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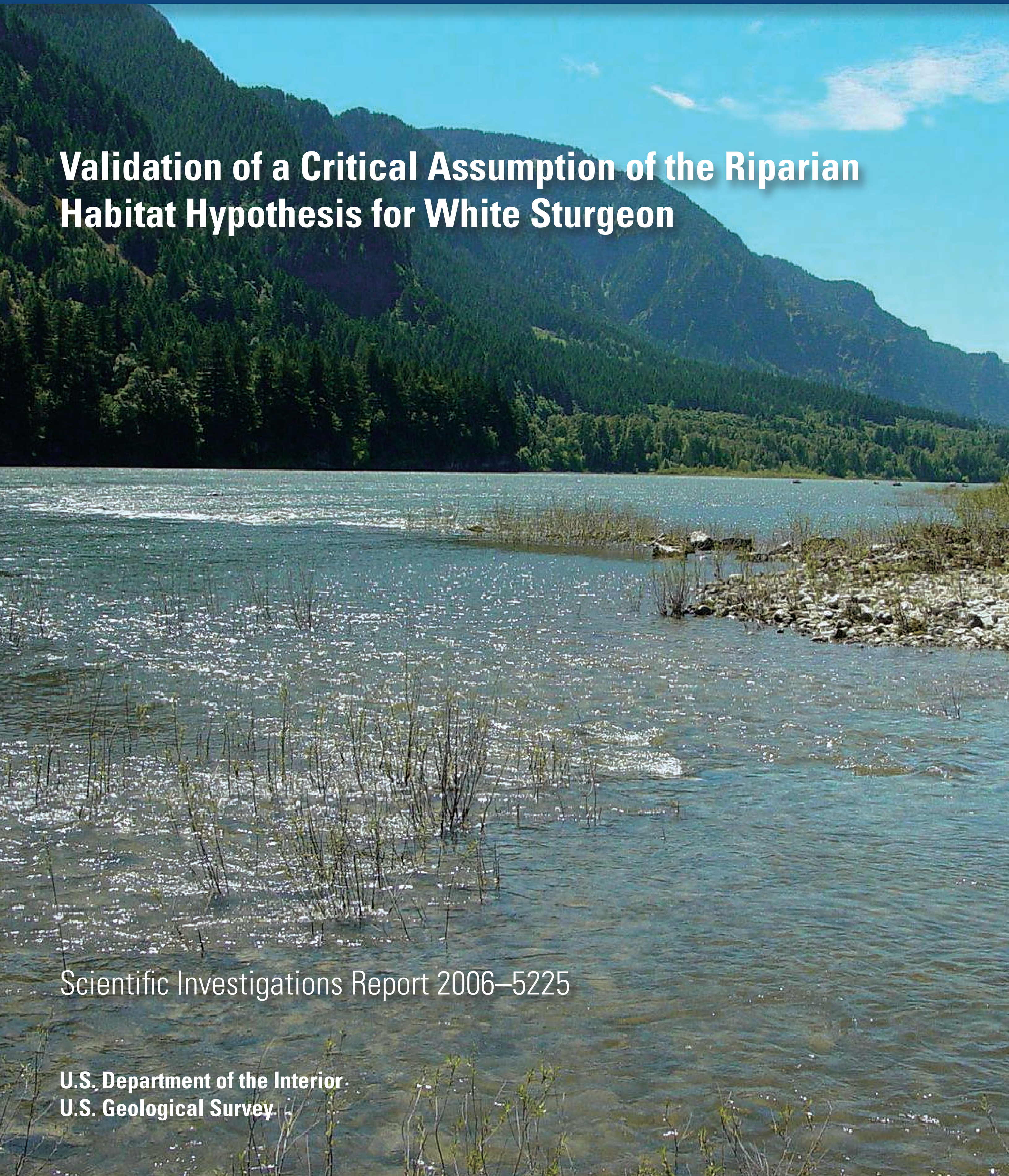

Validation of a Critical Assumption of the Riparian Habitat Hypothesis for White Sturgeon

Scientific Investigations Report 2006–5225

U.S. Department of the Interior
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Cover: Seasonally inundated riparian habitat downstream of Bonneville Dam at the head of Ives Island near North Bonneville, Washington.
(Photograph by Corey D. Wright, U.S. Geological Survey, June 2005.)

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B.K. van der Leeuw, M.J. Parsley, C.D. Wright, and E.E. Kofoot

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Conversion Factors

Multiply	By	To obtain
centimeter (cm)	0.3937	inch (in.)
cubic foot per second (ft^3/s)	0.0283	cubic meter per second (m^3/s)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	2.113	pint (pt)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
meter per second (m/s)	3.281	foot per second (ft/s)
kilogram (kg)	2.205	pound avoirdupois (lb)
thousand cubic feet per second ($k\times ft^3/s$)	0.0283	one thousand cubic meters per second ($k\times m^3/s$)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times °C)+32$$

Datums

Horizontal coordinate information is referenced to the World Geodetic System 1984 Datum (WGS 84).

Map projection format is Universal Transverse Mercator (UTM) Universal Polar Stereographic (UPS).

Universal Transverse Mercator (UTM) Zone is 10 North.

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Validation of a Critical Assumption of the Riparian Habitat Hypothesis for White Sturgeon

By Bjorn K. van der Leeuw, Michael J. Parsley, Corey D. Wright, and Eric E. Kofoot

Abstract

In June 2005, we confirmed that white sturgeon *Acipenser transmontanus* embryos, free embryos, and larvae could be found in shallow seasonally flooded riparian habitat in the Columbia River downstream of Bonneville Dam. This validates a critical assumption of the Coutant Riparian Habitat Hypothesis that during white sturgeon spawning, embryos are either deposited in, or transported to, seasonally flooded riparian habitat.

Sampling for early life stages of white sturgeon took place in the vicinity of Ives and Pierce islands using eight types of collection gear. A total of 1,372.9 hours of sampling was completed with 254 embryos, 6 free embryos, and 1 larva collected.

Surface substrates were characterized in August 2005 for 9 of the 21 sites where embryos, free embryos, and larvae were found. The sites characterized were composed of 0.35 percent fines, 53.56 percent gravel, 45.69 percent cobble, and 0.41 percent boulder.

Background and Objectives

White sturgeon populations vary considerably in abundance and age structure throughout the Columbia River Basin (Beamesderfer and others, 1995). The construction of a series of hydroelectric dams on the Columbia and Snake rivers has created functionally discreet populations of white sturgeon within the basin (North and others, 1993). The abundance and density of white sturgeon is greatest in the unimpounded river downstream of Bonneville Dam. This area supports one of the largest and most productive sturgeon populations in the world (DeVore and others, 1995). Conversely, the geologically isolated white sturgeon population from the Kootenai River has been listed as endangered since 1994. White sturgeon populations in the Snake River downstream from Hells Canyon Dam appear to be persisting, but at a lower abundance than prior to impoundment.

Prior to Coutant's (2004) promotion of the Riparian Habitat Hypothesis, variations in population status among areas had been attributed to a number of factors. In particular, construction and operation of hydroelectric dams on the Columbia and Snake rivers have directly affected white sturgeon populations in several ways. For example, fish cannot migrate up and down the river as they historically did (North and others, 1993), and areas of spawning habitat have been reduced (Parsley and Beckman 1994). Variations in population characteristics also have been attributed to differences in exploitation rates and recruitment success, access to marine food resources, and suitability of hydrologic conditions and available habitats (Beamesderfer and others, 1995; DeVore and others, 1995).

Coutant (2004) developed a hypothesis to explain variability in spawning success among white sturgeon populations. A critical assumption of the hypothesis is that white sturgeon embryos are either deposited in or transported to shallow seasonally flooded riparian habitat and adhere to newly wetted rocks and vegetation during incubation. He proposed that newly hatched free embryos (eleutheroembryos) remain in these shallow waters, hiding in crevices for protection from predation. When free embryos transition to exogenous feeding larvae, this riparian habitat would theoretically offer plentiful food. When water recedes with decreasing discharge, juvenile sturgeon would also retreat to deeper channels. This hypothesis is supported by findings from the unregulated lower Fraser River where white sturgeon embryos and larvae were collected in island complexes and side channels but not in the main channel (Perrin and others, 2003).

It is generally accepted that white sturgeon embryos and larvae can be found on the riverbed substrate in various water depths and habitats downstream of dams (Parsley and others, 1993; McCabe and Tracy 1994). Previous work in the Columbia River primarily investigated the timing and general location of white sturgeon spawning and did not focus on the occurrence of embryos or larvae in shallow riparian habitats. Parsley and others, (1993) and McCabe and Tracy (1994) collected embryos in depths of 4–27 m and 3–23 m, respectively. Accurate information concerning the spatial distribution of embryos and larvae downstream of hydroelectric dams is critical in assessing how construction and operation of dams may affect survival of early life stages of sturgeon.

