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Feeding Ecology of Juvenile White Sturgeon (*Acipenser transmontanus*) in the Lower Columbia River

Abstract

The white sturgeon (*Acipenser transmontanus*) supports important recreational and commercial fisheries in the lower Columbia River. Little is known about the ecology of white sturgeon, and the feeding ecology in particular has received only limited investigation. From April through October 1988, the feeding ecology of juvenile white sturgeon was studied in two areas of the lower Columbia River. Overall, the tube-dwelling amphipod *Corophium salmonis* was the most important prey for the two size classes of juvenile white sturgeon studied. However, during all sampling periods and at both areas (River Kilometers [RKm] 153 and 211), Size Class I white sturgeon (144-350 mm fork length) preyed more heavily on *C. salmonis* than did Size Class II white sturgeon (351 to 724 mm). Other temporally important prey for Size Class I white sturgeon included *Corophium spinicorne*, *Neomysis* sp., Chironomidae larvae, and eulachon (*Thaleichthys pacificus*) eggs; other temporally important prey for Size Class II white sturgeon included the bivalve *Corbicula fluminea*, *Corophium spinicorne*, Chironomidae larvae, and eulachon eggs. Index of Feeding analysis indicated that juvenile white sturgeon in both areas contained less food in September-October than in either May-June or July-August. Generally, the relationships between densities (abundances) of specific benthic organisms and white sturgeon diets were poor at RKm 153 and 211. Despite the importance of *Corophium salmonis* in the diets of juvenile white sturgeon, it was not abundant in the benthos (mean density, <185 organisms/m^2 in April and September).

Introduction

The white sturgeon (*Acipenser transmontanus*), the largest North American sturgeon, is an anadromous species found along the west coast of North America from the Aleutian Islands, Alaska, to Monterey, California (Scott and Crossman 1973). Some populations in the Columbia River Basin are essentially landlocked due to dam construction (Cochnauer *et al.* 1985, Beamesderfer *et al.* 1990).

Historically, the population of white sturgeon in the Columbia River (Oregon and Washington) supported an intense commercial fishery, with catches peaking in 1892 at more than 2.4 million kg (Craig and Hacker 1940). However, due to overfishing, catches declined, and in 1899 the total catch was less than 33,250 kg. During the early 1900s, annual catches were less than 104,930 kg (Craig and Hacker 1940).

Since the early 1900s, white sturgeon populations in the Columbia River, particularly the one downstream from Bonneville Dam (the lowermost dam), recovered sufficiently to support important recreational and commercial fisheries. Presently, the lower Columbia River (from the mouth to Bonneville Dam) supports one of the largest populations of white sturgeon. In 1991, the estimated recreational and commercial harvests in the lower Columbia River were 22,700 and 3,800 fish, respectively (Washington Department of Fisheries and Oregon Department of Fish and Wildlife 1992). Based on the number of recreational angler trips in 1991, the white sturgeon is second only to salmonid species as the most popular recreational fish in the lower Columbia River (Washington Department of Fisheries and Oregon Department of Fish and Wildlife 1992).

Little is known about the ecology of white sturgeon, and the feeding ecology of juveniles in particular has received only limited investigation. The diets of small juvenile white sturgeon (<800 mm total length) have been described in the Sacramento-San Joaquin River Basin, California (Schreiber 1962, Radtke 1966), and in the Columbia River and its estuary (Muir *et al.* 1988). However, most of the white sturgeon collected by Muir *et al.* (1988) were from the estuary; only a small number ($N < 54$) were collected upstream from the estuary over a 3-month period.

We examined the seasonal feeding characteristics of two size classes of juvenile white sturgeon (144-350 mm fork length and 351-724 mm fork length) in two areas of the lower Columbia River in 1988. We assessed both the importance of various prey eaten and the feeding intensity. Also, we examined the relationship between the feeding characteristics of juvenile white sturgeon and benthic invertebrate communities and the relationship between white sturgeon catches and benthic invertebrate abundance.

