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Title: Selected Life History Aspects of American Shad (*Alosa sapidissima*) and Predation on Young-of-the-year Shad in Lake Umatilla of the Columbia River.

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Dr. Richard A. Tubb

Selected life history aspects of American shad, *Alosa sapidissima*, collected in Lake Umatilla of the Columbia River during 1980 and 1981 were examined and compared to other shad populations. Mean fork lengths of adult shad captured in 1981 were 405-, 415- and 423-mm for age III, IV and V males; 425-, 444- and 457-mm for age III, IV and V females. The mean age at maturity was determined to be 3.2 years for males and 3.5 years for females while the rate of repeat spawning was 36% and 45% for males and females, respectively. Four-year-old shad accounted for 58.5% of the spawning adults in the two years. Absolute fecundity ranged from 97,168 to 284,240 eggs with a mean of 193,074 eggs per female. Young-of-the-year shad were more abundant in 1980 than in 1981. In both years, the tailrace zone was the most important spawning area and the island zone the most important rearing area for young-of-the-year shad in the reservoir. Growth of young shad in Lake Umatilla was similar in all sampled macrohabitats and appears to be dependent on year class strength, water temperature and water

flow. Out-migrating young-of-the-year shad passing through John Day Dam were significantly larger than young-of-the-year shad in reservoir habitats indicating size, as well as temperature, influences the timing of downstream migration. Predation on young shad by resident predator fish species was variable and appeared to be dependent on the abundance of young-of-the-year shad.

Selected Life History Aspects of American Shad (*Alosa sapidissima*) and Predation on Young-of-the-year Shad in Lake Umatilla of the Columbia River.

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INTRODUCTION

The construction of dams on the Columbia River has led to many changes in the aquatic fauna of the river. Exotic species of fish, which in most cases were introduced to the Columbia River decades before the first hydroelectric project, were only moderately successful prior to the impoundments. The success and impact of the exotic species increased dramatically with the installation of each new dam. The objectives of this study were: (1) To provide information on selected life history aspects of one of the successful exotic species, the American shad (*Alosa sapidissima*), and to compare these findings with shad populations in other areas; and (2) to study the food habits of five introduced predator species and describe the predation on young-of-the-year (yoy) shad by these species. The predators of interest were the largemouth bass (*Micropterus salmoides*), smallmouth bass (*M. dolomieui*), black crappie (*Pomoxis nigromaculatus*), white crappie (*P. annularis*) and and yellow perch (*Perca flavescens*).

The American shad has developed a strong and growing population since its introduction to the Columbia River in 1871 (Welander 1940). During the 1979 spring spawning migration, 1.35 million adult shad were counted in the fish passage facility of The Dalles Dam (U.S.A.C.E. 1979). Prior to the completion of this dam in 1957, and the subsequent inundation of Celilo Falls, shad were restricted to the lower Columbia River. The species range now extends to Grand Coulee Dam on the Columbia River and past Lower Granite Dam on the Snake River. The habitat available to shad for spawning and rearing has been increased many-fold by the numerous hydroelectric impoundments in the Columbia drainage. This is particularly true of the central basin area where The Dalles, John Day and McNary dams have flooded extensive areas of flat terrain. Massman (1952) reported that shad spawning occurs in deep channels near large areas of flat shallows which are important rearing grounds. With the increase of available habitat there has been a corresponding increase in the size of the shad population in the Columbia River (Fig. 1).

The increase of the shad population has caused commercial interests to be focused on shad as a alternative fishery to the severely depleted stocks of salmonid species. However, the commercial shad catch in the river has declined (Fig. 2). This fishery reached a peak in 1962 when 238,500 shad were taken (O.D.F.W. and W.D.F. 1981). The reason for this decline is two-fold: 1) the concurrent timing of the shad spawning migration with migrations of three salmonid species, and 2) a limited market.

The spawning migrations of summer steelhead (Salmo gairdneri), summer chinook (Oncorhynchus tshawytscha) and sockeye salmon (Oncorhynchus nerka) overlap with the shad migration. Population levels of these three salmonid species in the Columbia River have declined to alarmingly low numbers. Indicative of this was the consideration in 1981 of all three species for protection from harvest

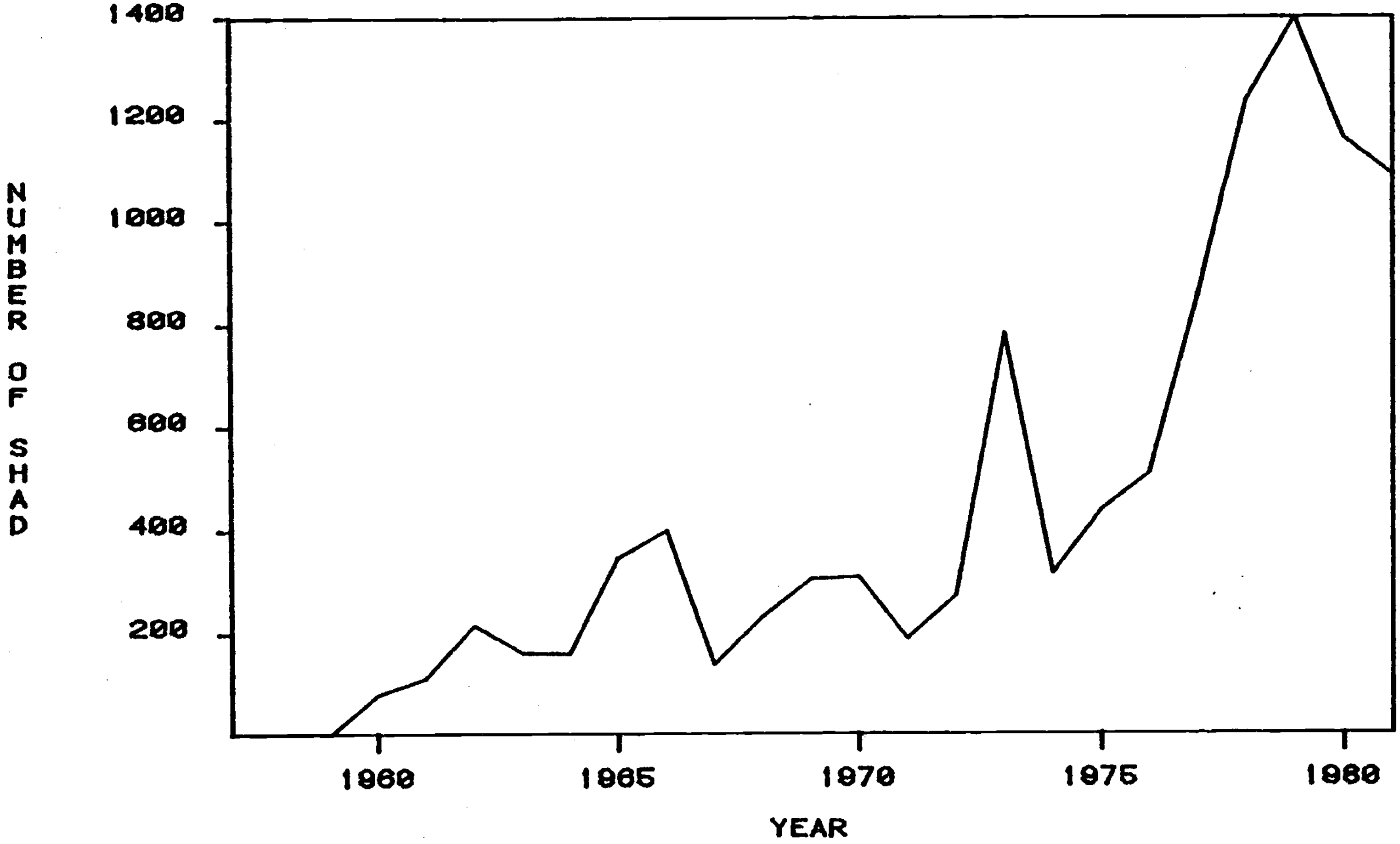

Figure 1. Number (x 1000) of adult American shad passing over The Dalles Dam since its completion in 1957 to 1981 (U.S.A.C.E. 1981).

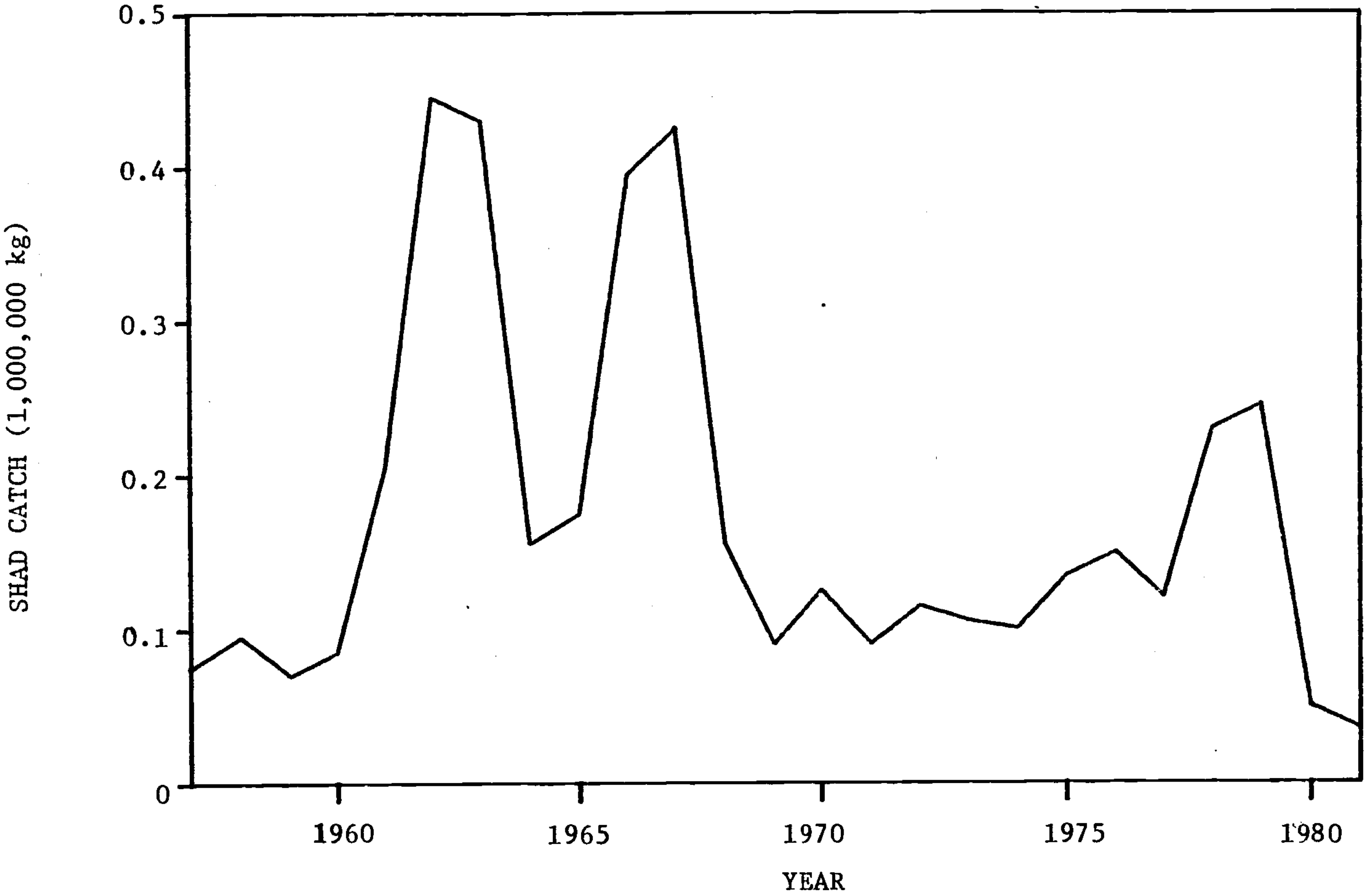

Figure 2. Columbia River shad landings. Data for 1957-1979 from the Oregon Department of Fish and Wildlife and Washington Department of Fisheries (1981). Data for 1980-1981 from Bowers (1981).

under the endangered species act. Because these salmonids are taken incidently to the shad in the gill net fishery, there have been attempts made to lessen the impact of the shad fishery on the three species. These attempts have led to restrictions of the gear used to capture shad and a shortening of the shad season (Hasselman 1966, Young 1971; Parks 1978). As captial and operating costs increase and the season length is shortened, fewer fishermen participated in the shad fishery. Only six boats fished in the 1981 shad season (J. Galbreath, [Oregon Department of Fish and Wildlife, Clackamas] personal communication).

