Appendix D

Annotated Bibliography

Shorty's Island / Meander Reach
Ecosystem Restoration
Kootenai River, Idaho

Detailed Project Report and Integrated Environmental Assessment

June 2012

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TABLE OF CONTENTS

D-1. STURGEON BEHAVIOR AND MIGRATION 1
D-2. STURGEON POPULATIONS AND MANAGEMENT.. 13
D-3. STURGEON HABITAT REQUIREMENTS.. 22
D-4. STURGEON RIVERS PHYSICAL AND CHEMICAL MEASUREMENTS AND MODELING... 27
D-5. WHITE STURGEON RESTORATION.. 33

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D-1. STURGEON BEHAVIOR AND MIGRATION

Bruch, R.M. and F.P. Binkowski. 2002. Spawning behavior of lake sturgeon (Acipenser fulvescens). Journal of Applied Ichthyology. 18:570-575.

This study monitored the spawning of adult sturgeon in the Wolf River, just below Shawano Dam. Qualitative description of movements, spawning, and spawning habitat (large rubble substrate was dominant, velocity was about 1 m/s) was provided.

Buckley, J. and B. Kynard. 1985. Habitat use and behavior of pre-spawning and spawning shortnose sturgeon, Acipenser brevirostrum, in the Connecticut River. Pages 111–117 in F. P. Binkowski and S. I. Doroshov, Editors. North American sturgeons: biology and aquaculture potential. Dr. W. Junk. Dordrecht, The Netherlands.

This study characterized bottom type and bottom velocities just downstream of Holyoke Dam, where adults congregated each spring. Tracking radio-tagged adults identified movements, and use of habitats in the dam area. Studies identified and characterized a site (rubble substrate, velocity variable to about 70 cm/s) that fish used most, but did not capture eggs and verify spawning.

Movements and ecology of pre-spawning and spawning shortnose sturgeon, Acipenser brevirostrum, were studied through 1979-1982 in a 2 km reach of the Connecticut River. Radio telemetry was used to monitor the movements of 18 sturgeon. An additional 165 sturgeon, captured by gillnets, provided information on spawning site selection, sex ratio, and reproductive condition. For 3 years the mean water velocities during the spawning period ranged from 0.36 to 1.2 m sec super(-1) in the spawning area. Substrate was cobble and rubble. Sturgeon spawned over a short time period (3-5 days), during decreasing river discharge of 679 to 301 m super(3) sec super(-1) and rising water temperature between 11.5 to 14.0 degree C. High river discharge over a prolonged period during the normal spawning season may preclude reproduction.

Cheong, T.S., M.L. Kavvas, and E.K. Anderson. 2006. Evaluation of adult white sturgeon swimming capabilitiesand applications to fishway design. Environmental Biology of Fishes. 77:197-208.

Wild adult sturgeons, *Acipenser transmontanus* were captured in the San Francisco Bay Estuary and Yolo Bypass toe drain to evaluate swimming performance regarding fish ladder type partial barriers. Hydrodynamic forces and kinematic parameters for swimming performance data were collected in a laboratory flume under three flow conditions through barriers and ramp. At a given swimming speed and fish size, the highest guidance efficiencies of successful white sturgeon passage occurred at an approach velocity of 0.33 m/s.

Fox, D. A., J.E. Hightower, and F.M. Parauka. 2000. Gulf sturgeon spawning migration and habitat in the Choctawhatchee River system, Alabama-Florida. Transactions of the American Fisheries Society. 129: 811-826.

Telemetry studies identified six spawning sites, all with a hard bottom substrate (limestone and gravel), high flows, and variable depth (1.4−7.9 m). Turbidity varied widely during spawning (12−114 NTU) as did flows. Depth may not be a significant factor, nor may turbidity.

Hall, W.J., T.I.J. Smith, and S.D. Lamprecht. 1991. Movements and habitats of shortnose sturgeon Acipenser brevirostrum in the Savannah River. Copeia. 1991:695–702.

This study identified movements of radio-tagged pre-spawning adults. Without verifying spawning occurred, the study identified the likely spawning habitat; a site with a clay rubble bottom (site where adults congregated for days prior to moving downstream).

Kempinger, J.J. 1988. Spawning and early life history of lake sturgeon in the Lake Winnebago System, Wisconsin. American Fisheries Society Symposium. 5:110-122.

This study identified spawning habitat and location, and used captures of early life stages to identify timing of dispersal (seasonal and daily), and abundance of migrants.

Khodorevskaya, R.P., G.I. Ruban, and D.S. Pavlov. 2009. Behavior, migrations, distribution, and stocks of sturgeons in the Volga-Caspian Basin. Special Publication No. 3. World Sturgeon Conservation Society.

This study has much information on behavior and dispersal patterns of early life stages of several species of sturgeons in the Volga River. Most Russian species initiate dispersal as free embryos, not as larvae like Kootenai sturgeon, and the free embryos disperse in the water column (some to the surface). No quantitative information on spawning or early life stages' habitats.

Kieffer, M.C. and B. Kynard. 1996. Spawning of shortnose sturgeon in the Merrimack River, Massachusetts. Transactions of the American Fisheries Society. 125:179–186.

A multiyear study that identifies spawning timing and habitat; foraging locations and habitats; and wintering location and habitat of shortnose sturgeon. Mark-recapture was used to estimate population abundance of this least abundant shortnose sturgeon population. A spawning location was identified over rubble-gravel substrate and velocities near 1 m/s.

Kieffer, M.C. and B. Kynard. In Press. Spawning Migration, Spawning Characteristics, and the Effect of River Regulation on Spawning Success of Connecticut River Shortnose Sturgeon. U.S. Geological Survey, Leetown Science Center, S.O. Conte Anadromous Fish Research Center.

Over the course of 17 years, the spring spawning migration and spawning of adult shortnose sturgeon (*Acipenser brevirostrum)* in the Connecticut River, Massachusetts, were studied. Increasing day length (13.4−14.2 h), not increasing temperature (7.0–9.7°C) or river flow during 13 April–2 May likely triggered pre-and non-spawning adults to leave wintering areas and migrate. Pre-spawning adults homed each year to the same 1.4-kilometer-long spawning reach at Montague, Massachusetts, where river current likely determined where spawning occurred. Spawning occurred when three spawning suitability windows were simultaneously open: (1) day length = 13.9−14.9 h (27 April–22 May), (2) mean daily water temperature = 6.5–15.9 ° C and (3) mean daily river discharge = 121–901 m^3/s. Annual spawning periods were short (3–17 days), which may be typical when only a few females are present. Spawning periodicity was 1–5 years (mean 1.4 years) for males and 2−10 years (mean 4.5 years) for females. Peaking operations at Cabot Station did not prevent females from spawning in the tailrace, but likely displaced and stranded early life stages. Over the course of 14 years, spawning at Cabot Station succeeded 10 years and failed 4 years (28.6% failure); while spawning at Rock Dam succeeded 3 years and failed 11 years (78.6% failure). Spawning failures at Rock Dam were due to river regulation. Females spawned in a wide range of water velocities (0.2−1.3 m/s); however, the flow regimes created by river regulation and peaking operations exceeded even their broad adaptation for acceptable water velocities.

[IS THIS A DUPLICATE/OUDATED ENTRY FROM KIEFFER/KYNARD ABOVE? CONFIRM/DELETE]:
Kieffer, M.C. and B. Kynard. In Press. Pre-spawning and non-spawning spring migrations, spawning, and effects of river regulation and hydroelectric dam operation on spawning of Connecticut River shortnose sturgeon. Special Publication No. 4. World Sturgeon Conservation Society.

A 19-year study that identified important extrinsic factors triggering spawning migration (photoperiod and water temperature) and triggering spawning (photoperiod, temperature, and discharge). A failure of pre-spawning migration was identified that was related to foraging conditions the previous summer-fall. Spawning timing, spawning site and spawning habitat characteristics, and spawning homing were also identified. A spawning failure (and likely destruction of eggs and free embryos) was found that was related to river regulation. A spawning index was unable to be developed to compare spawning year to year.

The study identified spawning habitat by tracking females for substrate type (dominant = rubble; subdominant = gravel-pebble), bottom velocity measured 50 cm above bottom (30−130 cm/s; mean, 70 cm/s), and a highly variable water depth (1−5 m), most in 1.5−1.9 m. Water velocity and substrate type are important factors in female preference for habitat to place eggs during spawning; water depth is likely not important.

Kohlhorst, D.W. 1976. Sturgeon spawning in the Sacramento River in 1973, as determined by distribution of larvae. California Fish and Game. 62:32-40.

Sturgeon eggs and larvae were captured in the Sacramento River, above the mouth of the Feather River. Spawning occurred from mid-February to late-May. Water temperatures ranged from 7.8 to 17.8 ºC. Maximum spawning temperature was 14.4 ºC. No relationship between spawning and temperature was observed.

•There was no relationship between spawning intensity and flows.
•The majority of the spawning occurred form Knight's Landing upstream to just above Colusa.
•Below Colusa the substrate is comprised of mud and sand and water current "moderate"
•Above Colusa, gravelly or rocky substrates and "moderate to fast currents" are present.
•Sturgeon spawning likely occurs farther upstream than this study suggests.

Kynard, B. 1997. Life history, latitudinal patterns, and status of the shortnose sturgeon Acipenser brevirostrum. Environmental Biology of Fishes. 48: 319-334.

Historically, shortnose sturgeon inhabited most major rivers on the Atlantic coast of North America; today only 16 populations may remain. Declines are due to blockage of spawning runs, harvest, dredging, regulation of river flows, and pollution. Adult abundance is less than the minimum estimated viable population for 5 of 11 of the surveyed populations, and all natural southern populations. Spawning and foraging habitats and spawning migration strategy throughout the species range are discussed.

Kynard, B. and M. Horgan. 2002a. Attraction of pre-spawning male shortnose sturgeon, Acipenser brevirostrum, to the odor of pre-spawning females. Journal of Ichthyology. 42: 205–209.

A behavioral laboratory study used a 2-choice water tank and gave males a choice of water with female odor or water with no female odor. Some males exposed to certain females (likely those in a late-stage of maturation) made unique looping movements, indicating they detected the female's odor. This is the first data indicating chemo-communication between adults.

Kynard, B. and M. Horgan. 2002b. Ontogenetic Behavior and Migration of Atlantic Sturgeon, Acipenser oxyrinchus oxyrinchus, and Shortnose Sturgeon, A. brevirostrum, with Notes on Social Behavior. Environmental Biology of Fishes. 63: 137-150.

This was one of several comparative laboratory studies of sturgeon early life stages using common methods. Free embryos of both species are photonegative, and seek cover at a spawning site. Larvae are strongly photopositive, leave cover, and begin dispersal and foraging. Dispersal is about 5 days for shortnose and about 14 days for Atlantic sturgeon, suggesting that the rearing grounds are close to the spawning area for Connecticut R. shortnose sturgeon, but much farther for Hudson R. Atlantic sturgeon. Juvenile Atlantic sturgeon have a size-dominate feeding hierarchy in a laboratory environment where food is limited. This suggests sturgeons have a complex system of social behavior and interactions.

Kynard, B., E. Henyey, and M. Horgan. 2002a. Ontogenetic behavior, migration, and social behavior of pallid sturgeon, Scaphirhynchus albus, and shovelnose sturgeon, S. platorynchus, with notes on the adaptive significance of body color. Environmental Biology of Fishes. 63: 389-403.

One of the many comparative laboratory studies of sturgeon early life stages using common methods. Pallid and shovelnose sturgeon initiate dispersal upon hatching as free embryos and are photopositive, prefer white substrate, and swim high > 1 m above bottom. As fish develop into feeding larvae, fish retain photopositive behavior avoid cover and forage on the bottom. Fish develop a black tail during dispersal, suggesting this color is adaptive for avoiding predation or for communication with other free embryos.

Kynard, B., P. Zhuang, L. Zhang, T. Zhang and Z. Zhang. 2002b. Ontogenetic Behavior and Migration of Volga River Russian sturgeon, Acipenser gueldenstaedtii, with a Note on Adaptive Significance of Body Color. Environmental Biology of Fishes. 65: 411-421.

Laboratory experiments were conducted with Volga River Russian sturgeon, to develop a conceptual model of early behavior. Hatchling embryos initiated a downstream migration, suggesting predation risk of embryos at spawning sites is high. They also selected bright, white substrate and open habitat. Larvae did not migrate. The embryos behavior and appearance was similar to sturgeon species in North America.

Kynard, B. and E. Parker. 2004. Ontogenetic Behavior and Migration of Gulf of Mexico Sturgeon, Acipenser oxyrinchus desotoi, with Notes on Body Color and Development. Environmental Biology of Fishes. 70: 43-55.

One of several comparative laboratory studies of sturgeon early life stages using common methods. This sub-species of Atlantic sturgeon is similar to the Atlantic form for behavior of free embryos, they seek cover and do not disperse. As fish develop into larvae, they slowly disperse downstream and begin foraging. This slow dispersal continued all summer and fall, when fish developed into juveniles. This behavior suggests larvae and juveniles have no certain rearing area, rather that food is limited, so fish disperse slowly downstream and use the entire river for rearing. A similar movement pattern was observed in Kootenai sturgeon.

Kynard, B. and E. Parker. 2005. Ontogenetic behavior and dispersal of Sacramento River white sturgeon, Acipenser transmontanus, with a note on body color. Environmental Biology of Fishes. 74: 19-30.

One of several comparative laboratory studies of sturgeon early life stages using common methods. Free embryos initiated brief downstream dispersal and were photonegative. This contrasted to dispersal by free embryos of some other sturgeon species, which display long intense dispersal behavior. Free embryos were photopositive. Larvae also did not disperse, but aggregated and foraged on the open bottom. Early juveniles initiated a strong dispersal downstream. Intense black-tail color was present on foraging larvae but weak or absent during juvenile dispersal, suggesting the black tail is not adaptive for juvenile migrants, but is for free embryo and larval migrants.

Kynard, B. and E. Parker. 2006. Ontogenetic behavior and dispersal of the early life intervals of Kootenai River White Sturgeon: A laboratory study. Final Report. Idaho Department of Fish and Game. Boise, Idaho. 24 pp.

One of several comparative laboratory studies of sturgeon early life stages using common methods. Early life stages of Kootenai white sturgeon have distinct different behaviors: upon hatching, free embryos seek cover and are photonegative. When free embryos develop into larvae, they leave cover, are photopositive, avoid cover, begin to feed, and disperse downstream. Peak dispersal lasts about 2 weeks, but a slow dispersal continued all summer, even after larvae developed into juveniles. This suggests that wild free embryos are at the spawning site (where eggs were spawned), but larvae are far downstream from the spawning site, perhaps all the way to Kootenay Lake. The dispersal stage of Kootenai white sturgeon, larvae, have a black tail, like the early dispersal stages (free embryo or larvae) of other sturgeon species.

Kynard, B., E. Parker, and T. Parker. 2005. Behavior of early life intervals of Klamath River green sturgeon, Acipenser medirostris, with a note on body color. Environmental Biology of Fishes. 72: 85-97.

One of several comparative laboratory studies of sturgeon early life stages using common methods. Free embryos were poor swimmers and preferred cover. Larvae initiated a downstream nocturnal dispersal and had a dark colored body with black tail. Post migratory larvae and juveniles foraged with strong nocturnal activity peak. Juveniles moved downstream at night until temperatures dropped below 8'C. Wintering juveniles preferred deep pools with low light and some rock structure and were only active at night. The strong sensitivity to illumination may be unique to green sturgeon.