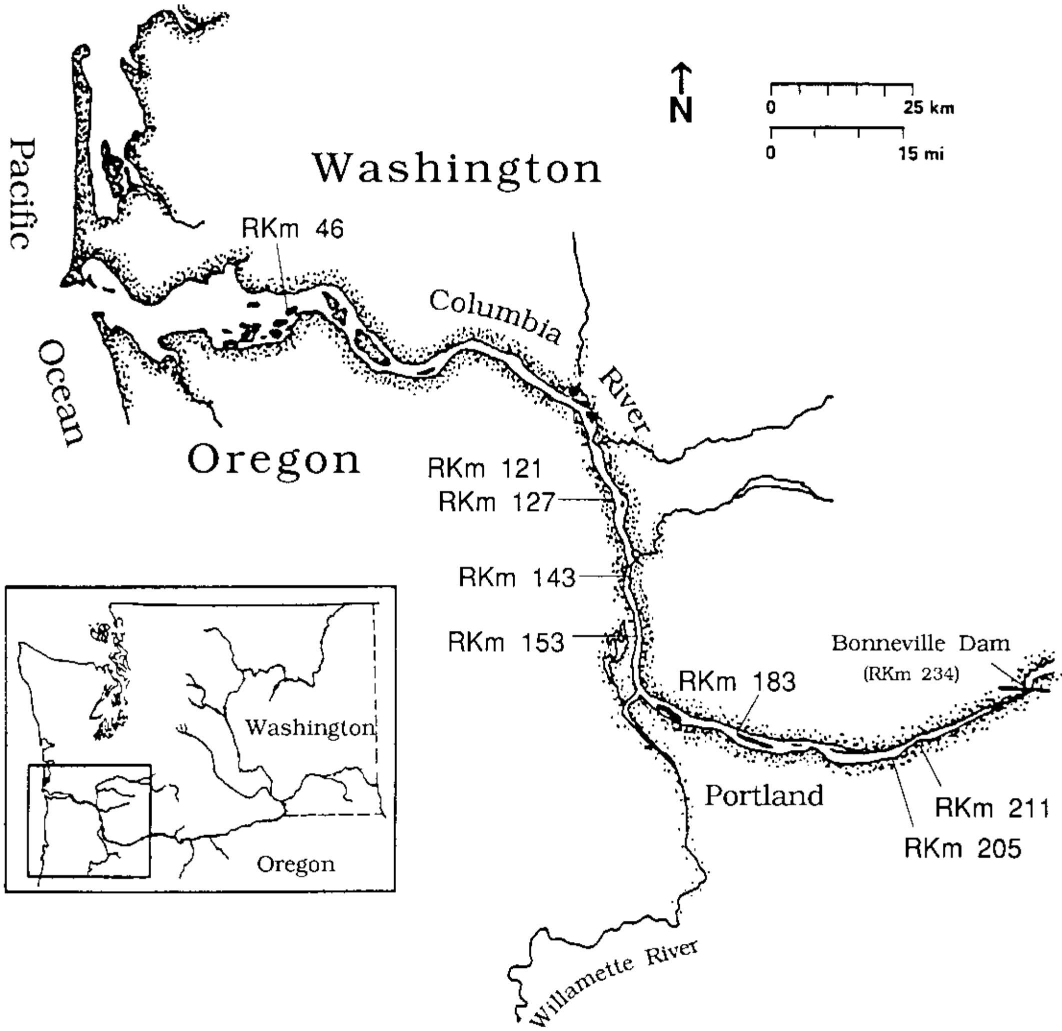

Figure 1. Map of the lower Columbia River showing the eight sampling areas where juvenile white sturgeon and benthic invertebrate samples were collected in 1988. Stomachs were collected from juvenile white sturgeon captured at River Kilometers (RKm) 153 and 211.

Methods

Juvenile white sturgeon were collected with a 7.9-m (headrope length) semiballoon shrimp trawl, which was towed by a 12.2-m boat, in eight areas of the lower Columbia River between River Kilometer (RKm) 46 and RKm 211 (Fig. 1). Mesh size in the trawl net was 38 mm (stretched measure) in the body; a 10-mm mesh liner was inserted in the cod end of the net. Trawling efforts were normally 5 min in duration in an upstream direction; boat speed varied depending upon water velocity, wind, and bottom topography. Distance traveled was estimated using a radar range-finder and used with the estimated fishing width of the net (5.3 m) to calculate the area fished. Sturgeon density for each effort was then calculated (number of sturgeon caught/area fished) and expressed as number/hectare (ha).

Trawling was done from late March through October. At each of the eight sampling areas, trawling was done along two or three parallel transects; one trawl was done along each transect. Transect 1 was closest to the Washington shore, Transect 2 was the middle transect, and Transect 3 was closest to the Oregon shore. In river sections where only two transects were established, Transect 2 was closest to the Oregon shore.

All fishes captured in the trawl were identified and counted. Generally, all white sturgeon were measured (fork length to the nearest mm) and weighed (g). When a large number of white sturgeon was collected in a sampling effort, a subsample of at least 50 fish was measured and weighed.