Unlike on the Atlantic coast, a large market for shad has never developed on the Pacific coast. In 1894, Columbia River fish canneries purchased shad only as an inducement to "independents" to sell their salmon to the cannery (Donaldson and Cramer 1971). This practice continues today as major fish packers refuse to handle shad because of low volume and a small market (Matthew O'Bradovich, Portland Fish Company, personal communication). This situation could change quickly if a selective fishing gear is found and large numbers of shad are harvested.

Shad populations on the Atlantic coast have sustained commerical fisheries since the 19th century. This commercial importance has caused the Atlantic populations to be studied extensively (for example, Massman 1952; Talbot and Sykes 1958; Hill 1959; Walburg and Nichols 1967; Leggett and Whitney 1972; Chittenden 1975; Leggett and Carscadden 1978). In comparison, little is known about the Pacific coast shad populations. Moreover, a hybrid of lotic and lentic environments is provided by the hydroelectric impoundments of the Columbia River. This extensive habitat is unlike that of any other river or reservoir system found within the present range of the American shad.

The five predator species of concern to this study have also benefited from the impoundment of the Columbia River. The expansion of habitat, slowing of water velocity and warming of water temperatures caused by the impoundments has been conducive to the advancement of these populations. Scott and Crossman (1973) list water temperatures in the 20-30 C range and negligible to slow water velocities as preferred habitat conditions for the centrarchid species and yellow perch. Summertime water temperatures in Lake Umatilla of 20 to 25 C are common and areas of minimal current are quite extensive. Unlike the shad, these warmwater predator species are lifetime residents in the reservoir and are, therefore, subjected to water management practices throughout their life cycle.

The effect on fish populations of daily and seasonal water level fluctuations caused by the power peaking demands of the hydroelectric projects is unknown. Inferences based on the known biology of each species can be drawn. For instance, yearly recruitment of the centrarchid species in Lake Umatilla may be highly variable. The bass and crappies build spawning nests in water 20 to 610 cm deep, usually less than 100 cm (Scott and Crossman 1973). Daily water level fluctuations below McNary Dam can be as high as 60 to 75 cm. Weekly and monthly variations are much higher. Should spawning occur prior to a draw down of the reservoir, complete loss of nest contents in shallow littoral areas would occur. Even if a successful hatch of eggs is achieved, yoy fish of all species may be forced from protective shoreline vegetation and become more vulnerable to predation in open waters.

The impact of increased numbers of predators on other fish species in the Columbia River has not been adequately assessed. Most research on predator food habits has been centered on the predator populations immediately above and below the dams. The prey item of most concern to these studies has been the downstream-migrating salmonid smolts. Predator-prey relationships in the remainder of these impoundments remains largely unexplored.

Study Site

The Columbia River, which flows 1,954 km and drains 667,931 km^2, empties into the Pacific Ocean at a latitude of 46° 11' N. Climatic conditions vary considerably throughout the river drainage, from the relatively mild climate of western Oregon and Washington to the extreme temperature ranges found in the mid-Columbia River basin and mountainous upper reaches of the Columbia and Snake River tributaries.

Once a fast flowing stream, the Columbia River is now a series of hydroelectric impoundments. This study was conducted in Lake Umatilla (Fig. 3), the largest impoundment in the mid-Columbia region. The reservoir extends 121 km from John Day Dam (river km 349) upstream to McNary Dam (river km 470) and has a total capacity of approximately 2.9 billion cubic meters. Habitat types within the reservoir vary greatly. Former riverine conditions are most closely approximated

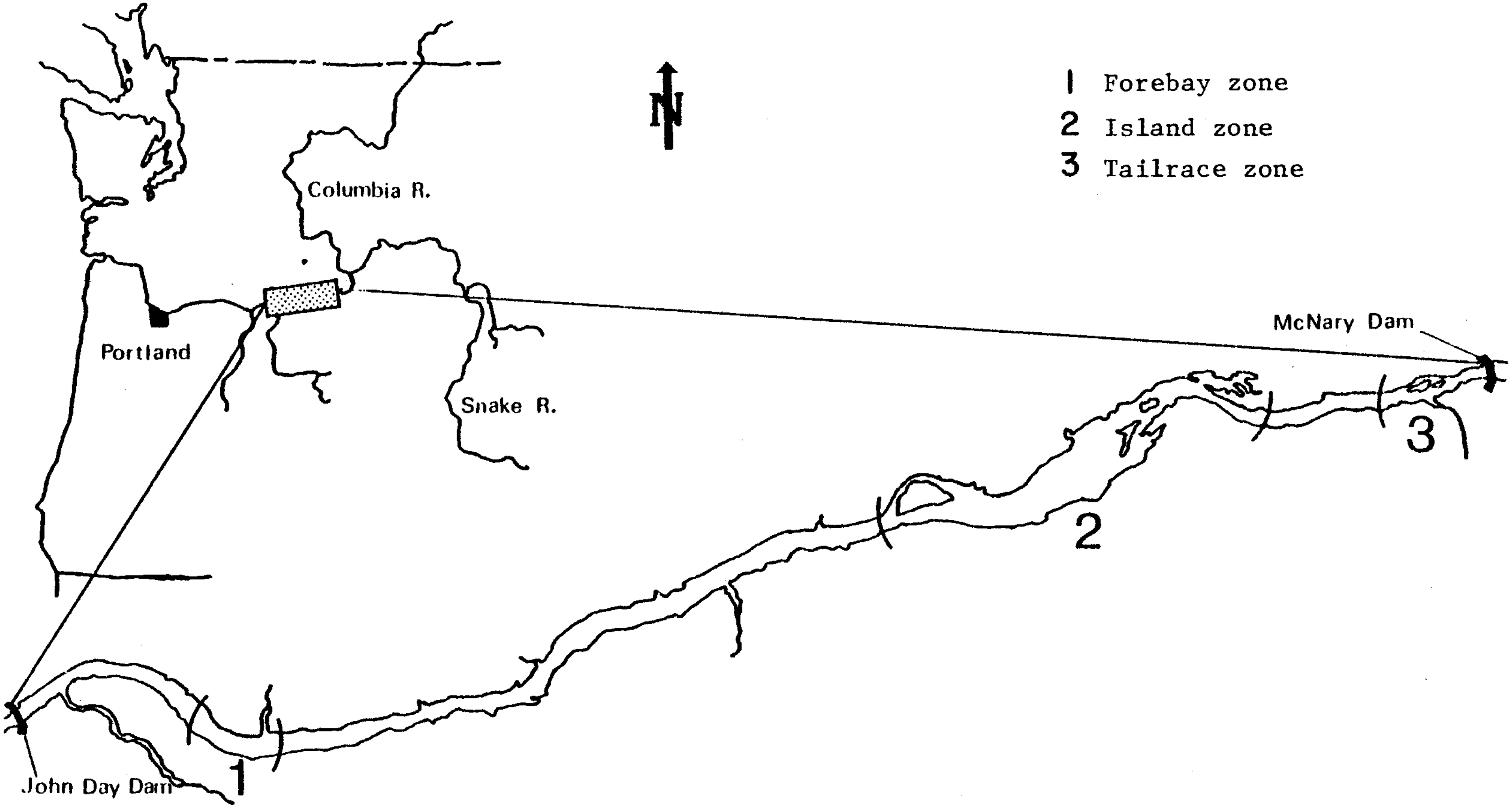

Figure 3. Lake Umatilla of the Columbia River system.

immediately below McNary Dam, where current is moderate to swift and inundation of the pre-dam stream bank is relatively limited.

From McNary Dam there is a downstream gradation into the Blalock Island area. Here a very large flat area, approximately 110 km^2, has been flooded and current is restricted to the former main channels. Water depths in the area, excluding the former channels, are on the order of 0.5 to 3.0 m. At approximately river km 407 a pronounced change to lentic conditions occurs. The shoreline is predominated by rock cliffs or rip-rap, water depths increase downstream to 50 m in the forebay of John Day Dam and water velocities are generally slow. Backwater areas associated with the reservoir follow a similar gradient with respect to water depths and stream bank characteristics; the water velocity is negligible. The physical characteristics of the Lake Umatilla have been described in detail by Hjort et al. (1981).

METHODOLOGY

Adult Shad

Sampling for adult shad in Lake Umatilla began when the first arrivals were reported at John Day Dam and continued for the duration of the 1980 and 1981 spawning migrations. Two types of gill nets were used extensively throughout the 1980 season. A floating gill net, similar to commercial shad gear (10 lb. break strength, 15.25-cm stretch mesh), was used as both a drift and stationary-type gear. Additionally, a sinking variable mesh gill net (38-, 51-, 64-, 76-and 102-mm stretch mesh, and 38.1- by 1.83-m) was used in an effort to avoid the previously reported bias for large fish which occurs from reliance on large mesh gill nets as the only means of capture (Fredin 1954; Carscadden and Leggett 1975a). Due to bottom irregularities and debris, the sinking gill net was used as a stationary gear only. A Smith-Root D.C. pulse (1/120 sec) electroshock unit was used for a 1-day sampling period.

In 1981, a D.C. pulse electroshock unit (Coffelt VVP-2E; 1/120 sec; 3500-watts; 1 to 4-amps) was used as the primary capture gear. The floating and sinking gill nets were used but to a lesser extent.

Fork length to the nearest millimeter and weight to the nearest gram were recorded, and scales were taken from the mid-lateral section of each captured shad. Scales were mounted between two glass slides and the age determined according to the method described by Judy (1961). The most common of three readings was used.

The stomachs of 30 adult shad were removed and examined for food contents. Inspection of several other stomachs were made incidental to the removal of ovaries.

Ovaries were removed from all adult female shad shortly after capture and weighed to the nearest 0.1 g. Ovaries from fish that were close to but were not yet spawning were preserved in Bouin's solution. Thirty-two preserved ovaries were weighed to the nearest 0.01 g; eggs were counted from 1.0 g cross sections from the anterior, posterior and mid-section of the ovaries. Total fecundity was estimated from extrapolation of the average egg count per gram to the total ovary weight (Lehman 1953).

Young-of-the-year shad

Sampling for yoy shad began on June 1 of each year and continued until November 13, 1980 and October 3, 1981. Samples were taken every 14 days in three macrohabitats; the John Day Dam forebay zone, the Blalock and Crowe Butte Island areas (island zone) and the McNary Dam tailrace zone (Fig. 3). Backwater and main channel sites were sampled in the three zones.

