REPORT D

1. Description of reproduction and early life history characteristics of white sturgeon populations in the Columbia River downstream from Bonneville Dam.

2. Definition of habitat requirements for spawning and rearing of white sturgeon and quantification of extent of habitat available in the Columbia River downstream from Bonneville Dam.

Prepared By:

George T. McCabe, Jr.
and
Susan A. Hinton

National Marine Fisheries Service
Northwest Fisheries Center
Coastal Zone and Estuarine Studies Division
2725 Montlake Blvd. East
Seattle, WA 98112

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ABSTRACT

During 1989, the National Marine Fisheries Service (NMFS) sampled white sturgeon *Acipenser transmontanus* eggs, larvae, and juveniles in the Columbia River downstream from Bonneville Dam. In conjunction with the Washington Department of Fisheries, 2,323 white sturgeon eggs were collected with plankton nets and artificial substrates between River Miles (RMs) 138 and 145. White sturgeon eggs were first collected with plankton nets on 27 April near Ives Island (RM 143), and last collected in plankton nets on 6 July at RM 140. The sampling site near Ives Island was used as an index area to monitor white sturgeon spawning throughout the season. Stage 2 (freshly fertilized) eggs were collected on 7 of the 10 days that eggs were collected near Ives Island, indicating that spawning was occurring throughout the spring. Between 27 April and 28 June, white sturgeon egg densities near Ives Island (in plankton nets) averaged 46.2 eggs/1,000 m^3 of water sampled, with the highest density on 17 May (171.3 eggs/1,000 m^3). We estimated that white sturgeon spawned on at least 43 days in 1989, beginning on 22 April and ending on 2 July. During the spawning period, Bonneville Dam discharge (mean hourly discharge by day) ranged from 3,348 to 8,872 m^3/s. White sturgeon eggs were collected at bottom-water temperatures ranging from 12 to 18°C, bottom-water turbidities ranging from 3.3 to 10.0 NTU, mean water-column velocities ranging from 0.7 to 2.6 m/s, and water depths ranging from 4.6 to 22.6 m. A total of 135 white sturgeon larvae were collected in plankton nets between RMs 108 and 144. Larvae were first collected on 8 May at RM 113, and last collected on 28 June near Ives Island and RM 140. From 27 April to 28 June, densities of larvae near Ives Island averaged 1.7 larvae/1,000 m^3 and ranged from 0.0 to 6.7 larvae/1,000 m^3.

In 1989, a total of 2,579 juvenile white sturgeon were collected with trawls, primarily a 7.9-m (headrope length) semiballoon shrimp trawl, in the Columbia River downstream from Bonneville Dam. Much of the sampling for juvenile sturgeon was conducted in five index areas--RM 28, RM 75-79, RM 88-95, RM 114, and RM 127-131--established as a result of 1987 research. Distributions of juvenile sturgeon were patchy; not only were there differences in catches among different areas of the river, but also differences in catches among parallel transects within the same area. Catches tended to be highest at RMs 95 and 131. The mean density of juvenile white sturgeon was highest at water depths (maximum) $\geq$18.3 m (83 $\pm$ 284 (mean $\pm$ SD) sturgeon/hectare) and lowest at depths <9.1 m (9 $\pm$ 32 sturgeon/hectare). In 1989, a total of 111 young-of-the-year white sturgeon were collected between RMs 29 and 101. Young-of-the-year preferred deeper areas of the river (mean minimum and maximum depths were 14.7 and 22.6 m, respectively).

Since the white sturgeon is a demersal species, two benthic surveys were conducted in conjunction with the juvenile sampling to determine the relationships between sturgeon densities and the benthos (benthic invertebrates and the substrate). The relationships between white sturgeon densities and benthic invertebrate densities, specifically *Corbicula manilensis* (a bivalve) and *Corophium salmonis* (a tube-dwelling amphipod) densities (both important prey items), were poor. The substrate in most of the sampling areas was primarily sand; like invertebrate densities, the relationship between white sturgeon densities and substrate texture was poor. The stomach contents of white sturgeon collected at RMs 95 and 131 were analyzed to determine what they were eating and relationships with the benthic invertebrate communities. Overall, the most important identifiable prey was

Corophium salmonis. Other important prey included *Corbicula manilensis*, *Neomysis* sp., *Corophium spinicorne*, Chironomidae larvae, and eulachon *Thaleichthys pacificus* eggs. Results from the stomach analysis indicated that food may be limited for juvenile sturgeon at RMs 95 and 131 in September-October.

A total of 1,675 juvenile white sturgeon were tagged with bird-banding tags in 1989. Twenty-four tagged sturgeon were recaptured in NMFS trawls; two of the recaptures had been tagged by NMFS in 1987 and ten had been tagged in 1988. All of the recaptures were made within a mile of where the fish were originally tagged.

INTRODUCTION

Under the agreement with the Oregon Department of Fish and Wildlife (ODFW), the National Marine Fisheries Service (NMFS) is responsible for segments of Objectives 1 and 3 of the study. Objective 1 is to describe reproduction and early life history of white sturgeon populations, and Objective 3 is to define habitat requirements for all life stages of white sturgeon and to quantify available habitat. The NMFS's research is conducted in the Columbia River downstream from Bonneville Dam--the Columbia River's only reach known to support all white sturgeon developmental stages in sufficient numbers to provide a control against which habitat availability and use between Bonneville and McNary dams can be compared. Also, under Objective 1, NMFS and the Washington Department of Fisheries (WDF) are attempting to determine the effect of variable flows at Bonneville Dam on spawning and the early life history of white sturgeon.

Specific research goals for 1989 were 1) to examine the spawning requirements of white sturgeon in the Columbia River downstream from Bonneville Dam; 2) to determine the downstream distribution of white sturgeon larvae in the Columbia River downstream from Bonneville Dam; 3) to determine the habitat requirements or preferences of juvenile white sturgeon in the Columbia River downstream from Bonneville Dam; and 4) to provide a detailed analysis of the food habits of juvenile white sturgeon in the Columbia River downstream from Bonneville Dam. This report describes progress on NMFS's studies from March 1989 to March 1990.

METHODS

Egg and Larval Sampling

In 1989, NMFS and WDF cooperatively sampled for white sturgeon eggs and larvae in the Columbia River downstream from Bonneville Dam. Sampling began in March and ended in August; generally, sampling was either biweekly or weekly (during the spawning period). A D-ring plankton net was used to collect white sturgeon eggs and larvae. This net was 0.8 m wide at the bottom of the mouth opening and was constructed of 7.9-mesh/cm nylon marquisette netting (Kreitman 1983). Depending upon the water velocity, two to four lead weights (4.5 or 9.1 kg each) were attached to the net frame to hold the net on the river bottom. A digital flow meter (General Oceanics Model 2030[1]) was suspended in the mouth of the net to estimate the water volume sampled. Typically, two plankton nets were fished simultaneously for about 30 min from an anchored 12.2-m research vessel.

Artificial substrates constructed of latex-coated animal hair were also used to collect white sturgeon eggs. The substrates were cut into 76 X 91 cm sections and secured to an angle iron frame with strips of flat bar. The strips were held in place with nuts and bolts, allowing fast removal of the substrate from the frame. Two sections of the artificial substrate were placed back to back in each frame. Because two pieces were used in each frame, it made no difference what side of the frame rested on the river bottom. Two short sections of cable were used to attach the frame to an

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[1] *Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.*

anchor, which held the substrate and frame in place on the bottom. A buoy line was attached to the anchor to allow retrieval of the substrate, frame, and anchor.

White sturgeon egg and larval sampling was done at various sites in the lower Columbia River from River Mile (RM) 95 to 145 (Figure 1). The most frequent sampling was done at a site near Ives Island (RM 143), which has been routinely sampled in past years by WDF and NMFS, and is considered an index area for monitoring white sturgeon spawning in the lower Columbia River. On 25 May, we also sampled with plankton nets in the Willamette River at Oregon City, Oregon; sampling was about 0.75 miles downstream from the falls at Oregon City.

White sturgeon eggs and larvae were fixed in an approximately 4% buffered formaldehyde solution and transferred to WDF. Egg and larval stages were determined by WDF based on descriptions developed by Beer (1981). The WDF's descriptions for larval stages 1-7 correspond to Beer's descriptions for his stages 1-day post hatch through 7-day post hatch. We were unable to estimate the number of days required to reach a specific larval stage because water temperatures in the Columbia River were not always comparable to laboratory temperatures in Beer's study. Timing of egg deposition was estimated using an equation developed by Wang et al. (1985); the water temperature at the time of egg collection was used in the equation.

Juvenile Sampling

A 7.9-m (headrope length) semiballoon shrimp trawl, identical to that used in 1987 and 1988, was used to collect juvenile white sturgeon. Mesh size in the trawl was 38 mm (stretched measure) in the body; a 10-mm mesh liner was inserted in the cod end of the net. Infrequently, a 4.9-m semiballoon shrimp trawl was also used to sample for juvenile white sturgeon. Mesh size in the body of the 4.9-m trawl was 32 mm; a 10-mm mesh liner was inserted in the cod end of the net. Trawl efforts were normally 5 min in duration in an upstream direction. The trawling effort began when the trawl and the proper amount of cable were let out, and the effort was considered ended when 5 min elapsed. Using a radar range-finder, we estimated the distance the net fished during each sampling effort. Bottom trawling was conducted from 27 March to 1 November. Trawling was primarily in five index areas (RM 28, RM 75-79, RM 88-95, RM 114, and RM 127-131) established as a result of 1987 research (Figure 1). The index sites were selected primarily to determine the habitat preferences or requirements of juvenile white sturgeon; no attempt was made to randomly select the sites. At RM 75-79, trawling was at RMs 75 and 79; at RM 88-95, trawling was at RMs 88 and 95. Trawling at RM 127-131 was at RMs 127 and 131. At each RM, two or three trawling efforts were completed along parallel transects. Transect 1 was closest to the Washington shore, Transect 2 was the middle transect, and Transect 3 was closest to the Oregon shore. In certain river sections where only two transects were established, Transect 2 was closest to the Oregon shore.