If white sturgeon early life stages do occur in shallow riparian habitats, construction and operation of the federal hydropower system may affect survival and subsequent recruitment to age-1. In shallow areas, they could be susceptible to desiccation due to short-term fluctuations in water elevations resulting from daily dam operations. These short-term fluctuations are known to strand outmigrating anadromous salmonids (Tiffan and others, 2002) during the same time that white sturgeon are known to spawn, incubate, and hatch. The dampening of the seasonal river discharge by dams to reduce flooding and increase power generation in winter has also reduced the seasonal water level fluctuations in areas where backwater effects are minimal, and thus reduced availability of newly inundated riparian habitats. Further, white sturgeon populations as a whole may suffer from a loss of productivity due to the extensive loss of riparian habitat caused by impoundment and stabilization of water levels within reservoirs.

Objectives of this study were to (1) determine if white sturgeon embryos, free embryos, and larvae occur in seasonally inundated riparian habitats, and (2) characterize surface substrates at sites where embryos, free embryos, and larvae were found.

Study Site

Sampling was done in the Columbia River about four river kilometers (rkm) downstream of Bonneville Dam. All collection efforts were made near Pierce and Ives Islands (fig. 1), at rkm 228.5 and 229.3, respectively.

The Columbia River downstream of Bonneville Dam is recognized as good white sturgeon spawning habitat, with successful recruitment to age-0 occurring each year. White sturgeon embryos are found in the first 11 km downstream of Bonneville Dam during spawning season (McCabe and Tracy, 1994). In the lower Columbia River, spawning occurs when water temperatures range from 10 to 18°C (Parsley and others, 1993).

The Columbia River immediately downstream of Bonneville Dam is highly regulated by discharge of the dam. Water surface elevations at Ives and Pierce Islands closely follow the amount of discharge from Bonneville Dam with minimal (< 0.3 m) tidal influence. The flow in the side channel that runs between the islands and the Washington shore is only slightly affected by the inflow of Hamilton and Hardy Creeks.

Figure 1. Aerial view of the study site on the Columbia River, Oregon and Washington.

Methods

Terminology of Early Life Stages

We used the terms embryo, free embryo, and larva to describe white sturgeon early life stages detected during sampling. These terms are adapted from Balon (1975, 1984).

The term embryo is used to define the life period that begins at fertilization and ends at hatch. White sturgeon embryos gain nutrition endogenously. The free embryo period begins when an embryo hatches from its egg casing. At this stage sturgeon still receive all nutrition endogenously from a yolk sac. This period ends with the transition to exogenous feeding. The larval period for sturgeon begins with the start of exogenous feeding and ends when fins and organs are fully formed.

Eight types of collection gear were used to sample for embryos, free embryos, and larvae (table 1). Two gears, artificial substrates and plankton nets, are commonly used to collect early life stages of white sturgeon. In addition to these gears we used kick nets, suction devices, and a view scope to search for embryos, free embryos, and larvae among rock crevices and in vegetation where artificial substrates and plankton nets have not been used.

Collection efforts were made in various areas including the main channel of the Columbia River, the shallows on the main channel side of the islands, the shallows along the Oregon shore, and the side channel that runs between the islands and the Washington shore. The federal navigation channel was not sampled due to a high volume of commercial and recreational boat traffic. Figure 2 shows an overview of areas sampled.

Table 1. Collection gears and effort of each gear used for the capture of white sturgeon embryos, free embryos, and larvae in the Columbia River near Ives and Pierce Islands.

Gear	Effort (hours)	Stage collected		
		Embryo	Free embryo	Larvae
Artificial substrate	1,273.45	254	0	0
Plankton net				
Boat D-shaped	2.75	0	0	0
Staked D-shaped	46.53	0	0	1
Staked square	25.60	0	0	0
Bilge pump	.83	0	0	0
Kick net	22.42	0	6	0
Slurp gun	.58	0	0	0
View scope	.75	0	0	0

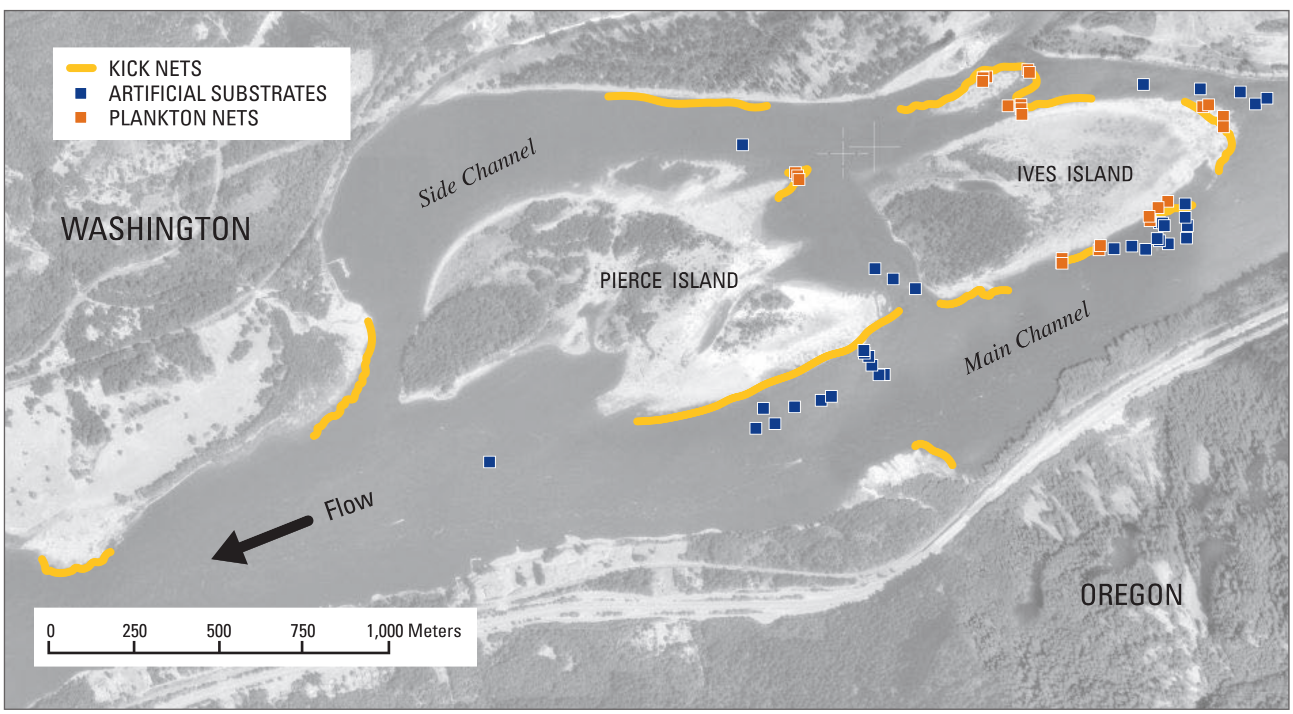

Figure 2. Study site, sampling areas, and collection gear types, Columbia River, Oregon and Washington.

White Sturgeon Early Life Stage Sampling

Artificial substrates based on McCabe and Beckman (1990) were deployed and retrieved from a 4.9-m aluminum johnboat. Individual 76 × 91-cm artificial substrates were placed on the river bottom parallel to the river current. Each artificial substrate was set individually with one claw anchor and a set of surface floats. A Global Positioning System (ETrex Legend®, Garmin International, Inc., Olathe, Kans.) waypoint was taken for the location of each artificial substrate. The water depth at the time of deployment was recorded for each substrate using the boat's depth sounder. After retrieval, artificial substrates were inspected visually and any embryos present were removed using forceps.

A 25 × 46-cm rectangular frame kick net (Watermark bottom aquatic kick net, Forestry Suppliers, Inc., Jackson, Miss.) with 500-micron mesh was used to sample for embryos, free embryos, and larvae in wadeable water. Kick net sampling was done by placing the long axis of the frame of the kick net on the substrate perpendicular to the river bottom. The substrate would then be disturbed directly upstream from the kick net (fig. 3). The nets also were repeatedly swept through inundated vegetation.

Plankton nets were used extensively during this study. Plankton nets were mounted in three configurations to sample both wadeable and non-wadeable water. Plankton nets were mounted on two differently shaped frames, D-shaped and square. The D-shaped net was fished with the flat side of the 'D' in contact with the river bottom. It measured 75 cm at its widest point and a maximum of 53 cm in height. The D-shaped plankton net was constructed of 2-mm knotless mesh. The square plankton net had a 50 × 50-cm frame with 500-micron mesh.

Wadeable water was sampled using D-shaped and square-framed plankton nets. The nets were staked into the substrate so the bottom of the frame was in contact with the substrate and the frame was perpendicular to the river bottom. Plankton nets were fished for variable time increments. Once staked into the substrate, plankton nets were visually monitored to assure they were fishing properly. After about 30 minutes of sampling, the collection cup of the plankton net was removed and the contents were poured into a 0.95-L glass jar. The collection cup was then reattached and the net was redeployed to continue sampling. The contents of the jar were visually inspected for the presence of white sturgeon embryos, free embryos, and larvae.

