course having a time series of sound population and harvest assessment information is critical to examining the impact of regulations. Also, having adequate enforcement of and compliance by users of, existing regulations is critical to ensuring the regulations are having the desired impact.

While no data exist to verify the effectiveness of the harvest ban enacted in 1915, just the act itself does indicate that the Wisconsin state government at the time adopted the philosophy, or better yet, an attitude that sturgeon stocks in the state had value and needed protection. When sturgeon harvest was finally legalized again on the Winnebago System in 1931 bag and size limits were set that were likely thought at the time to be reasonable yet restrictive enough to provide some protection to the stock. Poaching was said to be widespread throughout this time period. Even though conservation wardens had been enforcing laws since the turn of the century, their numbers were relatively low and areas quite large (K. Corbett, DNR, personal communication). In the early 1940's the first biologists were hired to study the Winnebago sturgeon stocks and evaluate the effectiveness of harvest regulations.

The first comprehensive set of regulations enacted with a complement of biological assessment data allowing for evaluation were those implemented in the 1950's when the set line and hook and line seasons were closed, the spearing season was shortened, the seasonal bag limit was reduced to one fish, and the minimum size limit was increased. The Upriver Lakes spearing season was also opened but within 10 years was scaled back to a two day season once every three years. At that time there were still fish in the population that hatched in the 19th Century. The most obvious and immediate impact of the enactment of these rules was a 58% reduction in the average annual harvest. The primary goal of harvest reduction had been attained likely as a result of the decreases in season length and bag limit. While the increase in the minimum size limit from 76 to 102 cm may have been responsible for some of the harvest reduction and seemed reasonable at the time, the increase definitely shifted spearing effort on to larger fish. A sharp rise in the total annual mortality rate in the late 1950's coincides with the increase in the size limit despite the 58% reduction in overall numbers of fish harvested.

In the early 1970's biologists and conservation wardens were still concerned about immature sturgeon being harvested in the spear fishery, and enacted another increase in the minimum size limit in 1974 from 102 to 114 cm in an effort to protect the fish until they could reach the size of maturity. This increase further squeezed increasing spearing effort on to even larger fish that comprised an even smaller component of the entire sturgeon population. As the average size of the fish in the harvest increased, the relative number of large trophy fish in the population, and thus in the harvest, decreased. The trend of increasing average size of harvested sturgeon accelerated with the 1985 enactment of the $1500 fine for possession of an illegal or sublegal size sturgeon. This fine typically grows to $3000 after adding court and other associated costs. From 1974 to 1985, with the relatively low fine during that time period, it is likely that spearers may not have been as careful in judging whether a sturgeon coming "through their hole" was legal size or not. It is also likely that from 1974 to 1985 some number of sublegal fish were taken off the lake without being registered. The implementation of the $1500 fine did make spearers better judges of the size of sturgeon swimming through their ice holes, but mistakes undoubtedly did happen from time to time, probably resulting in the fish being "kicked off" the spear and back down the hole. While there are no records of the number of fish kicked off, surveys conducted by Sturgeon for Tomorrow indicate that in some years the "kick off" rate could be as high as 25% to 30% of the harvest (W. Casper, Sturgeon for Tomorrow, personal communication). Despite whatever spearing mortality was occurring in the 1980's though, the legal stock of sturgeon was growing in numbers and estimated total annual mortality rates were relatively low, although we do not know what the sex-specific effect of "kick offs" in the Lake Winnebago spear fishery was.

Greater frequency of clear water winters in the late 1980's and into the 1990's resulted in a number of record or near record harvests. Exploitation of adult females tripled and the overall total annual mortality rate doubled. Using expanded harvest assessment data including sex and maturity of harvested fish, another set of comprehensive regulation changes similar in scale to those enacted in the 1950's were enacted between 1992 and 1997. The spearing season was shortened to nine days in 1996 and then to a set 16 days in 1997 and the minimum size limit was decreased from 114 to 91 cm. Other regulations included a strengthening of laws on the transportation of unregistered fish and use of spearing shanties before the spearing season, a prohibition of angling in a spearing shanty, and a reduction of the daily sturgeon registration hours. The package was enacted as Phase 1 of an effort to develop and implement a comprehensive Safe Harvest Management Program for the lake sturgeon population of the entire Winnebago System including the Wolf and upper Fox Rivers and the Upriver Lakes. The impact of the new regulations was seen in 1997 with adult females dropping from 46% of the harvest with a 114 cm minimum size limit and longer season, to 34% of the harvest with a 91 cm size limit and a shorter season, and seeing the exploitation of adult females decreasing to the recommended 5% level.

Phase 2 of the new regulation package will involve management of the two day Upriver Lakes harvest which is scheduled to occur again in the year 2001. Continued aggressive harvest and population assessment will allow other short term impacts to be determined, as well as allow potential long term impacts to be forecast with some degree of confidence.

The vital components contributing to the success of the Winnebago Sturgeon Management Program are:

1) Sound, long term, biological assessment of the lake sturgeon population and harvest. As those that work on sturgeon know, it generally takes decades of consistent data to determine trends and the lasting impacts of management actions and/or regulations with these species. Sound assessments conducted fairly consistently since the 1940's provide a strong data base for decision making.