Kynard, B., E. Parker, D. Pugh, and T. Parker. 2007a. Use of laboratory studies to develop a dispersal model for Missouri River pallid sturgeon early life intervals. Journal of Applied Ichthyology. 23: 365 – 374.

Authors used observations on dispersal timing, swimming height, and movement rate in artificial streams and estimated bottom velocity in the river to estimate total dispersal distance. Dispersal distance estimated using a mean bottom velocity of 30 cm/s and fish swimming < 1 m above the bottom was about 300 km.

This laboratory study determined the effect of velocity on dispersal timing, intensity, and the holding ability of free embryos. It also estimated swimming height, and drift distance of dispersing free embryos. Current velocity mainly controlled dispersal rate and the study estimated that drift could carry free embryos 304 km. The swim-up-and drift behavior of free embryos likely serves to keep fish moving downstream and to escape from backwater areas when currents take them there.

Kynard, B., E. Parker, B.E. Kynard, and T. Parker. 2007b. Dispersal Characteristics, Drift Distance, and Wintering Behavior of Young Kootenai River White Sturgeon: A Laboratory Study. Final Report. Idaho Department of Fish and Game. Boise, ID. 35pp.

Kootenai white sturgeon (*Acipenser transmontanus*) free embryos observed in four artificial stream tanks with eddy and rock cover habitat and a channel flow with either a fast current regime (two tanks, mean, 23.4 cm/s) or a slow regime (two tanks, mean, 16.9 cm/s) did not have a behavioral dispersal. A few fish moved downstream during two weak peaks: early-free embryos seeking cover (and slow velocity) and late-free embryos likely affected by development. The strong dispersal by early-larvae was greatly affected by velocity regime.

Early-larvae in fast velocity initiated dispersal earlier, with greater intensity, and the dispersal lasted longer than in slow velocity (14 d vs. 11 d). A velocity trigger for dispersal response by early-larvae may exist: ≥ 16.9-cm/s velocity triggers the response by most larvae, but 7 cm/s does not. Downstream movement of late-larvae and early-juveniles was similar with small to moderate peaks in intensity in both velocity regimes and most fish used edge, not channel or eddy habitat.

A passive drift model, using conservative estimates for all factors, estimated the strong early-larval dispersal could move fish downstream ≥ 90 km to the lower river, even to Kootenay Lake. Foraging behavior and use of current in artificial streams by larvae and juveniles suggest rearing habitat is the lower river, not the lake.

Most of the river's length downstream from the spawning reach only provides dispersing larvae daytime foraging resources, and a passage route to the lower river. Because larvae can reach the lower river using only the dispersal by early-larvae, the weak–moderate downstream movement by older larvae and juveniles in artificial streams may reflect another function other than dispersal.

Both years -0 and 1 juveniles preferred dark habitat during wintering: dark substrate color and no illumination. However, juveniles differed for preference of substrate size: year -0 fish preferred small substrate and year -1 fish preferred large substrate. This difference suggests the two groups are spatially segregated during winter.

Kynard, B., E. Parker, and B.E. Kynard. 2008. Behavior and habitat of young Kootenai River white sturgeon. Final Report. Kootenai Tribe of Idaho. Bonners Ferry, ID. 24pp.

During tests to determine the effect of four combinations of small, medium, and large rocks on downstream movement and selection of rocks by free embryos (days 0−11 fish), fish selected small rocks (3−6 cm diameter pebble) significantly more than medium size rocks (7−12 cm diameter small rubble), or large rocks (13−20 cm diameter medium-large rubble). However, ≤ 10% of the free embryos were moving downstream in any of the four rock combinations, so any composition provided habitat for the 15 free embryos in tests. The data on selection of rock size suggested restored spawning-rearing habitat for eggs and free embryos should have between 30−50% small pebbles for free embryos. Larger rubble should suffice for spawning and egg attachment-rearing. Although the lowest number of fish passes by early larvae (days 12−16 fish) occurred when the highest percent of large rubble (60%) was present, rock size did not have a significant effect on downstream movement. Also, most early larvae using rocks continued to use small rocks, like free embryos. With increasing larval age, an increasing percent moved downstream and selected open habitat.

Location and behavior of days 17−40 larvae moving downstream one-half loop around stream tanks with 60% small vs. 60% large rocks follow: (1) in all tanks, most fish were at the water surface (30 cm above the bottom) or in the water column, and (2) most were in the fastest flow near the outside wall. Mean movement speed (ground speed) of larvae in the 17 cm/s (mean water velocity) was 14.4 cm/s (range: 1.85−31.9 cm/s). Thus, fish were moving at about 84% of the mean water speed. There was a significant trend for fish speed to be slower over small substrate (P = 0.03), an unexpected result. Modeling the dispersal of wild foraging larvae that encounter and respond to diverse physical factors (velocities and bottom substrates) and biological factors (in particular, forage habitat and prey abundance) will be difficult because of the lack of data on behavior of larvae in the river.

Winter underwater video surveys in the meandering reach of the Kootenai River found sand was the dominant substrate and small woody debris was the dominant cover. In the river delta, mud was the dominate substrate in shallow water (0.9−1.8 m deep) and sand dominated the deep water samples (15.2−27.4 m deep). Small woody debris and logs were the dominant cover types in the lower river sites; sparse vegetation and detritus were the dominant cover types in the delta. Previous studies found wintering year-0 juveniles preferred sand not rock substrate, and sand is abundant in both the lower river and delta.

Summer underwater video surveys in the meandering reach found sand dunes, clay terraces, and mud were the dominant substrate types; whereas in the littoral zone of the lake, mud dominated shallow water sites (0.9−1.8 m deep) and sand dominated all other sample sites in mid-depth (7.6−15.1 m deep) or deep water (15.2−27.4 m deep). In the river, sparse vegetation, detritus, small rocks, and clay bits were the dominant cover types, whereas in the littoral zone of the lake, cover was mainly detritus or sparse vegetation at all depths.

Observations on wintering Kootenai YOY found they were active at 4−5 ºC, the river temperature in the meandering reach, where YOY are likely located. If correct, then the alteration of natural winter river temperature by releasing reservoir waters impounded by Libby Dam may cause an energetic bottleneck for winter survival of YOY.

Kynard, B., E. Parker, and B.E. Kynard. 2010. Ontogenetic behavior of Kootenai River White Sturgeon, Acipenser transmontanus, with a note on body color: A laboratory study. Environmental Biology of Fishes. 88: 65-77.

One of several comparative laboratory studies of sturgeon early life stages using common methods, this paper publishes the information from the 2006 report by the same authors. Free embryos are photonegative and hide under cover and have a grey body. Late-embryos are photopositive and somewhat prefer white substrate, use cover less with age and develop a black tail. Larvae forage in the day, use cover less, prefer bright habitat and have a light-grey body and black tail. And initiate a mostly nocturnal dispersal. As they age the entire body and tail is a dark-grey color. The study suggests wild larval Kootenai sturgeon have a long slow dispersal style and that larvae could easily move to the lower river or Kootenay Lake. Major geographic behavioral variation exists among early life stages of several white sturgeon populations (Sacramento, Columbia, and Kootenai rivers) and this adaptation should be considered in restoration programs.

Kynard, B., D. Pugh, T. Parker, and M. Kieffer. 2011. Review of Using a Semi-natural Stream to Produce Young Sturgeons for Conservation Stocking: Maintaining natural selection during spawning and rearing. March 28, 2011. Volume 27, Issue 2, p. 420-424, April 2011. Special Issue: Proceedings of 7th Conference on Sturgeons, Wuhan, China, October 25-31, 2009.

Young sturgeons used for restoration stocking are presently produced using the same methods used for commercial culture. However, most biologists would agree that commercial culture techniques relax natural selection on many factors that are critical to a successful life history of a wild sturgeon. To determine if young sturgeons could be produced without relaxing natural selection factors, we developed a semi-natural stream where we annually studied mating of wild shortnose sturgeon, *Acipenser brevirostrum*, observed gametes released freely in the water, and also, estimated the number of spawned eggs and the number of larvae produced. Some females and males were more successful during spawning than others, suggesting an unequal fitness during spawning among wild individuals, which is different than fitness of individuals in hatcheries. Male and female gametes must connect quickly in the fast current or fail, a factor that does not exist in hatcheries. The maximum number of dispersing larvae produced was 8,000–16,000 (about 425–851 larvae/m_2 of bottom area). These larvae should be superior for conservation stocking than cultured larvae.

Kynard, B., D., M. Kieffer, M. Burlingame, P. Vinogradov, and B.E. Kynard. YEAR? Demography, movements, spawning habitat, and spawning success of adult Connecticut River shortnose sturgeon at Holyoke Dam. Special Publication No. 4, World Sturgeon Conservation Society.

A multi-year study of PIT-tagged and radio-tagged juveniles and adults to determine the seasonal timing of migrations by life stages, sex, and reproductive stages of fish that migrate up to Holyoke Dam. There were multiple migrations, one in the spring which contained pre-spawning males and a few females and juveniles, and then, multiple migrations during summer-fall that contained mostly females (pre-spawning and non-spawning) and juveniles. Summer migrations were to move fish to the foraging-wintering and spawning area upstream of the dam. Strategy of most pre-spawning females was to move to the upstream foraging-wintering area in the summer-fall prior to spawning, and then, migrate only 12 km to spawn in the spring. Males and a few females coming from the lower river in spring, after 5 months of wintering where they lose weight, had to migrate at least 100 km and many had to pass two major rapids (5+ km long); thus, the strategy of pre-spawning females seems an energetic strategy. An increase in river discharge triggered the summer-fall migrations.

Kynard, B., D. Pugh, M. Kieffer, and T. Parker. In Press. Spawning of shortnose sturgeon in an artificial stream: Adult behavior and early life history. Special Publication No. 4, World Sturgeon Conservation Society.

Individual adults were observed in an endless artificial stream for courtship, spawning behavior, habitat selection, and then the early life stages were observed for dispersal and production of migrant larvae. Individuals differed greatly for spawning success: some females did not spawn, some males did not spawn (and some males spawned but there was great variability among males for spawning bouts). The spawning behavior sequence of shortnose sturgeon is described.

It was found that photoperiod, not water temperature, controls spawning readiness of females. Females placed small batches of eggs at discrete sites (3–4 spawning bouts/h) and many had a spatial bias to repeatedly spawn at the same location. Females spawned mostly in moderate−fast velocities over a uniform rocky substrate, suggesting bottom velocity is more important for a specific spawning location than substrate. Egg drift ceased a few days after spawning, but a few free embryos drifted daily, mostly at night. Larvae initiated a nocturnal dispersal lasting 6–9 d (3 d peak) that moved them from the stream.

Density of females (and number of eggs spawned) greatly affected annual production of larvae (156−16,002), with increasing density having a significant negative effect on production. The greatest survival from egg to larva (31.98%) resulted from an estimated density of 1,938 eggs/m2.The maximum number of larvae produced was 8,000–16,000 (about 425–851 larvae/m^2 of bottom area). Maximum survival of spawned eggs to dispersing larvae was obtained at an egg density of about 5,000 eggs/m^2.

Kynard, B., P. Zhuang, T. Zhang, and L. Zhang. 2003. Ontogenetic behavior and migration of Dabry's sturgeon, Acipenser dabryanus, from the Yangtze River, with notes on body color and development rate. Environmental Biology of Fishes. 66: 27-36, 2003.

Fish were observed daily from day 0 to day 30 for preference of bright habitat and cover, swimming distance above the bottom, up and down-stream movement, and diel activity. In other previously studied sturgeon species representing three genera on three continents, Dabry's sturgeon is the first that does not disperse as an embryo or larva.

Loew, E.R., Sillman, A.J. 1993. Age-related changes in the visual pigments of the white sturgeons (Acipenser transmontanus). Canadian Journal of Zoology. 71:1552−1557.

This study found an ontogenetic change in development of rods and cones, and correspondingly, the ability of fish to see infrared light. White sturgeon larvae cannot see infrared light, but juveniles can detect it at about 10 months of age.

Neufeld, M. and P. Rust. 2010. Movement and Habitat Use of Kootenay White Sturgeon in BC and Idaho – 2005-2008. Bonneville Power Administration, Northwest Power and Conservation Council's Fish and Wildlife Program, Idaho Department of Fish and Game, and the Kootenai Tribe of Idaho.

Telemetry data collected between 3/2005 – 2/2008 of up to 70 adult sturgeon was analyzed. Total length ranged from 121 – 308 cm. Weights ringed from 14 – 95 kg. Total area of habitat used by individuals ranged from 53 to 232 km. The most significant use was the area around the Creston Delta in all months. In the spring movement was observed into the staging and spawning reach (RKM 170 – 250). The opposite trend was observed in the summer months.

Paragamian, V.L. and R.C.P. Beamesderfer. 2003. Growth estimates from tagged white sturgeon suggest that ages from fin rays underestimate true age in the Kootenai River, USA and Canada. Transactions of the American Fisheries Society. 132:895-903.

Growth estimates from tagged white sturgeon in the Kootenai River indicated that age estimates from fin rays were underestimates of the true ages. Ages estimated from fin rays were 30–60% less than the apparent ages from tagging data. Thus, actual ages may be 1.5–2.0 times the ages estimated from fin rays. Apparent aging bias will result in substantial changes in population parameters estimated from age, including growth, mortality, longevity, and year-class strength, which will have significant implications for efforts to preserve this endangered species and enable it to recover.

Paragamian, V.L. and J.P. Duehr. 2005. Variations in vertical location of Kootenai River White Sturgeon during the pre-spawn and spawning periods. Transactions of the American Fisheries Society. 134(1): 261.

This study aims to determine the general water column habitat use of Kootenai River white sturgeon (*Acipenser transmontanus)* during the prespawn and spawning periods using depth-sensitive radio transmitters that were attached to five male and four female white sturgeon. Of 209 contacts, 75% (156) were made within the bottom one-third of the water column. Mean depth of the fish during the daytime prespawn and daytime spawning period was different (9.7 and 6.5 m, respectively), and the distribution between these two periods was significantly different. Some of the variation was likely due to the deeper habitat of the daytime prespawn staging reach compared with that of the daytime spawning period location (12.6 and 7.7 m, respectively). White sturgeon used a variety of locations throughout the water column, were closer to the river bottom during the spawning period, and were much more mobile during the spawning period than previously believed.

Seventy-five of the total telemetry contacts were made when adults were in the bottom one-third of the water column. Adults were closer to the bottom during spawning periods. The technique was not useful for identifying when or where fish spawned.

Paragamian, V.L. and G. Kruse. 1996. Kootenai River white sturgeon Acipenser transmontanus spawning characteristics and habitat selection post Libby Dam. Pp. 41−49. In: Culture and Management of Sturgeon and Paddlefish Symposium Proceedings. S.I Doroshov, F. Binkowski, T. Thuemler, D. Mackinlay, Eds. International Congress on the Biology of Fishes. San Francisco State University.

Data on temperature and flow during spawning, 1991−1995, of Kootenai River white sturgeon. Also, HSI curves for river temperature during spawning, average water velocity when eggs were captured, and water depth where eggs were captured on bottom mats. Most spawning occurred from the last week in May to mid-June; eggs were captured from 10-80 cm/s velocity, but most at 15−25 cm/s; and eggs were captured at 4−13 m depth, most at 8−12 m.

