

Spawning and Rearing Habitat Use by White Sturgeons in the Columbia River Downstream from McNary Dam

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Abstract.—Spawning and rearing habitats used by white sturgeons *Acipenser transmontanus* were described from water temperature, depth, and velocity measurements and substrate types present at sites where eggs, larvae, young-of-the-year, and juveniles (ages 1–7) were collected. Spawning and egg incubation occurred in the swiftest water available (mean water column velocity, 0.8–2.8 m/s), which was within 8 km downstream from each of the four main-stem Columbia River dams in our study area. Substrates where spawning occurred were mainly cobble, boulder, and bedrock. Yolk-sac larvae were transported by the river currents from spawning areas into deeper areas with lower water velocities and finer substrates. Young-of-the-year white sturgeons were found at depths of 9–57 m, at mean water column velocities of 0.6 m/s and less, and over substrates of hard clay, mud and silt, sand, gravel, and cobble. Juvenile fish were found at depths of 2–58 m, at mean water column velocities of 1.2 m/s and less, and over substrates of hard clay, mud and silt, sand, gravel, cobble, boulder, and bedrock.

The white sturgeon *Acipenser transmontanus* is an important recreational and commercial resource of the Pacific Northwest. This ancient fish from the Lower Jurassic is the largest freshwater fish in North America; it is restricted to Pacific coastal waters and river systems from central California to southern Alaska. White sturgeons attain lengths of over 6 m and weights in excess of 580 kg, and may live 100 years or more (Scott and Crossman 1973).

Since the late 1930s, extensive hydroelectric development has occurred in the main-stem Columbia River and its tributaries. This development isolated the once diadromous white sturgeon in impoundments created by dams and altered the natural hydrograph of the river by reducing peak discharges in spring and increasing discharges in winter. Existing knowledge about the habitat used or preferred by white sturgeons is limited, and thus the effects of hydroelectric development and operations on them are largely unknown. However, physical changes to riverine environments caused by hydroelectric dams have adversely affected sturgeons in other river systems (Khoroshko 1972; Votinov and Kas'yanov 1978; Deacon et al. 1979; Rochard et al. 1990).

Participants in a workshop to identify white sturgeon research priorities (Fickeisen et al. 1984) ranked the need for habitat information as the

highest priority. Two bibliographies on white sturgeons (Fickeisen 1985; Lane 1985) listed over 200 publications and reports, none of which addressed the water temperature, depth, velocity, and substrate used by white sturgeons. Most field investigations of white sturgeons have addressed relative abundance and distribution in various areas (Stevens and Miller 1970; Kohlhorst 1976; Gray and Dauble 1977; Coon 1978; Malm 1981; Cochauer 1983), age and growth (Coon 1978; Kohlhorst et al. 1980; Hess 1984), and movements (Bajkov 1951; Miller 1972; Haynes et al. 1978; Haynes and Gray 1981). These investigators commented generally on the habitat used by adult and larval white sturgeons but presented no data to support their statements.

White sturgeon spawning in the wild has rarely been documented. Kohlhorst (1976) collected naturally spawned white sturgeon eggs from the Sacramento River, and spawning downstream from each of the four dams on the lower 470 km of the Columbia River has been confirmed (Duke et al. 1990; McCabe and McConnell 1988). Naturally spawned eggs have also been collected from the Kootenai River in northern Idaho (K. Apperson, Idaho Department of Fish and Game, personal communication).

We present new information on the spawning and rearing habitats of white sturgeons in the Co-

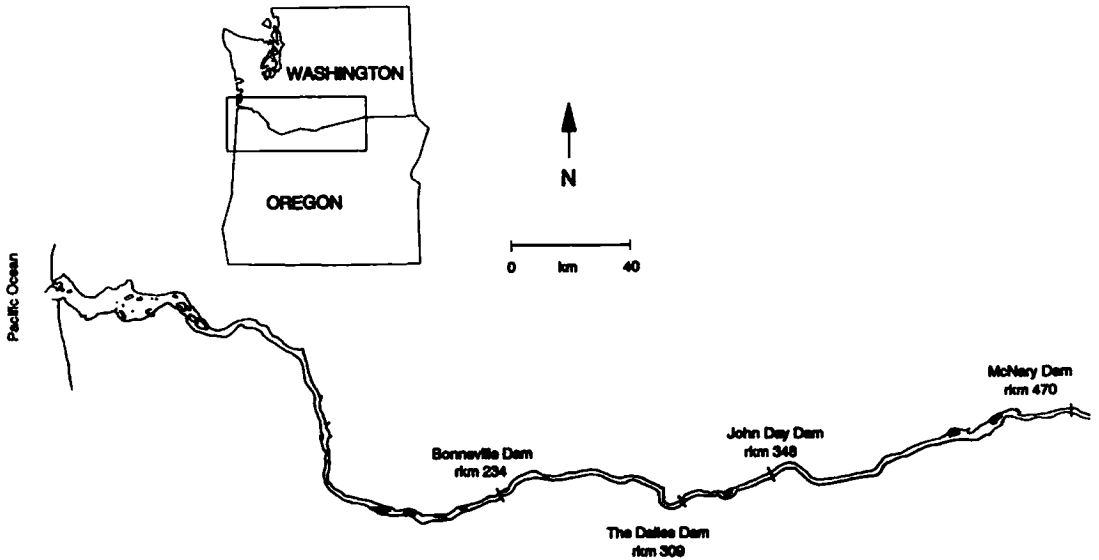


FIGURE 1.—The study area on the Columbia River showing locations of the four main-stem dams.