Non-wadeable water was sampled with D-shaped plankton nets. Two D-shaped plankton nets were simultaneously deployed from a 7.6-m aluminum boat anchored in the current. Each plankton net was weighted with two 9-kg lead balls on the bottom of the frame to facilitate the net reaching the substrate and being held in an upright position in the strong currents. The plankton nets were retrieved and checked after each one-half hour of sampling. The collection cup of the plankton net was removed and the sample was visually inspected for embryos, free embryos, and larvae.

Three gears were used less than one hour each and were minor components of the study. A manual bilge pump (Thirsty-mate® Hand Pump; West Marine, Watsonville, Calif.) was used to suction the interstitial spaces of the substrate. A slurp gun (Rick's Tackle, Long Beach, Calif.) was used in a similar manner as the bilge pump. A view scope (Aqua Scope II™; Lawrence Enterprises, Seal Harbor, Maine) was used to observe submerged vegetation for attached embryos.

Due to the various gears used, effort was measured in hours. The measurement of effort in hours acted as an estimation of effort and a relative comparison of use among gears, but was not an attempt to compare the effectiveness of gears or quantify the amount of habitat sampled.

River Environment

Data pertaining to river environment were collected from multiple sources. Elevation and flow data for Bonneville tailrace and Ives Island were taken from the Fish Passage Center website (Fish Passage Center, 2005). Temperature data for Ives Island was also obtained from the Fish Passage Center website (Fish Passage Center, 2005). The gage recording the Ives Island data was near the upriver terminus of the channel on the north side of Ives Island. Temperature data for the Bonneville tailrace were from the Columbia River Data Access in Real Time website (Columbia River Data Access in Real Time, 2005). Bonneville tailrace data were collected by a water-quality monitoring station near Cascade Island directly on the downstream side of the Bonneville Dam.

River environment data were collected during field sampling of all free embryo and larva capture sites. Depth was recorded using a top set wading rod (Swoffer Instruments, Inc., Seattle, Wash.). Temperature data were collected using a YSI handheld water-quality meter (Model 85D, YSI, Inc., Yellow Springs, Ohio) Velocity measurements were made with a Swoffer direct reading current velocity meter (Model 2200, Swoffer Instruments, Inc., Seattle, Wash.) attached to a Price AA bucket wheel. Six velocity readings were taken over a one-minute period and then averaged to obtain a composite velocity for each capture site.

Embryo, Free Embryo, and Larva Staging

Embryos, free embryos, and larvae captured during field sampling were immediately placed in sample vials containing 95 percent ethanol. After about one month, the alcohol was removed from the samples and replaced with a 10 percent solution of formalin. After a minimum one-month fixation in formalin the samples were drained and then filled with 70 percent ethanol. During the process of switching mediums of preservation, the sample vials were filled with distilled water for 10 minutes and then drained to remove any latent residues.

Figure 3. Sampling with kick nets at the head of Ives Island, downstream of Bonneville Dam. Flooded vegetation is predominantly Pacific willow *Salix lasiandra*. Photographs show the type of habitat where free embryos were collected.

Embryos, free embryos, and larvae were inspected using a dissecting microscope. Each embryo was assigned a numbered stage of development based on Beer (1981). Free embryos and larvae were assigned a stage of development in days post-hatch based on Beer (1981).

Substrate Characterization

During August 2005, riverbed substrates were characterized at sites where embryos, free embryos, and larvae were collected. Grid counts (Bunte and Abt, 2001) were used to sample surface substrates for characterization. A 120 × 120-cm portable sampling frame was used to randomly select substrate particles for measurement. Substrate particles that were directly underneath each intersection of the grid were measured using a gravelometer. The grid spacing of the sampling frame was 13.2 cm. The sampling frame grid contained 64 intersections (fig. 4).

A Global Positioning System receiver was used to navigate to the sites in which early life stages were captured during the June sampling period. At each site the portable sampling frame was laid upon the substrate. At each site, 128–137 (mean = 130) substrate particles were measured, therefore, the sampling frame had to be placed a minimum of twice at each site. When a particle was large enough to be contacted by two intersections of the sampling grid it was measured only once. In this case, the sampling frame would be laid down a third time to make up for particles that could be measured only once because they were touched by two grids. When it was necessary to lay the sampling frame down a third time, a random number from 1 to 8 was chosen along with a random side from which to start the measurements. This random number combination would determine from which transect of the grid the particles would be measured.

A. Site 47. Larval capture site

B. Site 18. Embryo capture site

Figure 4. Sampling frame laid over substrates during August 2005 at Ives Island.

A US SAH-97 hand-held particle size analyzer (commonly known as a gravelometer) was used to measure the b-axis of each particle. The US SAH-97 has 14 square holes that range from 2 to 180 mm. Particles greater than 180 mm were measured with a ruler built into the side of the gravelometer. Each substrate particle measured was put into one of 16 size classes. The smallest classification for a particle-size class is fines (< 2 mm) and the largest is boulder (≥ 256 mm). Each particle was measured individually based on which hole it could fit through in the gravelometer. Particles were tallied to create a size class percentage frequency of each sample. A complete guide for using the US SAH-97 particle-size analyzer is outlined in Potyondy and Bunte (2002).

Results

Sampling Gears

Three of the eight sampling gears collected white sturgeon embryos, free embryos, or larvae (table 1). Artificial substrates were successful in collecting white sturgeon embryos. They were fished for a total of 1,273.45 hours. Kick nets were used for 22.42 hours and were effective in capturing white sturgeon free embryos. One larva was collected during the 46.53 hours that staked D-shaped plankton nets were fished.

The bilge pump, slurp gun, and the view scope were all used less than one hour and did not collect early life stages of sturgeon. D-shaped plankton nets deployed from a boat were fished 2.75 hours and did not capture embryos or larvae except for one fungus-covered sturgeon embryo that was not counted in the total. Square-shaped plankton nets that were staked into the substrate were fished for 25.60 hours and did not capture embryos or larvae.

White Sturgeon Embryos

All white sturgeon embryos detected during field sampling were collected on artificial substrates. A total of 254 viable embryos were collected. An additional 23 dead or damaged embryos were collected, but were not included in the total.

Samples were collected with artificial substrates during June 6-10 and 13-17, 2005. Artificial substrates were not set during the weekend of June 11-12, 2005, due to increased recreational boat traffic. A total of 33 sets were completed accounting for 1,273.45 hours of effort. Artificial substrates had a mean soak time of 38 hours and 35 minutes (range 22:20–48:30). White sturgeon embryos were collected in 17 of 33 artificial substrate sets (fig. 5), whereas 15 sets resulted in no catch of sturgeon embryos and one set captured only two dead embryos. Appendix 1 lists all embryo capture sites.

The average set depth of the 17 artificial substrates that captured embryos was 2.15 m (range = 0.61–3.35), however variations in river discharge continuously altered depths.