Fishes captured in the bottom trawls were identified and counted. Generally, all white sturgeon from a sampling effort were measured (total and fork lengths (mm)) and weighed (g). In instances when a large number of sturgeon was collected in a sampling effort, a subsample of at least 50 sturgeon was measured and weighed. White sturgeon were tagged to provide data

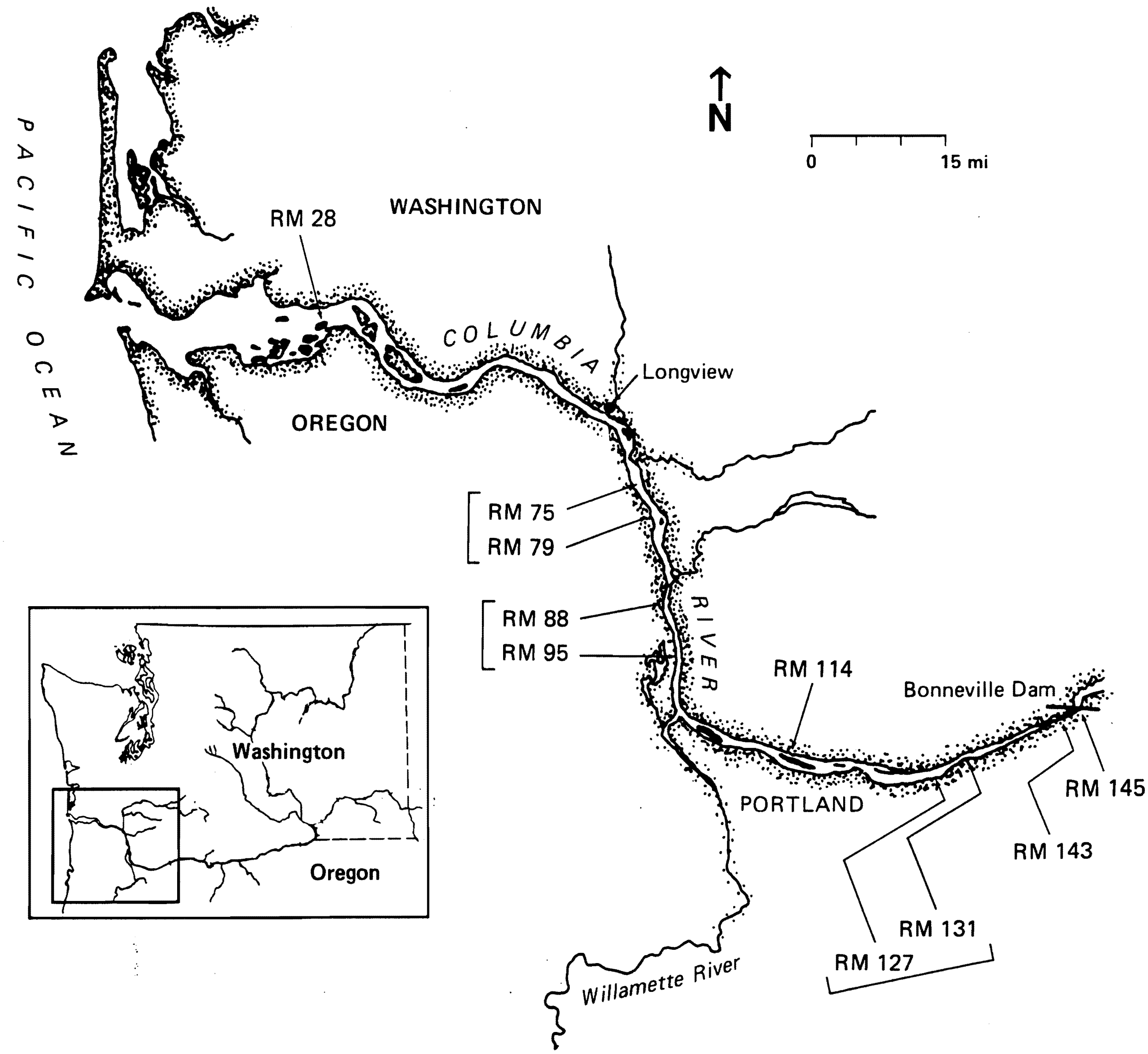

Figure 1. Lower Columbia River showing white sturgeon sampling areas.

on movement and growth. A monel metal bird-banding tag was placed around the anterior ray of the right pectoral fin. Also, we routinely examined juvenile white sturgeon for the nematode parasite *Cystoopsis acipenseri* (Chitwood and McIntosh 1950). When present, the parasite is contained in blister-like cysts under the skin. Throughout the field season, pectoral rays were removed from juvenile white sturgeon and given to the U.S. Fish and Wildlife Service (FWS) for age determinations. A portion of the anterior ray of the left pectoral fin was removed by cutting at or just distal to the fin articulation.

In 1988, stomachs were taken from white sturgeon captured in two areas of the lower Columbia River (RMs 95 and 131) to determine what they were eating and the relationships between the benthic invertebrate communities and sturgeon food. Analysis of the stomach contents was not completed until 1989. Sturgeon stomachs were taken during three time periods--1) May-June, 2) July-August, and 3) September-October. In each area, we tried to take 25 stomachs from each of two size-classes of sturgeon during each of the three time periods. The two size-classes of sturgeon were 1) $\leq$350 mm fork length and 2) 351 to 725 mm fork length. Stomachs were removed from the sturgeon on board the sampling vessel and placed in individual vials containing a 7% buffered formaldehyde solution. The stomachs were later transferred to vials containing a 70% ethyl alcohol solution. Individual food items in each stomach were identified to the lowest practical taxonomic level, sorted, counted, and weighed to the nearest 0.1 mg.

Benthic Sampling

To help determine the habitat requirements or preferences of white sturgeon, benthic invertebrate and sediment samples were collected with a 0.1-m^2 Van Veen grab sampler (Word 1976) at the five index areas. Two benthic surveys were conducted in 1989--one in April and one in September. During each survey, a total of 240 grab samples were collected at 40 sampling stations. Five benthic invertebrate samples (replicates) and one sediment sample were collected at each sampling station; two stations were established along each bottom trawling transect--one near the beginning and the other near the end. When practical, each benthic invertebrate sample was sieved through a 0.5-mm screen and the residue preserved in a buffered formaldehyde solution ($\geq$4%) containing rose bengal, an organic stain. If it appeared that most of the material would not wash through the sieve, then the entire sample was preserved and sieved at a later time. Later the samples were washed with water and preserved in a 90% alcohol solution to prevent the destruction of calcareous invertebrate parts by formaldehyde. Each benthic invertebrate sample was sorted and the invertebrates were identified to the lowest practical taxonomic level and counted. Sediment samples were analyzed by the U.S. Army Corps of Engineers (North Pacific Division Materials Laboratory, Troutdale, Oregon) for sediment grain size and percent organic carbon (total volatile solids).

Physical Conditions

Selected physical parameters, in addition to the sediment structure, were measured in conjunction with the biological sampling--depth (m) (minimum and maximum); bottom-water temperature (°C); bottom-water turbidity (NTU); and water velocities at 0.2 of the total depth, 0.8 of the total depth, and about

0.6 m above the bottom. By averaging the water velocities measured at 0.2 and 0.8 of the total depth, we calculated a mean water-column velocity. Water velocities were routinely measured only during egg and larval sampling. Depth was measured with electronic depth sounders, and velocity was measured with a Gurley current meter attached to a 45.4-kg lead fish. Turbidity was determined in the laboratory using a Hach Model 2100A Turbidimeter.

Data Analyses

Physical and biological data collected during the season were entered into computer files following formats agreed to by the four agencies involved in the sturgeon study--FWS, ODFW, NMFS, and WDF. Selected computer programs were used to analyze the data.

Linear and multiple regressions were used to determine the relationships between measured physical parameters (water temperature, turbidity, water velocity, and Bonneville Dam discharge) and densities of white sturgeon eggs (stage 2) observed at Ives Island. Stage 2 eggs are freshly fertilized eggs and their presence indicates recent spawning. Egg densities, which were expressed as number/1,000 m^3 of water, were transformed to $\log_{10}$ of (number + 1) prior to analysis.

Using the distance fished during a trawl effort and the estimated fishing width of the net(s), we calculated the area fished for each effort. The fish densities (by species) for each effort were calculated and expressed as number/hectare (ha) (10,000 m^2). The estimated effective fishing widths of the 4.9- and 7.9-m semiballoon shrimp trawls were 3.3 and 5.3 m, respectively.

For data analysis, young-of-the-year (Y-O-Y) white sturgeon were separated from older juvenile sturgeon using length frequencies. For this report, a white sturgeon's birth date is assumed to be 1 January, although in reality the birth date is generally sometime later in the year.

Linear regression was used to compute the fork length-weight relationship for white sturgeon; the data were transformed ($\log_{10}$) prior to computing the relationship. A condition factor, C (Everhart and Youngs 1981), was computed for each white sturgeon using the formula:

$$C = (W/L^3) \times 10^5;$$

W = weight (g) and L = length (mm, fork length). A mean condition factor and standard deviation (SD) were calculated for all white sturgeon measured and weighed.

Densities of white sturgeon in three different depth ranges--$\leq$9.0, 9.1 to 18.2, and $\geq$18.3 m--were compared using the nonparametric Kruskal-Wallis test (Elliott 1977); the data were not transformed for this test.

Benthic invertebrate data were analyzed both by individual station and by combining stations in an area. Information calculated for each station included the number of taxa, mean number/m^2 and SD for each taxon, mean number of invertebrates/sample and SD, and total mean number of invertebrates/m^2 and SD. For the index areas, the relationships between white sturgeon densities and benthic invertebrate densities, specifically *Corbicula manilensis* and

Corophium salmonis, were examined using linear and multiple regressions. White sturgeon densities were transformed to $\log_{10}$ of (density + 1) and benthic invertebrate densities were transformed ($\log_{10}$) prior to analyses.