lumbia River. This information can be used to evaluate the effects of hydroelectric development and operations on the availability of habitat for white sturgeons.

Study Area

The Columbia River downstream from McNary Dam at river kilometer (rkm) 470 to the mouth (rkm 0) is divided into three impoundments and an unimpounded river reach (Figure 1). The unimpounded reach (rkm 0–234), henceforth referred to as the lower river, has a surface area of 61,300 hectares and is considered estuarine from the mouth to rkm 75. The lower river has an extensive nonvegetated littoral zone; this zone, which encompasses 55% of the total area of the lower river, is less than 4 m deep. The lower river has a predominantly sand substrate. The impoundments vary in size, depth, and substrate composition. Their littoral zones are generally vegetated with submergent plants. Bonneville Pool (rkm 234–309) has a surface area of 7,600 hectares and has a predominantly sand substrate; 20% of the pool is less than 4 m deep. The Dalles Pool (rkm 309–348) has a surface area of 3,600 hectares and the substrate is bedrock, cobble, and sand; 9% of the pool is less than 4 m deep. John Day Pool (rkm 348–470) has a surface area of 19,800 hectares and the substrate is mud, sand, gravel, and cobble; 25% of the pool is less than 5 m deep. Water velocities are highest in the tailrace of each

dam. Additional information on the study area can be found in Ebel et al. (1989).

Flows in the Columbia River depend on snowmelt and rainfall in headwater areas and are regulated by an extensive network of storage, diversion, and run-of-the-river dams throughout the watershed. Flows at Bonneville Dam during our study in 1987–1991 varied seasonally and annually (Figure 2); the May–July average flow was lowest in 1988 (4,520 m³/s) and highest in 1991 (7,240 m³/s).

Methods

We determined the physical habitat used by white sturgeons by measuring water depth, mean

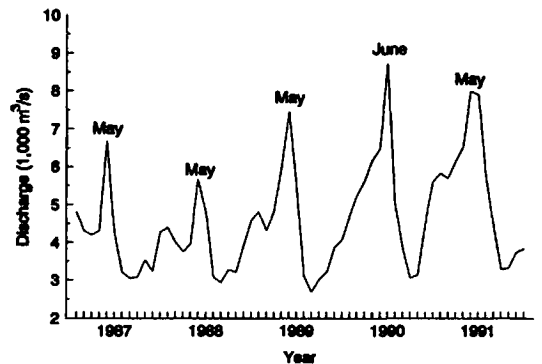


FIGURE 2.—Mean monthly discharge (1,000 m³/s) at Bonneville Dam, 1987–1991.

TABLE 1.—Substrate types by particle size.

Type	Particle size (mm)
Organic debris ^a	
Hard clay	0.00024–<0.004
Mud and silt	0.004–<0.062
Sand	0.062–<2
Gravel	2–<64
Cobble	64–<250
Boulder	250–4,000
Bedrock ^a	

^a These substrates were not classified by particle size.

water column and near-substrate water velocities, and water temperature and by classifying the substrate at locations where newly spawned eggs, yolk-sac larvae, young of the year, and juveniles (ages 1–7) were collected with various fishing gears during 5 years of study. Each observation of habitat use resulted from an effort with a fishing gear that collected at least one white sturgeon of any life stage (Bovee 1986). Because observations were not weighted by the number of fish in the catch, biases associated with gear selectivity and efficiency in ascertaining fish presence at a sampling location were reduced. Observations were pooled among years and among impoundments. Habitat use is presented separately for the free-flowing lower river and the impoundments.

Observations were made in the lower river and The Dalles Pool from 1987 through 1991, in the Bonneville Pool from 1988 through 1991, and in the John Day Pool from 1989 through 1991. We sampled for eggs and larvae from April through July. We sampled for older fish primarily from April through September, but expended some effort in each of the other months of the year. Most sampling was done during daylight hours. Some habitat variables were not measured at every sampling site.

Water depth was measured to the nearest 0.3 m with a recording depth sounder. When depth varied during a sampling effort, we recorded the maximum depth.