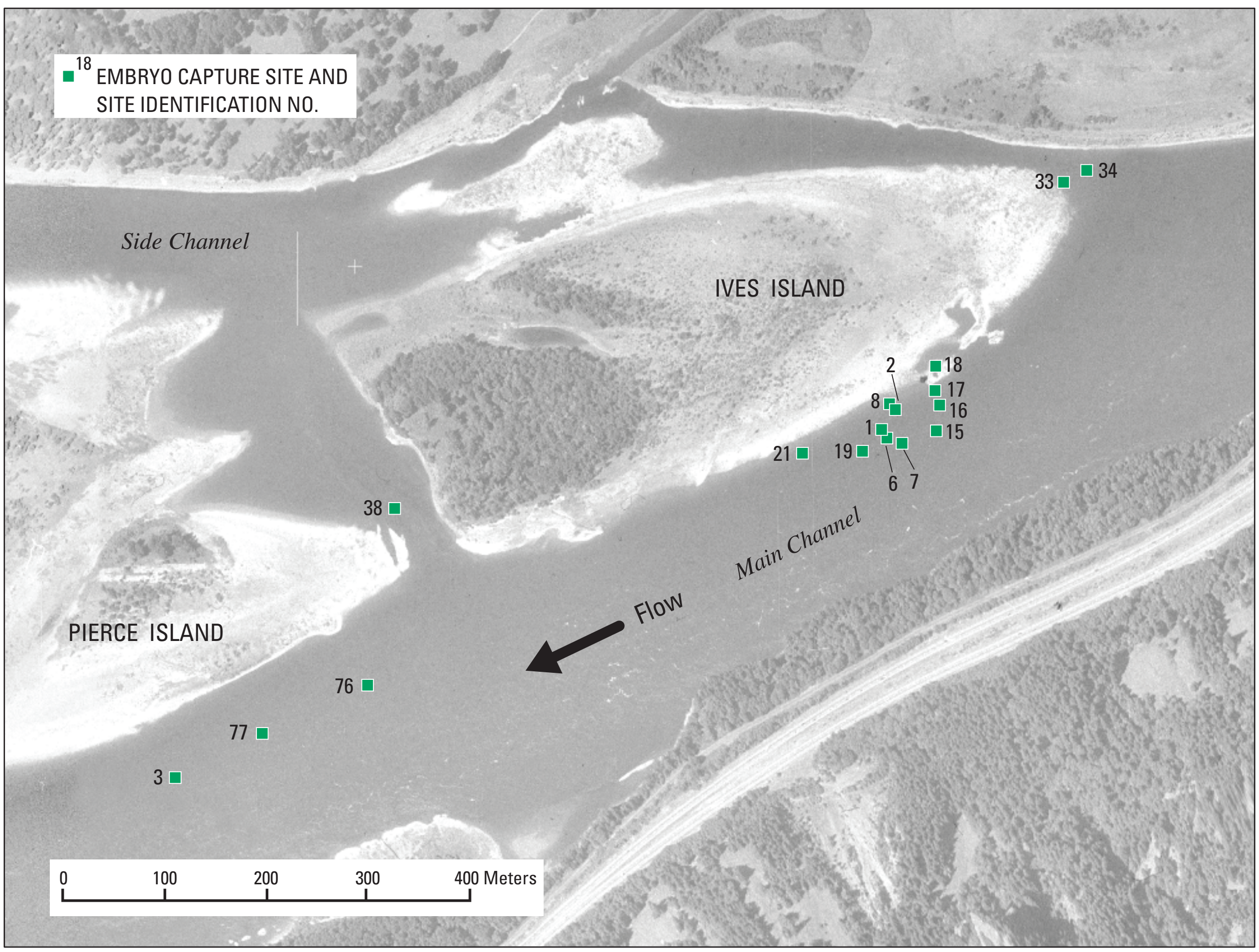

Figure 5. Artificial substrates sites where white sturgeon embryos were collected, Columbia River near Ives and Pierce Islands.

The mean water temperature during the sampling period of artificial substrates, as measured downstream of Bonneville Dam at Cascade Island (Columbia River Data Access in Real Time, 2005), was 15.9°C (range = 15.4–16.4°C).

Based on embryological development stages outlined in Beer (1981) we collected embryos that were from stage two (changing pigmentation) to stage 13 (early neurulation). Stage one (unfertilized) eggs were not captured during sampling. An additional four stages occur after early neurulation and prior to hatching, but we did not detect any embryos from these stages. The most prevalent stage collected was stage six (fourth through sixth cleavage), with 78 of the 254 embryos from this stage. Table 2 presents a complete outline of embryos collected and staged during this study.

White Sturgeon Free Embryos and Larvae

The presence of white sturgeon free embryos and larvae in shallow wadeable habitat was confirmed near Ives Island downstream of Bonneville Dam. Six 0-1 day post-hatch free embryos were captured on June 8-9, 2005, using kick nets at sites 22, 31, and 32 at the head of Ives Island (fig. 6). Free embryos at this stage are in “hiding phase” (Brannon and others, 1985) exemplified by low mobility due to the presence of a large yolk sac and the lack of developed fins. The free embryos were detected at water depths of 0.31–0.70 m within the interstitial spaces among the cobble/gravel substrate that is the dominant riverbed matrix of the nearshore environment of Ives Island. The temperature range was 15.9 to 16.0°C at the time of capture for free embryos. Composite velocities of 1.38, 2.50, and 1.50 m/s were measured at free embryo capture sites 22, 31, and 32, respectively.

One white sturgeon larva was captured (site 47; fig. 6) in a water depth of 0.59 m on June 14, 2005, in a D-shaped plankton net anchored to the substrate. This larva was estimated to be 10 days post-hatch and would have been exogenously feeding. The temperature at the capture site was 16.7°C. A composite velocity of 0.88 m/s was measured at the capture site. Appendix 1 lists all free embryo and larval capture locations.

Substrate Characterization

In August 2005, substrate composition characterization was completed for some of the sites where white sturgeon early life stages were captured. Substrate sampling in August, after water levels dropped, allowed easy access to many sites that would have been difficult to sample during the high flows of June. However 12 sites were still too deep to be effectively sampled by wading with a sampling frame. Grab samplers were considered, but cobbles and boulders would make such sampling devices ineffective.

Substrates were characterized at 9 sites, including 5 of the 17 sites where at least one white sturgeon embryo was collected and all 4 sites where free embryos and larvae were captured. The combined percentage frequency averages for all 9 sites characterized were: 0.35 percent fines, 53.56 percent gravel, 45.69 percent cobble, and 0.41 percent boulder. The combined percentage frequency averages for the five embryo sites characterized were: 0.00 percent fines, 52.88 percent gravel, 46.39 percent cobble, and 0.73 percent boulder. The combined percentage frequency averages for the three free embryo and one larva sites characterized were: 0.78 percent fines, 54.40 percent gravel, 44.82 percent cobble, and 0.00 percent boulder. Detailed information about each site is presented in Appendix 2. Data and plots for substrates are based on methods outlined in Potyondy and Bunte (2002).

Table 2. White sturgeon embryos collected in the Columbia River near Ives and Pierce Islands.

[Numbers represent embryos collected at all sites combined. Embryos are divided into stages based on Beer (1981)]

Stage	Stage name	No. of eggs
1	Unfertilized egg	0
2	Changing pigmentation	55
3	First cleavage	3
4	Second cleavage	6
5	Third cleavage	13
6	Fourth through sixth cleavage	78
7	Late cleavage	38
8	Early epithelial	17
9	Late epithelial	10
10	Involution	22
11	Large yolk plug	51
12	Small yolk plug	1
13	Early neurulation	10
Mort	Damaged or dead embryo	23

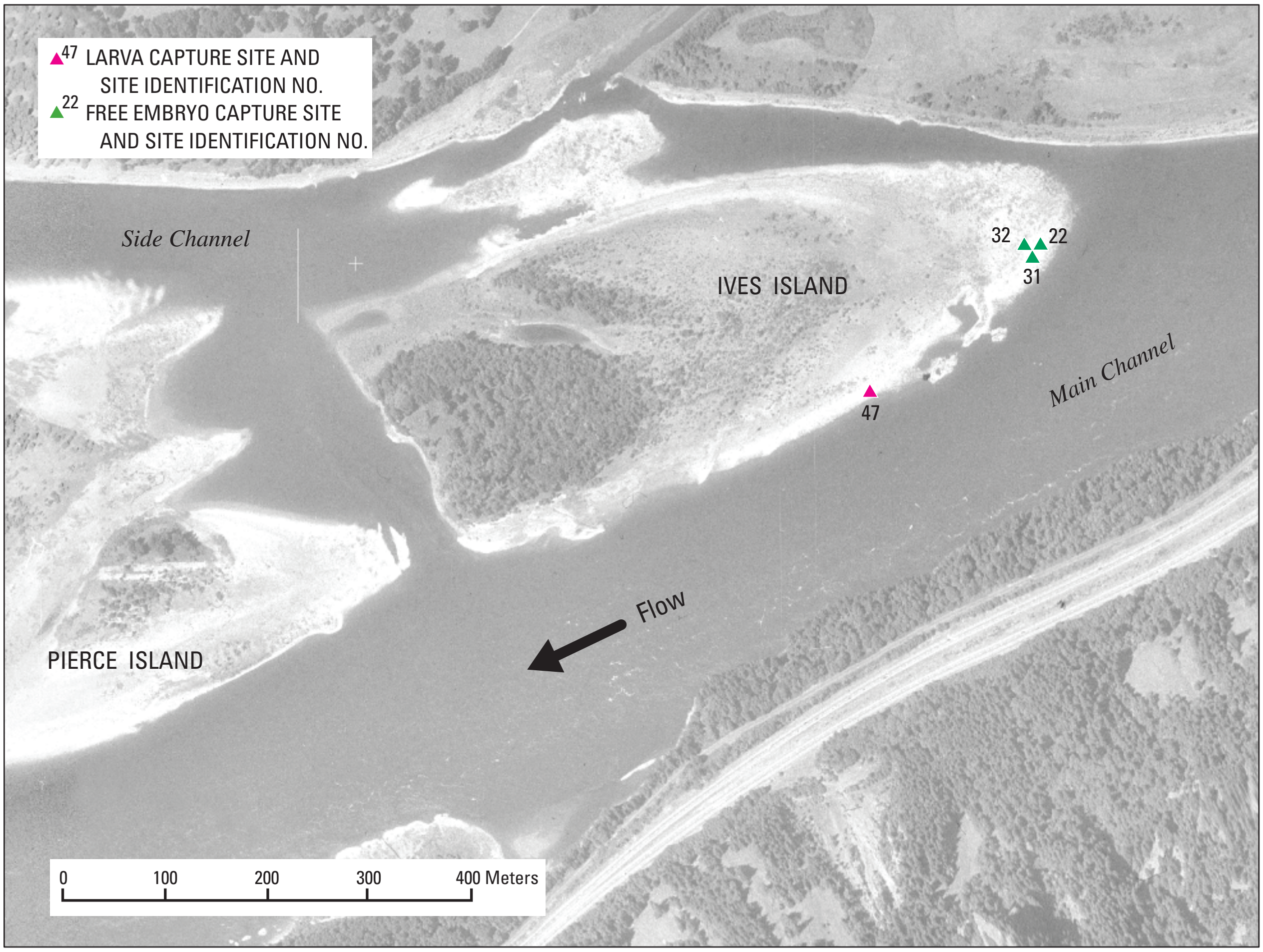

Figure 6. Capture sites where white sturgeon free embryos and larva were collected, Columbia River at Ives Island.