Stomachs were taken from a subsample of white sturgeon captured at two areas (RKm 153 and 211; Fig. 1) to determine their diet and its relationship to the benthic invertebrate community. White sturgeon stomachs were taken during three time periods: (1) May-June, (2) July-August, and (3) September-October. At each area, we tried to obtain 25 stomachs from each of two size classes of white sturgeon during each sampling period. The two size classes were (I) 144 to 350 mm fork length and (II) 351 to 724 mm fork length. Stomachs were removed from the white sturgeon at capture, placed in individual vials containing a 7% buffered formaldehyde solution, and later transferred to vials containing 70% ethyl alcohol. Food items in each stomach were identified to the lowest practical taxonomic level, counted, and weighed (pooled by taxon) to the nearest 0.1 mg using a Mettler H-80 mechanical balance[1].

A condition factor, C (Everhart and Youngs 1981), was computed for each white sturgeon selected for stomach analysis using the formula

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

where W = weight (g) and L = length (mm, fork length). Condition factors were compared between the three time periods for each size class using analysis of variance (ANOVA).

The diets of white sturgeon at RKm 153 and 211 were analyzed using two approaches. The relative contribution of a prey taxon to the diet was determined using a modification of the Index of Relative Importance (IRI) described by Pinkas *et al.* (1971)

$$IRI = (N + W)\,F,$$

where N = percent number of a prey item, W = percent weight of a prey item, and F = percent frequency of occurrence of a prey item. Index of Relative Importance values for individual prey items were then converted to percentages. To determine feeding intensity in each area, an Index of Feeding (IF) was calculated using the equation

$$IF = (Ws \div Wf) \times 100\%,$$

where 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 (Ryan *et al.* 1976).

Benthic macroinvertebrates were collected in April and September 1988 at two stations along each bottom trawling transect at the eight sampling areas (Fig. 1). Five benthic invertebrate samples were collected at each sampling station using a 0.1-m^2 Van Veen grab sampler (Word 1976). Each sample was sieved through a 0.5-mm screen and the residue preserved in a buffered formaldehyde solution (>4%) containing rose bengal. If it appeared that most of the material would not quickly wash through the sieve, the entire sample was preserved and sieved at the laboratory. The samples were later washed with water and preserved in a 90% alcohol solution. Benthic invertebrates were identified to the lowest practical taxonomic level and counted. Eulachon (*Thaleichthys pacificus*) eggs were also counted. When large numbers of eulachon eggs occurred in samples, their numbers were estimated by subsampling.

The relationships between white sturgeon densities (April and October) and *Corbicula fluminea* and *Corophium salmonis* densities (April and September) at the eight sampling areas were examined using simple and multiple regressions. Benthic invertebrate data collected in September were used to characterize the October period. White sturgeon densities were transformed to $\log_{10}$ of (density + 1) and benthic invertebrate densities were transformed ($\log_{10}$) prior to analysis.

Results

Stomach Contents

A total of 292 stomachs were taken from white sturgeon collected at RKm 153 and 211 in 1988. The amphipod *C. salmonis* was the most important prey item at both areas (Table 1). During all three time periods in both areas, percent Index of Relative Importance (%IRI) for *C. salmonis* was higher for the smaller Size Class I white sturgeon than for the larger Size Class II white sturgeon, indicating that the smaller juveniles preyed more heavily on *C. salmonis*. The importance of *C. salmonis* for Size Class I white sturgeon at RKm 153 remained

TABLE 1. Summary of white sturgeon diets 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 (144-350 mm fork length) and Size Class II (351-724 mm fork length)—from two areas of the Columbia River, River Kilometers 153 and 211. Only prey items with %IRI values greater than 1 (for at least one size class and season) are shown.

Prey item	May-Jun		Jul-Aug		Sep-Oct	
	Size I	Size II	Size I	Size II	Size I	Size II
River Kilometer 153						
Corbicula fluminea	<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 Kilometer 211						
Corbicula fluminea	<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

relatively consistent throughout the study, ranging from 75 to 82 %IRI during the three periods; whereas, at RKm 211, the %IRI of *C. salmonis* was more varied, ranging from 44 (September-October) to 75 %IRI (July-August).