Water velocities were measured with cable-suspended Gurley current meters or Price "AA" current velocity sensors connected with Swiffer Instruments model 2200 direct-reading current velocity meters.¹ Sounding weights used to deploy the sensors ranged from 13.6 to 45 kg. Measurements were taken at 0.2 and 0.8 of the water depth

and within 1 m of the substrate. Mean water column velocity was calculated by averaging the velocities measured at 0.2 and 0.8 of the water depth (Buchanan and Somers 1969).

Substrate type was determined by visual observation from samples taken with a 0.1-m² Van Veen grab, from substrate collected in our fish sampling gears, from commercially available navigation charts and preimpoundment air photos, and from unpublished data collected in other studies. Substrate types were defined by particle size (Table 1).

Water temperatures were measured with handheld digital or mercury thermometers or obtained from digital recording thermographs that were placed on the substrate in the dam tailraces.

Eggs and yolk-sac larvae were collected from the drift in plankton nets and 3-m-wide beam trawl nets; both gears were fished on the substrate (McCabe and McConnell 1988; Palmer et al. 1988). Eggs were also collected on artificial substrates placed in spawning areas (McCabe and Beckman 1990). The plankton nets were constructed of 1.59-mm knotless nylon mesh attached to an inverted U-shaped frame (1.3-cm-diameter stainless steel rod) 0.76 m across the bottom and 0.54 m high. Two to six lead weights (4.5 or 9.1 kg each) attached to the net frame held the net on the substrate. Single or paired nets were fished from an anchored boat for 5–60 min. Paired nets were considered one effort. The 3-m-wide by 0.5-m-high beam trawl net was also constructed of 1.59-mm knotless nylon mesh and was attached to an aluminum alloy frame that had weighted skids. This gear was either fished passively on the substrate or was towed slowly upriver; tows lasted 5–30 min.

All white sturgeon eggs collected were assigned a developmental stage based on criteria established by Beer (1981). We used observations of newly spawned eggs (eggs that were changing pigmentation and had not undergone first cleavage) to define habitat use by spawning white sturgeons. We used observations of newly spawned and older eggs to define egg incubation habitat.

Larval, young-of-the-year, and juvenile white sturgeons were captured with towed bottom trawls of various designs, including the 3-m beam trawl described above. The trawls most frequently used were a 7.9-m semiballoon shrimp trawl (McCabe and McConnell 1988) and a 6.2-m high-rise trawl (Palmer et al. 1988; Parsley et al. 1989). Tows were 5–15 min in duration and were made in an upstream direction.

¹ The use of trade names does not imply endorsement by the U.S. Fish and Wildlife Service or the National Marine Fisheries Service.

Sampling sites were chosen to encompass most of the habitats in the study area. However, we did not sample with towed bottom trawls in areas with snags or rock ledges. Most sites were repetitively sampled, usually at intervals of at least 24 h, during three or more seasons regardless of whether white sturgeons were ever collected at the site.

Results

Spawning and Egg Incubation

White sturgeons spawned from April through July, when water temperatures were 10–18°C (Figure 3), as determined by the collection of newly spawned eggs. White sturgeons spawned in the impoundments at water temperatures greater than 12°C, but spawning in the lower river was common at water temperatures of 10–12°C. Most spawning occurred at 14°C (Table 2). Estimated spawning dates back-calculated from eggs in more advanced developmental stages indicated that limited spawning also occurred in some years in all four areas at 18–20°C.

Newly spawned eggs were collected from the drift near the substrate at depths of 4–24 m (Figure 4), and spawning activity of adult fish was observed on a few occasions at one location where the depth was about 7 m. Over all the develop-

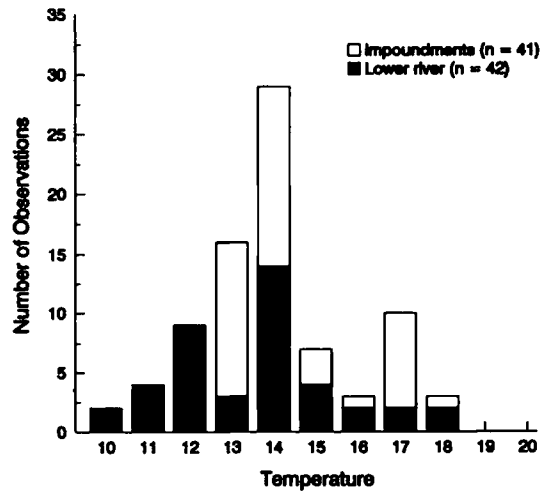


FIGURE 3.—Water temperatures (°C) on days when newly spawned white sturgeon eggs were collected in the Columbia River, 1987–1991.

mental stages, eggs were collected at depths of 4–27 m (Figure 4).