The food of white sturgeon in each of two areas during three time periods was analyzed using two approaches. The importance of a prey taxon was determined using a modification of the Index of Relative Importance (IRI) described by Pinkas et al. (1971):

$$IRI = (N + W) F;$$

N = percent number of a prey item, W = percent weight of a prey item, and F = percent frequency of occurrence of a prey item. IRI values were then converted to percentages. To determine feeding intensity in each area, an Index of Feeding (IF) was calculated:

$$IF = \frac{Ws}{Wf} \times 100\%;$$

Ws = weight of stomach contents of a fish and Wf = weight of a fish. Differences among IF values were statistically tested using the Mann-Whitney test (Elliott 1977).

RESULTS

Egg and Larval Sampling

In 1989, a total of 2,323 white sturgeon eggs were collected between RMs 138 and 145 (Table 1); 2,018 eggs were collected with plankton nets and 305 eggs were collected with artificial substrates. White sturgeon eggs were first collected with plankton nets on 27 April near Ives Island (RM 143). Eggs were last collected in plankton nets on 6 July at RM 140.

The sampling site near Ives Island was used as an index area to monitor white sturgeon spawning during 1989 (Table 2). White sturgeon eggs were collected at this site on all sampling days from 27 April (when eggs were first collected) to 28 June (when eggs were last collected). The density of white sturgeon eggs at Ives Island was highest on 17 May (171.3 eggs/1,000 m^3). At Ives Island, stage 2 (freshly fertilized) eggs represented 71% of the total eggs collected in plankton nets and were collected on 7 of the 10 sampling days that eggs were collected at this location, indicating that spawning was occurring throughout the spring. Stage 2 eggs also represented at least 30% of the eggs from an individual sampling effort on 6 of the 10 sampling days. Stage 2 eggs were first collected on 27 April and last collected on 8 June (Table 3).

In areas downstream from Ives Island, only 14% of the total eggs collected were stage 2 eggs; also, stage 2 eggs were not as frequently collected in these areas as at Ives Island (Table 3). These data indicate that spawning intensity was much greater in the area near Ives Island. Most of the stage 2 eggs collected upstream from Ives Island were collected on artificial substrate placed just downstream from the spillways (RM 145); stage 2 eggs were collected near the spillways on 10, 11, and 24 May.

Table 1. Numbers of white sturgeon eggs and larvae collected in the Columbia River downstream from Bonneville Dam, 1989; plankton nets and artificial substrates were used to collect eggs, and plankton nets used to collect larvae. Fungus-infected eggs collected in plankton nets are shown in parentheses and are included in the numbers reported for the nets. Area refers to the geographic range in RM.

Sampling period	Eggs			Larvae	
	Area (RM)	Net	Substrate	Area (RM)	Net
30 Mar-27 Apr	143	385	47	143	0
1-17 May	139-145	892 (7)	37	108-144	51
22 May-1 Jun	139-145	121 (15)	215	113-143	41
7-21 Jun	138-145	616 (9)	6	113-143	35
28 Jun-6 Jul	140-143	4 (3)	0	140-143	8
19 Jul-17 Aug	143	0	0	143	0
TOTAL		2,018 (34)	305		135

Table 2. White sturgeon egg and larval catches near Ives Island (RM 143) in the Columbia River downstream from Bonneville Dam, 1989. Water temperatures were measured just above the bottom; Bonneville Dam flows were average hourly discharges (for each day). At least two plankton net samples were collected on each sampling day.

Date	Temp. (°C)	Velocity (m/s)		Bonneville Dam total discharge (1,000 m^3/s)	Eggs/ 1,000 m^3	Larvae/ 1,000 m^3
		Mean column	Bottom			
30 Mar	7	-	-	5.36	0.0	0.0
18 Apr	10	1.9	1.5	6.56	0.0	0.0
27 Apr	12	2.2	1.5	6.84	127.9	0.0
1 May	12	2.0	1.7	6.77	17.2	0.0
10 May	13	2.4	-	8.25	39.0	0.9
17 May	14	2.3	1.6	7.96	171.3	2.6
24 May	14	2.2	1.4	6.68	8.5	0.3
1 Jun	14	2.2	1.6	6.93	8.8	6.7
8 Jun	16	2.6	2.0	7.48	87.9	1.9
15 Jun	17	2.2	1.5	5.91	0.3	1.8
21 Jun	17	1.9	1.0	4.77	0.4	0.0
28 Jun	18	1.6	1.1	4.00	0.9	3.2
6 Jul	19	1.6	1.0	4.06	0.0	0.0
19 Jul	20	1.0	0.6	2.58	0.0	0.0
31 Jul	20	1.5	1.3	3.14	0.0	0.0
17 Aug	20	1.0	0.6	2.69	0.0	0.0

Table 3. Numbers of white sturgeon eggs (by developmental stage) collected with plankton nets in three areas downstream from Bonneville Dam, 1989. Upstream and downstream areas were defined in relation to Ives Island.

Date (RM)	Egg developmental stage																	
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Total
UPSTREAM																		
10 May (144)	1	0	0	0	1	2	4	1	0	2	0	0	0	0	0	1	0	12
IVES ISLAND																		
27 Apr (143)	348	0	0	0	6	9	3	0	0	16	3	0	0	0	0	0	0	385
1 May (143)	17	1	1	0	6	0	2	4	2	1	7	4	1	6	1	1	0	54
10 May (143)	70	6	0	3	10	0	9	3	0	3	13	0	0	0	3	7	0	127
17 May (143)	525	16	0	14	16	0	0	0	0	0	0	0	0	0	14	14	0	599
24 May (143)	18	0	1	0	1	0	2	2	2	1	0	0	0	0	0	0	0	27
1 Jun (143)	1	0	0	1	1	0	0	0	0	0	0	1	1	0	2	5	4	16
8 Jun (143)	99	8	0	8	24	12	81	13	24	14	0	0	0	0	0	0	0	283
15 Jun (143)	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
21 Jun (143)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Total	1,078	31	2	26	64	21	97	22	28	36	24	5	2	6	20	27	4	1,493[a]
DOWNSTREAM																		
1 May (139)	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2
1 May (140)	1	0	0	0	5	8	9	3	1	5	0	5	1	1	0	0	0	39
10 May (140)	14	2	0	1	0	0	3	3	1	1	6	6	2	0	1	0	0	40
17 May (139)	0	0	0	0	0	0	1	1	0	0	0	1	0	1	1	7	0	12
24 May (139)	0	0	0	0	2	0	0	0	0	2	0	0	0	0	1	0	0	5
24 May (140)	6	1	5	5	1	5	11	1	1	7	4	6	1	0	0	0	0	54
1 Jun (139)	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	1	0	4
8 Jun (139)	2	3	0	1	2	2	2	0	0	0	0	2	0	0	0	1	0	15
8 Jun (140)	48	0	17	0	34	15	98	30	35	6	6	9	0	0	0	0	0	298
21 Jun (140)	0	0	0	1	0	0	0	1	0	0	0	2	1	1	2	0	0	8
21 Jun (142)	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
6 Jul (140)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Total	71	6	22	8	44	30	124	39	40	21	16	32	6	3	7	10	0	479[b]

[a] *Does not include 18 eggs of unknown developmental stages.*
[b] *Does not include 16 eggs of unknown developmental stages.*

Based on back calculations using the developmental stages of eggs, we estimated spawning began on 22 April and ended on 2 July. During this period, spawning was estimated to have occurred on at least 43 days--9 days in late April, 23 days in May, 10 days in June, and 1 day in early July. During the spawning period, water temperatures (measured at Bonneville Dam) ranged from 12 to 18°C and Bonneville Dam discharge (mean hourly discharge by day) ranged from 3,348 to 8,872 m^3/s (Figure 2).

Results of linear regression analyses indicated the following relationships among egg (stage 2) densities at Ives Island (from 27 April to 28 June) and temperature, turbidity, mean water-column velocity, and Bonneville Dam discharge: 1) 36% of the variation in catch could be attributed to temperature, 2) 73% of the variation to turbidity, 3) 33% of the variation to mean column velocity, and 4) 54% of the variation to Bonneville Dam discharge. Using multiple regression, 90% of the variation in catch could be attributed to the combination of temperature, turbidity, and mean column velocity.

Artificial substrates placed downstream from the spillways at Bonneville Dam (at the lower boundary of the restricted zone) collected 256 white sturgeon eggs (five successful sampling efforts); whereas, artificial substrates placed downstream from the Second Powerhouse turbines collected no white sturgeon eggs. Water velocities were not measured at these sites; however, velocities appeared to be low downstream from the Second Powerhouse when the substrate was deployed and retrieved. Water velocities downstream from the spillways were relatively high when the spillways were being used. Artificial substrates were also placed downstream from the First Powerhouse, but only two eggs were collected on one occasion.

In 1989, a total of 135 white sturgeon larvae were collected in plankton nets between RMs 108 and 144 (Table 1). Larval sampling was also conducted downstream from RM 108; however, no larvae were collected in this area. Larvae were first collected on 8 May at RM 113 (I-205 Bridge), and the last larvae were captured on 28 June near Ives Island and RM 140. Overall, 66% of the larvae that were staged were classified as post hatch or stage 1 (Table 4). Densities of larvae near Ives Island ranged from 0.0 to 6.7 larvae/1,000 m^3 (Table 2).

The physical conditions under which eggs and larvae were collected were very similar. Bottom-water temperatures at sites where eggs were collected in plankton nets ranged from 12 to 18°C; bottom-water turbidities ranged from 3.3 to 10.0 NTU; mean water-column velocities ranged from 0.7 to 2.6 m/s; water velocities about 0.6 m above the bottom ranged from 0.5 to 2.0 m/s; and water depths ranged from 4.6 to 22.6 m. White sturgeon larvae were captured where bottom-water temperatures ranged from 13 to 18°C; bottom-water turbidities ranged from 3.3 to 9.2 NTU; mean water-column velocities ranged from 0.7 to 2.6 m/s; water velocities about 0.6 m above the bottom ranged from 0.5 to 2.0 m/s; and water depths ranged from 4.6 to 22.6 m.

No white sturgeon eggs or larvae were collected in the Willamette River at Oregon City on 25 May.