Discussion

Through field sampling we proved that white sturgeon embryos, free embryos, and larvae are present in shallow water adjacent to spawning areas, confirming a critical assumption of the Coutant (2004) Riparian Habitat Hypothesis. While we did not attempt to test the hypothesis itself—that the presence of riparian habitat is critical to the success of white sturgeon populations—we did prove that some proportion of the eggs, free embryos, and larvae can be found in inundated riparian habitats. The high water velocities characteristic of this white sturgeon spawning area are likely to disperse embryos and free embryos throughout the river channel, with some ultimately settling near the shoreline in shallow water. The free embryos detected by kick netting at the head of Ives Island were able to enter interstitial spaces among the gravels and cobbles to keep from being washed further downstream.

Potential for Dewatering Early Life Stages

These findings raise concerns that water level fluctuations caused by load-following operations at Bonneville Dam or other hydropower system related operations could dewater these early life stages. Water-surface elevation gages at Bonneville Dam and near Ives Island (Fish Passage Center, 2005; Columbia River Data Access in Real-Time, 2005) reveal that water elevations in this area can decrease more than 1 m during a 24-hour period (fig. 7).

Embryos that adhere to the substrate in shallow areas will incubate about 4–10 days before hatching. Thus, the potential for dewatering is related to the original depth at which the embryos attach as well as seasonal and short-term cyclical fluctuations in water levels. If embryos happen to attach to the riverbed during a period of daily cyclical high water elevation, the risk for dewatering increases, particularly if the seasonal hydrograph is declining. However, if embryos adhere to the

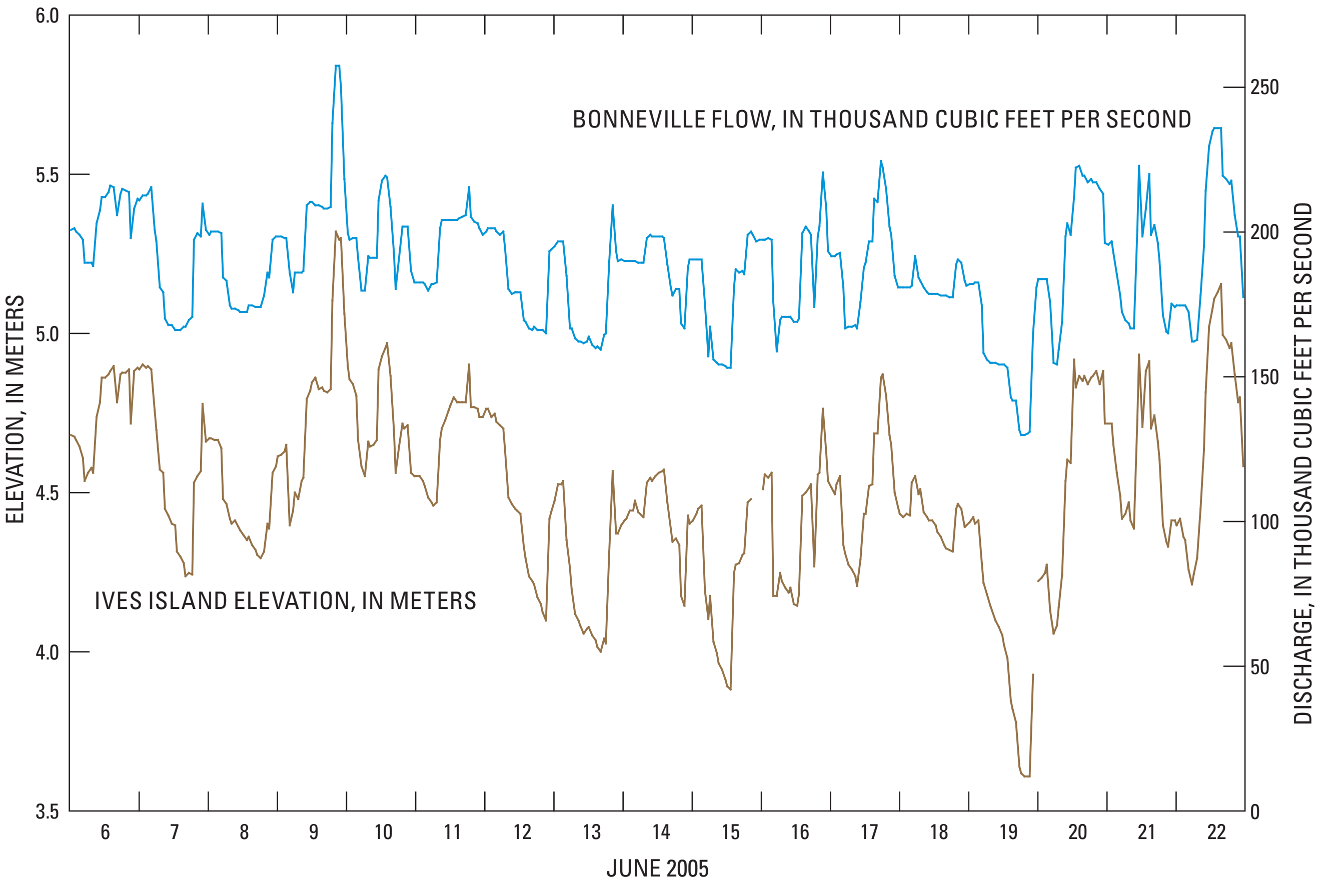

Figure 7. Water elevation at Ives Island and river discharge at the Bonneville Dam tailrace measured during the June 2005 sampling period. Discharge is reported in cubic feet per second x 1,000 (ft^3/s) for consistency with common reporting of Columbia River flows.

riverbed during the ascending limb of a seasonal hydrograph, the water depth over the incubation site may continue to increase despite daily fluctuations in water surface elevation caused by tides or hydropower operations.

In this study, embryos were collected on five artificial substrates that were set in less than 1.5 m of water. The potential for dewatering at these capture locations was evaluated by assessing the difference in water elevations between the set time of the artificial substrates and an estimate of when the embryos would have hatched. According to Deng and others (2002), white sturgeon embryos hatch in about 7 days at water temperatures of 16°C. Table 3 shows that although none of the locations sampled were dewatered during the embryo incubation period, water depth at two sites dropped to less than 0.17 m. Embryos in very shallow water may be exposed to fluctuating water temperatures and reduced water velocities may deprive eggs of oxygen, increase the chance of fungal growth, and increase risk of predation. After hatch, white sturgeon free embryos are dispersed by the river currents before settling to the river bottom. After absorbing their yolk sac, they emerge from the interstitial spaces of the substrate and disperse downstream as larvae. In this study, free embryos and the single larva captured were found in areas where the water depths were 0.31–0.70 m. These areas were shallower than areas where embryos were collected. Thus, these older stages may be more susceptible to dewatering.

Table 4 shows that the site where the single larva was captured was dewatered within 24 hours and that the water depth at another site where a free embryo was captured dropped to 0.06 m. Figure 8 shows that all sites where free embryos and the larva were captured were dewatered for short periods within days. Since these early life stages are more mobile than the adhesive embryos, they may be able to avoid dewatering by moving to deeper areas or by remaining within interstitial spaces among gravels and cobbles that retain water.

The sampling we conducted specifically targeted near shore habitats. Research has not been undertaken to systematically sample all depths downstream of a white sturgeon spawning area to describe the spatial distribution of spawned embryos within the river channel. Further research should be done to determine the distribution of white sturgeon early life stages throughout the river channel to characterize the role of permanently wetted versus seasonally inundated habitats.

Laboratory studies should be performed to test the ability of white sturgeon embryos, free embryos, and larvae to withstand dewatering. If white sturgeon embryos, free embryos, and larvae are regularly present in shallow water habitat, it can be reasoned that water level fluctuations due to load following at hydroelectric dams may have an adverse effect on the growth and survival of these early life stages. Experiments should investigate the influence of duration of dewatering and effects of fluctuating water temperatures on survival and growth of young fish.

Table 3. Collection data and water elevations associated with embryos collected on artificial substrates set in less than 1.5 meters of water near Ives Island.

[**Ives Island water elevation: Collection**, water elevation at the time an artificial substrate was set; **Minimum**, minimum water elevation recorded within 168 hours (7 days) post set time; **Difference**, difference between collection elevation and minimum elevation. **Depth: Collection**, water depth in which artificial substrate was set; **Minimum**, water depth embryo would be exposed to at minimum water elevation]

Collection			Ives Island water elevation (meters)			Depth (meters)	
Site	Set date	Set time	Collection	Minimum	Difference	Collection	Minimum
8	06-07-2005	11:20	4.40	4.00	0.40	0.91	0.51
18	06-08-2005	12:09	4.37	3.89	.48	.61	.13
21	06-08-2005	13:32	4.35	3.88	.47	1.22	.75
33	06-13-2005	10:16	4.06	3.61	.45	.61	.16
34	06-13-2005	10:28	4.06	3.61	.45	.91	.46

Table 4. Capture data and Ives Island water elevations associated with free embryo and larval white sturgeon captured near Ives Island.