A variety of gear was used to sample the life stages from egg to out-migrating juveniles. Modified bongo nets were used to collect eggs, prolarvae and larvae. The nets had a mouth diameter of 0.365-m and Nitex netting of 0.505-mm barmesh formed a cylinder 2.02-m long. A beam trawl with a mouth opening of 1.0-m x 0.33-m and 0.505-mm bar-mesh Nitex netting 2.40-m long was added to the sampling scheme in 1981 (Hjort et al. 1981). After a 10-minute tow was made, the entire sample was preserved with 10% Formalin. Prolarval and larval shad were measured to the nearest 1.0-mm.

Collections of juvenile shad for growth analysis were made in 1980 with a beach seine (30.48-m 2.44-m, 6.35-mm stretch mesh) and square trap nets of the same mesh size. The trap nets were set perpendicular to shore with 22.85-m long leads and 15.25-m long wings all measuring 1.52-m deep. In 1981, juveniles were captured using the seine and electroshock unit. Length to the nearest 1.0-mm was recorded.

Length data on out-migrating juvenile shad from 1976 through 1981 were obtained from the National Marine Fisheries Service. These data were gathered in a gatewell dipping operation on the John Day Dam. Sims et al. (1981) presented a detailed description of this operation and its efficiency.

Predators

The sampling for predator species commenced on April 1, 1980 and 1981 and continued until November 30, 1980 and October 3, 1981. Biweekly sampling was conducted in backwater and main channel areas of each zone.

Predator species were captured in 1980 with the previously described gill nets and seine. Gill net sets were lifted after 1-hour to reduce the amount of digestion and regurgitation of stomach contents. In 1981, the primary means of capture was the electroshock unit. Some predators were captured with the gill nets and seine.

Smallmouth bass, black crappie and white crappie were collected during both years. Largemouth bass were largely unavailable during 1980 because of their ability to avoid capture by gill nets. Yellow perch were added to the sampling scheme in 1981 after a cursory inspection of stomach contents in 1980.

Upon capture of a predator, the entire stomach was removed and preserved in 10% Formalin. When possible, piscine prey items were identified to species and invertebrates to family. Prey items were enumerated, length and volume were recorded, as well as the total volume of stomach contents. An Index of Relative Importance (IRI) value was calculated for each prey item using the percentage frequency of occurrence (F) and percentage composition by number (N) and volume (V), where: $IRI = (N + V) \times F$ (Pinkas et al. 1971; Prince et al. 1978).

RESULTS AND DISCUSSION

Adult Shad

In 1980, the first adult shad arrived at John Day Dam on May 18. A total of 638,037 shad were counted during the migration with peak numbers over the dam occurring between June 19 and July 8 in water temperatures of 13.5-16.5 C. The first arrivals of 1981 were on May 21, the total number of shad passed the dam was 527,675 and the peak occurred between June 28 and July 6 in water temperatures of 14.0-16.0 C (USACE 1980, 1981).

The capture of adult shad by gill nets in 1980 was hampered by high water flow and large amounts of debris in the water; 80 shad were collected in a period from June 24 to August 14. The use of the electroshock unit in 1981 proved to be a more efficient method of capturing shad and 221 adults were collected from June 7 to August 10.

Despite the use of three types of collecting devices gear in 1980, gear selectivity remained a problem. The gill nets showed selectivity for size and sex of adult shad (Table 1). The range of fork lengths overlap but most means were significantly different. Female shad, which are larger than males (Walburg 1960), constituted a larger percentage of the catch in the large mesh gill net. The smaller males were selected for by the small mesh net. The electroshock unit was the least selective of the three gear types.

The age-length relationship (Fig. 4) for both males and females differed significantly (student's t-test; $P < 0.05$) between the two

Table 1. Sex and length of adult American shad captured by three different gear types in Lake Umatilla, 1980.

Type of gear	% Male	Mean length (mm)	Length range (mm)	% Female	Mean length (mm)	Length range (mm)
Small mesh gill net	88.2	388	365-431	11.8	418*	368-467
Electroshock unit	69.2	392	355-410	30.8	432*	426-442
Large mesh gill net	6.4	407*	380-435	93.6	464*	435-498

* - indicates significant difference at $P < 0.01$ using students t-test; N = 72

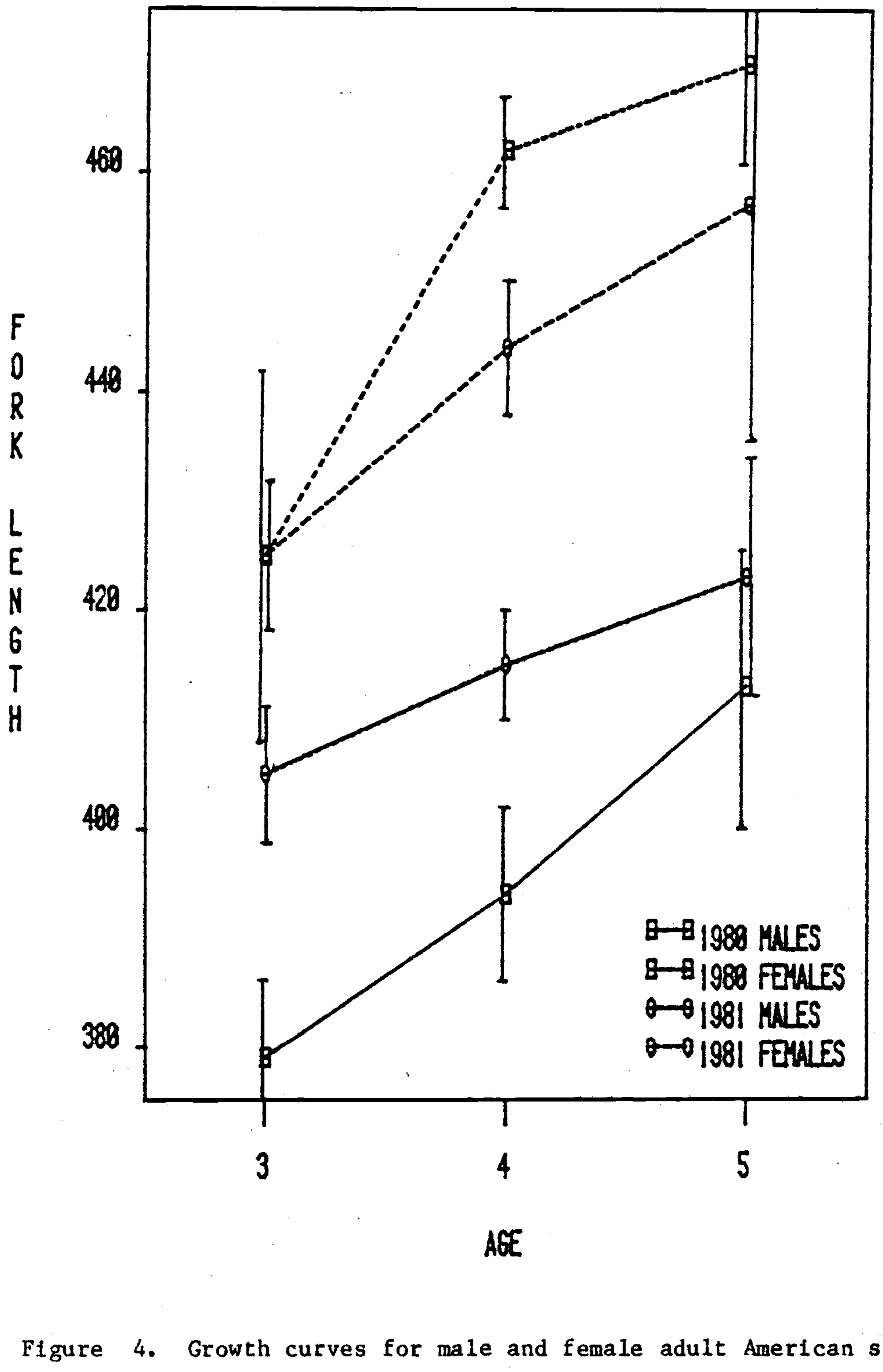

Figure 4. Growth curves for male and female adult American shad captured in Lake Umatilla in 1980 and 1981. Each vertical bar represents mean ± 1 SD. Fork length in mm.

years with the exception of three year old females. A combination of gear selectivity and the sexual dimorphism in size was the probable cause of these differences. Because progressively larger shad are captured with increasing mesh size (Carscadden and Leggett 1975b), the large mesh gill net would have selected the larger females from each year class while the small mesh gill net selected for the smaller males of each year class. For this reason, the 1980 age-length data were biased and the 1981 results were more representative of the population. The age-growth relationship of adult shad collected in Lake Umatilla was similar to that reported by Leggett and Carscadden (1978) for northern Atlantic coast populations (Fig. 5).

The shad sampled during this study were found to mature at significantly younger ages than shad from southern Oregon rivers (Mullen 1972). Furthermore, the mean maturity ages of these Pacific coast shad populations were lower than those reported for several Atlantic coast populations (Table 2).

Freshwater growth rates, oceanic growth rates and heredity of anadromous fish species have been variously proposed, demonstrated and discussed as having an effect on age at first spawning (Cole 1954; Alm 1959; Jones 1959; Carscadden and Leggett 1975b; Schaffer and Elson 1975; Leggett and Carscadden 1978). To attribute the difference in age at maturity of east and west coast shad populations to any one of these factors without quantitative data on juvenile growth rates and environmental differences would be speculative, at best.

Year class strength was perhaps most responsible for the relatively low ages at maturity of shad from Lake Umatilla.