Paragamian, V.L., and G. Kruse. 2001. Kootenai River white sturgeon spawning migration behavior and a predictive model. North American Journal of Fisheries Management. 21(1): 10-21.

Autumn and spring, adult white sturgeon migrate from the lower Kootenai R and Kootenay Lake, BC to prespawn staging reaches in Idaho and in spring, and migrate further to a spawning reach near Bonners Ferry, Idaho. Monitored 49 mature sturgeon with radio and sonic telemetry from 1991 – 1997. They responded to mitigated flows and rising water temperatures. Changes in river stage and temperature were the best predictors of the probability that females would migrate to the spawning reach. A model was developed to predict spawning migration during various flows and temperatures. 93% correct in predicting movement.

Paragamian, V.L., G. Kruse, and V. Wakkinen. 1997. Kootenai River fisheries white sturgeon spawning and recruitment evaluation. Annual Report 1996. Idaho Department of Fish and Game and Bonneville Power Administration. Portland, Oregon.

This study measures the responses of KRWS to test flows that began in July 1996 and heavy flows created by unusually heavy precipitation. These flows created conditions for sturgeon spawning similar to those occurring before the construction of Libby Dam. Spawning activity and eggs were collected. At least 18 spawning events occurred, between June 6 – 25. Mark and recapture data was used to estimate adult and juvenile populations, where 1,469 adults and 87 wild juveniles were estimated. The study concludes that a test flow for 1997 is recommended that is similar in magnitude to that of 1996.

Paragamian, V.L., V.D. Wakkinen, and G. Kruse. 2002. Spawning locations and movement of Kootenai River white sturgeon. Journal of Applied Ichthyology. 18(9): 608-616.

The objective of this study was to compare, within each spawning season and between seasons, the spatial and temporal pattern of egg collections (an indicator of spawning location) and the spatial and temporal pattern of suspected spawners, as determined by their movement from 1994 to 1999. Within a year, spawning occurs at downstream locations, then moves upstream. The first recorded spawning each year ranged from May 6 to June 8. The latest date eggs were collected ranged from June 12 to June 28. There appears to be at least five primary spawning areas, located in the vicinity of outside meander bends:

- Lower Shorty's Island – rkm 228.7-229.5
- Middle Shorty's Island – rkm 230.0-231.0
- Kootenai National Wildlife Refuge – rkm 235.2-235.9
- Kootenai National Wildlife Refuge – rkm 236.1-236.9
- Deep Creek – 238.9-239.9

Statistical analysis of velocities at different egg collection locations in the Kootenai River indicated no difference in velocities between locations and years.

It was proposed that the influence of the backwater effect on sturgeon spawning site selection by hydraulic conditions and therefore the operations of the river has altered the location of the hydraulic conditions that sturgeon select to spawn in, thus putting the fish over sand substrates rather than cobbles and gravels.

Paragamian, V.L., V. Wakkinen, V. Whitman, and J. Duehr. 2003. Kootenai River white sturgeon spawning and recruitment evaluation. Idaho Department of Fish and Game. Annual Progress Report, Project 03-09. Boise, Idaho.

This paper reports on continued monitoring of sturgeon spawning in the Kootenai River. Flows were estimated at 65% of normal. A total of 139 white sturgeon eggs were collected. Eggs were collected in three of the 14 geographic sections sampled. The most eggs were collected in the Middle Shorty's Island reach (rkm 229.6 – 231.5), followed by the U.S. Highway 95 section (rkm 244.7-246.6), and the Kootenai National Wildlife section (rkm 234.8 – 237.5). Ten spawning events were recorded from May 25 to June 23, 2001. The Kootenai Tribe of Idaho released 135,000 white sturgeon larvae from hatchery; 97 were captured. Attempts to capture wild white sturgeon larvae were unsuccessful. A group of adult sturgeon were observed in the in the reach near the Union Pacific Railroad bridge (rkm 245.5 and 245.7). Fish were observed in water as shallow as 0.6 meters deep.

Paragamian, V.L., R. MacDonald, G.J. Nelson, and G. Barton. 2009. Kootenai River velocities, depth, and white sturgeon spawning site selection - a mystery unraveled? Journal of Applied Ichthyology. 25: 640−646.

Recent coring of the bottom in the present spawning sites of adults found cobble was present, but covered with about 1 m of sediment. This suggests adults return to the same reach of river to spawn, then spawn over sand, but there should be cobble present. If true, this suggests that the spawning reach of females is hard-wired, and that fish cannot alter their choice of spawning reach if the substrate in the reach changes. Sedimentation appears to have occurred due to the construction of Libby Dam upstream of the spawning site and the resulting reduction in river flow.

Paragamian, V.L. and P. Rust, G.J. Barton, R. Weakland. In Press. Habitat selection by female white sturgeon within an aquatic landscape during the spawning season.

The hydraulic and bathymetric habitat selection of two KRWS were studied during two different spawning seasons in 2002 and 2003. Both years the females were not randomly distributed in the water column and spend a significant amount of time swimming near the river bottom (lower 20% of the water column 6-9m). While migrating through the reach they followed the horizontal and vertical form of the river thalweg. They avoided inside bends of shallow water and stayed close to the deeper outside bends. They stayed within the spawning reach 10 to 27 days and selected previously identified spawning locations. Spawning gravel and cobble substrates are recommended for habitat enhancement.

Pavlov, D.S., A.M. Pakhorukov, G.N. Kuragina, V.K. Nezdeliy, N.P. Nekrasova, D.A. Brodshly, and A.L. Ersler. 1978. Some features of the downstream migrations of juvenile fishes in the Volga and Kuban rivers. Journal of Ichthyology. 18:363-374.

This paper reviews the downstream dispersal patterns of early life stages of several sturgeon species. It includes patterns of seasonal and diel movement and also, data on vertical distribution during dispersal of several species. No useful information on substrate or water velocity is included.

R.L. & L. Environmental Services Ltd. 1999. Movements of White Sturgeon in Kootenay Lake 1994-1997. Report prepared by B.C. Ministry of Environment, Lands, and Parks, Nelson, B.C. R.L. & L. Report No. 613F: 22 p. + 4 app.

The objective of this study was to summarize movements of white sturgeon within, into, and out of Kootenai Lake between 1994 and 1997. Movement patterns of Kootenai white sturgeon were compared to those for white sturgeon in other systems, especially those within British Columbia. Reasons for observed differences were discussed and recommendations are made for future studies.

Ruban, G.I. 2005. The Siberian sturgeon Acipenser baerii Brant: Species structure and Ecology. Special Publication No. 1. World Sturgeon Conservation Society.

This paper is a review of Siberian Sturgeon *(A. baerii)* in Russia. Of particular interest is the section on sturgeons spawning in rivers draining into Lake Baikal (a lake similar to Kootenay Lake). The juvenile sturgeons rear in the lower river and lake margins, but nothing is known about early life stage dispersal strategy of any species.

Stevens, D.E. and L.W. Miller. 1970. Distribution of sturgeon larvae in the Sacramento-San Joaquin River system. California Fish and Game. 2: 80-86.

In the late 1960s, larval white sturgeon were collected in the Sacramento-San Joaquin river system. Larvae were caught in the Sacramento River between Collinsville and Rio Vista, in Suisin Bay, and in the San Joaquin River.

- Only one larval sturgeon was captured in the Delta.
- One larvae was captured upstream of the confluence of the Sacramento River and the Feather Rivers – indicates spawning upstream.
- Catch data were related to flow into the Delta – increased catches with increased flow.

•Suggested that spawning occurs upstream in gravely reaches.

Webber, J.D., S.N. Chun, T.R. MacColl, L.T. Mirise, A. Kawabata, E.K. Anderson, T.S. Cheong, L. Kavvas, M.M. Rotondo, K.L. Hochgraf, R. Churchwell, J.J. Cech, Jr. 2007. Upstream swimming performance of adult white sturgeon: Effects of partial baffles and a ramp. Transactions of the American Fisheries Society. 136: 402-408.

Wild adult white sturgeon *Acipenser transmontanus* captured in the San Francisco Estuary and Yolo Bypass toe drain were swum in a variable-speed aluminum flume (24.4 m long 32.1 m wide 31.4 m deep) to evaluate swimming behavior around simulated fish-ladder-type partial baffles. The tail-beat frequency of fish significantly increased in the high velocity (to 2.52 m/s) regions of the flume adjacent to the energy-dissipating baffles, where sturgeon were able to pass by swimming in bursts, followed by a resting and recovery period in slower water. Successful white sturgeon passage structures should incorporate rapid-velocity (e.g., 0.84–2.52-m/s) sections between somewhat slower (e.g., 0.51–0.68-m/s) sections for rest and recovery.

Wei, Q., B. Kynard, D.G. Yang, X.H. Chen, H. Du, L. Shen, and H. Zhang. 2009. Using drift nets to capture early life stages and monitor spawning of the Yangtze River Chinese sturgeon (Acipenser sinensis). Journal of Applied Ichthyology. 25: 100-106.

Methods for setting and capturing drifting sturgeon early life stages in a large river using bottom-set D-nets are described for Chinese sturgeon in the Yangtze River. Eggs were mostly captured (about 97,000); 2,400 free embryos were captured; and zero larvae were captured. This supported dispersal research in the lab that found dispersal from the spawning site was by free embryos, not larvae. Timing and numbers of eggs captured identified two annual spawning periods, using in late October and early November. The percent of fertilized eggs declined after 3-Gorges Dam caused a decrease in the river temperature, suggesting an important effect of damming on sturgeon reproduction.

Yang, D., B. Kynard, Q. Wei, X. Chen, W. Zheng, H. Du. 2006. Distribution and movement of Chinese sturgeon , Acipenser sinensis, on the spawning ground located below the Gezhouba Dam during spawning seasons. Journal of Applied Ichthyology. 22 (1): 145-151.

Sonic tracking of adult pre-spawning Chinese sturgeons (*Acipenser sinensis*) show, most of the time, fish were within 7 km of the dam. The movements indicate fish continue to attempt to move farther upstream to pass the dam. The fish were found in areas of major water spills or strong flow. Tracking (and accompanying capture of eggs) identified the main spawning sites, and enabled characterization of spawning habitat (bottom type and bottom velocity). Spawning adults were tracked and spawning habitat characterized as follows: substrate (dominant = rubble and boulders), bottom velocity (50 cm above bottom = about 1 m/s), water depth = ≥16 m.

Zhuang, P., B. Kynard, L. Zhang, T. Zhang, and W. Cao. 2002. Ontogenetic Behavior and Migration of Chinese Sturgeon, Acipenser sinensis. Environmental Biology of Fishes. 65: 83-97, 2002.

Using laboratory experiments, the behavioral preference of young Chinese sturgeon to physical habitat (water depth, illumination intensity, substrate color, and cover) was examined and their downstream migration was monitored. Hatchling free embryos were photopositive, preferred open habitat, and immediately upon hatching, swam far above the bottom using swim-up and drift. Downstream migration peaked on days 0–1, decreased about 50% or more during days 2–7, and ceased by day 8. Days 0–1 migrants were active both day and night, but days 2–7 migrants were most active during the day. After ceasing migration, days 8–11 embryos were photonegative, preferred dark substrate and sought cover. Free embryos developed into larvae and began feeding on day 12, when another shift in behavior occurred–larvae returned to photopositive behavior and preferred white substrate. The selective factor favoring migration of free embryos upon hatching and swimming far above the bottom may be avoidance of benthic predatory fishes.

D-2. STURGEON POPULATIONS AND MANAGEMENT

Anders, P.J., D.L. Richards, and M.S. Powell. 2002. The First Endangered White Sturgeon Population (Acipenser transmontanus): Repercussions in an Altered Large River-floodplain Ecosystem. Pages 67-82 In: W. Van Winkle, P. Anders, D. Dixon, and D. Secor, Eds. Biology, Management and Protection of North American Sturgeons. American Fisheries Society Symposium 28.

The Kootenai River ecosystem in Idaho, Montana and British Columbia, Canada has been altered and degraded during the past 75 years. Reverberating trophic responses to cultural denutrification were temporally correlated with the collapse of the functional Kootenai River ecosystem and its native white sturgeon (*Acipenser transmontanus*) population. Depressed biological productivity, alteration of spawning and rearing habitats, fish species abundance changes, altered predator-prey dynamics, and consistent white sturgeon recruitment failure constituted biological (ecological) responses to Kootenai River Basin development. We propose an integrated hypothesis that during some years natural recruitment failure may have been caused by female stock limitation, in other years (those lacking female stock-limitation), we propose that recruitment failure was due to one or more post-spawning early life mortality factors.

Anders, P., S. Ireland, and the Kootenai River White Sturgeon Recovery Team. 2007. Kootenai River White Sturgeon Recovery Implementation Plan and Schedule; 2005 - 2010. 2004-2005 Technical Report. Project No. 200200200. (BPA Report DOE/BP-00019398-1).

This Plan and Schedule delineate research, monitoring and evaluation actions believed necessary to protect, rehabilitate, and maintain Kootenai River white sturgeon in conjunction with activities highlighted in the population's Recovery Plan (USFWS 1999). This Plan is intended to be adaptive in nature, and therefore is subject to future modification as directed. This approach involves simultaneous implementation of multiple remedial actions to achieve the desired outcome in the shortest amount of time possible. This 5-Year Plan has four main components corresponding to the four primary strategies in the 1999 Recovery Plan: 1) Recruitment restoration, 2) Conservation aquaculture, 3) Monitoring and evaluation, and 4) Recovery Plan adaptation and revision.

Apperson, K.A. and P.J. Anders. 1991. Kootenai River white sturgeon investigations and experimental culture. Annual Progress Report FY90. Idaho Department of Fish and Game. Prepared for the U.S. Department of Energy, Bonneville Power Administration. Project No. 8865. Portland, OR.

Setline and angling techniques were used to sample sturgeon from the Kootenai River between Kootenai Falls and Kootenay Lake during 1989 – 1990. Data indicate there is a complete lack of recruitment of juveniles into the population. The youngest fish sampled was the 1977 year class and the population was estimated at 880 individuals. Culture of one pair of sturgeon was of limited success. Contaminants were found in the eggs. Ongoing sonic telemetry study revealed long distance movements. No relationship was found between sturgeon movement and water temperature, flow, and flow change.

Bemis, W.E. and Kynard, B. 1997. Sturgeon rivers: an introduction to acipenseriform biogeography and life history. Environmental Biology of Fishes. 48: 167-183.

An overview of the global distribution of all 27 species of *Acipenseriform* in order to understand their biogeographic history, and life history patterns. They originated in Europe with early diversification in Asia. Common life history is rare. Variation within and between species is the rule. Anadromy, amphidromy, and potadromy is represented in sturgeons. Various spawning migration strategies are discussed. Rivers where spawning occurs should be studied to identify life histories.

Duke, S., P. Anders, G. Ennis, R. Hallock, J. Hammond, S. Ireland, J. Laufle, L. Lockard, B. Marotz, V. Paragamian, and R. Westerhof. 1999. Recovery plan for Kootenai River white sturgeon (Acipenser transmontanus). Journal of Applied Ichthyology. (15):157-163.

This paper provides a review of the KRWS draft recovery plan that was prepared by USFWS and other agencies in the United States and Canada. The short-term recover objectives of the recovery plan are to prevent extinction and re-establish successful natural recruitment. The long-term objectives are the re-establishment of a self sustaining population and the restoration of productive habitat, in order to downlist to threatened status, and subsequently delist this population when recovery is well established.