[**Stage:** numbers of specimens of each stage collected are in parentheses. **Ives Island water elevation: Capture**, water elevation at time of capture; **Minimum**, minimum water elevation recorded within 24 hours post-capture; **Difference**, maximum decrease in water elevation within 24 hours post-capture. **Depth: Capture**, water depth measured at time of capture; **Minimum**, water depth at each site within 24 hours post-capture]

Stage	Capture			Ives Island water elevation (meters)			Depth (meters)	
	Site	Date	Time	Capture	Minimum	Difference	Capture	Minimum
Free embryo (4)	22	06-08-2005	14:25	4.36	4.29	0.07	0.31	0.24
Free embryo (1)	31	06-09-2005	13:07	4.86	4.55	.31	.70	.39
Free embryo (1)	32	06-09-2005	13:07	4.86	4.55	.31	.37	.06
Larva (1)	47	06-14-2005	13:25	4.57	3.88	.69	.59	-.10

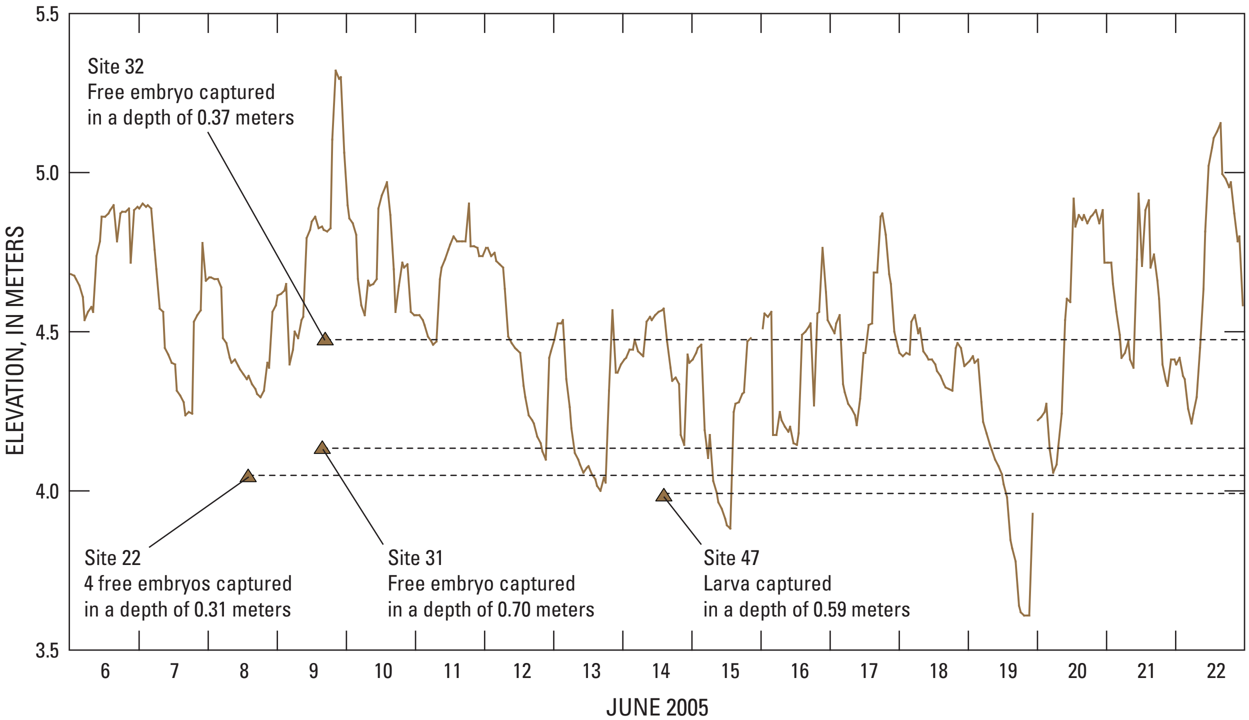

Figure 8. Water elevation changes at Ives Island and depths at free embryo and larvae capture sites. Horizontal dashed lines indicate minimum water surface elevations needed to maintain water over capture sites. All sites were dewatered for short periods after free embryos or larvae were captured. Site 47 was dewatered less than 24 hours after one larva was captured there.

Acknowledgments

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Appendixes

Appendix 1. Geographic coordinates for white sturgeon early life stage collection sites.

[Map datum is WGS 84, UTM Zone 10N. **Capture:** for embryo sites: date/time an artificial substrate was retrieved; for free embryos and larvae: date/time collection gear was checked and the presence of white sturgeon noted]

Site	Latitude	Longitude	Life stage	No. collected	Capture	
					Date	Time
1	45.62258271	-121.9892485	Embryo	31	06-07-2005	09:55
2	45.62289954	-121.9889513	Embryo	5	06-07-2005	10:20
3	45.61771374	-121.0038865	Embryo	2	06-07-2005	11:35
6	45.62254046	-121.9891958	Embryo	1	06-08-2005	11:25
7	45.62241121	-121.9888307	Embryo	23	06-08-2005	11:00
8	45.62297238	-121.9890932	Embryo	1	06-08-2005	12:29
15	45.62257919	-121.9881090	Embryo	131	06-10-2005	09:20
16	45.62292762	-121.9880778	Embryo	8	06-10-2005	10:09
17	45.62313231	-121.9881475	Embryo	13	06-10-2005	10:23
18	45.62350572	-121.9881395	Embryo	2	06-10-2005	10:26
19	45.62229428	-121.9896724	Embryo	30	06-10-2005	10:50
21	45.62228238	-121.9908966	Embryo	1	06-10-2005	11:09
22	45.62495504	-121.9863766	Free embryo	4	06-08-2005	14:25
31	45.62489829	-121.9864324	Free embryo	1	06-09-2005	13:07
32	45.62493341	-121.9865616	Free embryo	1	06-09-2005	13:07
33	45.62611006	-121.9854349	Embryo	1	06-15-2005	09:30
34	45.62628692	-121.9849599	Embryo	1	06-15-2005	09:51
38	45.62157528	-121.9993039	Embryo	1	06-15-2005	11:23
47	45.62309953	-121.9894973	Larva	1	06-14-2005	13:25
76	45.61899584	-121.9999048	Embryo	2	06-17-2005	09:46
77	45.61831858	-122.0021020	Embryo	1	06-17-2005	10:24

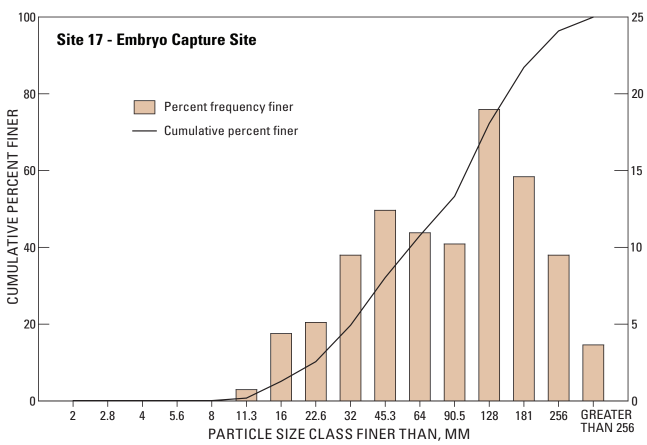
Appendix 2. Substrate data and frequency graph by site.

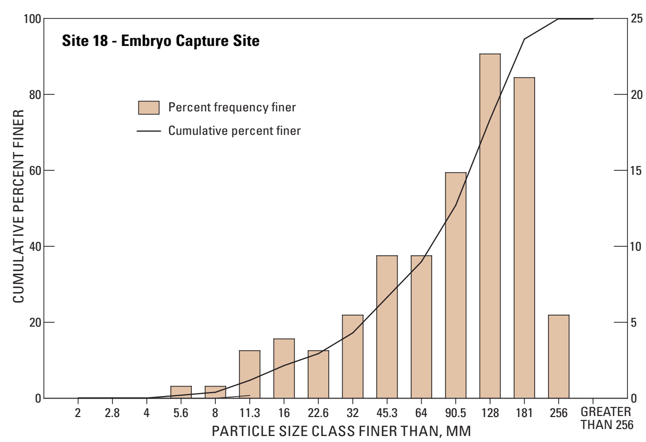
[**Site:** 17.
Date: 08-16-2005.
Type of site: Embryo.
Location description: Ives Island, upper main channel, water's edge.
Substrate description: Cobble, gravel, boulder, periphyton covered.
Vegetation description: Absent.
GPS: Lat/Long. UTM Zone 10N. WGS 84.
Waypoint: 45.62313231 -121.9881475]