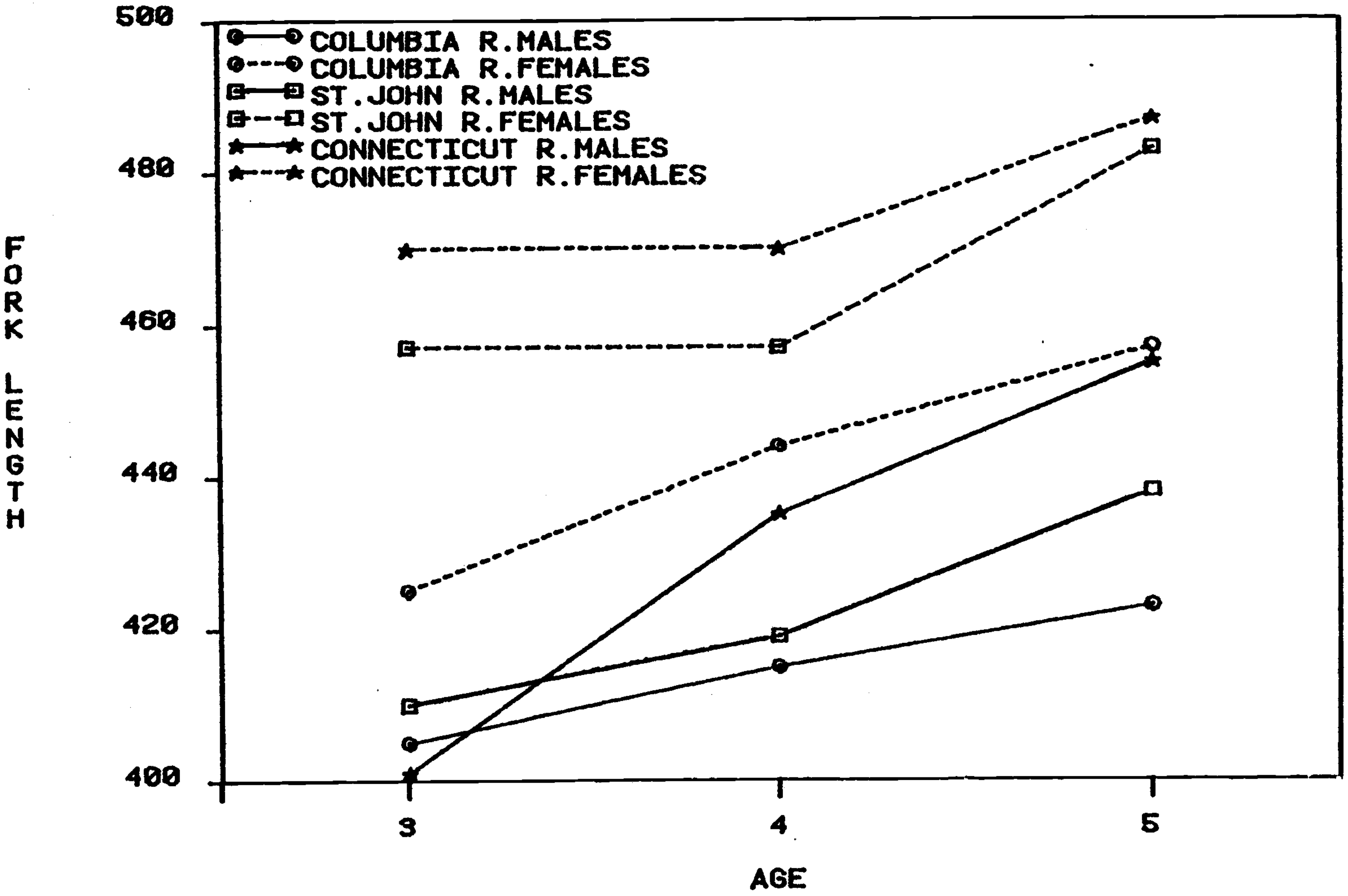

Figure 5. Age-length relationships for male and female adult American shad from three river systems. Columbia River from this study, 1981 only. St. John and Connecticut rivers from Leggett and Carscadden (1978). Fork length in mm.

Table 2. Mean age at maturity and percentage of repeat spawning of male and female American shad in several Pacific and Atlantic coast streams.

River	Number of years sampled	Latitude (°N)	Males		Females	
			Mean age at maturity	% Repeat spawning	Mean age at maturity	% Repeat spawning
PACIFIC						
Coquille*	7	43° 07'	3.4	92	4.0	62
Coos*	11	43° 22'	3.3	90	3.9	54
Umpqua*	9	43° 42'	3.4	75	4.0	43
Smith (Ore.)*	8	43° 42'	3.4	90	4.0	57
Siuslaw*	7	43° 58'	3.6	92	4.1	58
Columbia (Lake Umatilla)**	2	46° 11'	3.2	36	3.5	45
ATLANTIC						
York***	7	37° 15'	4.2	31	4.7	19
Connecticut***	12	41° 16'	4.1	46	4.8	32
St. John (N.B.)***	2	45° 16'	4.2	81	4.5	65
Miramichi***	3	47° 01'	4.2	59	4.6	54

* Mullen (1972)

** This study.

*** Leggett and Carscadden (1978)

Successively larger year classes produced in 1977 and 1978 were recruited into the spawning population for the first time as three year olds in 1980 and 1981, respectively. The entrance of three year old virgin spawners from the 1977 year class served to lower the mean age at maturity of the population in 1980. The age was expected to increase the following year when four-year-old virgin spawners entered the spawning populations; however, the larger group of three-year-old spawners recruited from the 1978 year class maintained the lower age.

Four-year-old shad which had spawned the previous year accounted for 34.3% of the spawning population of the two years. These fish combined with four-year-old virgins made up the largest (58.5%) single age class (Table 3). The age class structure of adult shad captured during this project reflects the progressively stronger year classes from 1975 to 1978. No adult shad from earlier year classes were found even though adult ages up to 12 years old have been reported in Pacific populations (Mullen 1972).

The Columbia River shad population, like those of southern Oregon rivers (Mullen 1972) and northern Atlantic coast streams (Talbot 1954; La Pointe 1957; Walburg and Sykes 1957; Leggett and Carscadden 1978), demonstrates iteroparity. The frequency of repeat spawning (sexes combined) was 45% and 44% for 1980 and 1981, respectively. The frequency of repeat reproduction in females (2 yr mean 45%; range 34-57) was higher than in males (2 yr mean 36%; range 24-48). These rates of repeat spawning are considerably lower than had been expected.

Table 3. Percentage of age and previous spawning age groups of American shad captured in Lake Umatilla in 1980 and 1981.

Present Age	Age at Previous Spawning	1980 (n = 73) %	1981 (n = 204) %	Years Combined (n = 277) %
3	-	23.3	32.4	30.0
3	2	-	1.0	0.7
				Total 30.7
4	-	24.7	24.0	24.2
4	3	32.9	34.8	34.3
				Total 58.5
5	-	6.9	-	1.8
5	3	1.4	1.0	1.1
5	4	4.1	2.9	3.2
5	4,3	6.9	3.4	4.3
				Total 10.4
6	5,4,3	-	0.5	0.4
				Total 0.4

Information gathered by Leggett and Carscadden (1978, Fig. 2) from Atlantic stream shad populations demonstrated, with few exceptions, an increase in repeat spawning with increasing latitude above 35°N. Based strictly upon this latitudinal gradient, the Columbia River shad population should have a repeat reproduction rate similar to that of the St. John River (New Brunswick) shad population. This expectation is supported by the very high rates of repeat reproduction in other Oregon shad populations. After accounting for the inflation of the observed rate caused by the use of commercial gear as the only means of capture (Carscadden and Leggett 1975b), the rate of repeat spawning in southern Oregon rivers probably fits the latitudinal gradient quite well.

Year class strength, distance from the sea to spawning grounds, and therefore energy expenditure, may account for the disparity between the expected and observed rates of repeat spawning in shad from Lake Umatilla. As in age at maturity, the effect of strong year classes in 1977 and 1978, and the subsequent recruitment of a large proportion of virgin spawners into the spawning populations of 1980 and 1981, was to initially depress the percent of repeat spawners followed by expected increases as these fish returned to spawn again.

The proportion of repeat spawners decreases as distance from the ocean to spawning grounds increases (Carscadden and Leggett 1975b). The energy reserves needed to complete the longer migration to the spawning area and then return to marine feeding grounds has been tied to this decrease in repeat reproduction (Carscadden and Leggett 1975b; Leggett and Carscadden 1978). Shad, spawning in the Connecticut

River, utilized approximately 55% of initial somatic energy reserves in making the roundtrip to and from spawning grounds 137 km upstream (Glebe and Leggett 1976). Shad spawning in, or above Lake Umatilla, must travel upstream at least 349 km. Because it is unlikely that higher initial reserves alone could compensate for the large difference in the energy requirement, it is necessary to consider another energy source (i.e., feeding during freshwater migration) and the possibility of lower energy allocation to gonadal production. However, the energy gain from these two factors appears to be insignificant with a probable result of fewer shad being able to complete the arduous journey to and from the spawning grounds.

All stomachs of adult shad that were examined during this study were empty, a finding which supports those of earlier investigators (Leim 1924; Hildebrand and Schroeder 1928; Moss 1946; Hildebrand 1963; Hasselman 1966; Hammann 1982). Chittenden (1976) reported some opportunistic feeding behavior by migrating adult shad when "suitably large planktonic forms were available" and also suggested smaller fish may make better use of the freshwater food resource. These suggestions and the success of Columbia River sports fishermen in capturing adult shad during migration with a variety of flies and lures, suggests the mechanism controlling adult freshwater feeding is a strict size selectivity and not a physiological response such as seen in adult Pacific salmon (Oncorhynchus sp.). Some feeding may occur but is probably minimal.

The absolute fecundity of the 32 female shad sampled ranged from 97,168 to 284,240 with a mean of 193,074 eggs. While there was a general increase of fecundity with increasing fish size and age, there was a slight decrease in fecundity with repeat spawning. Mean virgin fecundity was estimated to be 171,000 eggs. By using the method of Leggett and Carscadden (1978),

$$F(_j\cdot) = Y\ (_j\cdot) + \Sigma\ [Y\ (i,j)\ x\ P\ (i,j)]$$

where:

$F(j)$ = mean lifetime fecunidty, population j

$Y(j)$ = mean virgin fecundity, population j

$Y(i,j)$ = mean fecundity of females in population j spawning for the ith time

$P(i,j)$ = proportion of the females in population j which spawn i times

the mean lifetime fecundity of shad collected in Lake Umatilla was determined to be 305,000. These fecundity values are generally comparable to those reported by Leggett and Carscadden for the St. John (mean virgin 135,000; mean lifetime 273,000) and Connecticut Rivers (mean virgin 256,000; mean lifetime 384,000).

Male shad in spawning condition were captured throughout the sampling period of both years. Prior to July 1, 20% of the males were not yet ripe; after August 1, 70% of the males were spent. The first ripe female shad were taken in the first week of July in both years, although the presence of eggs and larvae (see below) indicated prior spawning. By the last week of July the incidence of spent females increased to 65% and all female shad captured during August were spent.

Year-of-the-Year Shad

Shad eggs were collected in 1980 and 1981 in the McNary Dam tailrace zone and main channel of the island zone; none were found in the forebay zone. In 1980, eggs were present in samples from June 25 to July 29 with peak abundance in the third week of July. In 1981, the chronology was similar to the previous year (Fig. 6), but the abundance of eggs was reduced (Hjort et al. 1981).

Eggs occurred throughout the water column where current was present but were most prevalent along the bottom. Highest numbers were found in the tailrace mid-channel and inshore habitats of the tailrace and island zones.

The exact location of shad spawning in Lake Umatilla remains unclear. The fertilized shad egg is only slightly heavier than water and is easily subjected to the influences of water current before settling to the bottom (Massman 1952; Scott and Crossman 1973). The high abundance of eggs found in the mid-channel of the tailrace zone, an area of high water velocity, indicated some spawning occurred immediately below or above McNary Dam. The possibility existed that spawning occurred in the fish passage facilities as shad are known to congregate in these ladders. The occurrence of shad eggs in samples taken at the upstream end of the island zone was evidence that some spawning did occur throughout the tailrace zone as Hjort et al. concluded. Evidence of shad spawning in other areas of the reservoir was not found.