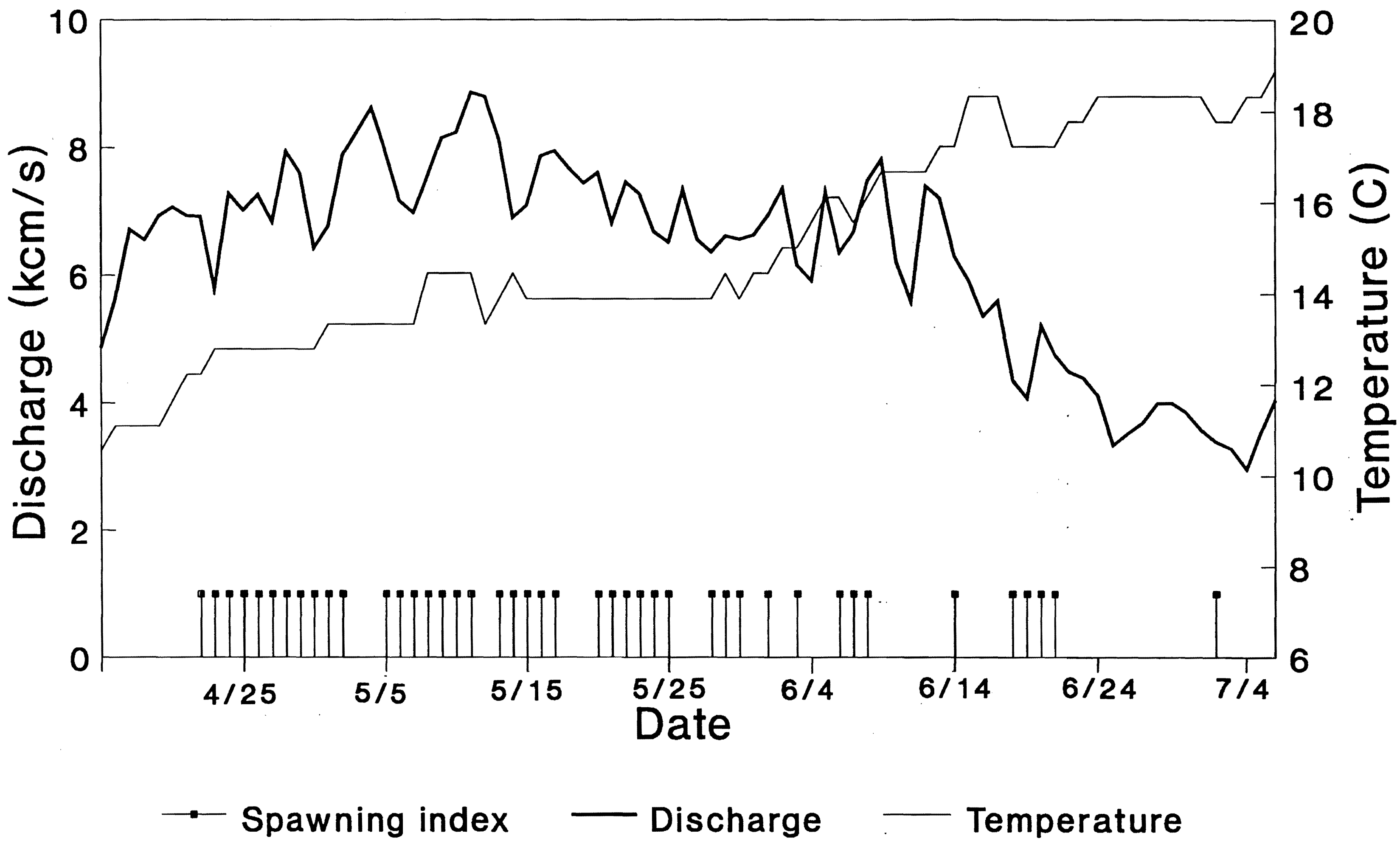

Figure 2. Water temperatures (°C) and Bonneville Dam discharges (mean hourly water discharges by day) from 15 April through 6 July 1989; discharge is shown as m^3/s x 1,000. Water temperatures were measured at Bonneville Dam. The spawning index shows the days on which white sturgeon spawning was estimated to have occurred.

Table 4. Numbers of white sturgeon larvae (by stage) captured downstream from Bonneville Dam, 1989.

Date (RM)	Larval stage								
	Post hatch	1	2	3	4	5	6	7	Total
IVES ISLAND									
10 May (143)	2	1	0	0	0	0	0	0	3
17 May (143)	3	0	0	0	0	0	0	0	3
24 May (143)	0	1	0	0	0	0	0	0	1
1 Jun (143)	4	8	4	0	1	0	0	1	18
8 Jun (143)	1	0	0	2	2	1	0	0	6
15 Jun (143)	3	2	2	0	0	0	0	0	7
28 Jun (143)	0	6	1	0	0	0	0	0	7
Total	13	18	7	2	3	1	0	1	45[a]
OTHER LOCATIONS									
8 May (113)	1	1	1	0	0	0	0	0	3
9 May (108)	0	1	0	0	0	0	0	0	1
9 May (120)	2	2	0	0	0	0	0	0	4
10 May (139)	0	1	0	0	0	0	0	0	1
10 May (140)	1	1	2	0	0	0	0	0	4
10 May (144)	0	0	1	0	0	0	0	0	1
17 May (120)	2	2	0	0	0	0	0	0	4
17 May (139)	11	5	1	0	0	0	0	0	17
22 May (113)	0	0	0	0	0	0	0	1	1
24 May (120)	0	0	0	0	0	1	0	0	1
24 May (139)	1	0	0	2	0	0	0	0	3
24 May (140)	1	0	0	0	0	0	0	0	1
1 Jun (139)	4	5	2	0	0	1	0	0	12
8 Jun (120)	1	0	0	0	0	0	0	0	1
8 Jun (138)	0	0	0	1	0	0	1	0	2
8 Jun (139)	0	0	0	0	1	2	0	5	8
8 Jun (140)	0	0	0	1	0	1	0	0	2
15 Jun (139)	2	1	0	0	0	0	0	0	3
20 Jun (113)	1	0	0	0	0	0	0	0	1
21 Jun (120)	0	0	0	0	1	0	0	0	1
21 Jun (139)	0	0	0	0	0	0	0	2	2
21 Jun (142)	1	0	0	0	0	0	0	0	1
28 Jun (140)	0	1	0	0	0	0	0	0	1
Total	28	20	7	4	2	5	1	8	75[b]

[a] *Does not include 10 larvae of unknown stages.*
[b] *Does not include 5 larvae of unknown stages.*

Juvenile Sampling

Abundance and Distribution

In 1989, a total of 2,579 juvenile white sturgeon were collected with trawls in the Columbia River downstream from Bonneville Dam. Of this total, 2,558 were collected with the 7.9-m semiballoon shrimp trawl. Distribution of juvenile white sturgeon in the Columbia River downstream from Bonneville Dam was patchy. Not only were there differences in catches among different areas of the river, but also differences in catches among parallel transects within the same area (Figure 3). Mean catches were highest at RM 95, Transect 1 (64 sturgeon/ha) and RM 131, Transect 2 (148 sturgeon/ha). The highest catch in 1989 was made at RM 132 on 23 October when 362 white sturgeon (2,458/ha) were collected in a 5-min trawling effort.

Size-Class Structure

The monthly size ranges of white sturgeon captured in 1989 were similar from March through June, prior to the appearance of Y-O-Y white sturgeon in July (Figure 4). The Y-O-Y group is the only age group that is easily discernible in the histograms, as there is considerable overlap in the lengths of the older age groups.

Young-of-the-Year

In 1989, a total of 111 Y-O-Y white sturgeon were captured between RMs 29 and 101 (Table 5); Y-O-Y comprised 4% of the total catch of juvenile white sturgeon. The Y-O-Y were first collected on 7 July.

The Y-O-Y were collected during trawling efforts where the depths ranged from 4.0 to 37.5 m; mean minimum and maximum depths were 14.7 and 22.6 m, respectively. As indicated by the mean depths, Y-O-Y preferred deeper areas of the river. The bottom substrates over which Y-O-Y were found were predominantly sand.

White sturgeon Y-O-Y grew rapidly during the summer and fall; the mean fork length increased from 85 mm in July to 240 mm on 1 November. At times, there was considerable variation in the lengths and weights of Y-O-Y white sturgeon collected on the same day.

Species Associations

Juvenile white sturgeon were commonly captured with American shad *Alosa sapidissima*, juvenile chinook salmon *Oncorhynchus tshawytscha*, eulachon *Thaleichthys pacificus*, peamouth *Mylocheilus caurinus*, northern squawfish *Ptychocheilus oregonensis*, leopard dace *Rhinichthys falcatus*, largescale sucker *Catostomus macrocheilus*, sand roller *Percopsis transmontana*, and sculpins (Cottidae) (Appendix D-1).