Specific actions needed for recovery include spring flow augmentation during the reproduction period; a conservation aquaculture program to prevent near-term extinction; habitat restoration, and research and monitoring programs to evaluate recovery progress.

Heise, R.J., W.T. Slack, and S.T. Ross. 2004. Spawning and Associated Movement Patterns of Gulf Sturgeon in the Pascagoula River Drainage, Mississippi. Transactions of the American Fisheries Society. 133(1): 221-230.

Objectives of this study are to identify and characterize spawning areas, determine spring movement patterns, and document homing fidelity by gill netting and radio-tracking. Through collection and rearing of Gulf sturgeon eggs, we verified that the Bouie River north of Hattiesburg, Mississippi (250 river kilometers upstream from the mouth of the Pascagoula River), is a spawning area. We also documented homing fidelity in the Bouie River using radiotelemetry and capture data. Spawning habitat was located in an upstream reach that consisted of hard substrata and gravel with turbulent, high flow.

Hurley, K.L., R.J. Sheehan, and R.C. Heidinger. 2004. Habitat Use by Middle Mississippi River Pallid Sturgeon. Transactions of the American Fisheries Society. 133(4): 1033-1041.

To learn more about habitat use and selection by pallid sturgeon, sonic transmitters were surgically implanted in 27 individuals from the middle Mississippi River. Of the seven macrohabitats identified, pallid sturgeon were found most often in main-channel habitats (39% of all relocations) and main-channel border habitats (26%); the between-wing-dam habitats were used less often (14%). Habitat use patterns also were similar across seasons and discharge regimes, except during spring months when between-wing-dam habitats saw greater use and main-channel and main-channel border habitat use declined. These changes may have been a response to high river stages associated with spring flooding, which may create favorable feeding areas in the between-wing-dam habitats. Enhancement and restoration of habitat diversity, particularly downstream island tip and between-wing-dam habitats, may be necessary for the recovery of pallid sturgeon in the middle Mississippi River.

Holtgren, M.J., S.A. Ogren, and A.J. Paquet. 2007. Design of a Portable Streamside Rearing Facility for Lake Sturgeon. North American Journal of Aquaculture. 69(4): 317-323.

A portable streamside rearing facility was designed and used to rehabilitate a remnant population of lake sturgeon (*Acipenser fulvescens)* in the Big Manistee River, Michigan, beginning in 2004. The streamside rearing facility facilitates rearing of wild-caught lake sturgeon larvae in their natal water. This rearing approach provides a cost-effective technique for small batch rearing, incorporates aspects of genetic conservation, and addresses concerns about imprinting and spawning site fidelity. This rearing method may be an important management tool for restoring remnant lake sturgeon populations. Successful rearing of lake sturgeon during the first 3 years of operation indicates that this portable design may be adapted and modified for other locations and fish species.

International Joint Commission. 1938. Order of Approval- Amended Appeal for Permission to Raise the Waters of Kootenai Lake. 15 pp.

The appeal is a request from the West Kootenay Power and Light Company to construct and operate certain works near and related to Corra Linn Dam, in and adjacent to the channel of the Kootenay River in British Columbia, and for the right to store water in Kootenay Lake. The appeal was granted and the construction and authorization of the works was approved pending specific storage and water surface elevation constraints outlined in the document.

Ireland, S.C., P.J. Anders, and J.T. Siple. 2002a. Conservation Aquaculture: An Adaptive Approach to Prevent Extinction of an Endangered White Sturgeon Population. American Fisheries Society Symposium 28:211-212.

The white sturgeon population in the Kootenai River was listed as endangered by the U.S. Fish and Wildlife Service in 1994 due to postglacial isolation and the virtual lack of recruitment since 1974. The Kootenai River White Sturgeon Conservation Aquaculture Program was initiated to preserve genetic variability, begin rebuilding natural age-class structure, and prevent extinction while measures are identified and implemented to restore natural recruitment. A breeding program has been implemented to guide recover, population management, and the systematic collection and spawning of wild adults before they are lost from the wild breeding population. Between 1990 and 2000, 33 families were produced from the mating of 51 wild white sturgeon broodstock. A total of 2,702 hatchery-reared white sturgeon were released into the Kootenai River between 1992 and 1999. The Kootenai River Conservation Aquaculture Program is currently meeting its objectives of reducing the threat of population extinction by providing frequent year classes from native broodstock, representing inherent within-population genetic diversity in its broodstock and progeny, and minimizing the introduction of disease into the recipient wild population.

Ireland, S.C., R.C.P. Beamesderfer, V.L. Paragamian, V.D. Wakkinen, and J.T. Siple. 2002b. Success of hatchery-reared juvenile white sturgeon (Acipenser transmontanus) following release in the Kootenai River, Idaho, USA. Journal of Applied Ichthyology. 18: 642-650.

In 1990, a conservation program began to evaluate the feasibility of using aquaculture to aid recovery of the white sturgeon population in the Kootenai River. Mature wild fish were captured and spawned. 2630 age 1-4 juvenile white sturgeon were released from 1992 to 1999. Subsequent catches of 39 wild and 620 hatchery juveniles in an annual monitoring program confirm that wild recruitment of KRWS is very low. Recapture data indicate hatchery-reared juveniles survival rates may be as high as 60% in the first year following release, and 90% thereafter. Growth rates were slightly lower than in other systems; 77% of optimum.

Growth rates were often poor the first year as hatchery fish adapted to natural conditions but then increased after the initial adjustment period. Relative weight decreased between release and recapture, which was inversely correlated with growth in length.

Justice, C., B.J. Pyper, R.C.P. Beamesderfer, V.L. Paragamian, P.J. Rust, M.D. Neufeld, and S.C. Ireland. 2009. Evidence of density- and size-dependent mortality in hatchery-reared juvenile white sturgeon (Acipenser transmontanus) in the Kootenai River. Canadian Journal of Fisheries & Aquatic Science. 66: 802−815.

Authors analyzed survival of marked groups (yearlings vs. 2 year old) to recapture as older juveniles using mark-recapture of fish stocked from 1992-2006. First year survival rates declined recently, particularly for fish <25 cm (fork-length) at stocking and 59% of variation in survival was explained by the estimated juvenile abundance. Length at release explained a large amount of within year variation in

survival. Results suggest releasing fewer larger (older) fish will contribute more to later recruitment than releasing many smaller (younger) fish.

Kootenai Tribe of Idaho (KTOI). 2007. Kootenai River White Sturgeon Conservation Aquaculture Program, 1990-2007 (2nd Edition). Bonners Ferry, Idaho. Report edited by R. Beamesderfer and P. Anders, Cramer Fish Sciences.

This report provides an overview of the first 17 years of the Kootenai River white sturgeon Conservation Aquaculture Program. The hatchery program was initiated as a stopgap measure in 1990 to produce fish from wild Kootenai River adults until effective habitat restoration measures could be identified and implemented. Continued failure of natural recruitment means that the next generation of Kootenai white sturgeon will come almost entirely from the hatchery. The existing program has evolved into a functional and effective recovery tool. Program objectives include reducing the threat of extinction by annually providing year classes from native broodstock, preserving genetic diversity, and minimizing other risks potentially associated with hatchery production.

Kootenai Tribe of Idaho (KTOI). 2009. Kootenai River Habitat Restoration Project Master Plan: A Conceptual Feasibility Analysis and Design Framework. Bonners Ferry, ID.

An ecosystem-based habitat restoration program was designed to address limiting factors associated with physical habitat morphology, riparian vegetation, aquatic habitat, and river stewardship. To be implemented in three phases, each including targeted feasibility analyses, development of preliminary designs, completion of environmental compliance activities, development of final designs and project implementation. Three reaches are targeted including the braided reach, the straight reach, the meander reaches. Restoration treatment strategies include: managing flows from Libby Dam and backwater from Kootenay Lake, manage land use practices, modify channel geometry, connect floodplain, enhance wetlands, construct off-channel habitat, revegetate floodplain, bank protection, instream habitat enhancement.

Kootenai Tribe of Idaho (KTOI). 2010. Kootenai River Native Fish Conservation and Aquaculture Master Plan. Bonners Ferry, Idaho. 297 pp.

The goals of the Kootenai sturgeon aquaculture program are to 1) prevent extinction of KRWS by preserving the locally adapted genotypes, phenotypes, and associated life history traits of the population; 2) restore a healthy age class structure to enhance demographic and genetic viability and persistence of the population; and 3) reestablish a sturgeon population capable of future Tribal Treaty subsistence and cultural harvest.

The Kootenai sturgeon aquaculture programs proposed in this Master Plan would:
•Upgrade the KRWS production facilities at the existing Tribal Sturgeon Hatchery near Bonners Ferry.
•Develop a new artificial production facility for KRWS and burbot at the confluence of the Moyie and Kootenai rivers (Twin River Hatchery).
•Establish two remote streamside incubation and early rearing facilities to imprint KRWS at upstream locations where more favorable spawning, incubation and early rearing habitats appear to currently exist.
•Collect native KRWS broodstock from the Kootenai River.
•Spawn, incubate, and rear KRWS and burbot.
•Refine aquaculture apparatus and techniques for KRWS and burbot.
•Release KRWS and burbot at appropriate developmental stages to suitable habitat in the Kootenai R.
•Support operation and monitoring at both facilities.

Until suitable habitat conditions have been restored, the Tribe's ongoing and proposed aquaculture programs will remain essential tools to preserve and manage remnant KRWS and burbot populations.

Kootenai Tribe of Idaho (KTOI) and Montana Fish, Wildlife & Parks (MFWP). 2004. Kootenai Subbasin Plan. Part I: Kootenai River Subbasin Assessment. Prepared for the Northwest Power and Conservation Council. Portland, OR.

The Kootenai Tribe and Montana Fish Wildlife and Parks prepared a subbasin plan in 2004 concurrent with subbasin plans that were prepared for the Northwest Power Planning Council for all of the subbasins within the Columbia River system. This subbasin assessment included a detailed evaluation of fish and wildlife habitats and focal species in the watershed, an assessment of limiting factors, and the development of a management plan to maintain and restore a healthy ecosystem.

Nilo, P., P. Dumont, and R. Fortin. 1997. Climatic and hydrological determinants of year-class strength of St. Lawrence River lake sturgeon (Acipenser fulvescens). Canadian Journal of Fisheries and Aquatic Sciences. 54: 774-780.

Results indicated that year-class strength was determined in the first few months of life and that climatic and hydrological conditions during the period which larvae drift from spawning grounds and exogenous feeding begins are critical to year class strength of St. Lawrence River lake sturgeon. Stronger year classes occurred with greater increases in water temperatures in May and June.

Pacific Watershed Institute and Resources (PWI). 1999. Kootenai River watershed assessment report. Prepared for the Kootenai Tribe of Idaho. Bonners Ferry, ID.

This assessment, sponsored by the KTOI reviewed, summarized and interpreted seven core reports and multiple scientific studies to provide an integrated evaluation of watershed health. Historical conditions are described with over 150 years of development that lead to the impairment of the Kootenai River. Lack of retention below Libby Dam was suggested as a limiting factor to production in the river. Stream channel alterations may also be contributing to the lack of production in the river by reducing retention time of nutrients through the system. Effective discharge releases from Libby Dam are recommended to be 75,000 cfs, higher than the 50,000 cfs recommended in the VARQ. Contaminants in the sediments and water column may also be affecting the early life stages of KRWS.

Paragamian, V.L., G. Kruse, and V. Wakkinen. 2001a. Kootenai River White Sturgeon Investigation, Annual Progress Report, Kootenai River White Sturgeon Spawning and Recruitment Evaluation, Period Covered: January 1, 1998 to December 31, 1998, Report to Bonneville Power Administration, Contract No. 00004691, Project No. 198806500, 53 electronic pages. Idaho Department of Fish and Game.

The objective of the investigation was to determine environmental requirements for adequate spawning and recruitment of white sturgeon. The study determined a range of river temperatures and discharges that produced the optimal spawning conditions for the white sturgeon.

Paragamian, V.L., G. Kruse, and V. Wakkinen. 2001b. Kootenai River White Sturgeon Investigation: Kootenai River White Sturgeon Spawning and Recruitment Evaluation Annual Progress Report January 1, 1999- December 31, 1999. Idaho Fish and Game. 46 pp.

The objective of the investigation was to determine environmental requirements for adequate spawning and recruitment of white sturgeon. The study determined a range of river temperatures and discharges that produced the optimal spawning conditions for the white sturgeon and also recommended the release of hatchery cultered larval white sturgeon to help resolve the issue of an egg to age 2+ survival bottleneck.

Richards, D. 1997. Kootenai River Biological Baseline Status Report. U.S. Department of Energy Bonneville Power Administration Environment, Fish, and Wildlife. 70 pp.

This report investigates the declining primary production of aquatic insect and fish populations. The populations have been altered due to changes in flow regimes, temperature patterns, and water quality caused by channelization, diking, impoundment, and pollution abatement measures in the watershed.

Rust, P., V. Wakkinen, and T. Kiser. 2007. Kootenai River white sturgeon spawning and recruitment evaluation. Idaho Department of Fish and Game Report No. 07-23.

Report reviews results of 2005 studies on telemetry tracking of pre-spawning adults, and sampling for eggs, larvae, and juveniles. Report also links movements of adults with water temperature and river discharge.

Rust, P., and V. Wakkinen. 2008. Kootenai River white sturgeon spawning and recruitment evaluation. Annual Progress Report. May 1, 2007 – April 30, 2008. Idaho Department of Fish and Game Report No. 08-16.

This study explored the environmental requirements for successful spawning and recruitment of the Kootenai River white sturgeon (*Acipenser transmontanus)* population ,through monitoring and evaluating the response of various life stages of Kootenai River white sturgeon, to mitigation flows supplied by the United States Army Corps of Engineers (Corps). The role of discharge (in itself) on sturgeon upstream migration extent remains uncertain. In 2007, although local inflow began in March, discharge from Libby Dam began to increase in mid-April, much earlier than previous years, and water temperatures were still less than 6°C. Yet, most of the sturgeon spawning migration did not begin until mid-May after water temperatures increased above 8°C and discharge was actually reduced. During 2006 and 2007, based on Vemco continuous passive telemetry monitoring techniques, a significant portion of our tagged sturgeon population migrated above Bonners Ferry into at least the lower end of the braided reach. The Vemco VRAP system proved to be a useful tool for determining movements of adult sturgeon in a specific reach of the Kootenai River. Based on the results of the 2006-2007 VRAP study, white sturgeon did not key in on the rock structure and relative use of the structure was low. Additionally, our substrate mat sampling failed to document any spawning on the structure despite an intense effort. Finding successful spawning habitats and understanding early life history requirements are still the biggest gaps in our understanding of Kootenai River white sturgeon.

Schaffter, R.G. and D.W. Kohlhorst. 1999. Status of white sturgeon in the Sacramento-San Joaquin Estuary. California Fish and Game. 85:37-41.

This report provided an update of the status of the white sturgeon. Overexploitation of the population in the 1980s was impairing the population, thus a "slot limit" was imposed for harvest. A satisfactory reduction in the exploitation rate occurred. However, mortality rates continued to increase, but this was believed to be due to drought conditions. Recruitment rates were higher in wet years (higher flows). Declines in recruitment were reported for drought years.