The median spawning temperature, as determined by the abundance of eggs, was approximately 17.5 C in 1980 and 16.0 C in 1981. These

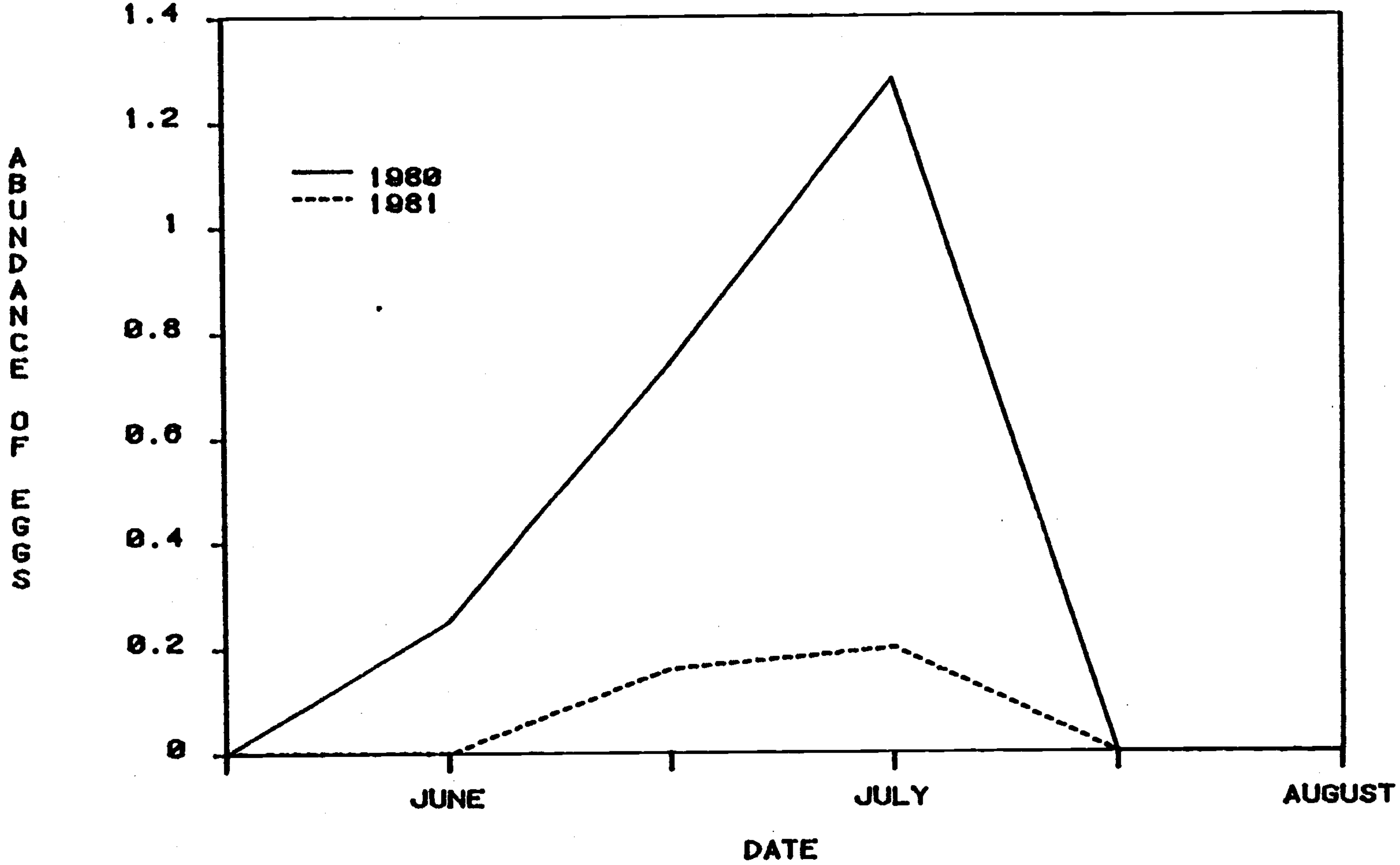

Figure 6. Average abundance of American shad eggs in bongo net samples from main channel of the tailrace zone of Lake Umatilla, 1980 and 1981. Derived from Hjort et al. (1981). Abundance = number per 10 m^3.

temperatures are comparable to spawning temperatures of shad in Atlantic rivers (Massman 1952; Talbot 1954; Walburg 1960; Marcy 1976). Extended incubation time and reduced survival is expected at water temperatures less than 15.5 C (Leim 1924) and although eggs were present in water temperatures lower than this during 1981, the peak abundance occurred in equal or higher water temperatures.

Collection of prolarval shad extended from June 28 to August 18 in 1980. Prolarvae, like the eggs, were only present in samples taken in the tailrace and island zones. In the tailrace zone, catches were highest in the main channel and least in the backwater areas (Fig. 7a,b); peak abundance occurred from July 1 to July 14, 1980. The island zone provided a contrast. Here prolarval shad were more abundant in the nearshore habitats and least abundant in the mid-channel. The peak abundance occurred one week later, July 14 to July 21, in the island zone and there were nearly ten times as many prolarvae in near shore areas as had been found in the tailrace channel.

In 1981, prolarvae were captured in all three zones during a one month period commencing July 7. Hjort et al. (1981) pointed out that the capture of prolarval shad in the forebay zone was the probable result of the more intensive nearshore sampling scheme used in 1981. Peak abundances occurred in all areas from July 7 to July 21. The highest density of prolarvae was again in the nearshore areas of the island zone. Major differences in the two years were: the decrease in tailrace channel abundance to a negligible amount (Fig. 8), and an overall decrease in prolarval abundance in 1981 compared to 1980.

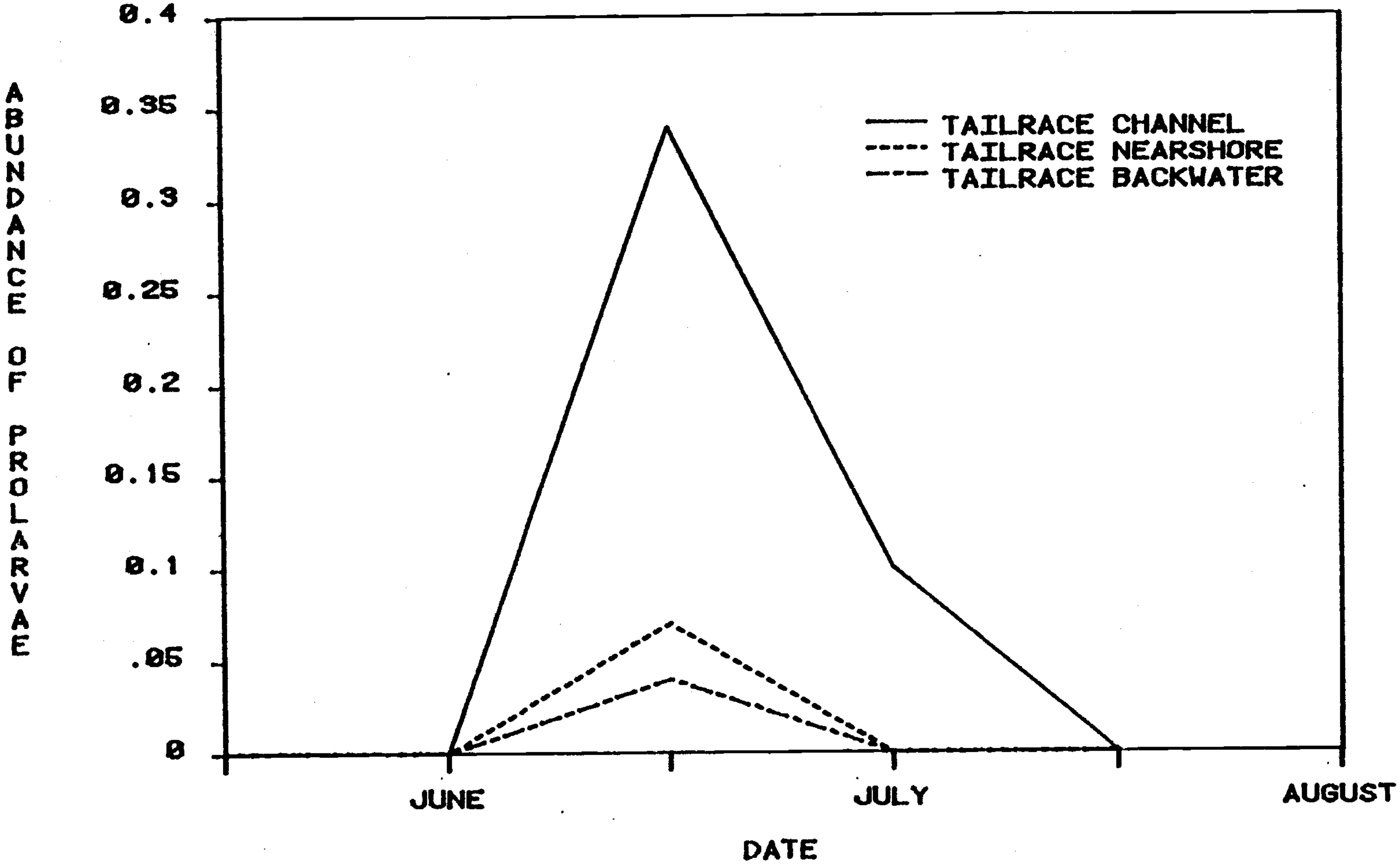

Figure 7a. Average abundance of American shad prolarvae from bongo net samples in the tailrace zone of Lake Umatilla in 1980. Derived from Hjort et al. (1981). Abundance = number per 10 m^3.

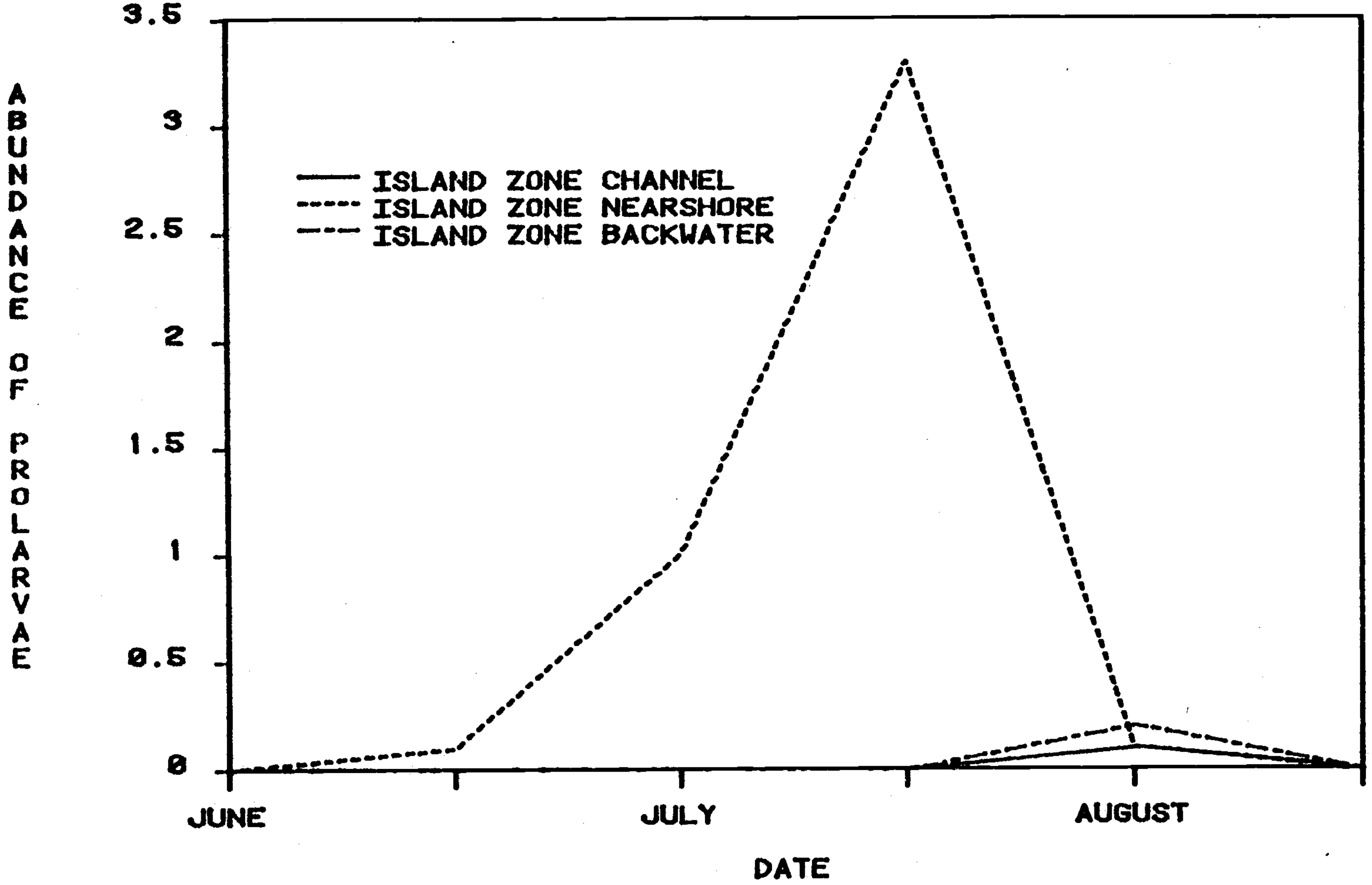

Figure 7b. Average abundance of American shad prolarvae from bongo net samples in the tailrace zone of Lake Umatilla in 1980. Derived from Hjort et al. (1981). Abundance = number per 10 m^3.