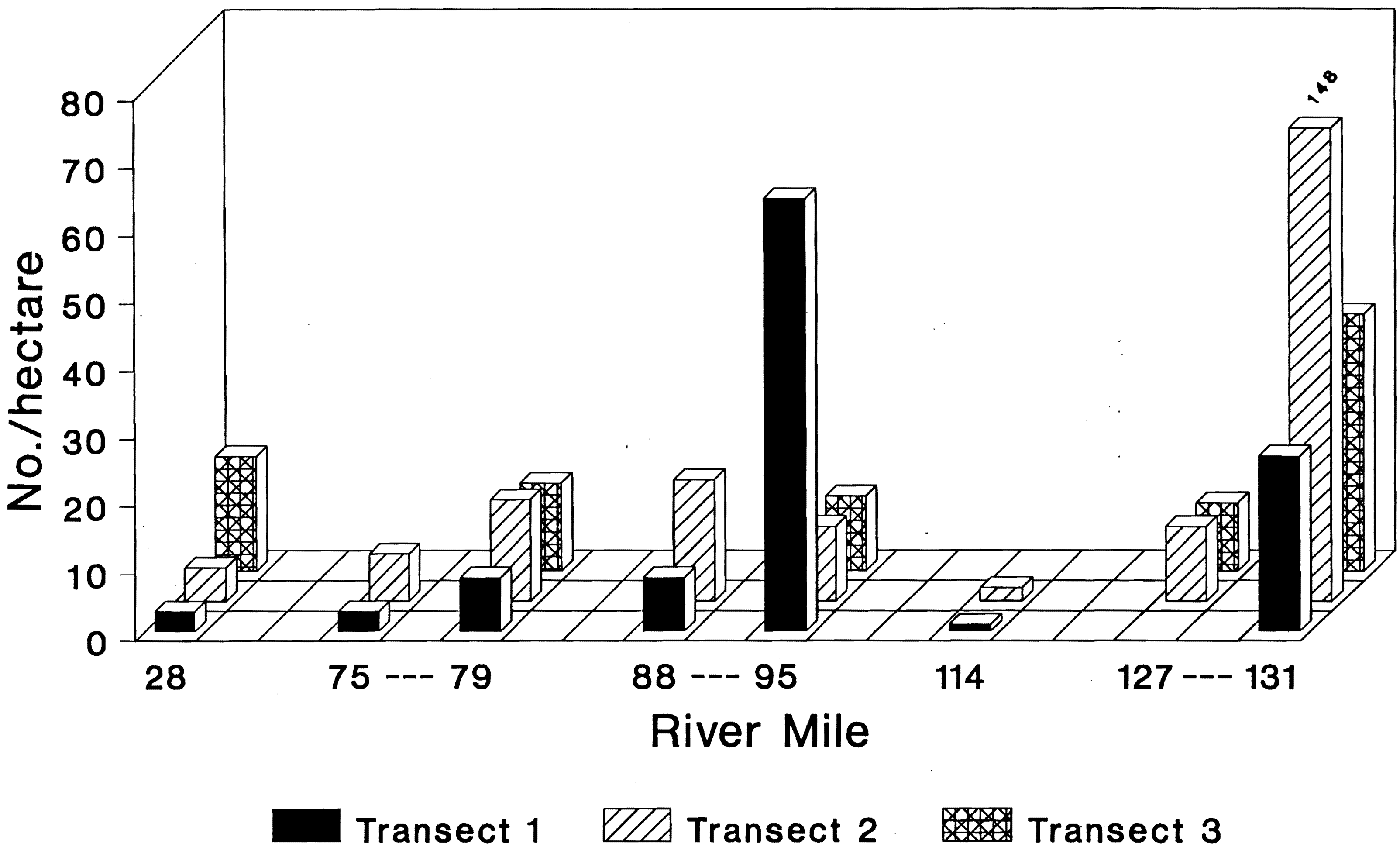

Figure 3. Estimated mean densities of juvenile white sturgeon at five index areas in the Columbia River downstream from Bonneville Dam, 1989.

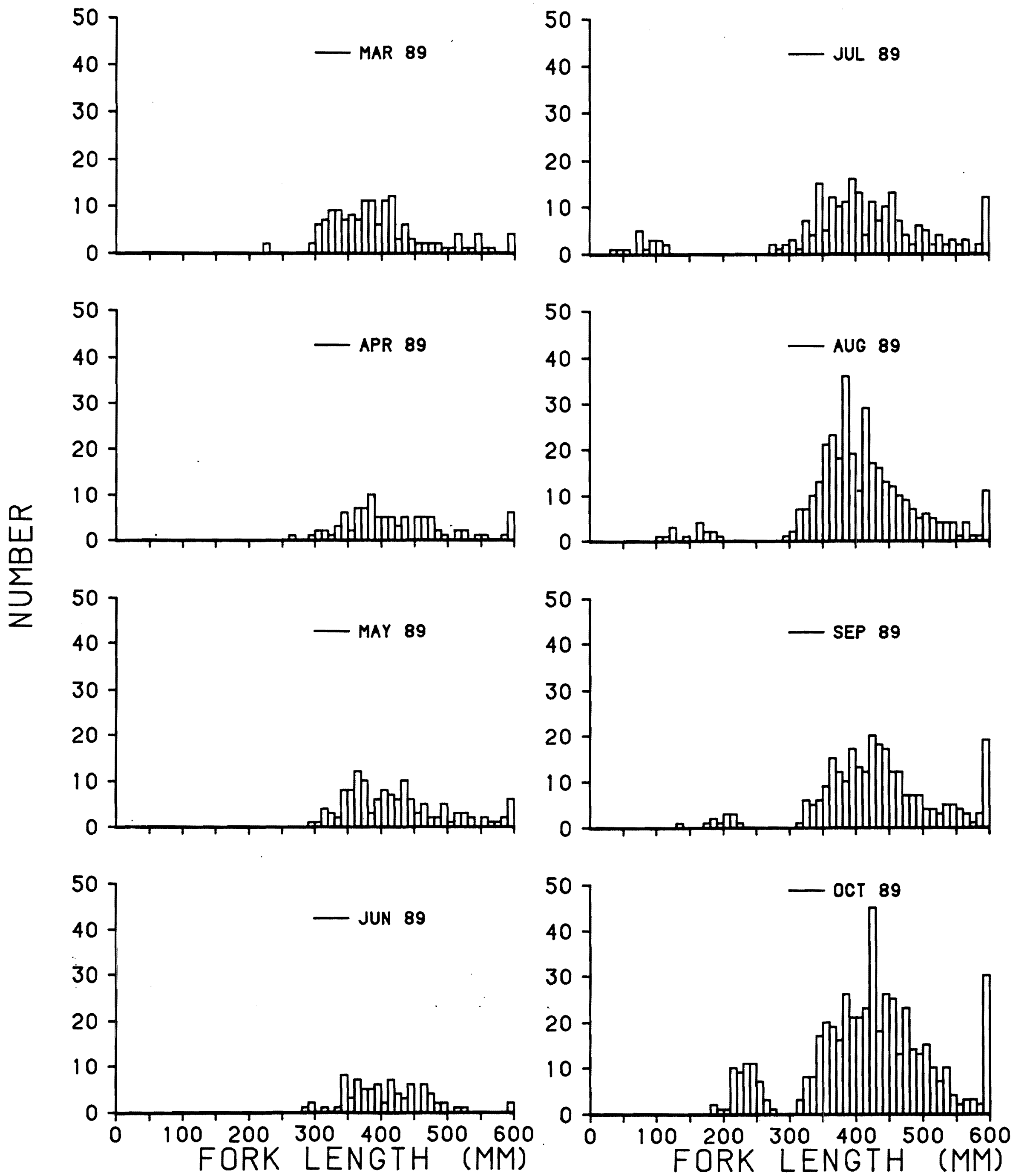

Figure 4. Length-frequency histograms for juvenile white sturgeon collected in the Columbia River downstream from Bonneville Dam, 1989. Sturgeon longer than 600 mm are included in the 600-mm interval.

Table 5. Summary of young-of-the-year white sturgeon catches in the Columbia River downstream from Bonneville Dam, 1989.

Month	Capture location (RM)	Number	Fork length (mm)		Weight (g)	
			Mean	SD	Mean	SD
Jul	30-95	17	84.6	±22.8	5.0	±3.1
Aug	30-95	15	154.9	±26.1	31.6	±13.5
Sep	29-95	12	197.5	±25.3	59.7	±18.7
Oct	30-101	56	233.6	±19.7	87.4	±18.5
Nov[a]	66-75	11	239.8	±13.9	90.5	±20.2

[a] *Sampling for November was conducted on 1 November.*

Tagging

A total of 1,675 juvenile white sturgeon were tagged in 1989. Twenty-four tagged sturgeon were recaptured in NMFS trawls (Table 6); 2 of the recaptures had been tagged by NMFS in 1987 and 10 had been tagged in 1988. All of the recaptures were made within a mile of where the fish were originally tagged. Sixteen of the tag recoveries were made at RM 131 to 132; recaptures from this area frequently showed negative growth.

Parasites

In 1989, a total of 1,822 juvenile white sturgeon were examined for the nematode parasite *Cystoopsis acipenseri*, and of this number, 24 (1%) were infected. The mean fork length of the infected fish was 337 mm, with a range from 294 to 405 mm; 23 of the infected fish were less than 400 mm long. The condition factor of infected fish was 0.6200 ± 0.0574, and the condition factor for non-infected sturgeon in the same length range was 0.6352 ± 0.0679.

Body Measurements and Condition Factor

The regression equation for the length-weight relationship of juvenile white sturgeon was $\log_{10}$weight, g = $-5.14 + 2.98$ ($\log_{10}$fork length, mm); N = 1,822; $r^2 = 0.98$. The mean condition factor of 1,822 juvenile white sturgeon was 0.6595 ± 0.0804.

Physical Conditions

Sampling for juvenile white sturgeon with the 7.9-m trawl was conducted in depths ranging from 2.7 to 37.5 m. There was a significant difference among sturgeon densities when grouped into three depth ranges (maximum depth): ≤ 9.0, 9.1 to 18.2, and ≥ 18.3 m (Kruskal-Wallis, $P < 0.01$). The mean density was highest at depths ≥ 18.3 m (83 ± 284 sturgeon/ha) and lowest at depths ≤ 9.0 m (9 ± 32 sturgeon/ha); at depths from 9.1 to 18.2 m, the mean density was 20 ± 51 sturgeon/ha. Bottom-water temperatures during juvenile white sturgeon sampling (7.9-m trawl samples) ranged from 6 to 21 °C.

Benthic Sampling

Benthic invertebrate densities varied temporally and spatially (Tables 7-11, Appendix D-2) in the Columbia River downstream from Bonneville Dam; eulachon eggs are included in the tables because of their importance in the diet of white sturgeon (see stomach contents analysis section). When large numbers of eulachon eggs occurred in samples, their numbers were estimated. Benthic invertebrate densities varied among areas and among transects within the same RM. Mean densities (area totals) for all areas, except RM 88-95, were higher during Survey 2 than during Survey 1. If eulachon eggs are excluded, mean benthic invertebrate densities (area totals) for all of the areas were higher during Survey 2 than during Survey 1. Major invertebrate taxa collected during the surveys included Turbellaria, Oligochaeta, *Corbicula manilensis, Corophium salmonis,* Chironomidae larvae, and Heleidae larvae. The relationships between white sturgeon densities and densities of *Corbicula*

Table 6. Individual recoveries (in 1989) of juvenile white sturgeon tagged in the Columbia River downstream from Bonneville Dam, 1987-1989.