Snyder, E.B. and G.W. Minshall. 2005. An energy budget for the Kootenai River, Idaho (USA), with application for management of the Kootenai white sturgeon, Acipenser transmontanus. Aquatic Sciences. 67:472-485.

This study examined the potential for autotrophic productivity and organic material to support higher trophic levels in three distinct geomorphic segments of the Kootenai River. Research indicated that the reservoir formed by Libby Dam was retaining significant quantities of nutrients and organic material and phosphorus was limiting periphyton accrual downstream. Thus, food limitation likely contributed to the decline in the white sturgeon population. The study found that autotrophic and detrital sources were generally insufficient to support the estimated fish biomass in the river, as they were limited by impoundment caused by the dam.

Thompson, M.W. 1981. Kootenay Lake Levels. International Joint Commission. Speech prepared by Murray W. Thompson, Chief Engineer, International Joint Commission. May 23, 1981, Nelson, B.C.

This article addresses misconceptions regarding the water levels of Kootenai Lake. Also includes a brief history of the control works at Corra Linn on the West Arm of the Kootenai River, a description of the role of the International Joint Commission and its International Kootenai Lake Board of Control, an explanation of the 1938 Order of Approval and the articles of the Columbia River Treaty pertaining to Kootenai Lake. The hydrology and fluctuations in water level of Kootenai are also discussed.

U.S. District Court - District of Montana, Missoula Division. 2008a. Case No. CV 03-29 DWM. Stipulated Settlement Agreement. Center for Biological Diversity, Wildwest Institute, Plaintiffs, and the State of Montana, Plantiff-Intervenor, v. U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, Defendents, and Kootenai Tribe of Idaho, Defendant-Intervenor.

This was a lawsuit seeking the Corps to reinitiate consultation pursuant to ESA Section 7a2 with the USFWS regarding the effects of the operations of Libby Dam on the endangered Kootenai River white sturgeon, challenging the Corps implementation of the RPAs in the BiOp and challenging the USFWS's critical habitat designation for sturgeon. Parties agreed to settlement of this action by clarifying the 2006 BiOp, document sharing and reporting, and other general provisions.

U.S. District Court - District of Montana, Missoula Division. 2008b. Case No. CV 03-29 DWM. Center for Biological Diversity, Wildwest Institute, Plaintiffs, and the State of Montana, Plantiff-Intervenor, v. U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, Defendents, and Kootenai Tribe of Idaho, Defendant-Intervenor. Stipulated Settlement Agreement. Exhibit A: Draft Request for Clarification of RPA to 2006 Biological Opinion.

Exhibit A of the Settlement Agreement requests clarification of the Reasonable and Prudent Measures to 2006 Biological Opinion. Interim Actions and Long Term Actions are addressed. In addition, the Action Agencies are to cooperate in good faith and support the Tribe's good-faith efforts to implement the Kootenai River Restoration Project Master Plan.

United States Fish and Wildlife Service (USFWS). 1994. Endangered and Threatened Wildlife and Plants; Determination of Threatened Status for the Kootenai River Population of the White Sturgeon. Adapted from Federal Register. 26 pp.

The Fish and Wildlife Service determines endangered status pursuant to the Endangered Species Act of 1973, as amended, for the Kootenai River population of the white sturgeon. The Kootenai River population of the white sturgeon is restricted to approximately 270 river kilometers of the Kootenai River, in Idaho, Montana, and British Columbia. With the exception of 1974, sturgeon recruitment has been declining since the mid-1960's, and there has been an almost complete lack of recruitment of juveniles into the population since 1974, soon after the Libby Dam in Montana began operation. The population also faces threats from reduced biological productivity, and possibly poor water quality and the effects of contaminants. This rule implements the protection and conservations provisions afforded by the Act for the Kootenai River population of the white sturgeon.

U.S. Fish and Wildlife Service (USFWS). 1999. Recovery Plan for the White Sturgeon (Acipenser transmontanus): Kootenai River Population. USFWS. Region 1. Portland, Oregon.

The recovery plan for the KRWS lists short and long term recovery objectives as downlisting and delisting. Recovery criteria include natural production of KRWS with a stable or increasing population and a long term flow strategy coordinated with the US and Canadian agencies, to produce environmental conditions necessary to produce recruits. Action needs include restoring KRWS habitats for spawning and early age recruitment and rearing, a conservation aquaculture program, increased flows during critical life history phases, and continued research and monitoring.

U.S. Fish and Wildlife Service (USFWS). 2000a. Biological Opinion: Effects to Listed Species from Operations of the Federal Columbia River Power System. Action Agencies: Army Corps of Engineers, Bonneville Power Administration, Bureau of Reclamation. Consultation Conducted by USFWS Regions 1 and 6. December 20, 2000.

The USFWS completed a BiOp Effects on Listed Species from Operations of the Federal Columbia River Power System (FCRPS) in 2000. The BiOp concluded that KRWS continued existence was jeopardized. The BiOp also included four RPAs to be addressed to eliminate species jeopardy including modifications to flow releases from Libby Dam to provide more natural flow timing and duration.

U.S. Fish and Wildlife Service (USFWS). 2000b. Federal Columbia River Power System Opinion Amendments. Army Corps of Engineers, Bonneville Power System. 9 pp.

During finalization of the FCRPS opinion, some editorial mistakes and minor omissions were made. Corrections to these mistakes or omissions are summarized in this document. The enclosure indicates appropriate test for amendment of the document.

U.S. Fish and Wildlife Service (USFWS). 2006. Fish and Wildlife Service Biological Opinion regarding the Effects of Libby Dam Operations on the Kootenai River White Sturgeon, Bull Trout, and Kootenai Sturgeon Critical Habitat. (1901F0279R).

This biological opinion amends and supplements the Service's 2000 Federal Columbia River Power System (FCRPS) biological opinion, with respect to the effects of the operations of Libby Dam on the Kootenai sturgeon and the bull trout in the Kootenai River. The Libby Dam BiOp seeks to address habitat attributes associated with Kootenai sturgeon and bull trout recovery that have been negatively impacted by operation of Libby Dam. Towards this end, the Libby Dam BiOp identifies a number of specific measures and objectives to address each identified habitat attribute.

U.S. Fish and Wildlife Service (USFWS). 2008a. Endangered and Threatened Wildlife and Plants; Critical Habitat Revised Designation for the Kootenai River Population of the White Sturgeon (Acipenser transmontanus): Final Rule. Federal Register Volume 73 Number 132, Rules and Regulations, pages 39505-39523. Accessed 12 July 2010 via http://ecos.fws.gov/speciesProfile/profile/speciesProfile.action?spcode=E087#crithab.

The U.S. Fish and Wildlife Service revised the designation of critical habitat for the Kootenai River population of the white sturgeon (*Acipenser transmontanus*) (Kootenai sturgeon) under the Endangered Species Act of 1973, as amended (Act). In total, 18.3 river miles (RM) (29.5 river kilometers (RKM)) of the Kootenai River are designated as critical habitat within Boundary County, Idaho. This designation maintains as critical habitat the 7.1 RM (11 RKM) ''braided reach,'' and the 11.2 RM (18 RKM) ''meander reach,'' from the February 8, 2006, interim rule (71 FR 6383). Included within this designation is the 0.9 mi (1.5 km) transition zone that joins the meander and braided reaches at Bonners Ferry, as described in the interim rule. The critical habitat areas constitute the best assessment at this time of areas determined to be occupied at the time of listing that contain the physical and biological features essential for the conservation of the species and that may require special management.

U.S. Fish and Wildlife Service (USFWS). 2008b. Clarification of the 2006 Fish and Wildlife Service Biological Opinion Regarding the Effects of Libby Dam Operations on the Kootenai River White Sturgeon, Bull Trout, and Kootenai Sturgeon Critical Habitat (1-9-01-F-0279R). Clarification of Reasonable and Prudent Alternative.

This document was submitted to the USACE in response to a request for clarification on the USFWS 2006 Biological Opinion on Libby Dam operations as a result of the law suit by the Center for Biological Diversity. The Clarification includes only aspects of the Reasonable and Prudent Alternative (RPA) that have changed as a result of the settlement agreement. The state of Montana has agreed to provide a waiver of its water quality standard for total dissolved gas (TDG).

The attributes and measures that are needed to adequately provide for successful Kootenai sturgeon spawning and natural in-river reproduction include: timing of augmentation flows, duration of peak augmentation flows for adult migration and spawning, duration of post-peak augmentation flows for incubation and rearing, minimum flow velocity, temperature fluctuation, depth at spawning sites, substrate extent/spawning structures, and minimum frequency of occurrence.

U.S. Fish and Wildlife Service (USFWS). 2008c. Modified Idaho Roadless Rule- National Forest Lands, Idaho- Biological Opinion and Conference Option. USDA Forest Service Regions 1 and 4. Snake River Fish and Wildlife Office. Boise, Idaho. Accessed via http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsm8_036264.pdf.

Clarification of the 2006 Fish and Wildlife Service Biological Opinion, Regarding the Effects of Libby Dam Operations on the Kootenai River White Sturgeon, Bull Trout, and Kootenai Sturgeon Critical Habitat (1-9-01-F-0279R.

Clarification and update of the BiOp due to the settlement agreement, as a result of the law suit by the Center for Biological Diversity. Some changes have been made to the Reasonable and Prudent Alternative (RPA). The state of Montana has agreed to provide a waiver of its water quality standard for total dissolved gas (TDG).

Upper Columbia White Sturgeon Recovery Team. 2002. Upper Columbia White Sturgeon Recovery Plan. Upper Columbia White Sturgeon Recovery Initiative. November 28, 2002. 90 pp.

This plan is the product of the upper Columbia White Sturgeon Recovery Initiative by Canadian, U.S., and aboriginal governments, industrial and environmental organizations, stewardship groups, and citizens. Implementation of this plan represents a proactive approach to species recovery and may provide an effective alternative to formal listing under a Canadian Species at Risk Act or the U.S. Endangered Species Act.

White sturgeon are a unique and precious component of the biodiversity and cultural heritage of the upper Columbia River that are currently threatened with extinction in the transboundary region of the upper Columbia River. With an almost complete failure of natural recruitment, it is estimated that severe population bottlenecks will occur within the next 10 years and the population will become functionally extinct by year 2044. If immediate action is not taken, too few fish will soon remain to take advantage of any suitable natural recruitment conditions that may occur.

The short-term objective is to assess population status and act to prevent further reduction in white sturgeon distribution, numbers, and genetic diversity within the current geographic range. The medium-term objective is to determine survival limitations (bottlenecks) for remaining supportable populations and establish feasible response measures. The long-term objective is to re-establish natural population age structure, target abundance levels, and beneficial uses through self-sustaining recruitment in two or more recovery areas. With continued commitment to a conservation hatchery program and restoration of natural recruitment within the next 20 years, at least 50 years will be required to rebuild a stable adult population and 100 years for restoration of a stable naturally-produced population.

Walters, J. 2005. Kootenai River Fisheries Investigations; Rainbow and Bull Trout Recruitment 2003-2004 Annual Report. Project No. 198806500. BPA Report DOE/BP- 00004691-6.

Study conducted to identify sources of rainbow and bull trout recruitment, monitor population sizes structure, and limitations to recruitment. Passage barriers were found in some watersheds, water temperatures were found to exceed suitability at two sites, nutrients were found to be limited. Populations increased in density following more conservative harvest regulations for rainbow.

Zaidi, M.K. and S. Ireland. 2008. Rescue efforts to save sturgeons in America. In: V. Lagutov (Ed.), Rescue of Sturgeon Species in the Ural River Basin. Springer Science and Business Media.

Sturgeon populations have declined worldwide due to overexploitation and habitat alteration. Hatcheries are being used worldwide for conservation stocking. In North America, habitat protection and protection of populations (Federal and State protected status) apply to all sturgeons.

Sturgeon populations have declined worldwide due to overexploitation, habitat alteration, and take for international trade. Hatcheries are being used worldwide for conservation stocking. In North America, habitat protection and protection of populations (Federal and State protected status) apply to all sturgeons.

D-3. STURGEON HABITAT REQUIREMENTS

Beamesderfer, R.C.P., and R.A. Farr. 1997. Alternatives for the management and protection of sturgeons and their habitat. Environmental Biology of Fishes. 48: 407-417.

This paper reviewed and summarized the life history and habitat requirements of sturgeons and alternatives for protection and restoration of habitat. Discussed limitations to the sturgeons in general – habitat loss and fragmentation, degradation, alteration, etc. on a broad scale, suggested that a system-wide program should be established to protect and enhance the populations that considers harvest, habitat, and supplementation.

Chiotti, J.A., J.M. Holtgren, and N A. Auer. 2008. Lake Sturgeon Spawning Habitat in the Big Manistee River, Michigan. North American Journal of Fisheries Management. 28(4): 1009-1019.

Spawning sites of lake sturgeon (*Acipenser fulvescens*) were verified using egg collection mats in the Big Manistee River in northwestern Lower Michigan. Photographs taken by a fixed-position underwater video camera were used to characterize the substrate at egg mat locations. Spawning locations consisted of 34-44% cobble and 0.04-8% sand, and non-spawning locations consisted of 2-43% cobble and 0.16-7% sand. Shannon diversity indices describing substrate heterogeneity at spawning locations were statistically higher than those for non-spawning locations in 2003 ($P = 0.002$). Four spawning events were documented at water temperatures ranging from 11.1°C to 14.8°C, and egg incubation periods ranging from 6 to 10 d. Depth at spawning sites was 1.5-3.0 m, average water velocity was 0.34-1.32 m/s, and near-substrate water velocity was 0.08-1.26 m/s.

Coutant, C.C. 2004. A riparian hypothesis for successful reproduction of white sturgeon. Reviews in Fisheries Science. 12:23-73.

This paper proposes that submerged riparian habitat during seasonal high flows is needed for early development. Where recruitment is successful, channels are complex and floodable riparian vegetation or rocky substrate is abundant.

Flowers, J.H., W.E. Pine III, and A.C. Dutterer. 2009. Spawning Site Selection and Potential Implications of Modified Flow Regimes on Viability of Gulf Sturgeon Populations. Transactions of the American Fisheries Society. 1266-1284.

This study examines how to manage riverine flows to meet human water needs and the needs of species that are federally listed as threatened or endangered, including the Gulf of Mexico sturgeon (*Acipenser oxyrinchus desotoi)*. Altered riverine flow regimes may affect spawning success, and possibly the recruitment patterns of the population. Through intensive field work, we documented Gulf sturgeon spawning site selection in the Apalachicola River, and then evaluated the relationship between river stage and the available spawning habitat at these sites. We then used an age-structured simulation model to assess the effects of changes in recruitment patterns on population viability using hypothetical scenarios, based on changes in flow regime and its effect on available spawning habitat. River discharges of less than 142 m3/s at Jim Woodruff Lock and Dam significantly reduced the spawning habitat available to Gulf sturgeon at all known spawning sites, potentially affecting recruitment.

Haxton, T.J., C.S. Findlay, and R.W. Threader. 2008. Predictive Value of a Lake Sturgeon Habitat Suitability Model. North American Journal of Fisheries Management. 28(5): 1373-1383.