Class name	Size class (millimeter)	No. of particles	Percent frequency	Cumulative percent finer
Fines	<2.0	0	0.00	0.00
Very fine gravel	<2.8	0	.00	.00
Very fine gravel	<4.0	0	.00	.00
Fine gravel	<5.6	0	.00	.00
Fine gravel	<8.0	0	.00	.00
Medium gravel	<11.3	1	.73	.73
Medium gravel	<16.0	6	4.38	5.11
Coarse gravel	<22.6	7	5.11	10.22
Coarse gravel	<32.0	13	9.49	19.71
Very coarse gravel	<45.3	17	12.41	32.12
Very coarse gravel	<64.0	15	10.95	43.07
Small cobble	<90.5	14	10.22	53.28
Small cobble	<128	26	18.98	72.26
Large cobble	<181	20	14.60	86.86
Large cobble	<256	13	9.49	96.35
Boulder	≥256	5	3.65	100.00
Total		137	100.00	

[**Site:** 18.
Date: 08-16-2005.
Type of site: Embryo.
Location description: Upper Ives Island, main channel side.
Substrate description: Cobble, gravel, some boulders, dry periphyton near pool of standing water.
Vegetation description: Absent.
GPS: Lat/Long, UTM Zone 10N, WGS 84.
Waypoint: 45.62350572 -121.9881395]

Class name	Size class (millimeter)	No. of particles	Percent frequency	Cumulative percent finer
Fines	<2.0	0	0.00	0.00
Very fine gravel	<2.8	0	.00	.00
Very fine gravel	<4.0	0	.00	.00
Fine gravel	<5.6	1	.78	.78
Fine gravel	<8.0	1	.78	1.56
Medium gravel	<11.3	4	3.13	4.69
Medium gravel	<16.0	5	3.91	8.59
Coarse gravel	<22.6	4	3.13	11.72
Coarse gravel	<32.0	7	5.47	17.19
Very coarse gravel	<45.3	12	9.38	26.56
Very coarse gravel	<64.0	12	9.38	35.94
Small cobble	<90.5	19	14.84	50.78
Small cobble	<128	29	22.66	73.44
Large cobble	<181	27	21.09	94.53
Large cobble	<256	7	5.47	100.00
Boulder	≥256	0	.00	100.00
Total		128	100.00	

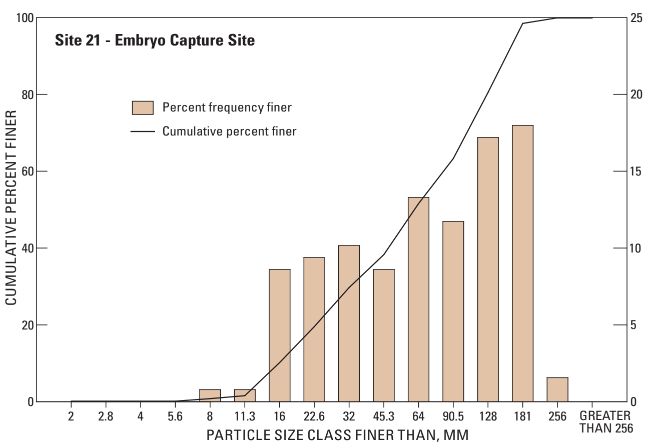




Appendix 2. Substrate data and frequency graph by site.—Continued

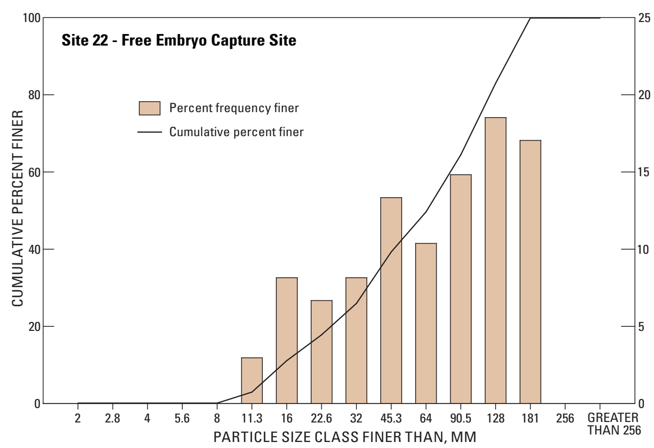
[**Site:** 21.
Date: 08-16-2005.
Type of site: Embryo.
Location description: Ives Island middle, main channel side, 0.6–0.9 meters of water.
Substrate description: Cobble, gravel, some boulder, periphyton covered.
Vegetation description: Absent.
GPS: Lat/Long, UTM Zone 10N, WGS 84.
Waypoint: 45.62228238 -121.9908966]

Class name	Size class (millimeter)	No. of particles	Percent frequency	Cumulative percent finer
Fines	<2.0	0	0.00	0.00
Very fine gravel	<2.8	0	.00	.00
Very fine gravel	<4.0	0	.00	.00
Fine gravel	<5.6	0	.00	.00
Fine gravel	<8.0	1	.78	.78
Medium gravel	<11.3	1	.78	1.56
Medium gravel	<16.0	11	8.59	10.16
Coarse gravel	<22.6	12	9.38	19.53
Coarse gravel	<32.0	13	10.16	29.69
Very coarse gravel	<45.3	11	8.59	38.28
Very coarse gravel	<64.0	17	13.28	51.56
Small cobble	<90.5	15	11.72	63.28
Small cobble	<128	22	17.19	80.47
Large cobble	<181	23	17.97	98.44
Large cobble	<256	2	1.56	100.00
Boulder	≥256	0	.00	100.00
Total		128	100.00	



[**Site:** 22.
Date: 08-12-2005.
Type of site: Free embryo.
Location description: Upper Ives Island, main channel side, dry land site in August.
Substrate description: Cobble, gravel, dry periphyton covered.
Vegetation description: Sparse, edge of willows.
GPS: Lat/Long, UTM Zone 10N, WGS 84.
Waypoint: 45.62495504 -121.9863766]

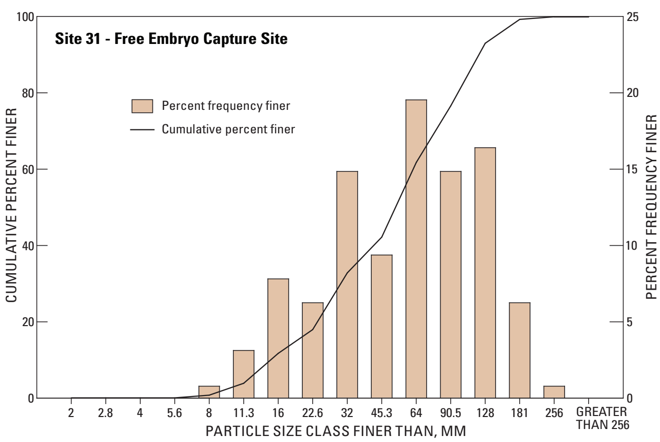
Class name	Size class (millimeter)	No. of particles	Percent frequency	Cumulative percent finer
Fines	<2.0	0	0.00	0.00
Very fine gravel	<2.8	0	.00	.00
Very fine gravel	<4.0	0	.00	.00
Fine gravel	<5.6	0	.00	.00
Fine gravel	<8.0	0	.00	.00
Medium gravel	<11.3	4	2.96	2.96
Medium gravel	<16.0	11	8.15	11.11
Coarse gravel	<22.6	9	6.67	17.78
Coarse gravel	<32.0	11	8.15	25.93
Very coarse gravel	<45.3	18	13.33	39.26
Very coarse gravel	<64.0	14	10.37	49.63
Small cobble	<90.5	20	14.81	64.44
Small cobble	<128	25	18.52	82.96
Large cobble	<181	23	17.04	100.00
Large cobble	<256	0	.00	100.00
Boulder	≥256	0	.00	100.00
Total		135	100.00	



Appendix 2. Substrate data and frequency graph by site.—Continued

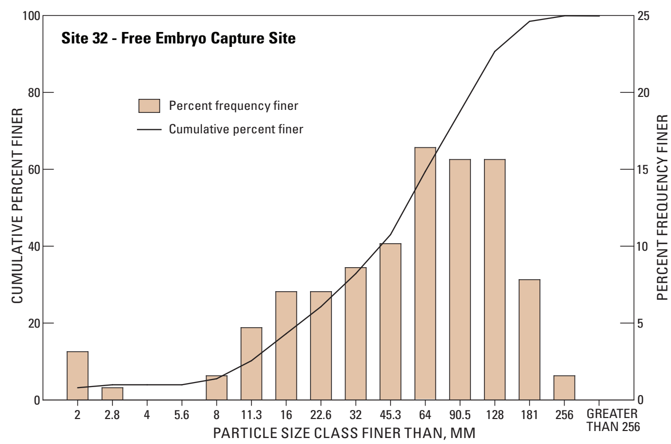
[**Site:** 31.
Date: 08-12-2005.
Type of site: Free embryo.
Location description: Upper Ives Island, main channel side, dry land site in August.
Substrate description: Cobble, gravel, dry periphyton covered.
Vegetation description: Moderate coverage, willows.
GPS: Lat/Long, UTM Zone 10N, WGS 84.
Waypoint: 45.62489829 -121.9864324]