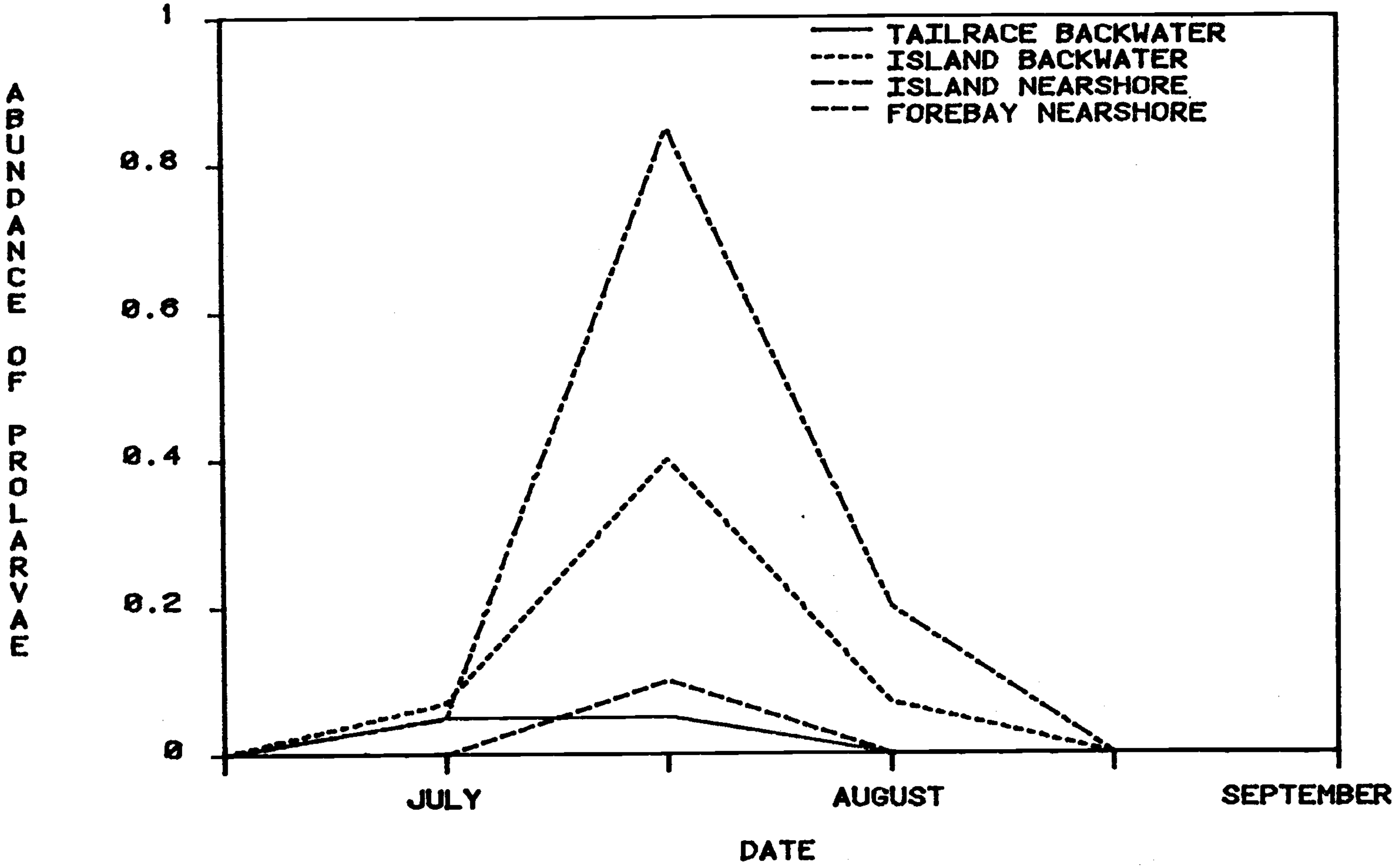

Figure 8. Average abundance of American shad prolarvae from bongo net samples at different macrohabitats in Lake Umatilla, 1981. Derived from Hjort et al. (1981). Abundance = number per 10 m^3.

Water current appeared to be the main mechanism involved in the dispersal of prolarval shad in Lake Umatilla. The relatively high abundance of prolarvae in the mid-channel of the tailrace zone in 1980 followed one week later by an abundance ten-fold greater in nearshore areas of the island zone, indicated a flushing of prolarvae into this zone. Prolarval shad, hatching in or above the tailrace zone, were subjected to the high water velocities of this zone as they rose into the water column from the substrate. Minimal fin development, and reduced mobility, apparently restricted the movement to preferred inshore habitats until the current dissipated in the island zone. The presence of low numbers of prolarvae in backwater areas indicated some active dispersion did occur.

The presence of larval shad was recorded from mid-July to mid-September of both years. During these periods the shad larvae were the most abundant species of larvae in the reservoir. In July 1980, shad accounted for 85% of all larvae in the nearshore habitat of the island zone (Hjort et al. 1981). While larvae were more abundant in 1980 than in 1981, the difference was not as large as that noted earlier in the prolarval abundances.

Peak abundance of larvae occurred 14 days earlier in 1980 than in 1981 and highest concentrations were found in the island zone (Fig. 9, 10). The difference in timing of peak larval abundance, after the coincidental timing of egg and prolarval peak abundances of the two years, can be partly attributed to slower development brought about by cooler water temperatures in 1981. Optimal development of young shad occurs in water temperatures of 17 C and above (Leim 1924). The water

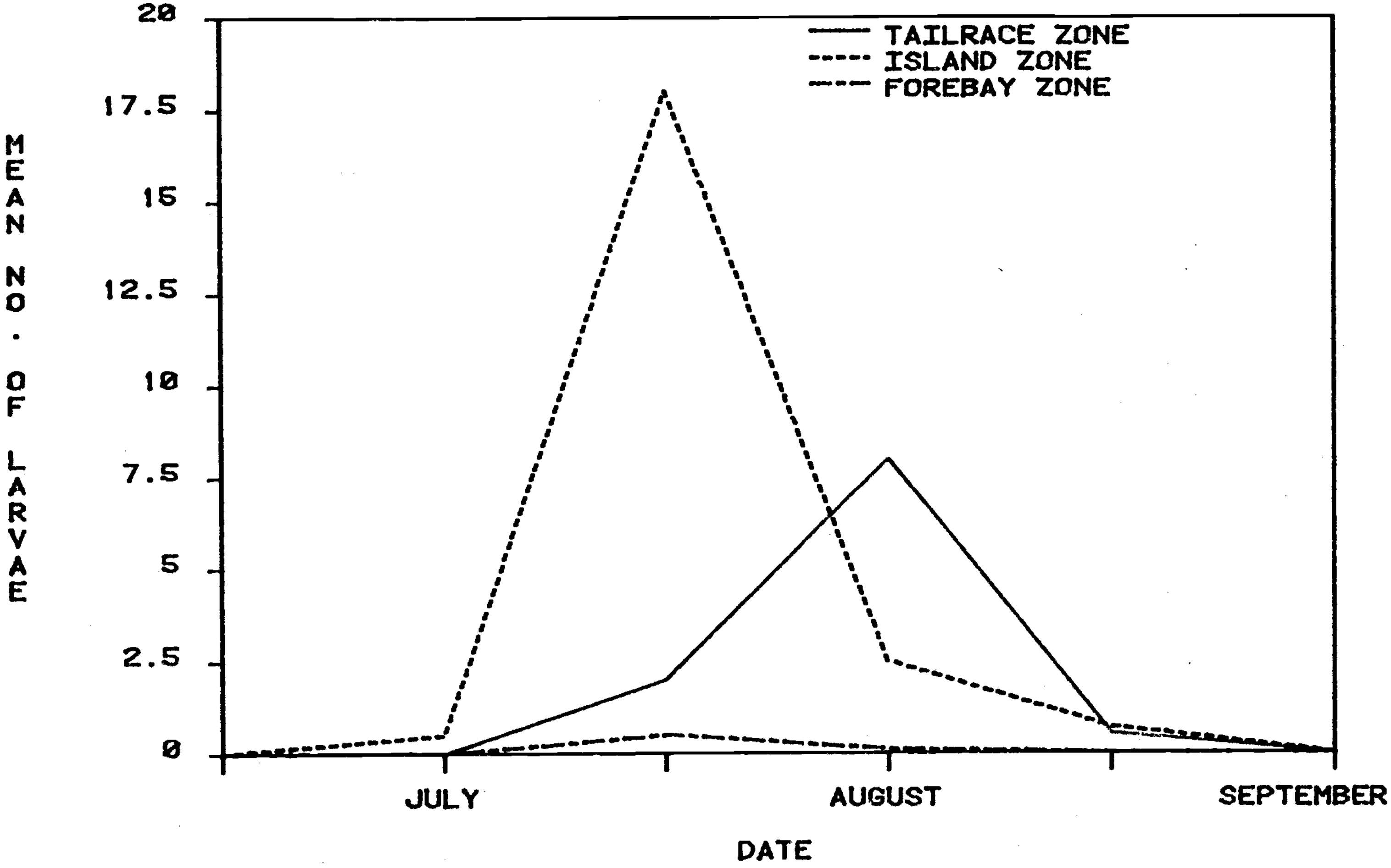

Figure 9. Average abundance of American shad larvae from bongo net samples of the three sampling zones of Lake Umatilla, 1980. Derived from Hjort et al. (1981). Abundance = number per 10 m^3.