White sturgeons spawned in extremely fast-flowing water. Mean water column velocities at sites where newly spawned eggs were collected ranged from 0.8 to 2.8 m/s, and velocities near

TABLE 2.—Physical habitat at sites where white sturgeons were collected in the Columbia River, 1987–1991.^a

Activity or life stage	Location	Water temperature (°C) ^b	Depth (m)	Mean water column velocity (m/s)	Velocity near the substrate (m/s)	Substrate type ^c
Spawning	Lower river	14 (10–18)	6 (4–23)	2.10 (1.0–2.80)	1.40 (0.60–2.40)	Boulder
	Impoundments	14 (12–18)	11 (4–24)	1.46 (0.81–2.10)	1.04 (0.52–1.62)	Cobble
Incubating eggs	Lower river	14 (4–23)	14 (4–23)	2.00 (0.80–2.80)	1.20 (0.50–2.40)	Boulder
	Impoundments	11 (4–27)	11 (4–27)	1.39 (0.50–2.10)	1.04 (0.18–1.77)	Cobble
Yolk-sac larvae	Lower river	16 (4–29)	16 (4–29)	1.60 (0.70–2.70)	1.00 (0.40–2.40)	Sand
	Impoundments	12 (5–58)	12 (5–58)	1.10 (0.41–2.10)	0.84 (0.27–1.68)	Cobble
Young of the year	Lower river	19 (9–38)	19 (9–38)	No data	No data	Sand
	Impoundments	30 (9–57)	30 (9–57)	0.38 (0.18–0.63)	0.31 (0.12–0.55)	Sand
Juvenile	Lower river	16 (2–40)	16 (2–40)	0.65 (0.40–1.10)	0.60 (0.20–0.80)	Sand
	Impoundments	19 (6–58)	19 (6–58)	0.61 (0.09–1.20)	0.37 (0.06–0.64)	Sand

^a Values are medians and (in parentheses) ranges.

^b Water temperature on days that newly spawned eggs were collected.

^c Mode.

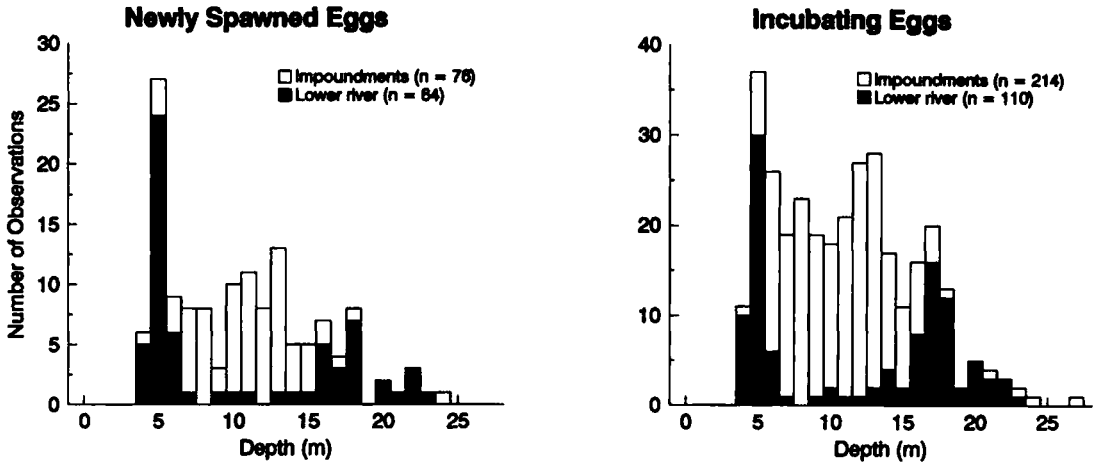


FIGURE 4.—Water depths where newly spawned and incubating white sturgeon eggs were collected in the Columbia River, 1987–1991.

the substrate were 0.5–2.4 m/s (Figure 5). Older eggs were collected from sites with mean water column and near-substrate velocities of 0.5–2.8 m/s and 0.2–2.4 m/s (Figure 5). Water velocities

were not measured on the few occasions when spawning activity was observed directly. The mean water column velocity at a location a few days after we observed spawning and at a river dis-