Size Class II white sturgeon also preyed primarily on *C. salmonis*, but, on occasion, they also consumed large quantities of the bivalve *Corbicula fluminea*, Chironomidae larvae, and eulachon eggs (Table 1). At RKm 153, %IRI for *Corophium salmonis* ranged from 38% in July-August to 51% in September-October. Additionally, eulachon eggs (12 %IRI) and *Corbicula fluminea* (11 %IRI) were important prey in May-June, and *C. fluminea* (19 %IRI) and *Corophium spinicorne* (7 %IRI) were important in July-August. At RKm 211, %IRI for *C. salmonis* ranged from 12% in May-June to 24% in July-October. Other important prey for this size class at RKm 211 included eulachon eggs (51 %IRI) and *Corbicula fluminea* (20 %IRI) in May-June, *C. fluminea* (35 %IRI) in July-August, and Chironomidae larvae (18 %IRI) in September-October.

The IF analysis indicated a reduction in feeding of juvenile white sturgeon at RKm 153 and 211 in September-October. At RKm 153, IF values for both size classes of white sturgeon were significantly lower (Mann-Whitney test, $P < 0.05$) in September-October than in either May-June or July-August (Table 2). At RKm 211, only Size Class II white sturgeon had significantly lower IF values in September-October than in May-June or July-August (Table 2). Besides lower IF values, the number of empty stomachs for both size classes in each area was highest in September-October, further indicating reduced feeding. There were no significant differences in C between the three time periods for either size class of white sturgeon (ANOVA, $P > 0.05$).

Water temperatures in areas where white sturgeon were collected for stomach analysis ranged from 13 to 18°C in May-June, 17 to 21°C in July-August, and 16 to 18°C in September-October.

TABLE 2. Comparisons of Index of Feeding (IF) for two size classes of juvenile white sturgeon collected at River Kilometers 153 and 211 in the Columbia River, 1988. Size Class I white sturgeon were 144-350 mm fork length and Size Class II white sturgeon were 351-724 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.

Size Class	Time period		
	May-Jun	Jul-Aug	Sep-Oct
River Kilometer 153			
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 Kilometer 211			
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, $P < 0.05$.

Benthic Invertebrates

Major benthic invertebrate taxa collected at RKm 153 included Oligochaeta, *Corbicula fluminea*, *Corophium salmonis*, Chironomidae larvae, and Heleidae larvae (Table 3). At RKm 211, major benthic invertebrate taxa included Turbellaria, Oligochaeta, *Corbicula fluminea*, Ostracoda, *Corophium salmonis*, Chironomidae larvae, and Heleidae larvae (Table 3). Eulachon eggs were included in the table because they were collected along with the benthic invertebrates and were important in the diet of white sturgeon. Densities of specific invertebrates often varied considerably among transects within each area.

Overall, the relationships between white sturgeon diets and specific benthic invertebrate densities were poor at RKm 153 and 211 (Figs. 2 and 3). Although *C. salmonis* was by far the most important prey for both size classes of white sturgeon in May-June and September-October at RKm 153, it was not an abundant benthic invertebrate (mean density, <185 organisms/m^2 in both April and September). Eulachon eggs, which were abundant in the benthos at RKm 153 during April, were an important food item for Size Class II white sturgeon during May-June. Heleidae larvae, although relatively abundant at RKm 153, particularly during April, were insignificant in white sturgeon diets. Likewise, oligochaetes were relatively abundant at RKm 153 during September, yet were not eaten by white sturgeon.

At RKm 211, *C. salmonis* was by far the most important prey in both May-June and September-October for Size Class I white sturgeon; however, it was not abundant in the benthos in either April or September (mean density, <120 organisms/m^2 in each month). *Corbicula fluminea* was the most abundant benthic invertebrate at RKm 211 in April and was also an important prey for Size Class II white sturgeon in May-June. Eulachon eggs were abundant at RKm 211 during April and were an important prey for both size classes of white sturgeon, particularly Size Class II fish, in May-June. In September, oligochaetes, *C. fluminea*, and Heleidae larvae were the most abundant benthic invertebrates at RKm 211, yet these taxa were unimportant in the diet of white sturgeon in September-October.

The relationships between white sturgeon densities and densities of *Corbicula fluminea* and *Corophium salmonis* at the eight sampling areas (data combined for all areas) were poor (Table 4). Simple regression analysis indicated that overall (combining the data for April and September-October), only 7% of the variation in white sturgeon densities was explained by *Corbicula fluminea* densities; 20% of the variation was explained by *Corophium salmonis* densities. Multiple regression analysis showed that 28% of the variation in white sturgeon densities was explained by using both *Corbicula fluminea* and *Corophium salmonis* densities as predictors. The data were also analyzed separately for the two time periods. For April, 12% of the variation in white sturgeon densities was explained by *Corbicula fluminea* densities, and 11% of the variation was explained by *Corophium salmonis* densities. Multiple regression analysis indicated that 26% of the variation in white sturgeon densities in April was explained by using both *Corbicula fluminea* and *Corophium salmonis* densities

TABLE 3. Mean densities (number/m^2) and standard deviations (SD) of major benthic taxa collected in April and September 1988 at River Kilometers (RKm) 153 and 211 in the Columbia River. The total for each transect includes both major taxa and less important taxa not shown.