Location (RM)		Days at large	Change in fork length (mm)	Change in weight (g)
Tagged	Recaptured			
29	29	14	-2	5
95	95	28	0	-15
95	95	293	22	340
95	95	295	2	85
95	95	308	0	15
95	95	322	6	-54
95	95	336	15	52
95	95	693	63	67
131	131	11	1	-18
131	131	17	-2	-6
131	132	28	-9	-32
131	131	28	-5	-9
131	131	29	0	1
131	130	96	-2	-2
131	131	98	2	-1
131	132	109	4	15
131	131	124	-6	-23
131	132	152	11	28
131	131	284	0	-29
131	131	322	3	-40
131	131	334	0	-20
131	132	461	-7	-46
131	132	538	128	360
131	131	748	-1	-57

Table 7. Mean densities (number/m²) and standard deviations (SD) of major taxa collected during two benthic invertebrate surveys in the Columbia River downstream from Bonneville Dam (RM 28); Survey 1 was in April 1989 and Survey 2 in September 1989. The total for each transect includes both major taxa and less important taxa not shown.

RM-transect	Taxon	Survey 1 Mean		Survey 1 SD	Survey 2 Mean		Survey 2 SD
28-1	Turbellaria	84	±	60	16	±	50
	Corbicula manilensis	40	±	50	72	±	65
	Corophium salmonis	12	±	17	1,505	±	2,020
	Heleidae larvae	106	±	54	332	±	264
	TOTAL	266	±	85	1,938	±	1,905
28-2	Turbellaria	52	±	59	0	±	0
	Corbicula manilensis	202	±	104	67	±	72
	Corophium salmonis	143	±	164	1,359	±	500
	Chironomidae larvae	36	±	28	2	±	4
	Heleidae larvae	642	±	289	299	±	177
	Invertebrate eggs	196	±	444	0	±	0
	Eulachon eggs	743	±	1,776	0	±	0
	TOTAL	2,046	±	1,855	1,743	±	514
28-3	*Neanthes limnicola*	62	±	34	103	±	77
	Oligochaeta	126	±	92	32	±	28
	Fluminicola spp.	689	±	773	151	±	157
	Corbicula manilensis	38	±	38	96	±	83
	Corophium spp.	0	±	0	15	±	25
	Corophium salmonis	604	±	321	3,272	±	1,232
	Chironomidae larvae	20	±	19	2	±	4
	Plecoptera	17	±	53	0	±	0
	TOTAL	1,572	±	1,117	3,677	±	1,337
	AREA TOTAL[a]	1,295	±	1,430	2,453	±	1,595

[a] *The mean density is the average of all samples taken in the area.*

Table 8. Mean densities (number/m²) and standard deviations (SD) of major taxa collected during two benthic invertebrate surveys in the Columbia River downstream from Bonneville Dam (RM 75 to 79); Survey 1 was in April 1989 and Survey 2 in September 1989. The total for each transect includes both major taxa and less important taxa not shown.

RM-transect	Taxon	Survey 1 Mean		Survey 1 SD	Survey 2 Mean		Survey 2 SD
75-1	Turbellaria	43	±	51	2	±	4
	Oligochaeta	56	±	61	61	±	68
	Corbicula manilensis	48	±	44	100	±	99
	Corophium salmonis	2	±	4	49	±	50
	Chironomidae larvae	14	±	10	0	±	0
	Heleidae larvae	489	±	312	326	±	328
	TOTAL	663	±	342	550	±	409
75-2	*Corbicula manilensis*	21	±	37	303	±	292
	Corophium salmonis	7	±	10	40	±	62
	Heleidae larvae	99	±	92	401	±	246
	TOTAL	148	±	118	760	±	414
79-1	Turbellaria	91	±	97	30	±	41
	Oligochaeta	238	±	471	464	±	386
	Corbicula manilensis	18	±	15	392	±	461
	Corophium salmonis	2	±	4	79	±	141
	Heleidae larvae	546	±	658	322	±	188
	TOTAL	902	±	837	1,295	±	773
79-2	*Corbicula manilensis*	26	±	29	366	±	398
	Corophium salmonis	1	±	3	41	±	21
	Heleidae larvae	219	±	198	341	±	263
	TOTAL	262	±	216	781	±	453
79-3	*Corbicula manilensis*	6	±	7	332	±	377
	Corophium salmonis	1	±	3	756	±	285
	Heleidae larvae	49	±	38	37	±	26
	TOTAL	68	±	38	1,146	±	619
	AREA TOTAL[a]	409	±	516	906	±	596

[a] *The mean density is the average of all samples taken in the area.*

Table 9. Mean densities (number/m^2) and standard deviations (SD) of major taxa collected during two benthic invertebrate surveys in the Columbia River downstream from Bonneville Dam (RM 88 to 95); Survey 1 was in April 1989 and Survey 2 in September 1989. The total for each transect includes both major taxa and less important taxa not shown.

RM-transect	Taxon	Survey 1 Mean		Survey 1 SD	Survey 2 Mean		Survey 2 SD
88-1	Oligochaeta	27	±	22	16	±	29
	Corbicula manilensis	14	±	21	105	±	77
	Corophium salmonis	62	±	137	1,059	±	493
	Heleidae larvae	100	±	107	63	±	40
	TOTAL	206	±	205	1,265	±	534
88-2	*Corbicula manilensis*	72	±	69	103	±	52
	Corophium salmonis	5	±	7	391	±	540
	Corophium spinicorne	0	±	0	54	±	86
	Heleidae larvae	275	±	338	47	±	59
	TOTAL	372	±	367	637	±	484
95-1	Oligochaeta	751	±	920	670	±	516
	Corbicula manilensis	699	±	848	174	±	213
	Corophium salmonis	33	±	49	41	±	27
	Heleidae larvae	271	±	285	88	±	126
	Eulachon eggs	7,359	±	16,331	0	±	0
	TOTAL	9,126	±	15,751	983	±	741
95-2	*Corbicula manilensis*	104	±	108	183	±	271
	Corophium salmonis	19	±	20	13	±	13
	Heleidae larvae	171	±	182	383	±	207
	TOTAL	308	±	232	635	±	400
95-3	Oligochaeta	22	±	18	12	±	13
	Corbicula manilensis	98	±	81	116	±	126
	Corophium salmonis	134	±	112	1,177	±	930
	Heleidae larvae	337	±	310	180	±	228
	TOTAL	600	±	330	1,518	±	709
	AREA TOTAL[a]	2,122	±	7,626	1,015	±	665

[a] *The mean density is the average of all samples taken in the area.*

Table 10. Mean densities (number/m²) and standard deviations (SD) of major taxa collected during two benthic invertebrate surveys in the Columbia River downstream from Bonneville Dam (RM 114); Survey 1 was in April 1989 and Survey 2 in September 1989. The total for each transect includes both major taxa and less important taxa not shown.

RM-transect	Taxon	Survey 1			Survey 2		
		Mean		SD	Mean		SD
114-1	Turbellaria	14	±	19	6	±	13
	Oligochaeta	2	±	4	15	±	20
	Corbicula manilensis	156	±	169	102	±	128
	Corophium salmonis	3	±	7	14	±	28
	Chironomidae larvae	43	±	38	2	±	4
	Heleidae larvae	275	±	155	256	±	139
	TOTAL	501	±	257	401	±	190
114-2	*Corbicula manilensis*	48	±	34	36	±	23
	Chironomidae larvae	4	±	5	14	±	36
	Heleidae larvae	155	±	158	408	±	269
	TOTAL	219	±	170	470	±	280
	AREA TOTAL[a]	360	±	256	436	±	235

[a] *The mean density is the average of all samples taken in the area.*

Table 11. Mean densities (number/m²) and standard deviations (SD) of major taxa collected during two benthic invertebrate surveys in the Columbia River downstream from Bonneville Dam (RM 127 to 131); Survey 1 was in April 1989 and Survey 2 in September 1989. The total for each transect includes both major taxa and less important taxa not shown.

RM-transect	Taxon	Survey 1 Mean		Survey 1 SD	Survey 2 Mean		Survey 2 SD
127-2	*Corophium salmonis*	20	±	19	10	±	9
	Chironomidae larvae	3	±	5	64	±	67
	Heleidae larvae	24	±	17	315	±	175
	TOTAL	59	±	37	434	±	235
127-3	Oligochaeta	290	±	433	443	±	644
	Corbicula manilensis	35	±	56	648	±	998
	Heleidae larvae	343	±	341	506	±	278
	TOTAL	682	±	720	1,638	±	1,365
131-1	Oligochaeta	6	±	11	168	±	111
	Corbicula manilensis	68	±	55	302	±	233
	Corophium salmonis	5	±	7	80	±	93
	Heleidae larvae	105	±	67	392	±	216
	TOTAL	194	±	79	974	±	398
131-2	Oligochaeta	15	±	17	19	±	33
	Corbicula manilensis	52	±	44	26	±	22
	Corophium salmonis	54	±	30	198	±	185
	Chironomidae larvae	22	±	13	35	±	27
	Heleidae larvae	108	±	107	88	±	110
	TOTAL	252	±	153	374	±	150
131-3	Oligochaeta	1,078	±	1,081	261	±	124
	Corbicula manilensis	120	±	53	34	±	56
	Ostracoda	8	±	13	47	±	68
	Corophium salmonis	766	±	270	205	±	188
	Chironomidae larvae	89	±	67	71	±	59
	TOTAL	2,137	±	1,090	643	±	253
	AREA TOTAL[a]	665	±	957	812	±	785

[a] *The mean density is the average of all samples taken in the area.*

manilensis and *Corophium salmonis*, two important prey items for juvenile sturgeon, were poor (Table 12). Results of linear regression indicated that less than 3% of the variation in sturgeon densities was explained by *Corbicula manilensis* densities; less than 12% of the variation was explained by *Corophium salmonis* densities. Results from multiple regression showed that no more than 12% of the variation in sturgeon densities was explained by using both *Corbicula manilensis* and *Corophium salmonis* densities as predictors.