Application of a HSM recently developed for lake sturgeon (*Acipenser fulvescens)* in northern rivers to three reaches of the Ottawa River, using measurements of the model's key variables (substrate type, water depth, and velocity) to generate spatially explicit predictions of habitat suitability. The predictive power of the model was then tested by comparing catch per unit effort (CUE) using short-set gill nets in areas predicted to have good (habitat suitability index values >0.6), and poor (values < 0.3) adult and juvenile foraging habitats. Consistent with model predictions, significantly more lake sturgeon were caught at sites within river reaches predicted to be of high quality, than at those predicted to be of low quality. Moreover, the average CUE at the reach scale correlated positively with the average predicted habitat foraging quality. On the other hand, the predictive power was generally low, such that most of the variation in CUE was unexplained by the fitted models. These results suggest that although the lake sturgeon HSM developed for northern rivers, has some predictive power in other contexts, the uncertainty of its predictions is still rather high.

Jamieson, B. and J. Braatne. 2001. Riparian cottonwood ecosystems and regulated flows in Kootenai and Yakima subbasins: impact of flow regulation on riparian cottonwood forests along the Kootenai River in Idaho, Montana, and British Columbia. 2000-2001 Technical Report, Project No. 200006800, BPA Report DOE/BP-00000005-2.

Riparian vegetation, and especially cottonwood and willow plant communities are dependent on normative flows, and especially, spring freshette to provide conditions for recruitment. The study concluded that human impacts on the floodplain were much more extensive in the reaches below the Libby Dam, than in our study reaches upstream of the reservoir. Much of the lower river is diked, and most of the floodplain is now farmland. Cottonwood stands do occur in the downstream reaches from Libby Dam however, and recent cottonwood recruitment at three transect sites has occurred as a result of spring flow releases for white sturgeon in the 1991 to 2000 period.

***Kock, T.J., J.L. Congleton, and P.J. Anders. 2006. Effects of Sediment Cover on Survival and Development of White Sturgeon Embryos. North American Journal of Fisheries Management. 26: 134-141. ***

An embryo incubation unit (EIU) was developed to assess the relationship between sediment cover and survival of white sturgeon embryos in the lab. Embryos had 0-5% survival rate under sediment cover of either 5 or 20 mm. Survival was not affected by ventilation hole size. The length of sediment cover reduced survival. Sediment cover also delayed hatch timing, and decreased larval length. Sediment cover may be an important early life stage mortality factor in rivers where white sturgeon spawn over fine-sediment substrates. The study demonstrated that sturgeon eggs (embryos) do not survive well in sand.

Miller, A.I., and L.G. Beckman. 1996. First record of predation on white sturgeon eggs by sympatric fishes. Transactions of the American Fisheries Society. 125: 338−340.

Sturgeon eggs were found in stomachs of northern squawfish, prickly sculpin, largescale sucker, and carp. Thus, providing evidence that predation on eggs occurs in rearing areas.

Paragamian, V.L., G. Kruse, and V. Wakkinen. 2001c. Spawning habitat of Kootenai River white sturgeon, post-Libby Dam. North American Journal of Fisheries Management. 21:22–33.

Kootenai River white sturgeon have been isolated from other populations for over 10,000 years. Libby Dam (1972) modified the flow and temperature regime of the river affecting spawning and recruitment. In only 2 years, of an 8 year study, eggs were collected over gravel/cobble substrate. In the other 6 years eggs were collected over sand substrate, exceeding 5 m depth, within main channel, velocities of 0.2-1.0 m/s and temps between 8.5-12'C. This differs from spawning habitat in the Columbia River where grave/cobble substrate is used and available and warmer water temperatures. Spawning over sand substrate might suffocate eggs which are adhesive.

Paragamian, V.L., and V.D. Wakkinen. 2002. Temporal distribution of Kootenai River white sturgeon spawning events and the effect of flow and temperature. Journal of Applied Ichthyology. 18(4- 6):542-549.

This study assesses the temporal distribution of white sturgeon spawning, in relation to flow and temperature, both natural and man-made variations. From 1994 to 2000, spawning was monitored by collecting eggs with artificial substrate mats. Spawning events were correlated with flows and temperature. Average daily temperature during spawning ranged from 7.5 to 14 ºC, with the highest probability of spawning (48%) at 9.5-9.9 ºC. Sixty-six percent of spawning events occurred when water temperatures were between 9.5 and 12.5 ºC. Average daily flow during spawning ranged from 141 to 1265 m^3 /s.

Parker, E. 2007. Ontogeny and life history of shortnose sturgeon (Acipenser brevirostrum Lesueur 1818): Effects of latitudinal variation and water temperature. PhD Dissertation. University of Massachusetts, Amherst. 62 pp.

The effect of rearing temperature on dispersal pattern was studied by rearing replicates of fish at 10, 15, and 20 ºC. Fish in the 10°C group had a single peak of dispersal lasting 8 days. Increasing the temperature (15 and 20°C) caused fish to begin dispersing at a younger age (in days after hatch), but also produced a dispersal with multiple peaks. Dispersal of sturgeon early life stages can be influenced by river temperature, and anthropogenic impacts that alter river temperature regimes have the potential to affect sturgeon dispersal patterns.

Parsley, M.J., L.G. Beckman, and G.T. McCabe. 1993. Spawning and rearing habitat use by white sturgeons in the Columbia River downstream from McNary Dam. Transactions of the American Fisheries Society. 122:217–227.

This study identified that spawning and egg rearing of white sturgeon in the Columbia River occurred in fast velocity, mean column velocity = 0.8-2.8 m/s within 8 km of each of the four lowermost dams.

Substrates where spawning occurred were mainly cobble, boulder, and bedrock. Free embryos are carried by the swift current downstream away from the spawning site.

Spawning and egg incubation occurred in fast flowing water (0.8-2.8 m/s mean water column velocity) within 8 km of each of the four lowermost dams. Spawning occurred over substrates of cobble, boulder, and bedrock. Yolk-sac larvae drifted downstream to deeper, lower velocity areas with finer substrates. Young-of-the year were found at depth of 9-57 meters, mean water column velocities of 0.6 m/s or less and substrates of clay, mud and silt, sand, gravel, and cobble. Juveniles were found at depths of 2-58 m, mean water column velocities of 1.2 m/s or less, and substrates ranging from clay to bedrock. Sturgeon spawned at water temperatures from 10 to 20 degrees C, median was 14 degrees C. Free embryos are carried by the swift current downstream away from the spawning site.

Parsley, M.J., and L.G. Beckman. 1994. White sturgeon spawning and rearing habitat in the lower Columbia River. North American Journal of Fisheries Management. 14:812–827.

This study identified that spawning habitat for white sturgeon in the Columbia River occurred in the tailrace below four dams. The study determined suitability of dam discharge for spawning. Suitability of habitat for YOY was identified using captures of YOY and habitat characteristics (water depth, mean column velocity, and substrate). YOY do not seem limited by these habitat factors.

Estimated white sturgeon spawning habitat in the tailraces of the four dams on the lower Columbia River, using the Physical Habitat Simulation System of the U. S. Fish and Wildlife Service's Instream Flow Incremental Methodology. The study identified suitable water depths, water velocities, and substrates. Rearing habitat was identified using GIS to identify areas with suitable water depths and substrates. Used date from Parsley et al. 1993 to develop suitability curves. The results indicated that the backwater effects from downstream reservoirs influenced the amount of available suitable habitat in the tailraces of The Dalles, John Day, and McNary dams.

Suitability of habitat for YOY was identified using captures of YOY and habitat characteristics (water depth, mean column velocity, and substrate). YOY do not seem limited by these habitat factors

Parsley, M.J., P.J. Anders, A.I. Miller, L.G. Beckman, G.T. McCabe, Jr. 2002. Recovery of white sturgeon populations through natural production: understanding the influence of abiotic and biotic factors on spawning and subsequent recruitment. American Fisheries Society Symposium. 28:55–66.

White sturgeon year-class strength is determined within the first 3 months after spawning, but little is known about the specific causes of mortality. Year class strength is dependent on the number of eggs spawned and the survival rates of the developing fish. Critical elements of development of a strong year class is dependent on successful spawning, and recruitment dependent on water temperature and the availability of suitable habitat. Increased river discharge, suitable water temperatures, and suitable habitat availability have shown to result in greater recruitment.

Perrin, C.J., A. Heaton, and M.A. Laynes. 2000. White Sturgeon (Acipenser transmontanus) spawning habitat in the Lower Fraser River, 1999. Report prepared by Limnotek Research and Development Inc. for BC Fisheries. 81 pp.

A description of spawning habitat used by white sturgeon in the lower Fraser River between Mission and Yale was compiled from field observations completed in spring and summer, 1999. This work provided an updated understanding of characteristics of spawning habitat that was initially described from observations in 1998. Locations of potential spawners were used to indicate the approximate location and time of spawning.

Perrin, C.J., L.L. Rempel, and M.L. Rosenau. 2003. White sturgeon spawning habitat in an unregulated river: Fraser River, Canada. Transactions of the American Fisheries Society. 132: 154-165.

Female Frasier River white sturgeon spawn mostly in the reduced velocity in side channels (mean, 1 m/s), not in the fast velocity in the main channel (1.5-2 m/s). Rock substrate is present in both: gravel in the side channels, cobble in the main channel. Females spawn in shallow water about 3 m deep, and authors speculate that the increased turbidity may create the reduced light intensity conditions needed for spawning. Unfortunately, they collected no information on light intensity to compare with intensity levels at spawning sites in deep water in regulated rivers.

Prince, A. 2008. Kootenay River White Sturgeon Traditional Knowledge and Habitat Assessment near Creston, B.C. Prepared for: Canadian Columbia River Intertribal Fisheries Commission. Cranbrook, BC.

Studies addressing the decline in the population, and recruitment failure of the KRWS in both Idaho and BC began in 1994, and include juvenile sampling focused on growth, survival, and distribution. A summary of juvenile habitats and traditional knowledge of sturgeon in the study areas was provided. Higher catch rates of juveniles were found below the nearest hatchery release points, in Kootenay Lake, and near the Creston delta. In two additional sampling sites, the site with riparian vegetation, low aquatic vegetation had higher catch rate of juveniles. The historical significance of KRWS was presenting including capture techniques, traditional uses (food), and ceremonies. Their historical distribution and critical habitats were also described. Spawning occurred in the Creston wetlands, Indian Creek and under current Sam's bridge.

Redwing Naturalists. 1996. History of Diking on the Kootenay River Floodplain in British Columbia. Habitat Enhancement of Fisheries & Oceans. 68 pp.

This review of diking programs on the Kootenai River floodplain in British Columbia was carried out through a literature search, examination of maps and aerial photographs and personal interviews with Creston residents who have been directly involved in land reclamation. Diking has resulted in isolating large portions of lateral channels within the floodplain and consequently greatly reduced continuity between the Kootenai river and floodplain wetlands. A brief discussion of possible implications to the fishery resource in included.

Young, W.T. 2002. Juvenile habitat use and growth of white sturgeon in the Kootenai River. Master's Thesis. University of Idaho, Moscow.

Fish were captured using gillnets and tracked using ultrasonic telemetry. All fish were captured in pools, but telemetry contacts were most frequent in glides. Contacts were located in glides (60%), outside bend (50%), near thalweg (52%). Contacts were often associated with sand substrates (61%) and no cover (42%). Nose velocities ranged from 0.0 to 0.52 m/s. The data indicated that depth may be more important than velocity for site selection. Although there was no cover where fish were located, large dunes (0.5-1.0 m in height) were near the locations that create velocity breaks and potential refuge from higher velocities.

Young, W.T. and D.L. Scarnecchia. 2005. Habitat use of juvenile white sturgeon in the Kootenai River, Idaho and British Columbia. Hydrobiologia. 537: 265-271.

Ultrasonic telemetry was used to assess habitat use by juvenile white sturgeon in the lower 120 km of the Kootenai River. Initially all fish were captured in deep pools. Subsequent tracking found fish used glides, the outside of river bends, and were near or in the thalweg. Physical habitat factors preferred included sand substrate (sand dunes), the absence of cover, high velocities, and deep water areas.

Ultrasonic telemetry was used to assess habitat use by juvenile white sturgeon in the lower 120 km of the Kootenai River. Initially all fish were captured in pools. Subsequent contacts were in glides, in the outside bend of the river channel, near or in the visually defined thalweg. Physical habitat conditions preferred included sand substrate (sand dunes), no cover, higher velocities and greater depths.

D-4. STURGEON RIVERS PHYSICAL AND CHEMICAL MEASUREMENTS AND MODELING

Barton, G.J. 2004. Characterization of Channel Substrate, and Changes in Suspended-Sediment Transport and Channel Geometry in White Sturgeon Spawning Habitat in the Kootenai River near Bonners Ferry, Idaho, Following the Closure of Libby Dam. U.S. Geological Survey. Water-Resources Investigations Report. 03–4324.

A yearlong study was conducted 111 to 129 km below Libby Dam to map habitat conditions for white sturgeon on the Kootenai River. Channel substrate was mapped, changes in suspended-sediment transport was analyzed, aggradation and degradation of the channel bed and changes in the particle size of bed material was determined. It was found that the annual suspended sediment load leaving the spawning reach decreased dramatically after the closure of Libby Dam in 1972, including less sand-sized particles. This is due to the reduction of high flows. Aggradation and degradation of the riverbed was as much as 2.5 meters in the spawning reach during the Libby Dam era. Regulated flows due to the dam have buried spawning gravels with sand, sand dunes have formed. The unregulated flows allowed for sand and silt deposition in the fall and flushing in the spring to expose spawning gravels.

Barton, G.J., Moran, E.H., and Berenbrock, C. 2004. Surveying cross sections of the Kootenai River between Libby Dam, Montana, and Kootenay Lake, British Columbia, Canada. U.S. Geological Survey. Open-File Report 2004–1045. 35 p.

U.S. Geological Survey collected stream channel cross-section and longitudinal data at about 400 locations along the Kootenai River between Libby Dam and Kootenay Lake. A total of 245 cross-sections were surveyed. These data will provide info that can be used to develop hydraulic flow models of the Kootenai River.

Barton, G.J., R.R. McDonald, J.M. Nelson, and R.L. Dinehart. 2005. Simulation of Flow and Sediment Mobility using a Multidimensional Flow Model for the White Sturgeon Critical-Habitat Reach, Kootenai River near Bonners Ferry, Idaho. U.S. Geological Survey Scientific Investigations Report 2005-5230. 54 p.

U.S. Geological Survey's Multi Dimensional Surface-Water Modeling System was used to construct a flow model for the critical-habitat reach of the Kootenai River white sturgeon, between river kilometers 228.4 and 245.9. The model was used to simulate water-surface elevation, depth, velocity, bed shear stress, and sediment mobility for various Kootenai River stream flows. Simulated conditions along the critical-habitat reach were compared with locations of white sturgeon spawning events, based on the number of spawning events per unit of effort during 1994-2001, to demonstrate how the model can be used to relate observed spawning or other observed habitat-related behavior to local physical characteristics of the river.

Barton, G., R. McDonald, J. Nelson, C. Berenbrock, M. Donato, P. VanMetre, and B. Mahler. 2006. Altered Dynamics of Kootenai River White Sturgeon Spawning Habitat and Flow Modeling. Proceedings of the Eight Federal Interagency Sedimentation Conference. Reno, NV.

A multidimensional flow model of certain reaches of the Kootenai River was developed to quantify physical habitat that is spatially distributed, as a means to assist the recovery of white sturgeon in the river. The U.S. Geological Survey used the agency's Multi Dimensional Surface Water Modeling System (MD_SWMS) to construct a flow model for the critical habitat reach near Bonners Ferry, Idaho. Substrate suitability for egg incubation is poor to moderate. Depth suitability ranges from poor to excellent and average velocity suitability is generally moderate and poor. Overall habitat suitability is better in the straight reach than the meander reach due to coarser substrate and higher velocities.