RKm-transect	Taxon	April 1988		September 1988	
		Mean	SD	Mean	SD
153-1	Oligochaeta	405	444	1,849	697
	Corbicula fluminea	1,198	1,455	213	153
	Heleidae larvae	640	1,094	431	306
	Eulachon eggs	134,366	105,229	0	0
	Total	136,655	103,352	2,507	956
153-2	*Corbicula fluminea*	513	530	39	36
	Heleidae larvae	939	545	198	175
	Total	1,592	1,049	251	202
153-3	*Corbicula fluminea*	428	369	68	122
	Corophium salmonis	389	285	545	262
	Chironomidae larvae	78	90	0	0
	Heleidae larvae	146	156	8	15
	Total	1,144	798	625	377
	Entire area[a]	49,701	88,979	1,128	1,161
211-1	Oligochaeta	13	24	78	50
	Corbicula fluminea	1,210	860	478	370
	Heleidae larvae	772	509	500	284
	Eulachon eggs	8,874	14,262	0	0
	Total	10,930	14,028	1,110	558
211-2	Turbellaria	66	130	7	12
	Corbicula fluminea	544	908	248	253
	Heleidae larvae	301	467	440	386
	Total	982	1,212	739	582
211-3	Oligochaeta	406	214	627	645
	Corbicula fluminea	224	216	70	50
	Ostracoda	59	94	5	8
	Corophium salmonis	309	143	221	84
	Chironomidae larvae	43	49	52	53
	Eulachon eggs	55	49	0	0
	Total	1,135	325	1,016	810
	Entire area[b]	4,122	8,850	955	657

[a] The average of all samples taken at RKm 153; in April, only 28 samples were analyzed for the entire area.

[b] The average of all samples taken at RKm 211; in April, only 29 samples were analyzed for the entire area.