Results from the sediment analysis indicated that the substrate in most of the sampling areas consisted primarily of sand (Table 13, Appendix D-3), although gravel and fines were present in relatively high proportions at some stations. The substrate along some of the individual transects varied as indicated by the ranges shown in Table 13, and at some transects the substrate varied from Survey 1 to Survey 2. With the exception of one station, total organic carbon associated with sediment at the stations was $\leq$2%. There was no apparent relationship between white sturgeon densities and sediment structure.

Stomach Contents Analysis

A total of 292 stomachs were taken from white sturgeon collected in two areas of the lower Columbia River (RMs 95 and 131) in 1988; however, analysis of the stomachs was not completed until 1989. Overall, the amphipod *Corophium salmonis* was the most important identifiable prey item at both RMs 95 and 131 (Table 14). During all three time periods in both areas, percent Index of Relative Importance (IRI) was higher for *Corophium salmonis* for Size Class I sturgeon ($\leq$350 mm fork length) than for Size Class II sturgeon (351 to 725 mm fork length), indicating that Size Class I sturgeon were preying more heavily on *Corophium salmonis* than were Size Class II sturgeon. The temporal importance of *Corophium salmonis* for Size Class I sturgeon at RM 95 remained relatively consistent, ranging from 75 to 82 %IRI during the three periods; whereas, at RM 131, the temporal importance of *Corophium salmonis* varied, ranging from 44 to 75 %IRI.

Size Class II sturgeon preyed heavily on *Corophium salmonis*, but they also preyed heavily on the bivalve *Corbicula manilensis*, Chironomidae larvae, and eulachon eggs at times. At both RMs 95 and 131, sturgeon fed on eulachon eggs only in May. At RM 95, the temporal importance of *Corophium salmonis* for Size Class II ranged from 38 %IRI in July-August to 51 %IRI in September-October. Also, eulachon eggs (12 %IRI) and *Corbicula manilensis* (11 %IRI) were important in May-June and *Corbicula manilensis* (19 %IRI) and *Corophium spinicorne* (7 %IRI) were important in July-August. At RM 131, the temporal importance of *Corophium salmonis* for Size Class II ranged from 12 %IRI in May-June to 24 %IRI in both July-August and September-October. Other important prey for Size Class II at RM 131 included eulachon eggs (51 %IRI) and *Corbicula manilensis* (20 %IRI) in May-June, *Corbicula manilensis* (35 %IRI) in July-August, and chironomids (22 %IRI) in September-October.

Other results from the stomach analysis indicated that food may be limited for juvenile sturgeon at RMs 95 and 131 in September-October. At RM 95, Index of Feeding (IF) for both size classes of sturgeon was significantly lower (Mann-Whitney test, $P < 0.05$) in September-October than in either May-June or July-August, indicating reduced in September-October; at RM 131, IF for Size Class II sturgeon was significantly lower in September-October than in either May-June or July-August (Table 15). The number of

Table 12. Summary of white sturgeon densities (number/ha) and benthic invertebrate densities (number/m^2) at five index areas in the Columbia River downstream from Bonneville Dam. Densities are shown for the invertebrates *Corbicula manilensis* (Cm) and *Corophium salmonis* (Cs), which are important prey for juvenile sturgeon. Benthic sampling for Survey 1 was from 10-14 April and sampling for Survey 2 was from 11-15 September. White sturgeon sampling for Survey 1 was from 27-29 March and sampling for Survey 2 was from 28 August-1 September.

RM-transect	Survey 1			Survey 2		
	Sturgeon density	Invertebrate density		Sturgeon density	Invertebrate density	
		Cm	Cs		Cm	Cs
28-1	0	40	12	5	72	1,505
28-2	36	202	143	20	67	1,359
28-3	0	38	604	17	96	3,272
75-1	14	48	2	10	100	49
75-2	10	21	7	10	303	40
79-1	0	18	2	0	392	79
79-2	17	26	1	20	366	41
79-3	9	6	1	-	332	756
88-1	54	14	62	21	105	1,059
88-2	7	72	5	25	103	391
95-1	29	699	33	106	174	41
95-2	8	104	19	46	183	13
95-3	27	98	134	13	116	1,177
114-1	7	156	3	0	102	14
114-2	12	48	7	0	36	5
127-2	36	2	20	5	32	10
127-3	6	35	9	5	648	18
131-1	24	68	5	35	302	80
131-2	218	52	54	94	26	198
131-3	274	120	766	12	34	205

Table 13. Summary of sediment characteristics at five sampling areas (juvenile white sturgeon) in the Columbia River downstream from Bonneville Dam, 1989; two samples were collected at different points along each transect. Sediment values are percentages of total.

RM-trans.	Survey 1 (April)				Survey 2 (September)			
	Gravel[a]	Sand[b]	Fines[c]	Org.[d]	Gravel	Sand	Fines	Org.
28-1	2	97-98	<1	<1	<1-4	96->99	<1	1
28-2	<1-1	99	<1	<1-1	1-2	97-99	<1	1
28-3	0	92-97	<1-8	1-2	0	91-99	1-9	1-2
75-1	3-13	87-97	<1	1	4-11	89-96	<1	1
75-2	<1	>99	0-<1	<1-1	1-13	87-99	<1	1
79-1	2-18	82-98	0-<1	<1-1	12-17	83-88	<1	<1-1
79-2	1-6	94-99	0-<1	<1-1	2	98	0-<1	1
79-3	<1	>99	0-<1	<1-1	<1-1	98->99	<1	1
88-1	0	>99	<1	1	0-<1	>99	<1	1
88-2	<1-1	99->99	0-<1	1	0-<1	10-99	<1-90	1
95-1	6	94	0	1	2-12	88-98	<1	1
95-2	<1-1	99->99	0-<1	1	<1-1	99->99	0-<1	1
95-3	<1	>99	0-<1	1	0-3	96->99	<1-1	1
114-1	5-8	92-95	0-<1	1	2-19	81-98	<1	1
114-2	1	99	0-<1	<1-1	<1-1	98->99	<1	1
127-2	0-<1	>99	<1	<1-1	0	>99	<1	<1
127-3	12-35	65-88	<1	1	12-55	45-88	0-<1	1
131-1	6	94	0-<1	1	7-17	83-93	0-<1	1-5
131-2	0	>99	<1	<1-1	0-9	88->99	<1-3	1
131-3	0	97-98	2-3	2	<1	97-98	2-3	1-2

[a] *Grain size $\geq$2 mm to <64 mm.*
[b] *Grain size 0.0625 to <2 mm.*
[c] *Grain size <0.0625 mm.*
[d] *Organic content.*

Table 14. Summary of white sturgeon diet studies from May through October 1988; numbers shown in the table are percents of total Index of Relative Importance (%IRI). Data are presented for two size-classes--Size Class I (≤350 mm fork length) and Size Class II (351-725 mm fork length)-- in two areas of the Columbia River, RMs 95 and 131. Only prey items with %IRI values greater than 1 (for at least one size-class and season) are shown.

RIVER MILE 95

	May-Jun		Jul-Aug		Sep-Oct	
Food category	Size I	Size II	Size I	Size II	Size I	Size II
Corbicula manilensis	<1	11	<1	19	0	3
Neomysis mercedis	0	0	4	<1	<1	<1
Corophium salmonis	82	40	75	38	75	51
Corophium spinicorne	3	2	4	7	5	3
Heleidae larvae	<1	<1	3	3	<1	<1
Eulachon eggs	2	12	0	0	0	0
Digested material	11	34	13	32	21	41

RIVER MILE 131

	May-Jun		Jul-Aug		Sep-Oct	
Food category	Size I	Size II	Size I	Size II	Size I	Size II
Corbicula manilensis	<1	20	<1	35	<1	<1
Neomysis sp.	0	0	<1	0	20	2
Neomysis mercedis	0	0	<1	<1	<1	1
Corophium salmonis	59	12	75	24	44	24
Corophium spinicorne	<1	<1	1	<1	<1	<1
Hemiptera	0	0	0	<1	<1	1
Chironomidae larvae	0	<1	4	2	11	18
Chironomidae pupae	<1	0	0	<1	<1	4
Heleidae larvae	<1	<1	2	1	0	0
Eulachon eggs	25	51	0	0	0	0
Fish (unidentified)	0	3	0	0	0	0
Digested material	16	13	17	35	23	49

Table 15. Comparisons of Index of Feeding (IF) for two size-classes of juvenile white sturgeon collected at RMs 95 and 131 in the Columbia River downstream from Bonneville Dam, 1988. Size Class I sturgeon were $\leq$350 mm fork length and Size Class II sturgeon were 351-725 mm fork length. Mean IF was calculated using only stomachs that contained food. The total number of stomachs collected and the number of empty stomachs are shown for each class.

RIVER MILE 95

Size Class	Time period		
	May-Jun	Jul-Aug	Sep-Oct
Size I			
a) mean IF	0.39	0.44	0.22[a]
b) total number	26	24	20
c) number empty	0	0	3
Size II			
a) mean IF	0.27	0.35	0.08[a]
b) total number	25	25	24
c) number empty	1	0	10

RIVER MILE 131

Size Class	Time period		
	May-Jun	Jul-Aug	Sep-Oct
Size I			
a) mean IF	0.31	0.23	0.20
b) total number	27	25	24
c) number empty	2	0	6
Size II			
a) mean IF	0.38	0.41	0.03[a]
b) total number	23	25	24
c) number empty	2	0	17

[a] *Mean IF for Sep-Oct was significantly less than IF for both May-Jun and Jul-Aug; Mann-Whitney test, $P < 0.05$.*

empty stomachs for both size classes in both areas was highest in September-October, indicating reduced feeding.

DISCUSSION

Egg and Larval Sampling

Catches of white sturgeon eggs in 1989 (n = 2,323) were considerably higher than catches in 1988 (n = 1,404; McCabe et al. 1989). The mean catch of white sturgeon eggs in plankton nets near Ives Island (RM 143) between 25 April and 20 June 1988 was 10.2 eggs/1,000 m^3, but between 27 April and 28 June 1989, the mean catch was 46.2 eggs/1,000 m^3. In 1989, white sturgeon eggs were collected over a slightly wider range than in 1988. Eggs in 1988 were collected between RMs 140 and 145, whereas in 1989, eggs were collected between RMs 138 and 145. In past studies by WDF, white sturgeon eggs have been collected as far downstream as RMs 118 (Kreitman 1983) and 136 (Kreitman 1983; Kreitman and Bluestein 1985).