Barton, G.J., R.R. McDonald, and J.M. Nelson. 2009. Simulation of streamflow using a multidimensional flow model for white sturgeon habitat, Kootenai River near Bonners Ferry, Idaho—A supplement to Scientific Investigations Report 2005–5230: U.S. Geological Survey Scientific Investigations Report 2009-5026. 34 p.

The two-dimensional flow model developed in 2005 by USGS was extended into the braided reach upstream of the current white sturgeon braded reach. It is believed that the braded reach may be suitable for spawning. The model was also extended downstream by several kilometers of the spawning reach. Model simulations were used to report on the length and percentage of longitudinal profiles that met the minimum criteria as stipulated in the BiOp.

Barton, G.J., R.J. Weakland, R.L. Fosness, S. Cox, and M.L. Williams. In Press (a). Geohydrologic Section and Sediment Chemistry for the Kootenai River White Sturgeon Habitat Restoration Project, Boundary County, Idaho. U.S. Geologic Survey.

In order to assess the feasibility of a Kootenai River habitat restoration project for the recovery of the endangered Kootenai River white sturgeon (*Acipenser transmontanus*) population, and the recovery of other native river biota, 34 geohydrologic sections of the Kootenai River and flood plain are presented that show the types of sediments available in the river for constructing habitat and the locations of shallow bedrock that could pose challenges in reconfiguring the channel. Bathymetric maps based on a 2008 multibeam echo sounder survey were used to describe the relation between geology and channel morphology.

The U.S. Geological Survey also collected and analyzed the physical and chemical nature of sediment cores collected at 24 locations in the river. The analysis shows that concentrations of harmful chemical constituents do not exceed guideline limits.

In addition, water levels from wells, Kootenai River stage for low streamflow, and mean annual peak and record high streamflow during the Libby Dam era are included with the geohydrologic sections. A general analysis of groundwater and surface-water relations is provided by geomorphic reach.

Barton, G.J., G. Hoffman, R.R. McDonald, and J.M. Nelson. In Press (b). Kootenai River White Sturgeon Critical Habitat with Free Flowing and Backwater Conditions, Boundary County, Idaho: Evaluation of Water Depth and Flow Velocity during 2006-09 Spawning Seasons. Funded by the Kootenai Tribe of Idaho, Bonneville Power Administration and USGS Cooperative Water Program. 12 p.

Simulations from a USGS developed multidimensional-flow model were used to compute the percentage of longitudinal profiles through a sub reach of the Kootenai River white sturgeon critical habitat that meet U.S. Fish and Wildlife Service 2006 Biological Opinion water depth and streamflow velocity criteria, on a daily interval during the 2006-09 spawning seasons. The Biological Opinion specifies a depth and streamflow velocity criteria for a sub reach of the critical habitat between RKMs 244.6 and 252.7, it includes the straight reach and lower three-fifths of the braided reach. Our evaluation showed that the 5-m depth criterion was met on about half of the days during peak flow augmentation during the 2006-09 spawning seasons. The 7-m water depth criterion was never met. The 1 meter per second stream velocity criterion was met daily during peak flow augmentation of the 2006-09 spawning seasons.

A recent population assessment concluded that the wild population was between 800 and 1,000 adults with the population declining by approximately 4 % a year (Brian Beamesderfer, Cramer and Assoc., written commun., 2009). At this rate there will be no remaining wild population by approximately 2080, although functional extinction could occur well before that time.

Barton, G.J., R.J. Weakland,. L.F. Ryan, and Marshall L.W. In Press (c). Characterizing substrate and morphology of the Kootenai River white sturgeon critical habitat, Boundary County, Idaho: Analysis for ecosystem restoration. Proceeding in the Joint 9th Federal Interagency Sedimentation and 4th Federal Interagency Hydrologic Modeling Conference. 12 p.

Kootenai River habitat restoration project planned to assist the recovery of Kootenai River white sturgeon. Projects considered include; modifying the channel and floodplain, installing in-stream structures, and creating wetlands. The U.S. Geological Survey has characterized the substrate and channel morphology of the KRWS critical habitat. Data from a multibeam echo sounder is used to create bathymetric maps and animations which show dune bedforms, gravel bars, clay terraces, clay steps, bedrock, and alluvial sand. Underwater videography was also recorded.

Bauer, S.B. 1999. Kootenai River Water Quality Summary 1997/1998. Prepared by Pocket Water, Inc. Submitted to Kootenai Tribe of Idaho Fish and Wildlife Department.

Water quality is one of many possible stressors that could be contributing to the decline of fisheries in the basin. Concern about declining fish populations in the Kootenai River has initiated a variety of studies to evaluate potential causative factors. Trace metals and nutrient data collected by the Tribe over approximately a year and a half period, between April 1997 and November 1998, were evaluated. The data was evaluated as a screening level assessment of a limited section of a complex watershed. The report addresses recommendations for standardizing data collection, laboratory analysis, and interpretation procedures where useful to increase sensitivity of the data sets to the overall goal of aquatic ecosystem recovery.

Bennett, W.R., G. Edmondson, K. Williamson, and J. Gelley. 2007. An investigation of the substrate preference of white sturgeon (Acipenser transmontanus) eleutheroembryos. Journal of Applied Ichthyology. 23: 539-542.

Laboratory experiments demonstrated that Frasier R. free embryos preferred small rocks for hiding. Fish preferred the largest (12 mm diameter) of a small-size rock group and the smallest (22 mm diameter) of a group of larger rocks. Free embryos have evolved a behavioral preference for rock size and prefer a size range of 12−22 mm diameter.

Berenbrock, C. 2005. Simulation of hydraulic characteristics in the white sturgeon spawning habitat of the Kootenai River near Bonners Ferry, Idaho. U.S. Geological Survey Scientific Investigations Report 2005-5110. 30 p.

It is believed that sturgeon choose to spawn in the transition locations between backwater and free-flowing water. A 1-D hydraulic flow model was created. The location of the transition between backwater and free-flowing water was determined using the model. Scenarios were run with discharge, water-surface elevation, and location of transitions between backwater and free-flowing water to determine backwater locations. A scenario was also run to determine velocities and discharges.

Berenbrock, C. 2006. Simulation of Hydraulic Characteristics for an Upstream Extension of the White Sturgeon Spawning Habitat of the Kootenai River, Idaho - A Supplement to Scientific Investigations Report 2005-5110. U.S. Geological Survey Scientific Investigations Report 2006-5019. 17p.

A 1-D hydraulic flow model of the Kootenai River was developed to evaluated hydraulic characteristics in a reach, to evaluate the enhancement of white sturgeon spawning conditions. The spawning habitat reach may be extended into the upstream braided and or canyon reaches as the substrate is suitable for spawning (cobbles and gravels), whereas the meander reach substrate is not suitable (medium to fine sand). Flow velocities are lowest and flow depths are greater in the meander reach.

Berenbrock, C. and J.P. Bennett. 2005. Simulation of flow and sediment transport in the white sturgeon spawning habitat of the Kootenai River near Bonners Ferry, Idaho. U.S. Geological Survey Scientific Investigations Report 2005-5173. 72 p.

Characterization of sediment transport of the Kootenai River in the white sturgeon spawning reach is needed by the Kootenai River White Sturgeon Recovery Team to predict sediment-transport conditions that improve spawning conditions for the white sturgeon (*Acipenser transmontanus*) in the Kootenai River near Bonners Ferry, Idaho. A 1-D sediment transport model was developed of the KRWS spawning habitat, and used to simulate the response of the hydraulic and sediment system to various discharges and water-surface elevations. Six different management alternatives were simulated to assess erosion and deposition under varying hydraulic conditions after 21 days. Alternatives had increasing discharges from 6,000 – 60,000 cfs. Sediment deposition was dominant in lower discharges and sandbeds changed little or not at all with gravel-cobble changes. Erosion was the dominant feature in the two highest discharge alternatives.

Fosness, R.L. and M.L Williams. 2009. Sediment characteristics and transport in the Kootenai River white sturgeon critical habitat near Bonners Ferry, Idaho: U.S. Geological Survey Scientific-Investigations Report 2009-5228. 40 p.

A suspended- and bedload-sediment sampling study was conducted in the critical habitat reaches for KRWS. Sites with differing hydraulic differences were sampled. Samples were analyzed to determine suspended- and bedload-sediment characteristics and transport rates, including total loading in the critical habitat reach. Total suspended-sediment discharge ranged from about 300 – 23,000 metric tons/day. Bedload-sediment discharge ranged from 0 – 271 tons/day and consisted of fine to coarse gravel in the upper reach and fine to coarse sand in the lower reach. A large quantity of fine-to-coarse gravel is present in the braided reach.

Kootenai Tribe of Idaho (KTOI), Idaho DEQ, and US EPA. 2006. Assessment of Water Quality in Kootenai River and Moyie River Subbasins (TMDL).

The Lower Kootenai and Moyie Rivers Subbasin Assessment (SBA) and TMDL have been developed for streams listed on the 1998 §303(d) list. The first part of this document, the SBA, is an important first step in developing the TMDL. The starting point for this assessment was Idaho's 1998 §303(d) list of water quality limited water bodies. Seven segments of the Lower Kootenai and Moyie River Subbasins were included on this list. The SBA examines the current status of §303(d) listed waters and defines the extent of impairment and causes of water quality limitation throughout the subbasin. The second part of this document, the TMDL analysis, quantifies pollutant sources and allocates responsibility for load reductions needed to return listed waters to a condition of meeting water quality standards.
Key resources identified include: aquatic life and habitat. Uses affected include: cold water aquatic life, salmonids spawning. Pollutants include: Sediment, metals, pH, temperature. Pollutant sources considered: agriculture, forest practices, roads, railroads, pipeline, urbanization, and natural background.

Kruse, G., and D. Scarnecchia. 2002. Contaminant uptake and survival of white sturgeon embryos. American Fisheries Society Symposium. 28:151-160.

Exposure of fish eggs and sperm during fertilization, and early development to contaminants in the river may be a cause of poor reproductive success of the KRWS. The goal of this preliminary experiment was to determine if treatments of various de-adhesion media affect contaminant uptake and survival of embryos of the endangered KRWS. Uptake of organochlorine pesticides, Aroclor 1200 series PCBs and metals and survival of embryos were assessed. Eight metals and tow organochlorine compounds (DDE and PCB Aroclor 1260) were detected in embryos. It was concluded that copper and Aroclor 1260 in the rearing media are potentially decreasing survival and incubation time of white sturgeon embryos. River bottom sediments may be a more significant route for uptake of metals compared with water and suspended solids.

Kruse, G. 2008a. Report of the 2005-2006 Chlorine Monitoring: Kootenai River at Bonners Ferry, Idaho. (Report Prepared in Partial Fulfillment of Project Number 200200200: Restore Natural Recruitment of Kootenai River White Sturgeon). Prepared for the Kootenai Tribe of Idaho. Bonners Ferry, Idaho. 40 p.

Chlorine is used by the City of Bonners Ferry for back-flushing of the city water intake and for municipal wastewater sterilization prior to releasing wastewater into the Kootenai River. Chlorine testing was undertaken to provide data to assess effects. Results show levels that frequently exceeded method detection limits (0.02 mg/L) and the method detection limit exceeded EPA freshwater Life Criteria (0.01 mg/L). Chlorine should be considered a potential limiting factor for aquatic health.

Kruse, G. 2008b. Kootenai River Sediment Drilling: Contaminant Assessment Report. Prepared for the Kootenai Tribe of Idaho, Bonners Ferry, Idaho. 10 p.

Due to concern for potential effects of contaminants associated with dredge material, sediment contaminant analysis was required prior to project implementation of large-scale river restoration efforts between RM 159.2 and 152. Contaminants of interest were identified and included: 1) Organochlorine pesticides, 2) PCBs (congeners and aroclors), 3) metals, and 4) asbestos. The results of sediment core sampling indicated the absence or minimal presence (<0.01%) of asbestos fibers. Although additive methods (TEQs, PECQs) indicate overall low toxicity of dredge sediment, criteria exceedances, potential for increased bioaccumulation, low organic carbon content, high method detection limits, and lack of comparative criteria preclude estimation of biological effects and suggest the need for biological testing with proposed dredge sediments prior to project implementation.

McDonald, R.R., G.J. Barton, J.M. Nelson, V. Paragamian. 2006. Modeling Hydraulic and Sediment Transport Processes in White Sturgeon Spawning Habitat on the Kootenai River, Idaho. U. S. Geological Survey. Golden, Co.

A two-dimensional flow and sediment-transport model was used along with the measured locations of sturgeon spawning from 1994-2002 to gain insight into the paradox between the current spawning location, and the absence of suitable substrate. Spatial correlations between spawning locations and the model simulations of velocity and depth indicate the white sturgeon tend to select regions of highest velocity and depth within any river cross-section to spawn. A simple sediment-transport simulation suggests that high discharge and relatively long duration flow associated with pre-dam flow events might be sufficient to scour the sandy substrate and expose existing lenses of gravel and cobble as lag deposits in the current spawning reach.

McDonald, R., J. Nelson, V. Paragamian, and G. Barton. 2010. Modeling the Effect of Flow and Sediment Transport on White Sturgeon Spawning Habitat in the Kootenai River, Idaho. Journal of Hydraulic Engineering. ASCE. Vol. 136, No. 12.

Since completion of Libby Dam in 1972, 1974 was the only year with documented significant recruitment of juvenile fish. Spatial correlations between spawning locations and simulated velocity and depth were examined using a quasi-3-dimensional flow and sediment-transport model along with the locations where sturgeon eggs were recorded. Results indicate that fish tend to select regions of higher velocity and greater depth within any river cross section to spawn, which occur in the same locations under both pre- and post-dam flow conditions. Additionally, modeling, corroborated by video of a significant flood event in 2006, indicates that high discharge and relatively long-duration flow events (once common under pre-dam conditions) are sufficient to periodically scour fine sediment overburden and expose gravel and cobble lenses (potentially suitable substrate) in many locations throughout the current spawning reach. Modeling and observations therefore indicate that the relative rarity of extremely high flows under the current post-dam regulation regime is at least partly responsible for the lack of successful spawning.

Paragamian, V.L., R.C.P. Beamesderfer, and S.C. Ireland. 2005. Status, population dynamics, and future prospects of the endangered Kootenai River white sturgeon population with and without hatchery intervention. Transactions of the American Fisheries Society. 134:518-532.

This paper presents a synthesis of sampling data from 1977 through 2001. Natural recruitment was inconsistent in the 1960s and then since the Libby Dam in the 1970s. Population projections describe a significant bottleneck in spawner numbers, as the wild population declines, but hatchery fish have not yet matured. The nest generation is expected to be produced primarily form hatchery spawning of only 113-203 wild females. Habitat restoration measures to improve survival and rearing conditions for the wild component are critical to recovery efforts in the long term.
Population estimates:
•Late 1970s – 7000
•2000 – 760
•Mortality rate of 6-9% per year
•2005 fewer than 500 adults predicted
•2030 fewer than 50 adult predicted

Paragamian, V.L. and M.J. Hansen. 2008. Evaluation of Recovery Goals for Endangered White Sturgeon in the Kootenai River, Idaho. North American Journal of Fisheries Management. 28(2): 463-470.