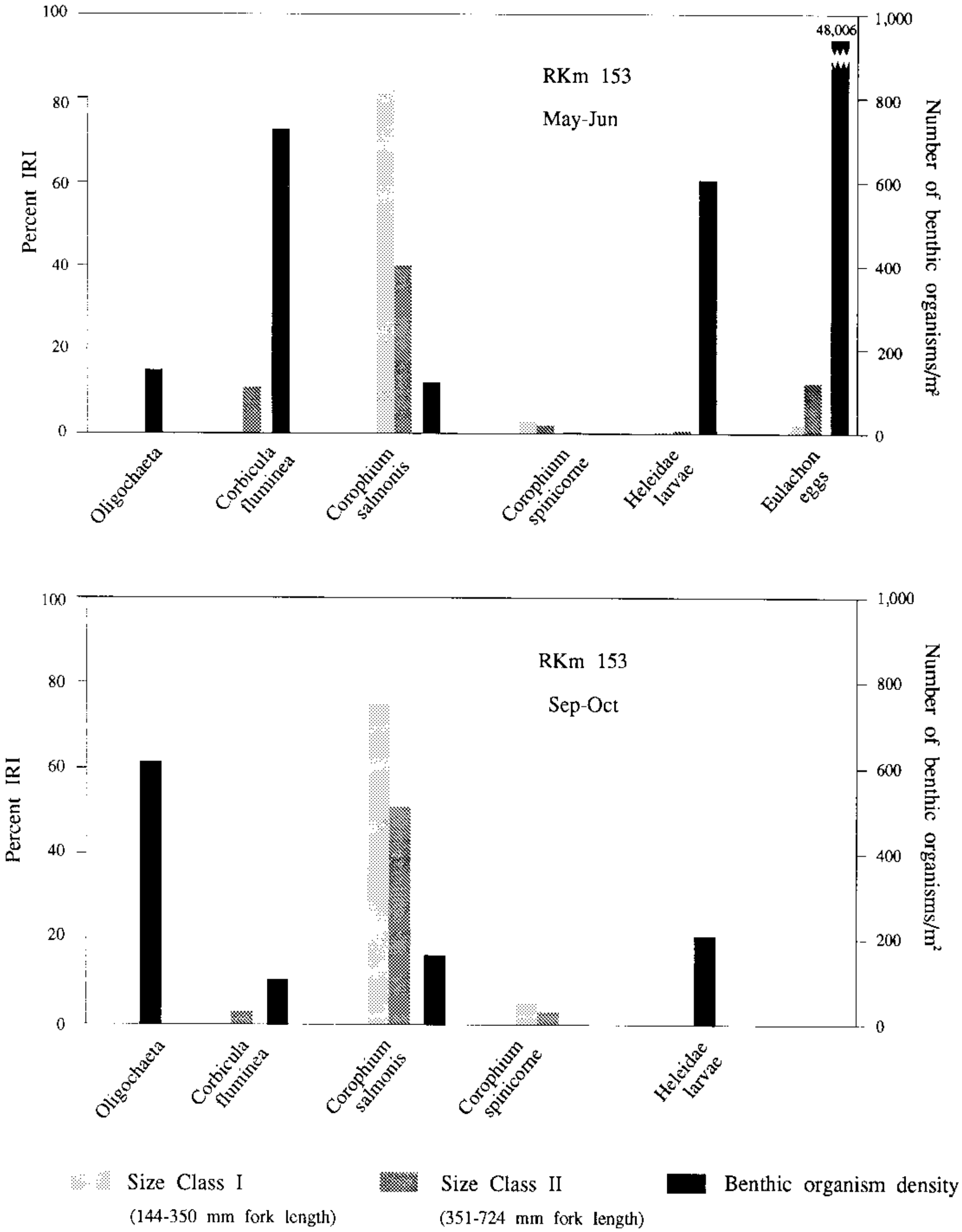

Figure 2. Percent Index of Relative Importance (%IRI) for prey of two size classes of juvenile white sturgeon collected during May-June and September-October 1988 at River Kilometer (RKm) 153 in the Columbia River. Also shown are densities of selected benthic organisms collected in April and September 1988; the April data are presented for the May-June period because no benthic sampling was done in May or June. Eulachon eggs are shown because they were collected along with the benthic invertebrates and were important white sturgeon prey.