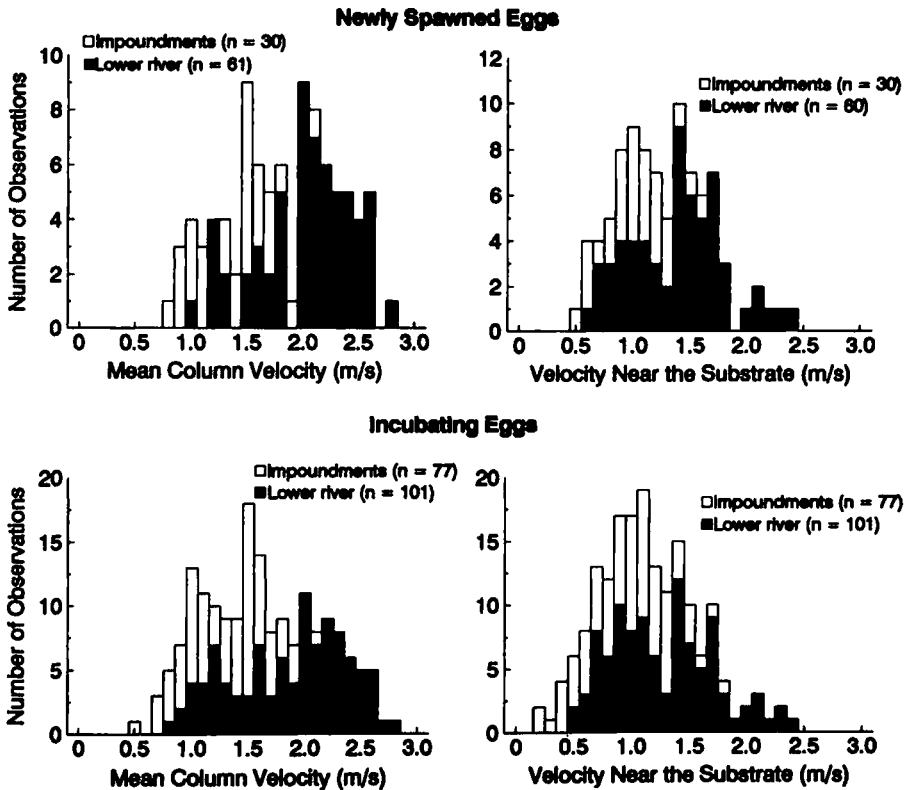


FIGURE 5.—Water velocities at sites where newly spawned and incubating white sturgeon eggs were collected in the Columbia River, 1987–1991.

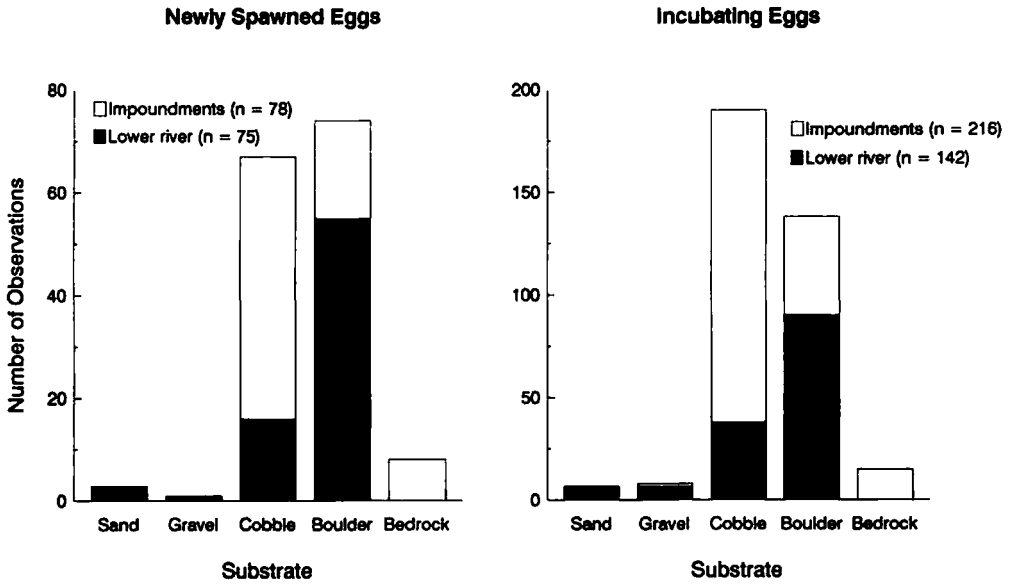


FIGURE 6.—Substrates over which newly spawned and incubating white sturgeon eggs were collected in the Columbia River, 1987–1991.

charge similar to when the spawning occurred was 2.1 m/s.

Most newly spawned and older eggs were collected over cobble and boulder substrates, but some were also collected over sand, gravel, and bedrock (Table 2; Figure 6).

Larvae

Yolk-sac larvae of white sturgeons were collected from sites where eggs were taken and from sites farther downstream, where river currents carried them after hatching. Larvae were collected at depths of 4–58 m, at mean water column and near-substrate velocities of 0.4–2.7 and 0.3–2.4 m/s, and over substrates of sand, gravel, cobble, boulder, and bedrock (Table 2; Figure 7).

Young of the Year

White sturgeon young of the year were captured downstream from spawning areas from June through November. Because of the long spawning season and short incubation period, young of the year were often captured while spawning was still in progress. As a result, the lengths of young of the year captured during the study varied from 20 to 321 mm total length.

Young of the year were captured from deep, low-velocity areas where substrate particle size was generally smaller than in the spawning areas. These fish were collected at depths of 9–57 m, at mean

water column and near-substrate velocities of 0.2–0.6 and 0.1–0.6 m/s, and over substrates of mud and silt, sand, gravel, cobble, and hard clay (Table 2; Figure 8). Most were captured in areas with sand substrates, particularly in the lower river.