2) Strong, effective enforcement of harvest and other resource protection laws. Conservation law enforcement officials have made a commitment and a consistent effort to enforce sturgeon harvest and habitat protection laws.

3) Sincere, meaningful involvement of the "sturgeon" public in the overall development and implementation of the sturgeon management program. This involvement needs to be facilitated by the responsible government agency and also needs to be comprehensive enough to involve all significant sturgeon interests with a stake in the management of the common stock of sturgeon. The DNR has made a commitment to actively involve sturgeon interests in the management program through the Sturgeon Advisory Committee, sturgeon workshops and presentations, and various information/education activities. Public interest, energy and resources may also manifest themselves in organizations like Sturgeon for Tomorrow which can be tremendous allies in developing and implementing an effective sturgeon management program.

4) Protection and enhancement of sturgeon habitat within the Winnebago System and natural reproduction. Fortunately dams built on the system were placed far enough upstream that the impact on sturgeon is negligible, and the fact that Winnebago has a long tradition of the sturgeon spear fishery and population has helped to prevent placement of new dams and other losses of critical habitat. The population has remained robust, despite some harvest problems, due to strong, consistent natural reproduction.

Public Involvement in Sturgeon Management

If it were not for the desire of individuals to harvest sturgeon there would, of course, be no need for a management program. As a natural fishery resource, sturgeon have various values, which have also somewhat changed over time. These values motivate harvest, which in turn, due to the sturgeon's high susceptibility to overharvest, put sturgeon stocks at some level of threat from overexploitation. Regulations attempt to limit harvest as well as protect the habitat the fish depend upon, but regulations are only as effective as the effort put into enforcing them and the willingness of the users to comply with them. The responsible government must make a commitment to management and to enforcement. The users also need to make a commitment to sturgeon preservation and regulation compliance. Providing the government has made a real commitment to management and enforcement, a management system is most likely to break down at the user level with users not accepting and/or understanding the management program and not complying with harvest regulations. The challenge, which of course becomes more complex in interstate or international situations, is to effectively involve the various parties interested in a sturgeon stock in the assessment of management issues and the development and implementation of management strategies and actions. The Winnebago System Sturgeon Management Program is a case study, albeit a relatively simple one compared to some of the complex issues biologists are attempting to deal with in the Caspian or in Europe, which can perhaps provide some basic insight into how a management program working with the pubic can be made most effective. Sturgeon assessment data, habitat protection and enhancement, regulations and enforcement are all made more effective when the "users" have understanding and ownership of the resource and the management strategies designed to positively affect the resource.

Synopsis

The lake sturgeon population and fishery of the Winnebago System has been the subject of an evolving, living management program that has attempted to address key issues of the day and has provided relative long term stability to the sturgeon stocks. The incremental and iterative management and regulatory actions taken since 1903 were likely always made with the best available data and understanding of those data at the time. A number of decisions and actions stand out as key events in the development and maturation of the Winnebago sturgeon management program:

* prohibiting sturgeon harvest in 1915,
* reopening harvest seasons in the early 1930's,
* hiring of professional biologists in the late 1940's,
* closing the set line fishery in 1952,
* decreasing the seasonal bag limit from 5 to 1 and shortening the harvest season in the late 1950's,
* implementing mandatory registration of harvested fish in 1955,
* the establishment of Sturgeon for Tomorrow in 1977 as a citizen advocacy group for sturgeon management and research,
* implementing the "Sturgeon Patrol" in 1977 to protect spawning fish,
* initiating the $1500 fine in 1985 for the possession of illegal sturgeon,
* expanding the sturgeon harvest and population assessment in 1991 to include sex and maturity of harvested fish,
* establishing the Winnebago Citizens Sturgeon Advisory Committee in 1992 to assist in the development of and compliance with new regulations and management actions,
* shortening of the season in 1996 and 1997, and
* reducing the size limit in 1997.

The current population of sturgeon in the Winnebago system is a product of the aforementioned decisions and actions, and therefore a living testament to the effectiveness of those decisions and actions. While there is currently some concern about the long term stability of the female spawning stock, the Winnebago System Sturgeon Management Program is addressing those concerns with the management, public involvement, and regulatory actions taken from 1991 through 1997.

Acknowledgments

The Winnebago sturgeon management program we have today would not be possible had it not been for the efforts and foresight of the various fisheries and law enforcement professionals who worked on the system, specifically Doc Schneberger, Robert Probst, Edwin Cooper, Richard Harris, Gordon Priegel, Tom Wirth, Charles Schlumpf, O.K. Johnson, L. Dunham, Doc Chase, Keith Reichenbach, Don Knoke, Chick Deringer, Ken Corbett, Harold Hettrick as well as those who still work on the system - Jack O'Brien, Kendall Kamke, Dan Folz, Fred Binkowski, Mike Primising, Lee Meyers, Mike Penning, Doug Rinzel, Robert Olynyk, Art Techlow III, Ross Langhurst, Dean Schoenike, Dennis Jones, Todd Wippermann, Mark Beilfuss, Mike Young, Mark Shepherd, Carl Mesman, Byron Goetsch and Wayne Jeidy. Also deserving equal credit for a successful program are sturgeon enthusiasts throughout the Winnebago Region who participate in the management program, and Sturgeon for Tomorrow, who has donated over $300,000 since 1977 to the cause of sturgeon management and research.

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