The eggs collected just downstream from the spillways and First Powerhouse at Bonneville Dam were probably released by sturgeon spawning near the downstream section of the dam, and not by sturgeon spawning in the Bonneville Pool. The FWS sampled intensively in the Bonneville Pool in 1989 and collected sturgeon eggs between RMs 189.9 and 191.5 (Michael Parsley, FWS, Cook, Washington, personal communication); Bonneville Dam is at RM 145.6.

A total of 135 white sturgeon larvae were collected in 1989, compared to 90 collected in 1988 (McCabe et al. 1989). From 25 April to 20 June 1988, the mean catch of larvae near Ives Island was 0.5 larvae/1,000 m^3, but from 27 April to 28 June 1989, the mean catch of larvae near Ives Island was 1.7 larvae/1,000 m^3. The downstream distribution of white sturgeon larvae in 1989 was similar to the distributions in 1987 and 1988, with at least one larva being collected more than 30 miles downstream from Bonneville Dam. In 1989, a larva was collected at RM 108, which is 5 miles farther downstream than any location at which larvae were collected in 1987 and 1988. River flows in spring 1989 were higher than flows in spring 1987 and 1988.

In 1989, white sturgeon eggs and larvae were collected during the same general time period as in 1987 (McCabe and McConnell 1988), 1988, and past WDF studies. Based on sampling in 1989 and past years, it appears that white sturgeon spawn in the Columbia River downstream from Bonneville Dam from late April through early July (Kreitman 1985; Kreitman and Bluestein 1985; Bluestein 1986; McCabe and McConnell 1988; McCabe et al. 1989).

White sturgeon spawning in 1989 was estimated to have occurred during a period when water temperatures (measured at Bonneville Dam) ranged from 12 to 18°C. Based on larval collections of white or green sturgeon *Acipenser medirostris*, Kohlhorst (1976) estimated sturgeon in the Sacramento River spawn at water temperatures ranging from 7.8 to 17.8°C, with peak spawning at 14.4°C.

It is not known precisely where the larvae collected downstream from Bonneville Dam originated, but assuming that sturgeon spawn over a rock or cobble bottom in high velocity areas, then the eggs were released in the area from Bonneville Dam to a point possibly about 6-7 miles downstream from the dam. River flow affects the downstream distribution of sturgeon larvae. Stevens and Miller (1970) noted a direct relationship between river flow and catches of white or green sturgeon larvae in the Sacramento-San Joaquin Delta, California. During low flows, fewer larvae were transported to the delta by river flows. Brannon et al. (1985) found that the behavior of white sturgeon larvae was affected by current velocity in laboratory experiments; there was an inverse relationship between water velocity and the amount of time larvae spent in the water column.

Size-Class Structure

Juvenile white sturgeon collected in the Columbia River downstream from Bonneville Dam showed considerable overlap in lengths among age groups. Because of the overlaps, it was generally difficult to separate age groups other than Y-O-Y. Accurate ageing of most white sturgeon 1 year and older requires reading a cross section of a hard body part, such as a pectoral ray. Hess (1984), who aged white sturgeon using pectoral fin rays, found that those collected in the lower Columbia River showed considerable variation in length for a specific age group. Virtually all the sturgeon aged by Hess were age 1 and older. Hess also noted that as the age increased, the length variation tended to increase. Results from the ageing of pectoral rays collected by NMFS in 1989 will be presented in FWS's annual report.

Young-of-the-Year

Catches of Y-O-Y white sturgeon in 1989 (n = 111) were considerably higher than catches in both 1987 (n = 49; McCabe and McConnell 1988) and 1988 (n = 11; McCabe et al. 1989). Possible reasons for the higher catches in 1989 include increased sampling in selected deeper areas of the river or better recruitment to the Y-O-Y stage.

Based on Y-O-Y collections in 1989, it would appear that river currents dispersed white sturgeon larvae farther downstream than indicated by larval collections in plankton nets. All Y-O-Y collected in 1989 were captured downstream from the mouth of the Willamette River (RM 101); Y-O-Y white sturgeon were routinely collected in the upper Columbia River estuary (RM 31) beginning in early July. We assume that Y-O-Y, particularly the smaller ones, were carried by river currents as larvae to the general area where we subsequently captured them as Y-O-Y.

Tagging

Recoveries of tagged sturgeon indicated negative or poor growth in many instances, particularly for fish recovered at RM 131; similar results were noted in 1988 (McCabe et al. 1989). It is possible that the tag affected growth. However, the only accurate way to determine if this was the case would be a laboratory experiment comparing the growth rates of tagged and untagged sturgeon. On the other hand, it is possible that juvenile sturgeon in at least certain areas of the Columbia River downstream from Bonneville Dam grow quite slowly. These observations of slow growth are consistent with results from the benthic invertebrate analysis, stomach contents analysis, and age determinations done by FWS. The FWS noted that juvenile white sturgeon collected downstream from Bonneville Dam grew slower than juvenile sturgeon collected in the impoundments between Bonneville and John Day dams (Parsley et al. 1989).

Stomach Contents Analysis and Benthic Invertebrates

For May-October 1988, juvenile white sturgeon at RMs 95 and 131 fed on organisms associated with the benthos. *Corophium salmonis* was an extremely important prey item at both RMs 95 and 131, yet its densities were less than 450/m² during the April 1988 benthic invertebrate survey (McCabe et al. 1989). For comparison, densities of *Corophium salmonis* in Cathlamet Bay, which is primarily a freshwater bay in the Columbia River estuary, ranged from 1,717 to 26,674/m² in April 1984 (Emmett et al. 1986). In 1988, *Corophium salmonis* densities at RM 28 (upper estuary) were 1,194 and 7,503/m² at two transects during the April benthic survey (McCabe et al. 1989). Considering the relatively low densities of *Corophium salmonis* in the benthos at RMs 95 and 131, it is possible that juvenile sturgeon are feeding on *Corophium salmonis* carried to them by the current or the sturgeon are moving to nearby areas with higher *Corophium salmonis* densities and feeding there. *Corophium* spp. have been observed in white sturgeon egg and larval samples collected with plankton nets fished along the bottom near Ives Island (RM 143). *Corophium volutator*, a related species, has been observed swimming above the bottom (Hughes 1988). If *Corophium salmonis* populations in freshwater sections of the lower Columbia River exhibit similar behavior, they would be dispersed by river currents. During the early part of the 1988 field season we tried to sample the portion of the water column just above the bottom using an epibenthic sled (McCabe and McConnell 1988); however, we were unable to consistently collect good samples. Often the epibenthic sled would fill with sand when towed along the bottom. Water velocities at RMs 95 and 131 are much lower than velocities near Ives Island; consequently, it requires more time to collect a good sample with a plankton net at the lower-velocity areas than at Ives Island. In May-June, the relationship between the importance of eulachon eggs in the diet of white sturgeon and their importance in the benthos was better than the relationship for *Corophium salmonis*. In 1988, eulachon eggs were an important part of the benthos and an important food item for juvenile white sturgeon in the Columbia River downstream from Bonneville Dam.

Based on benthic invertebrate samples collected at the five index areas, it is reasonable to assume that the diet of juvenile white sturgeon in freshwater areas of the Columbia River downstream from Bonneville Dam would be similar to the feeding habits observed at RMs 95 and 131. Muir et al. (1988) found that *Corophium salmonis* was the most important prey item for white sturgeon <800 mm (total length); the juvenile sturgeon were collected in the Columbia River downstream from the mouth of the Willamette River and in the Columbia River estuary.

Results from combined juvenile sturgeon and benthic invertebrate sampling in 1989 indicated that use of areas for rearing by juvenile white sturgeon could not be accurately predicted by benthic invertebrate densities. Based on 1988 and 1989 research, much of the river downstream from Bonneville Dam apparently could serve as rearing habitat for juvenile white sturgeon, although there are preferred areas.

Plans for 1990

Plans for 1990 include sampling for white sturgeon eggs, larvae, and juveniles downstream from Bonneville Dam. Specifically, we plan to use plankton nets and artificial substrates to study the spawning characteristics of white sturgeon in the lower Columbia River. These data collected downstream from Bonneville Dam, an area designated as a control for the overall sturgeon study, will be provided to FWS, which is conducting similar research in impoundments upstream from Bonneville Dam. As in previous years, physical measurements will be made in conjunction with the egg and larval sampling, to determine, among other relationships, the relationship between river flow and egg and larval catches.

Using biological and physical data collected in 1990, we will continue to examine the specific habitat preferences or requirements of juvenile white sturgeon. Bottom trawling will be done in various habitats downstream from Bonneville Dam, with much more emphasis on the area between RMs 28 and 75. Limited benthic sampling will be done at some sites.

In conjunction with FWS, we will begin quantifying spawning and rearing habitat available for white sturgeon in the Columbia River downstream from Bonneville Dam. Other activities planned for 1990 include continued tagging of juvenile white sturgeon and examination of juveniles for the nematode parasite *Cystoopsis acipenseri*.

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APPENDIX D-1

Summaries of individual trawling efforts for white sturgeon in the Columbia River downstream from Bonneville Dam, 1989 (not included in basic report; available upon request to NMFS, Point Adams Biological Field Station, P.O. Box 155, Hammond, OR 97121).

APPENDIX D-2

Summaries of benthic invertebrate studies (by station) conducted during April and September 1989 in the Columbia River downstream from Bonneville Dam (not included in basic report; available upon request to NMFS, Point Adams Biological Field Station, P.O. Box 155, Hammond, OR 97121).

APPENDIX D-3

Summaries of sediment studies (by station) conducted during April and September 1989 in the Columbia River downstream from Bonneville Dam (not included in basic report; available upon request to NMFS, Point Adams Biological Field Station, P.O. Box 155, Hammond, OR 97121).