Juveniles

Juvenile white sturgeons were captured at depths of 2–58 m, at mean water column and near-substrate velocities of 0.1–1.2 and 0.1–0.8 m/s, and over substrates of mud and silt, sand, gravel, cobble, boulder, and hard clay (Table 2; Figure 9). In the lower river, nearly all (99.7%) of the juveniles were captured over sand, which was the predominant substrate in this reach. Juveniles ranged from 150 to 1,030 mm in fork length.

Discussion

Spawning adult white sturgeons and those in the egg–juvenile stages used a variety of water depths, velocities, and substrates in the study area. White sturgeon spawning coincided with peak flows during spring and early summer, which may have aided downriver dispersal of newly hatched larvae to habitat favorable for growth. The median water temperature at which spawning occurred in our study area (14°C) is equivalent to the temperature identified as optimal for white sturgeon egg development (Wang et al. 1985). Limited spawning

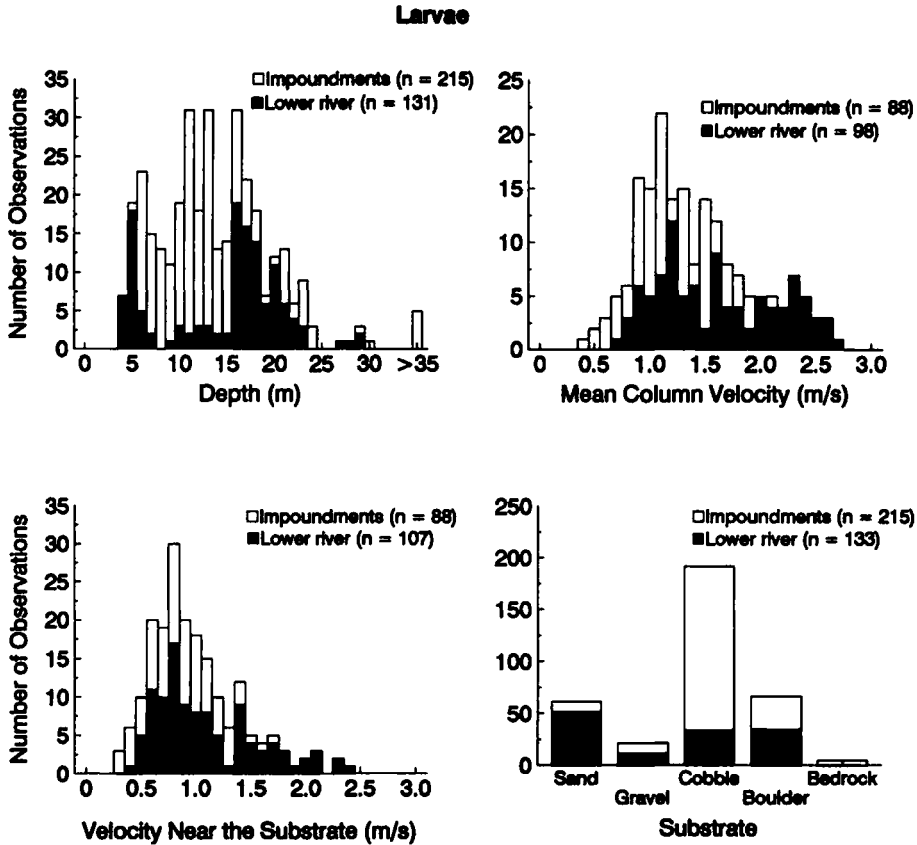


FIGURE 7.—Water depths, mean water column and near-substrate velocities, and substrates where white sturgeon larvae were collected in the Columbia River, 1987–1991.

occurred at 18–20°C, but Wang et al. (1985) reported that elevated mortality occurred among developing white sturgeon embryos incubated at 18°C, and complete mortality occurred in embryos incubated at 20°C.

Spawning and egg incubation were observed at a range of water depths and velocities. White sturgeons are believed to be broadcast spawners; therefore, water depth per se may not be important in the selection of a spawning site. All newly spawned eggs were collected in areas of high water velocities, which would displace eggs downriver from the location where spawning occurred. We do not know where in the water column white sturgeons spawn. However, on a few occasions we observed adult fish breaching and rolling at the surface in turbulent water where the water depth was approximately 7 m and the mean water column velocity was approximately 2 m/s. We collected newly spawned eggs within 1 m of the water surface immediately downstream from the site.

Spawning may have occurred in areas of higher

water velocity than where newly spawned eggs were collected. However, safety concerns, difficulty in retrieving our nets, and the potential for loss of gear precluded sampling those areas. High water velocities, which were influenced by river discharge and channel morphology, precluded sampling in some areas during peak river discharges. Generally, we did not attempt to collect eggs from areas where mean water column velocities were faster than 2.1 m/s in the impoundments and 2.7 m/s in the lower river. Six of the nine collections made at mean water column velocities of less than 1.2 m/s were from one location (rkm 307), on the outer edge of an eddy formed by a slight bend in the northern shoreline downstream from The Dalles Dam. Velocities beyond the eddy were higher.