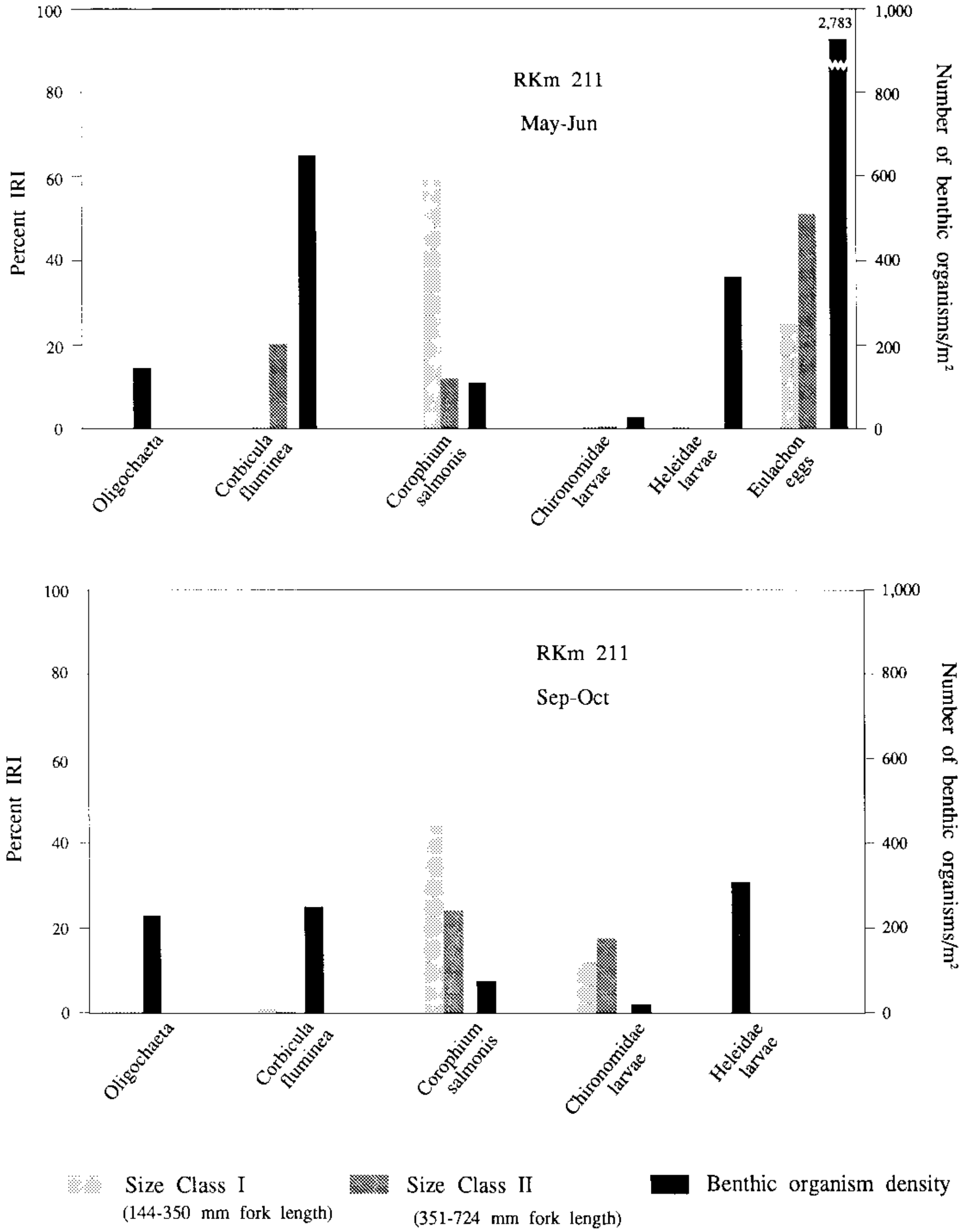

Figure 3. Percent Index of Relative Importance (%IRI) for prey of two size classes of juvenile white sturgeon collected during May-June and September-October 1988 at River Kilometer (RKm) 211 in the Columbia River. Also shown are densities of selected benthic organisms collected in April and September 1988; the April data are presented for the May-June period because no benthic sampling was done in May or June. Eulachon eggs are shown because they were collected along with the benthic invertebrates and were important white sturgeon prey.

TABLE 4. Summary of white sturgeon densities (number/ha) and benthic invertebrate densities (number/m²) at eight sampling areas (River Kilometer [RKm]-transect) in the lower Columbia River, 1988. Mean densities are shown for the invertebrates *Corbicula fluminea* (Cf) and *Corophium salmonis* (Cs), which are important prey for juvenile white sturgeon.

RKm-transect	Apr			Sep-Oct		
	Sturgeon density	Invertebrate		Sturgeon density	Invertebrate	
		Cf	Cs		Cf	Cs
46-1	0	29	55	0	171	604
46-2	6	88	6,574	0	103	1,516
46-3	24	563	1,046	0	234	4,567
121-1	0	3	5	12	594	20
121-2	0	115	86	0	365	68
127-1	251	4	2	51	536	49
127-2	48	108	6	74	67	16
127-3	8	351	75	6	357	316
143-1	0	177	231	0	212	17
143-2	23	219	3	10	461	5
153-1	561	1,198	2	334	213	4
153-2	–	513	29	18	39	5
153-3	–	428	389	3	68	545
183-1	0	201	1	0	292	18
183-2	0	176	9	8	661	68
205-2	0	42	33	2	56	6
205-3	54	572	12	7	686	3
211-1	78	1,210	26	198	478	9
211-2	531	544	5	763	248	8
211-3	0	224	309	0	70	221

[a] Sturgeon were collected in October 1988.

[b] Benthic invertebrates were collected in September 1988.

as predictors. For the September-October period, 3% and 32% of the variations in white sturgeon densities were explained by *Corbicula fluminea* and *Corophium salmonis* densities, respectively. Multiple regression analysis of the September-October data showed that 33% of the variation in white sturgeon densities was explained by using both *Corbicula fluminea* and *Corophium salmonis* densities as predictors.

Discussion

The feeding ecology of juvenile white sturgeon in our study, in general, agrees with findings from the lower Columbia River feeding study of Muir *et al.* (1988). Although fewer white sturgeon stomachs were analyzed for content during their study, they also found that the predominant prey for white sturgeon less than 800 mm (total length) captured in the lower Columbia River and its estuary was *Corophium salmonis*. In Muir *et al.*'s (1988) study, neither *Corbicula fluminea* nor eulachon eggs were important prey for white sturgeon less than 800 mm long; this was in contrast to what we observed. Muir *et al.* (1988) sampled in the Columbia River only in July-September when eulachon eggs would not be present. This time period was well past the spawning migrations of eulachon.