Class name	Size class (millimeter)	No. of particles	Percent frequency	Cumulative percent finer
Fines	<2.0	0	0.00	0.00
Very fine gravel	<2.8	0	.00	.00
Very fine gravel	<4.0	0	.00	.00
Fine gravel	<5.6	0	.00	.00
Fine gravel	<8.0	1	.78	.78
Medium gravel	<11.3	4	3.13	3.91
Medium gravel	<16.0	10	7.81	11.72
Coarse gravel	<22.6	8	6.25	17.97
Coarse gravel	<32.0	19	14.84	32.81
Very coarse gravel	<45.3	12	9.38	42.19
Very coarse gravel	<64.0	25	19.53	61.72
Small cobble	<90.5	19	14.84	76.56
Small cobble	<128	21	16.41	92.97
Large cobble	<181	8	6.25	99.22
Large cobble	<256	1	.78	100.00
Boulder	≥256	0	.00	100.00
Total		128	100.00	



[**Site:** 32.
Date: 08-12-2005.
Type of site: Free embryo.
Location description: Upper Ives Island, main channel side, dry land site in August.
Substrate description: Cobble, gravel, dry periphyton covered.
Vegetation description: Heavy coverage, willows.
GPS: Lat/Long, UTM Zone 10N, WGS 84.
Waypoint: 45.62493341 -121.9865616]

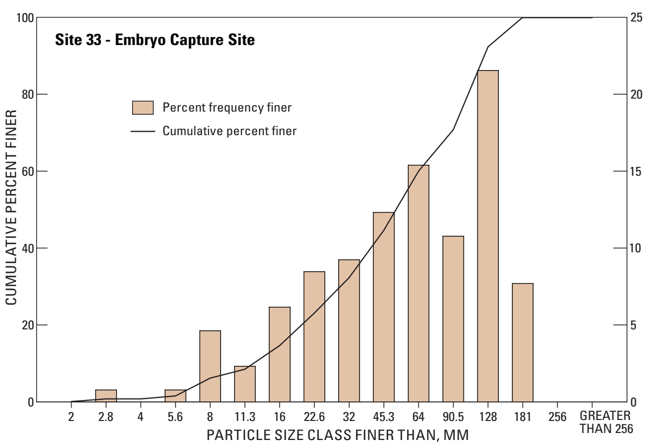
Class name	Size class (millimeter)	No. of particles	Percent frequency	Cumulative percent finer
Fines	<2.0	4	3.13	3.13
Very fine gravel	<2.8	1	.78	3.91
Very fine gravel	<4.0	0	.00	3.91
Fine gravel	<5.6	0	.00	3.91
Fine gravel	<8.0	2	1.56	5.47
Medium gravel	<11.3	6	4.69	10.16
Medium gravel	<16.0	9	7.03	17.19
Coarse gravel	<22.6	9	7.03	24.22
Coarse gravel	<32.0	11	8.59	32.81
Very coarse gravel	<45.3	13	10.16	42.97
Very coarse gravel	<64.0	21	16.41	59.38
Small cobble	<90.5	20	15.63	75.00
Small cobble	<128	20	15.63	90.63
Large cobble	<181	10	7.81	98.44
Large cobble	<256	2	1.56	100.00
Boulder	≥256	0	.00	100.00
Total		128	100.00	



Appendix 2. Substrate data and frequency graph by site.—Continued

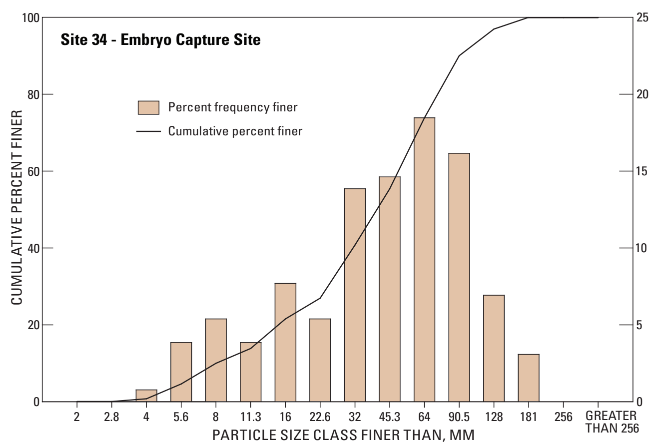
[**Site:** 33.
Date: 08-12-2005.
Type of site: Embryo.
Location description: Upper Ives Island, shallow water at eastern tip island, start of side channel.
Substrate description: Cobble, gravel, periphyton covered.
Vegetation description: Absent.
GPS: Lat/Long, UTM Zone 10N, WGS 84.
Waypoint: 45.62611006 -121.9854349]

Class name	Size class (millimeter)	No. of particles	Percent frequency	Cumulative percent finer
Fines	<2.0	0	0.00	0.00
Very fine gravel	<2.8	1	.77	.77
Very fine gravel	<4.0	0	.00	.77
Fine gravel	<5.6	1	.77	1.54
Fine gravel	<8.0	6	4.62	6.15
Medium gravel	<11.3	3	2.31	8.46
Medium gravel	<16.0	8	6.15	14.62
Coarse gravel	<22.6	11	8.46	23.08
Coarse gravel	<32.0	12	9.23	32.31
Very coarse gravel	<45.3	16	12.31	44.62
Very coarse gravel	<64.0	20	15.38	60.00
Small cobble	<90.5	14	10.77	70.77
Small cobble	<128	28	21.54	92.31
Large cobble	<181	10	7.69	100.00
Large cobble	<256	0	.00	100.00
Boulder	≥256	0	.00	100.00
Total		130	100.00	



[**Site:** 34.
Date: 08-16-2005.
Type of site: Embryo.
Location description: Upper Ives Island, shallow water at eastern tip island, start of side channel.
Substrate description: Cobble, gravel, periphyton covered.
Vegetation description: Absent.
GPS: Lat/Long, UTM Zone 10N, WGS 84.
Waypoint: 45.62628692 -121.9849599]

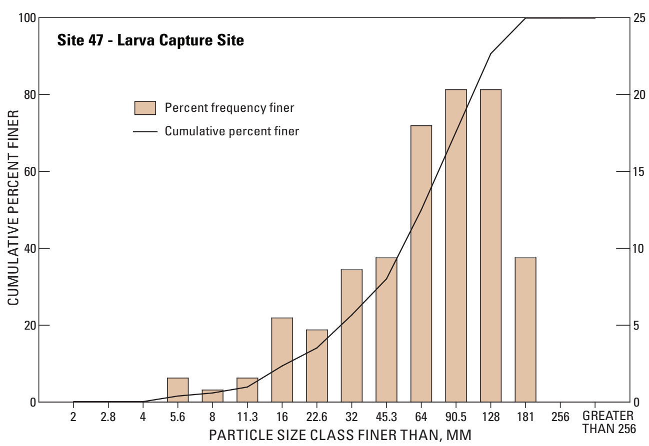
Class name	Size class (millimeter)	No. of particles	Percent frequency	Cumulative percent finer
Fines	<2.0	0	0.00	0.00
Very fine gravel	<2.8	0	.00	.00
Very fine gravel	<4.0	1	.77	.77
Fine gravel	<5.6	5	3.85	4.62
Fine gravel	<8.0	7	5.38	10.00
Medium gravel	<11.3	5	3.85	13.85
Medium gravel	<16.0	10	7.69	21.54
Coarse gravel	<22.6	7	5.38	26.92
Coarse gravel	<32.0	18	13.85	40.77
Very coarse gravel	<45.3	19	14.62	55.38
Very coarse gravel	<64.0	24	18.46	73.85
Small cobble	<90.5	21	16.15	90.00
Small cobble	<128	9	6.92	96.92
Large cobble	<181	4	3.08	100.00
Large cobble	<256	0	.00	100.00
Boulder	≥256	0	.00	100.00
Total		130	100.00	



Appendix 2. Substrate data and frequency graph by site.—Continued

[**Site:** 47.
Date: 08-16-2005.
Type of site: Larva.
Location description: Ives Island, middle, main channel side.
Substrate description: Cobble, gravel, dry periphyton covered.
Vegetation description: Sparse.
GPS: Lat/Long, UTM Zone 10N, WGS 84.
Waypoint: 45.62309953 -121.9894973]

Class name	Size class (millimeter)	No. of particles	Percent frequency	Cumulative percent finer
Fines	<2.0	0	0.00	0.00
Very fine gravel	<2.8	0	.00	.00
Very fine gravel	<4.0	0	.00	.00
Fine gravel	<5.6	2	1.56	1.56
Fine gravel	<8.0	1	.78	2.34
Medium gravel	<11.3	2	1.56	3.91
Medium gravel	<16.0	7	5.47	9.38
Coarse gravel	<22.6	6	4.69	14.06
Coarse gravel	<32.0	11	8.59	22.66
Very coarse gravel	<45.3	12	9.38	32.03
Very coarse gravel	<64.0	23	17.97	50.00
Small cobble	<90.5	26	20.31	70.31
Small cobble	<128	26	20.31	90.63
Large cobble	<181	12	9.38	100.00
Large cobble	<256	0	.00	100.00
Boulder	≥256	0	.00	100.00
Total		128	100.00	



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Validation of a Critical Assumption of the Riparian Habitat Hypothesis for White Sturgeon

SIR 2006–5225