This paper evaluated recovery goals for endangered white sturgeon (*Acipencer transmontanus*) in the Kootenai River, Idaho using demographic statistics in a stochastic density-dependent population model to estimate recruitment rates needed for population recovery. The future abundance of white sturgeon in the Kootenai River was simulated over a 25-year period, and a range of hypothetical recruitment rates to estimate the level of recruitment that would lead to population recovery (7,000 fish, the number present before the population suffered recruitment failure). The population would decline to only 57 individuals after 25 years, and only 6 individuals after 50 years if recruitment failure continued. The population would reach the target carrying capacity of 7,000 individuals within 25 years only when each adult produced 0.4 age-1 recruits, a recruitment rate equivalent to reaching the target level of recruitment in the recovery plan every year. In contrast, the population would grow to only 1,200 individuals if the target level of recruitment in the recovery plan was produced in only 3 of every 10 years, as specified in the recovery plan. Suggests that recovery goals for white sturgeon in the Kootenai River are modified as follows: (1) a population goal of 7,000 subadults and adults; (2) population recovery within 25 years; and (3) a minimum recruitment rate of at least 20 age-1 juveniles detected from each year-class in each of 10 years by use of a standardized monitoring protocol.

Tetra Tech, Inc. 2004a. Kootenai River Geomorphic Assessment - Bonners Ferry, Idaho. Prepared for the U.S. Army Corps of Engineers, Seattle District. Seattle, Washington. 122 p.

Recognizing changes in substrate conditions as a possible factor contributing to the declining Kootenai River white sturgeon population, the USFWS issued a BiOp in 2000 to assess the effects of Libby Dam and recommend reasonable prudent measures (RPM). The specific purpose of this work is to initiate a geomorphic assessment of the Kootenai River in order to support the determination of the potential options and their feasibility to achieve improved and suitable Kootenai River white sturgeon spawning and rearing substrate in the lower Kootenai River. Based on geomorphic information, and other site assessment information, this study evaluates and reports on the potential feasibility of hydrogeomorphic measures for recovering suitable sturgeon spawning and recruitment habitat in the Kootenai River from the Canadian border upstream to Kootenai Falls with special emphasis on the reach of the river currently designated critical habitat for the Kootenai River white sturgeon.

Recovery measures were recommended that included flow restriction measures, the creation of spawning habitat, and sediment transport alteration mechanisms. Recommendations for further investigations include more information on historic hydraulic conditions, sediment supply, affects of potential increased flows from Libby Dam, and the potential use of structures to scour sediment from spawning areas.

D-5. WHITE STURGEON RESTORATION

Anders, P.J.. June 2002. Conservation Biology of White Sturgeon (Acipenser Transmontanus). A Dissertation Presented in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy with a Major in Forestry, Wildlife and Range Sciences in the College of Graduate Studies, University of Idaho.

Addresses pertinent evolutionary and population genetics, population biology, and management issues facing the White Sturgeon. Discussions of genetic diversity, current distribution, life history characteristics, and population status are presented. A white sturgeon conservation aquaculture program is analyzed that maintains within-population demographic and genetic vigor while minimizing potential effects of pathogens and disease transfer to the wild populations. An analysis of empirical and theoretical factors, responsible for the currently endangered status of the Kootenai River white sturgeon population is presented.

Anders, P.J., J.T. Siple, D.L. Smith, and T.W. Burnstead. 2003. Critical Habitat Restoration for Kootenai River White Sturgeon: Empirical Definition of Spawning, Incubation, and Early Rearing Habitat Requirements. S.P. Cramer and Associates, Kootenai Tribe of Idaho, University of Idaho, and River Masters Engineering. 30 pp.

This report provides an innovative approach to directly measure habitat conditions and parameter values associated with successful spawning, incubation, and rearing of Kootenai River white sturgeon. Empirical habitat conditions were directly measured in an engineered-natural habitat channel designed specifically for this purpose. Empirical values were generated by this project that provided targets for river-scale restoration of critical habitat. This project was complementary to ongoing USGS and USACE habitat assessment and modeling activities in the Kootenai River. The channel was used to provide the empirical basis for river-scale restoration of critical habitat for Kootenai River white sturgeon.

Freshwater Fish Society of British Columbia (FFSBC). 2007. White Sturgeon Recovery Initiative: Efforts for Recovery. Kootenai River White Sturgeon Recovery Initiative. Accessed 19 July 2010 via http://www.gofishbc.com/Sturgeon.htm.

The FFSBC first gained experience in sturgeon conservation culture through its involvement with the KTOI (specifically for the culture of the trans-boundary sturgeon population in British Columbia) and the Kootenay River White Sturgeon Recovery Plan. In 1998, construction of the Kootenay White Sturgeon

Conservation Hatchery was completed at the Kootenay Trout Hatchery complex near Fort Steele. The FFSBC receives fertilized sturgeon eggs from the KTOI and the young fish are cultured for about a year, then are released into the Kootenai River in Idaho and Kootenay Lake.

Holderman, C., R. Hardy, P. Anders, H. Andrusak, K. Ashley, J. Hammond, B. Shafii. 2005. Kootenai River Ecosystem Project; An Ecosystem Approach to Evaluate and Rehabilitate a Degraded, Large Riverine Ecosystem, 2005-2004 Technical Report. Project No. 199404900, 269 electronic pages, (BPA Report DOE/BP-00004029-1).

This study was designed to identify limiting factors affecting fisheries and provide solutions to restore ecosystem complexity and function. Starting in 2000, an annual multi-trophic level investigation was initiated to determine system productivity below and above Libby Dam. Primary, secondary, tertiary trophic levels and nutrients were sampled spatially and temporally to determine if bottom-up nutrient limitation is detrimentally affecting the ecosystem. Very low levels of phosphorous and nitrogen have been found, suggesting ultra-oligotrophic conditions in some reaches. Chlorophyll a levels, macroinvertebrate, and salmonid densities are well below similar-sized regional rivers. Macroinvertebrate biomass, diversity, and fish condition factors are low and generally decline with increased distance from the dam. The fish community structure has shifted to feeding and spawning generalists. Kootenai River white sturgeon (Acipenser transmontanus), burbot (Lota lota) and several salmonid species (Oncorhynchus spp.), important to Kootenai Tribal and regional sport fisheries, are scarce relative to historical accounts. A large-scale, controlled, nutrient enhancement experiment is being considered by the Kootenai Tribe and Idaho Fish and Game to stimulate productivity in the Kootenai River starting in 2005.

Kruse, G. 2002. Kootenai River Focus Watershed Coordination. Project No. 1996-08702. BPA Report DOE/BP-00009996-1.

This report provides information about the Kootenai Watershed and its physical characteristics, and encapsulates the Focus Watershed Program. The primary goal of the Focus Watershed Program is facilitation, education, outreach and communication for various activities throughout the Kootenai River basin. Objectives and tasks completed include involving affected parties using knowledge of public scoping, meeting facilitation, mediation, dispute resolution and consensus building and working with agency staff to implement habitat enhancement projects for native fish species using knowledge of fluvial forms and processes, fish population dynamics and migrations, riparian botany and revegetation, land management practices (i.e. forestry, grazing, road-building and agriculture) and dam operation.

Kootenai River Habitat Restoration Project. 2011. Phase 2 Draft Concept Summaries.

The draft concept summaries is a collection of short analyses detailing existing conditions, proposed restoration treatments, feasibility considerations, and next steps for nine different potential restoration locations on the Kootenai River. Specific areas of interest are: the Straight Reach, Bonners Ferry Islands, North Side Channels, South Arm Kootenai, Braided 2 Meanders, Webber Slough/Crossport, Cow Creek, Phase 1B Extension, and Phase 1A Extension.

Kootenai River Network. 2006. Kootenai River Focus Watershed Coordination. 2003-2004 Annual Report. Project No. 199608702. 10 pp. BPA Report DOE/BP-00009996-3.

The Kootenai River Network (KRN) was contracted by the Bonneville Power Administration to provide Kootenai River basin watershed coordination services. Accomplishments include a Kootenai River Network Annual General Meeting in Bonners Ferry in May 2003 and the International Restoration Tour in July 2004, as well as coordinating several habitat, restoration, and monitoring projects and communication, education, and outreach efforts.

Kootenai Tribe of Idaho. 2010a. Kootenai River Habitat Restoration Project: Braided Reach 1, Phase 1 Feasibility Analysis and Preliminary Design. Bonners Ferry, ID. July 2010.

The Kootenai River Habitat Restoration Project is a large-scale ecosystem-based river habitat restoration project that will be implemented in a 55-mile reach of the Kootenai River, extending from the confluence of the Moyie and Kootenai Rivers, downstream to the international border. The project will be implemented in three sequenced phases: Phase 1 will begin in Braided Reach 1 and the existing spawning area in the Meander Reaches; Phase 2 will proceed downstream through Braided Reach 1, Braided Reach 2, and the Straight Reach; and Phase 3 will include work in Meander Reach 1 and Meander Reach 2. Additionally, two Continuing Authorities Program (CAP) Section 1135 projects implemented by the USACE in partnership with the KTOI, may be included under the umbrella of the Kootenai River Habitat Restoration Project: 1) the Shorty's Island/Meander Reach Ecosystem Restoration project (included as part of Phase 1), and 2) the Braided Reach Ecosystem Restoration Project (included as part of Phase 2).

The primary purpose of this document is to address feasibility and design issues necessary to move the proposed Braided Reach 1, Phase 1 projects forward to the next stage of feasibility analysis and design and to present the preliminary designs for the Phase 1a and 1b projects. The preliminary designs will be further refined into final designs based on additional feasibility analysis, regulatory requirements, and based on input received on the preliminary designs as a result of review of this document. Pending completion of final design, and all necessary permitting and environmental compliance requirements, implementation of the Braided Reach 1, Phase 1 projects is targeted to begin in late summer 2011.

Kootenai Tribe of Idaho (KTOI), Idaho Department Fish and Game (IDFG) and the International Kootenai/y Ecosystem Restoration Team (IKERT). 2009. Kootenai River Nutrient Restoration Project-Annual Implementation Report prepared by Cramer Fish Sciences, Anders, P. and R. Ericksen, Editors. 55 p.

This report contains conference call participants' contact information, action items, and meeting notes from five conference calls discussing the Kootenai River nutrient project. Conference calls took place on June 26, July 17, July 31, August 21, and October 2 of 2008. IKERT Nutrient Restoration Subcommittee members include Charlie Holderman (KTOI), Eva Schindler (BC MOES), Genny Hoyle (KTOI), Greg Hoffman (USACE), Hassen Yassien (Ward and Associates), Ken Ashley (GVRD, Ashley and Associates), Lee Watts (BPA), Paul Anders (CFS/UI), Peter Ward (Ward and Associates), Ryan Hardy (IDFG), Cathy Gidley (IDFG), Sue Ireland (KTOI), and Vaughn Paragamian (IDFG). Weekly water quality results from Aquatic Research Incorporated (ARI) Labs, phosphorous batch testing, and lists of permits and approvals for experimental Kootenai River nutrient addition are also included in Appendices 1 through 3, respectively.

Mallette, C., Editor. 2008. White sturgeon mitigation and restoration in the Columbia and Snake Rivers upstream from Bonneville Dam. Annual progress report (April 2006-March 2007) to the Bonneville Power Administration.

This paper reports the progress of determining the effects of mitigative measures on productivity of white sturgeon populations in the Columbia River downstream from McNary Dam, and on determining the status and habitat requirements of white sturgeon populations in the Columbia and Snake rivers upstream from McNary Dam. Reporting includes: 1) an update of abundance, life history parameters, and population dynamics of white sturgeon in Bonneville Reservoir, 2) a summary of annual recruitment of age-0 white sturgeon in four Columbia River reservoirs, 3) Progress on implementing the fisheries management component of the white sturgeon management plan, 4) Progress updates on young-of-the-year recruitment in Bonneville Reservoir and indices of white sturgeon spawning habitat for 2006 for McNary, John Day, The Dalles, and Bonneville dam tailrace spawning areas, 5) A summary of work for capture and mark efforts on white sturgeon in Bonneville Reservoir for population abundance estimates, and, 6) Progress update on the maturation cycle in wild white sturgeon.

Munson, B., V. Munson, and R. Rogers. 2003. Kootenai River Focus Watershed Coordination Annual Report 2002-03. Project No. 1996-08702 BPA Report DOE/BP-00009996-2.

This report provides information about the Kootenai Watershed and its physical characteristics, and reviews what the Focus Watershed Program accomplished during the contract period June 1, 2002 through May 30, 2003. Accomplishments include Coordination of activities of interest groups in the Kootenai River drainage related to watershed improvement and education and outreach, and maintaining a communication network among private and public groups in the Columbia River basin.

Tetra Tech, Inc. 2004b. Kootenai River Habitat and Ecosystem Restoration Strategies (HERS), Bonners Ferry, Idaho. Prepared for the U.S. Army Corps of Engineers, Seattle District. 12 July 2004.

The purpose of this report was to initiate a geomorphic assessment of the Kootenai River in order to support the determination of the potential options and their feasibility, to achieve improved and suitable Kootenai River white sturgeon spawning and rearing substrate in the lower Kootenai River, generally near and downstream of Bonners Ferry, Idaho. The issue of changes in substrate involves a variety of factors that need to be considered to both understand the possible problem as well as potential measures to improve conditions. This report presents an initial investigation into the substrate associated issues with a focus on fluvial geomorphic considerations.

Thornton, C.I., T.R. Rounsaville, and A.L. Cox. 2007. Substrate Enhancement Pilot Project for Improving White Sturgeon Spawning in the Kootenai River: Phase 3 Physical Modeling Data Report. Prepared by Colorado State University. Fort Collins, Colorado. Prepared for the Seattle District of the U.S. Army Corps of Engineers. Seattle, Washington. 119 p.

The study evaluated two artificial substrate configurations proposed to improve spawning habitat for white sturgeon in the Kootenai River near Shorty Island. The primary goal of the research program was to evaluate the long-term interaction of the substrate structures with the channel bed. In support of this goal, a testing program was implemented to evaluate dune movement and sedimentation. The dune movement analysis investigated the long-term stability of the structures, as well as impacts on the channel bed caused by the structures. Sedimentation analysis investigated the amount, and spatial variation of sand deposited within the substrate structures to determine if and where spawning habitat would be compromised. The secondary objective of this phase of physical modeling was to quantify the hydraulic changes induced by the substrate structures. Based on the study a variety of observations and conclusions were made concerning designing substrate structures that will perform well within the dune environment of the portion of the Kootenai River being considered for substrate augmentation.

Wildland Hydrology Consultants. 2008. Kootenai River Conceptual Design. Submission to the Kootenai Tribe of Idaho illustrating a potential approach to Kootenai River Habitat Restoration.

The proposed habitat restoration conceptual design addresses the causes and consequences of land use and changes and their effects on the fish populations. Makes recommendations to offset the limiting factors for specific fish and the causes of physical habitat and biological impairment. The design also addresses the physical characteristics to establish a stable balance between river morphology, and the variables that influence river processes. Objectives include: sustainable and self-maintaining river design, decrease flood stage, decrease streambank erosion, reconnect floodplains, reestablish riparian vegetation, maintain agricultural economic base, stable morphology, reduce risk to infrastructure, reduce land drainage problems, reduce maintenance costs, improve recreational opportunities, improve aesthetics.

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