Although RKm 153 and 211 are intensively used by juvenile white sturgeon, these areas do not have high standing crops of *C. salmonis*. In both areas, *C. salmonis* had mean densities less than 125/m² (average of all samples taken in each area) during April 1988. For comparison, the mean density of *C. salmonis* at four stations (RKm 30-40) in Cathlamet Bay, which is primarily a freshwater bay in the Columbia River estuary, was 7,739/m^2 in April 1984 (Emmett *et al.* 1986). At RKm 46 (upper estuary), the mean density of *C. salmonis* was 2,420/m^2 in April 1988.

Considering the relatively low densities of *C. salmonis* in the benthos at RKm 153 and 211 and their importance in white sturgeon diets, it is possible that juvenile white sturgeon are (1) feeding on *C. salmonis* carried to them by the current drift, (2) moving to nearby areas with higher *C. salmonis* densities and feeding there, or (3) very efficiently feeding on *C. salmonis*, even when not abundant. *Corophium* spp. are often important river drift organisms and have been observed in white sturgeon egg and larval samples collected with plankton nets fished along the bottom at RKm 193 and 230 (Muir 1990). Davis (1978) observed that *C. salmonis* undergoes a vertical diel migration in the water column in the Columbia River estuary. *Corophium volutator*, a related Atlantic species, has also been found to swim above the bottom during part of its life cycle (Hughes 1988). If *C. salmonis* populations in freshwater sections of the lower Columbia River exhibit similar behavior, they could be dispersed by river currents. During the early part of the 1988 field season, we tried to sample invertebrate drift just above the bottom using an epibenthic sled; however, the sled would often fill with sand when towed along the bottom.

Juvenile white sturgeon may feed in shallow water, where *C. salmonis* is sometimes more abundant. In 1990, monthly mean densities of *C. salmonis* at individual stations in shallow water (1-6 m deep) at RKm 153 often exceeded 1,200 organisms/m^2, whereas monthly mean densities at the deeper water stations (11-21 m deep) generally were less than 105 organisms/m^2 (McCabe and Hinton 1991). However, at RKm 211, monthly mean densities of *C. salmonis* at the three shallow-water stations were low and usually did not exceed 76 organisms/m^2 (McCabe and Hinton 1991). The populations of *C. salmonis* found at the shallow-water stations at RKm 153 may represent a good food source for juvenile white sturgeon in the area. Although juvenile white sturgeon in the lower Columbia River typically favor deeper water ($\geq$9.1 m) during daylight (McCabe and Hinton 1990), they may move into shallower water at night to feed. Studies using juvenile white sturgeon that have been tagged with sonic or radio tags are needed to describe their diel movements.

Juvenile white sturgeon may not be selectively preying on *Corophium salmonis* and *Corbicula fluminea*. They may be preying primarily on *Corophium salmonis* and secondarily on *Corbicula fluminea* because these invertebrates are more available to them than other benthic invertebrates. *Corophium salmonis* is a tube-dwelling amphipod that migrates vertically in the water column in the Columbia River estuary (Davis 1978). This amphipod has also been observed crawling over the bottom in the Columbia River estuary (G. T. McCabe, Jr., personal observation). *Corbicula fluminea* is primarily a filter feeder (Way *et al.* 1990) with short siphons and apparently lives in close proximity to the substrate surface. Eulachon eggs, which were an important white sturgeon prey during May-June, are found attached to the substrate surface. Oligochaetes and Heleidae larvae may be found deeper in the substrate, and therefore be largely unavailable to juvenile white sturgeon.

Benthic invertebrate populations were not sampled monthly, and it is likely that some invertebrate densities were higher or lower in May-June than indicated by the April survey. Also, numbers of invertebrates in October may have differed from those during the September survey. However, based on benthic data collected monthly at RKm 153 and 211 in 1990 (McCabe and Hinton 1991), it is unlikely that *Corophium salmonis* densities at the deeper water stations (typically where white sturgeon are more abundant during daylight) ever reached moderate or high densities. McCabe and Hinton (1991) observed that densities of *C. salmonis* fluctuated from June through September but remained low; densities never exceeded 380 organisms/m^2 and were usually less than or equal to 101/m^2.

In conclusion, results from our study highlight the importance of benthic invertebrates, particularly *C. salmonis*, in the diets of juvenile white sturgeon in the lower Columbia River. Seasonal changes were observed in the diets of juvenile white sturgeon, with reduced feeding occurring in September-October. Despite the importance of benthic invertebrates in the diets of juveniles, the relationships between densities of specific benthic organisms and white sturgeon diets were generally poor.

Acknowledgements

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Notes

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

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