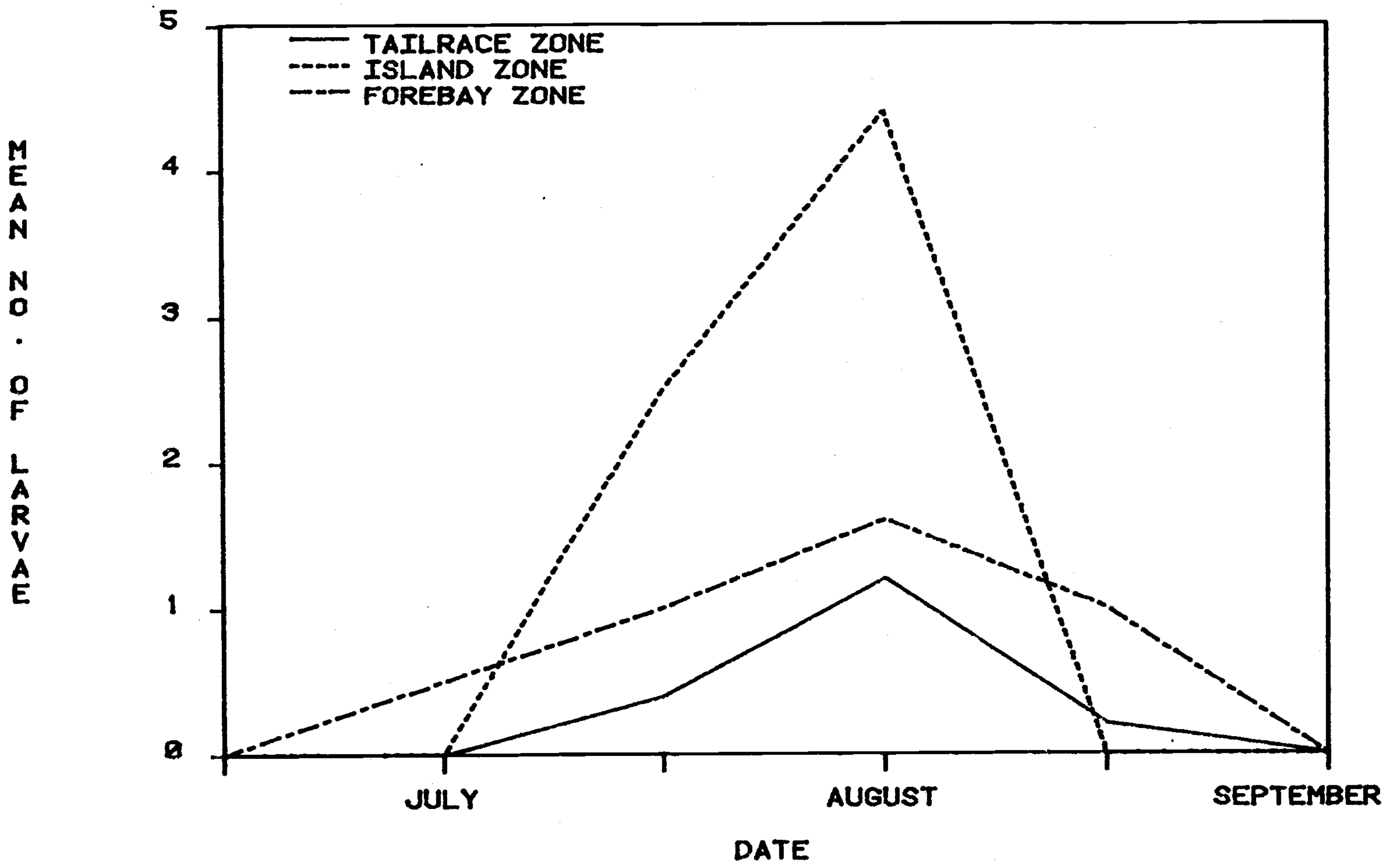

Figure 10. Average abundance of American shad larvae from bongo net samples of the three sampling zones of Lake Umatilla, 1981. Derived from Hjort et al. (1981). Abundance = number per 10 m^3.

temperature of Lake Umatilla first reached 17 C on July 13, 1980 and 12 days later (July 25) in 1981.

The island zone, an area of extensive flat-bottomed shallows similar to those described by Massman (1952) as important rearing areas in Virginia streams, was the most important rearing area for larval shad in Lake Umatilla. Larval abundance in this zone was more than double that of either the tailrace or forebay zones.

Within each zone there was a greater dispersion of larval shad to all habitats than was found in prolarvae. Larval shad was the first life stage to occur in backwater areas in significant numbers. The dispersion of larval shad into these areas was the probable result of intraspecific competition for food resources and increased mobility with fin development. The backwater areas of all three zones, particularly those areas having high densities of zooplankton, contained more large larvae than did other habitats (Hjort et al. 1981).

The first juvenile shad were collected in the first week of August in both years and peak abundances occurred in mid-September. Juveniles continued to be sampled until November 13, 1980, and until the end of project sampling on October 3, 1981.

Juvenile shad were ubiquitously distributed in the reservoir and associated backwaters. Visual observations of numerous young shad breaking the water surface in the late evening hours were made in all habitats. Seine data (Table 4) indicated that shad were the most abundant species in all inshore habitats of the reservoir in 1980. As noted previously, shad were far less abundant in 1981 and this was

Table 4. Individual species seine catch-per-unit-effort in six macrohabitats of Lake Umatilla, July through September 1980 (Hjort et al. 1981).

	Catch-per-Unit-Effort								
	Squawfish	Peamouth	Largescale Sucker	Black Crappie	White Crappie	Smallmouth Bass	Largemouth Bass	American Shad	# of Sets
FOREBAY ZONE									
Backwaters	0.167	0.167	0.167	5.167	0.167	0.500	0.333	19.000	6
Open waters	0.000	0.000	0.000	0.000	0.000	0.867	0.000	118.467	5
ISLAND ZONE									
Backwaters	0.000	0.400	0.400	16.400	0.000	1.600	2.400	19.000	5
Open waters	2.143	1.905	4.048	0.286	0.000	0.429	0.143	79.286	
TAILRACE ZONE									
Backwaters	2.167	23.569	2.167	3.667	0.000	5.708	0.167	181.167	6
Open waters	1.167	1.389	0.250	0.083	0.000	0.056	0.000	133.861	6

reflected in juvenile catches by a much reduced catch per unit effort (CPUE) (Table 5). However, an increase in CPUE did occur in the backwaters of the island zone during 1981 and shad was still the most abundant species in these waters, as well as, in the main channel of the forebay.

Initial growth of young shad in Lake Umatilla appeared to be relatively constant in 1980 and 1981. A flattening of the growth curves occurred in mid-September of 1980 (Fig. 11). An inflection point was not reached during reservoir sampling in 1981. Later samples of the downstream migrants from gatewells at John Day Dam indicated a leveling of the growth curve occurred in mid-October (Fig. 12).

The emigrating yoy shad measured at the John Day Dam were significantly (student's t-test; $P < 0.05$) larger than those found elsewhere in the reservoir. There were no other consistent size differences of significance in the macrohabitats sampled, although young shad found in the main channel of the tailrace zone tended to be slightly larger in both years.

Downstream migrating shad were taken in the gatewell dipping operation at John Day Dam from the beginning of August in each year from 1976 to 1981. Although downstream migrants were taken in water temperatures as high as 23 C, a large increase in CPUE occurred when water temperatures dropped below 15 C (Table 6). An exception to this was 1980 when shad left the reservoir at a more constant rate and the peak of migration took place in water temperatures of 19-21 C. Few shad remained in the reservoir after the water temperature had dropped

Table 5. Individual species seine catch-per-unit-effort in six macrohabitats of Lake Umatilla, July through September 1981 (Hjort et al. 1981).

	Catch-per-Unit Effort								
	Squawfish	Peamouth	Largescale Sucker	Black Crappie	White Crappie	Smallmouth Bass	Largemouth Bass	American Shad	# of Sets
FOREBAY ZONE									
Backwaters	0.000	0.000	0.000	13.333	1.667	0.500	1.833	5.500	6
Open waters	0.000	0.000	0.000	0.000	0.000	0.200	0.000	17.600	5
ISLAND ZONE									
Backwaters	0.250	0.000	0.000	5.750	4.750	1.250	0.000	358.750	4
Open waters	8.278	8.333	8.167	0.000	0.000	0.278	0.000	8.278	9
TAILRACE ZONE									
Backwaters	8.333	8.667	9.667	0.500	0.833	1.000	3.000	2.833	6
Open waters	5.500	3.833	3.222	0.556	0.000	0.444	2.333	2.722	9

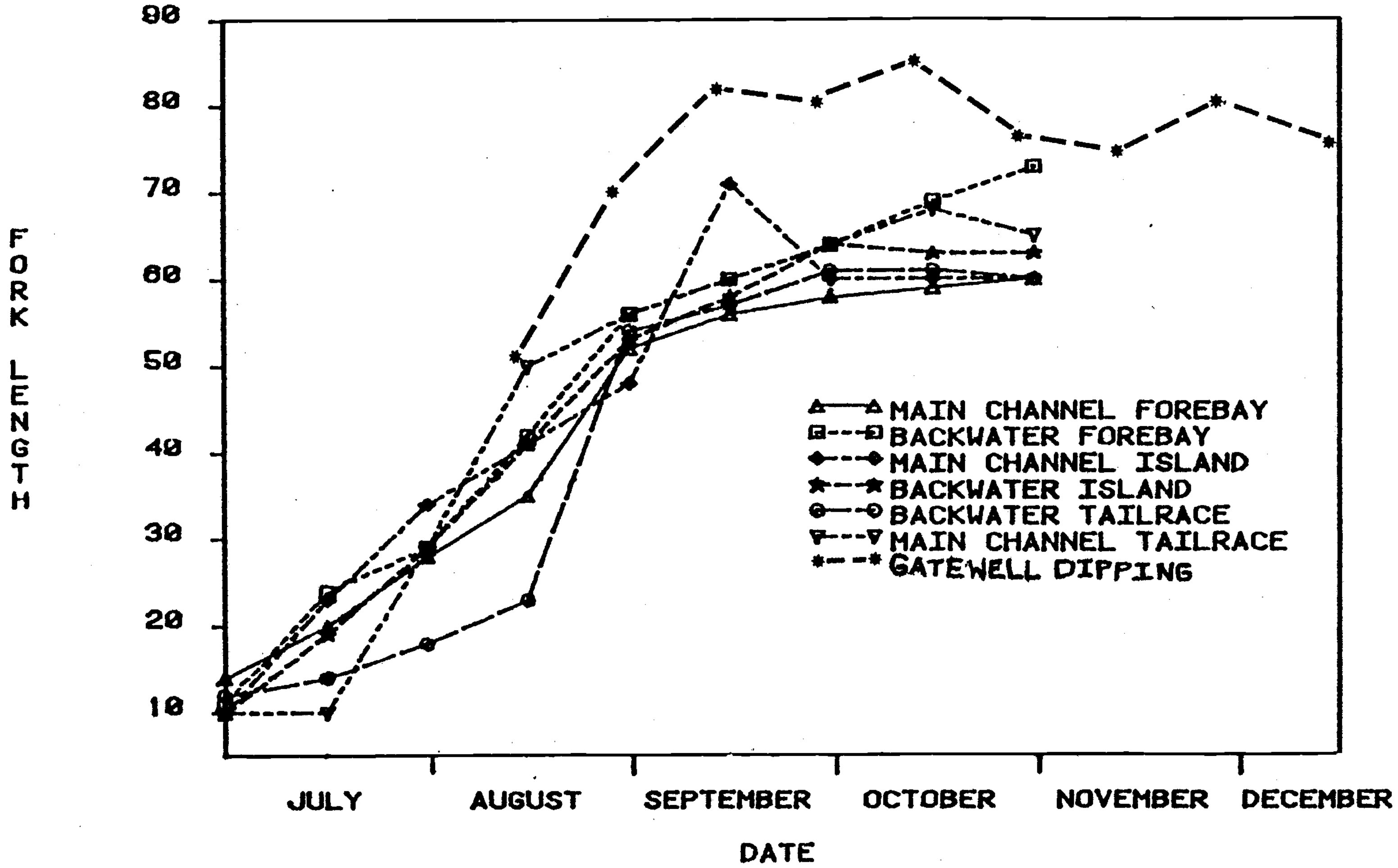

Figure 11. Mean fork length (mm) of yoy American shad from six macrohabitats in Lake Umatilla and gatewell dipping at John Day Dam in 1980.