We do not know if an upper limit exists for water velocities used by spawning white sturgeons in the study area. Velocities in excess of 3.7 m/s were measured adjacent to and upstream from several sites where eggs were collected. Spawning

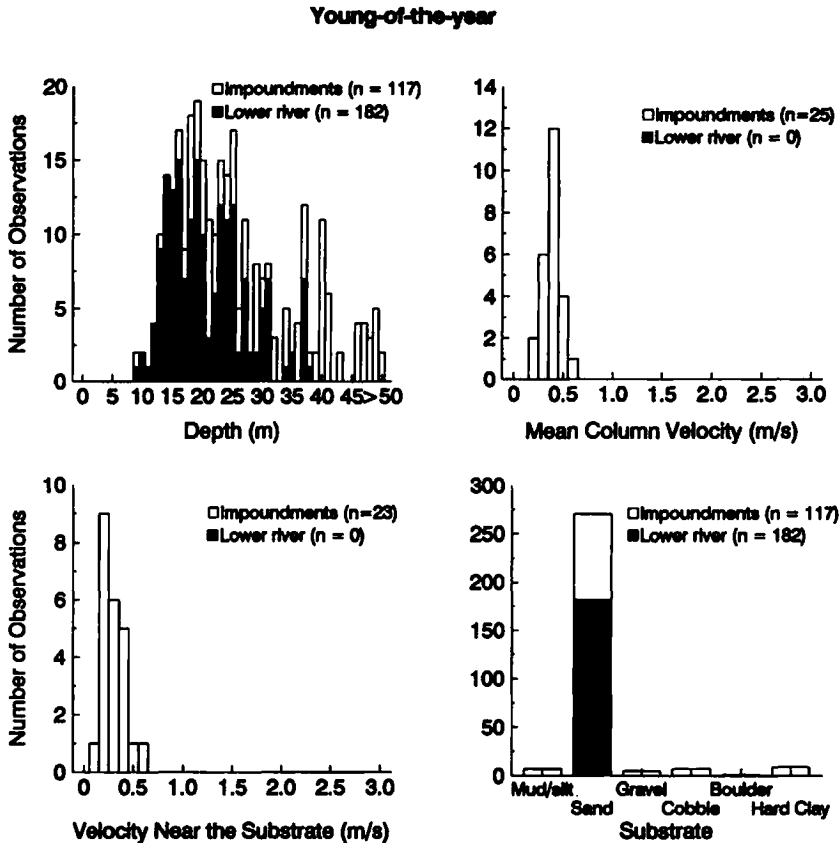


FIGURE 8.— Water depths, mean water column and near-substrate velocities, and substrates where young-of-the-year white sturgeons were captured in the Columbia River, 1987–1991.

adults may exceed 2 m in length, and they probably can negotiate water velocities of 4–6 m/s (2–3 body lengths/s). Swimming performance studies have shown that *Acipenser* spp. of the Volga River can sustain swimming at velocities of 1.2–4.5 body lengths/s (Malinin et al. 1971).

Most eggs were collected over substrates of cobble or boulder. Those that were collected over sand were probably spawned upstream over coarser substrates. Gravel substrates were not common in our study area, but gravel occurred in combination with cobble and boulders in many places. Each of these substrates provided a solid base of attachment for the adhesive eggs of the white sturgeon. We do not know if substrate imbeddedness, angularity, or interstitial spaces between particles are important for attachment. Substrate irregularities would protect the eggs from the scouring action of water currents, but might also provide refuge for egg predators.

The coarser substrates found in areas used by

white sturgeons for spawning probably reflect the water velocities in those areas. Finer substrates are displaced from areas of high water velocities. A preference for spawning in high water velocities would ensure a suitable substrate. Spawning by other sturgeons occurs in swift water over gravel or rock (Dees 1961; Nikolskii 1961; Magnin 1966; Buckley and Kynard 1985; Crance 1986). Kohlhorst (1976) reported that white sturgeons in the Sacramento River may spawn over mud, sand, or gravel, but his conclusion may be questioned because it is based mostly on catches of larvae that may have been dispersed widely from the spawning sites.

The white sturgeon larvae that we captured from the drift were probably in transport between areas. Brannon et al. (1984, 1985) investigated the behavior of yolk-sac white sturgeons raised in circular aquaria. They identified a "swim-up" phase that may be a mechanism for downstream dispersal from spawning areas. Newly hatched larvae

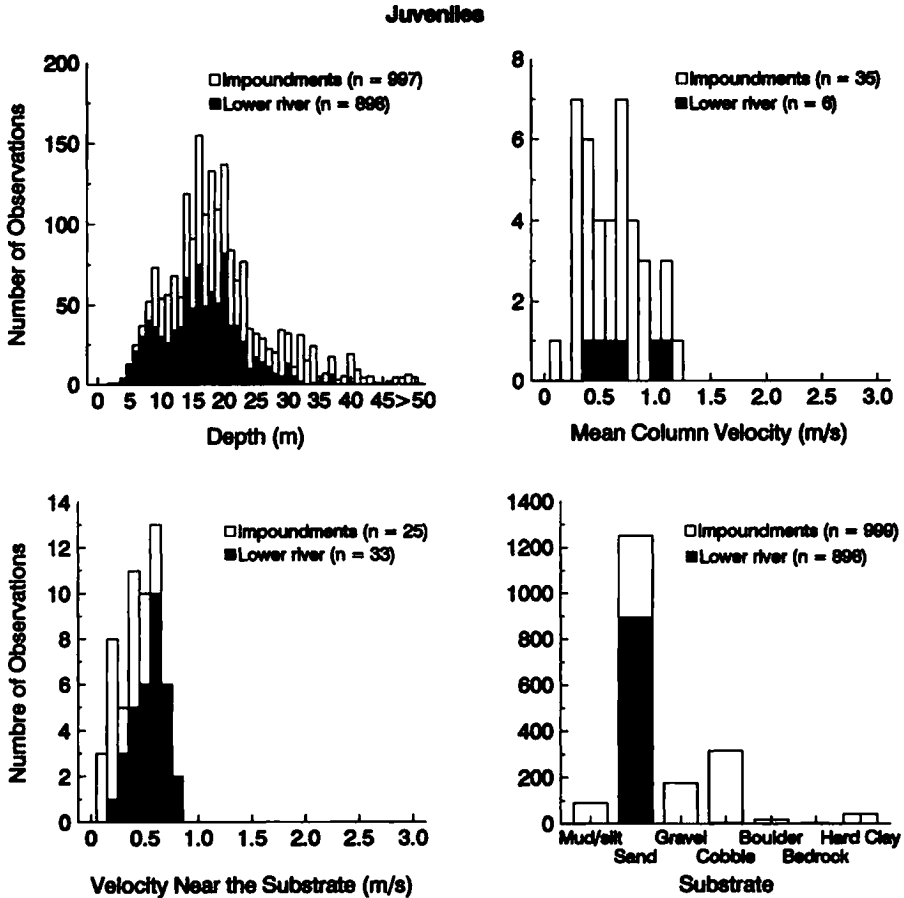


FIGURE 9.—Water depths, mean water column and near-substrate velocities, and substrates where juvenile white sturgeons were captured in the Columbia River, 1987–1991.

swam towards the surface and remained in the water column for a length of time that was inversely related to water velocity. The larvae then sought cover in or on the substrate and appeared to be photophobic (Brannon et al. 1985). This “hiding” phase lasted until the yolk was absorbed (about 12 d after hatch), after which they attempted to feed on the substrate and in the water column. If food was not present, the fish reentered the water column, a behavior that in nature would presumably cause them to be transported downstream. Feeding fish showed a slight preference for sand substrates but also occupied detritus and gravel substrates if food was present (Brannon et al. 1985). The post-yolk-sac larvae we collected may have used depth as a form of cover. They were taken in deep, slow-moving water where the illumination was reduced and finer substrates predominated.

The habitats in which we captured young-of-the-year and juvenile white sturgeons indicate a tolerance of but not necessarily a preference for a wide range of environmental conditions. Most observations of young of the year and juveniles were from the unimpounded lower Columbia River and the Bonneville Pool, where sand was the predominant substrate. Other substrates were available in The Dalles and John Day pools, but poor recruitment to the young-of-the-year stage in these pools during our study limited the potential for observing these fish and juveniles over these other substrates.

Young-of-the-year and juvenile white sturgeons were most often captured within the thalweg, and sampling adjacent to the thalweg in shallow water rarely collected white sturgeons. Haynes and Gray (1981) suggested that larger juvenile and adult white sturgeons make feeding forays into shallow

water during hours of darkness. Most of our observations were made during the day, but those made at night showed no movement of young-of-the-year or juvenile fish into shallow areas. However, we have collected white sturgeon juveniles and adults in shallow water (<7 m deep) with gill nets set for 24 h (U.S. Fish and Wildlife Service, unpublished data). A preference for the thalweg and deeper water may have prevented fish from becoming stranded in isolated pools as river levels fluctuated naturally prior to impoundment.

Although we provide the most thorough description to date of the habitat used by larval, young-of-the-year, juvenile, and spawning white sturgeons, our sampling was limited to habitats suitable for our fishing gear. We were unable to sample for young-of-the-year and juvenile white sturgeons with our bottom trawls in areas with rugged bottom topography, although we did sample for eggs and larvae in these areas with stationary gears. Sampling was not conducted at water velocities faster than 2.8 m/s, but only a small amount of this habitat was present. Telemetry studies of juvenile and adult fish would help verify observations from this study. Additional information on larval and young-of-the-year habitat preferences for velocities and substrates may be best obtained through laboratory studies.

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