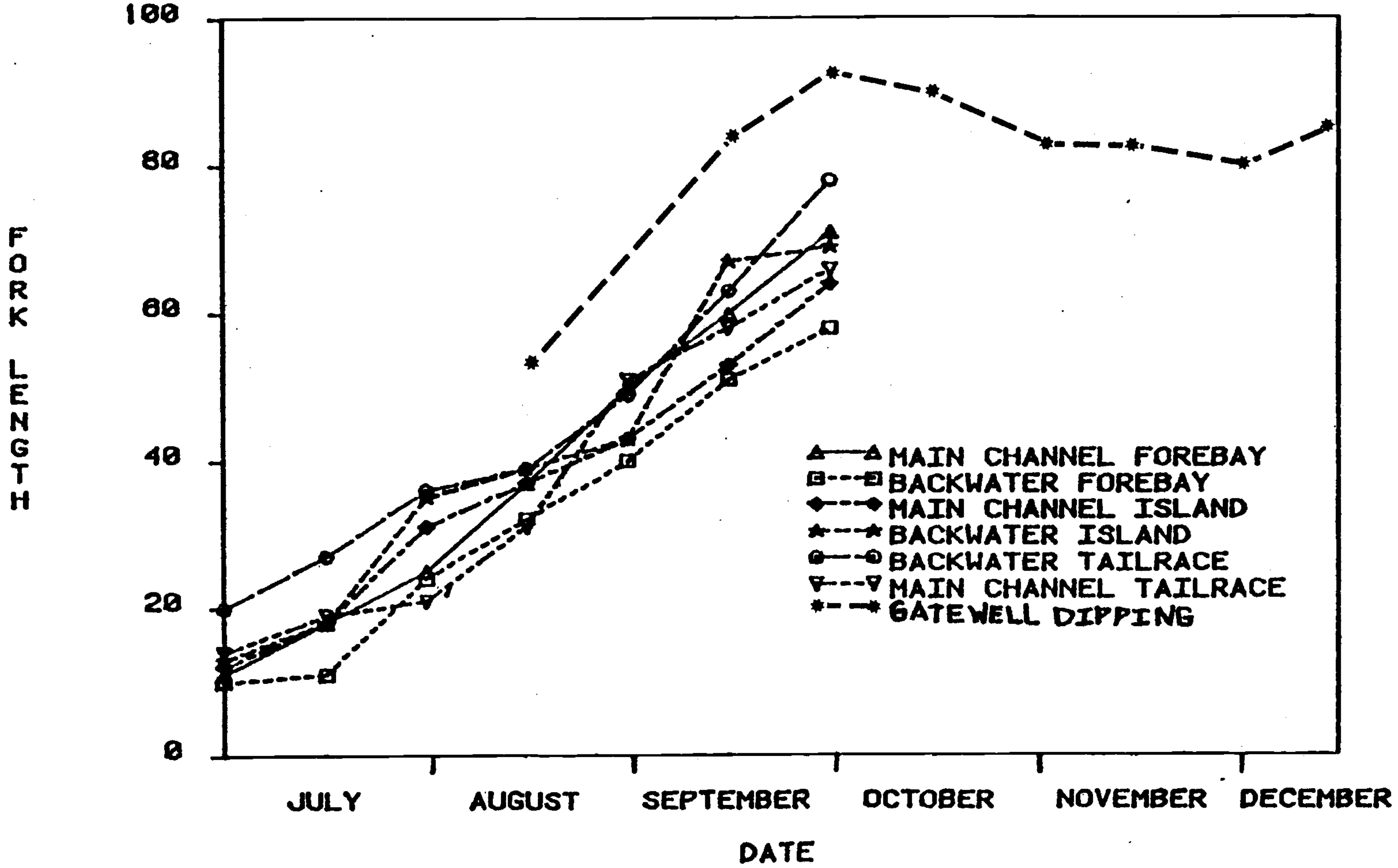

Figure 12. Mean fork length (mm) of yoy American shad from six macrohabitats in Lake Umatilla and gatewell dipping at John Day Dam in 1981.

Table 6. Gatewell dipping catch-per-unit-effort of juvenile shad migrating downstream through John Day Dam. 1976-1981.

Year	CPUE for entire migration	CPUE, water temperature ≤ 15°C
1976	38.1	60.4
1977	105.4	195.5
1978	279.7	724.9
1979	2298.0	5501.7
1980	555.5	424.8
1981	262.8	664.4

to 6 C and a high mortality of these fish due to prolonged exposure to low temperatures would have been expected (Chittenden 1972).

Water temperature has long been identified as having an influence on the downstream migration of juvenile shad (Sykes and Lehman 1957; Chittenden 1969; Leggett and Whitney 1972; Marcy 1976). The large increase in CPUE in the gatewell operation when the water temperature dropped below 15 C supports the findings of Sykes and Lehman (1957) who found that the emigration of juvenile shad is accelerated when water temperatures fall below 15.5 C. The results of this study also demonstrated the partial dependence of migration timing on juvenile length noted earlier by Marcy (1976). The significant difference in size between yoy shad collected in the reservoir and emigrating shad in the gatewells clearly demonstrated that the largest juveniles of the population were the first to leave the reservoir.

Data from the gatewell operation from 1976 to 1981 showed a distinct length profile for the emigrating yoy shad of each year (Fig. 13). Generally, the lengths of downstream migrants increased until the water temperatures decreased to 14-15 C. The mean length of migrants then declined for a period of time followed by a rise to a point lower than the length recorded at 14-15 C. This general pattern is very much like that described by Marcy (1976) for Connecticut River juvenile shad.

The length differences between years may be due to the negative correlation that exists between freshwater growth rates and juvenile shad abundance, a relationship which arises from intraspecific competition for food resources and space (Marcy 1976; Leggett 1977a).

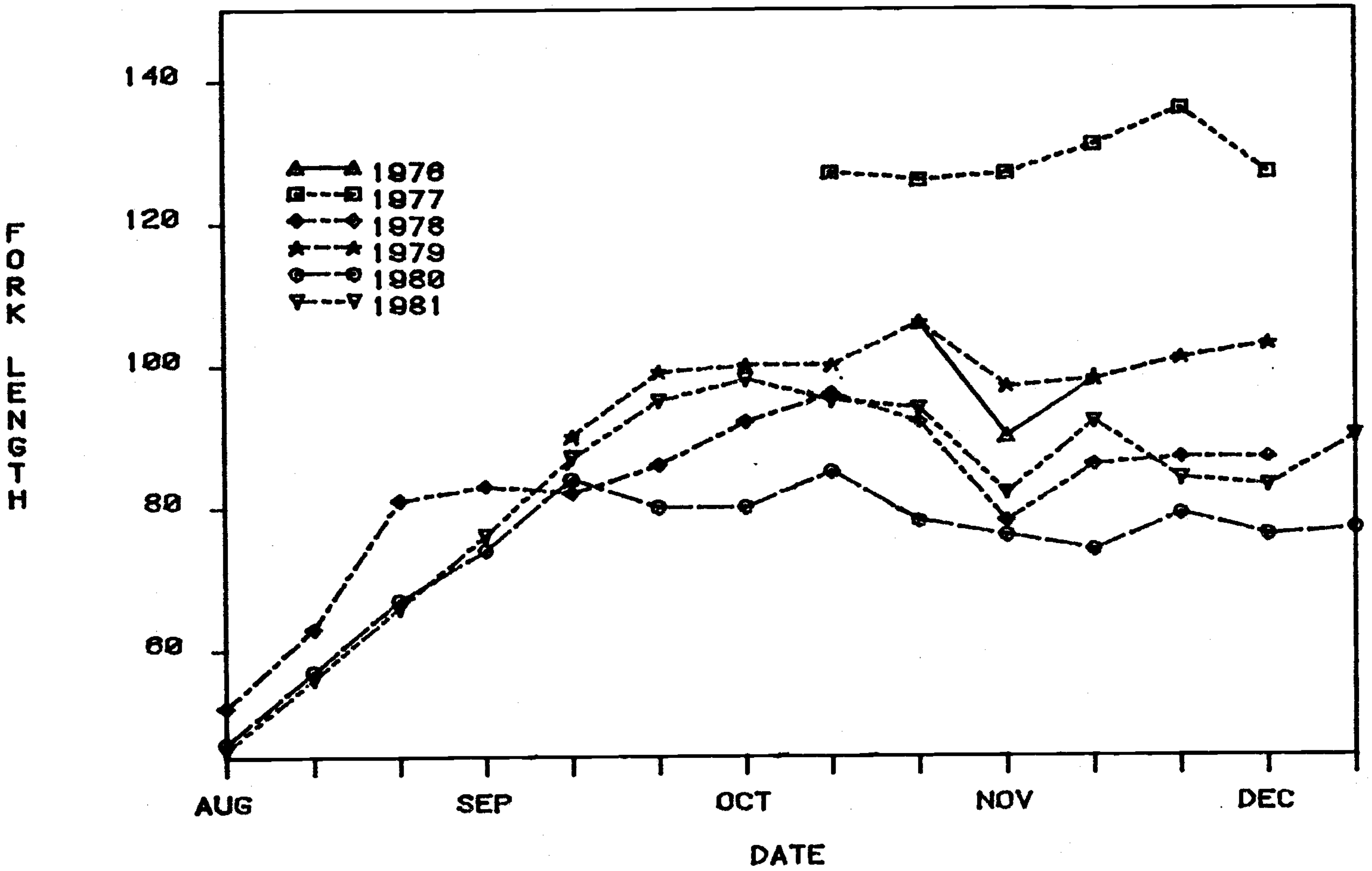

Figure 13. Mean fork length (mm) of juvenile American shad from gatewell dipping at John Day Dam, 1976-1981. Years followed by a common letter are not significantly different (Student's t-test; P < 0.05).

By using the gatewell dipping CPUE as an index of year class strength and comparing these data to the yearly length profiles, two discrepancies are readily apparent; 1979 produced the largest year class yet had the second largest size profile and 1977, which had the second weakest year class, produced yoy shad remarkably larger than those produced in any other year. Temperature and water flow rates apparently caused these differences. In 1979, water temperatures in excess of 17 C were recorded at the John Day Dam on 119 days. This compares to 75 days in 1980, the year of the next largest year class and smallest out-migrant size profile. Severe drought conditions in 1977 led to reduced water flow and slightly warmer water temperatures than in 1976, a combination which when added to the small year class gave a markedly larger size of out-migrant.

The mean fork lengths of juvenile shad leaving Lake Umatilla in 1980 and juvenile shad collected in the Columbia River estuary (Hammann 1982) are similar (Fig. 14). The apparent lack of growth during the downstream migration may be due to increased intraspecific competition in the lower river and the movement of larger individuals through the estuary into the ocean. Observations in the Connecticut River indicate that juvenile shad from nursery areas above the Enfield Dam grew faster and emigrated at a larger mean size than did juveniles rearing in the lower river where juvenile abundance was much higher (Marcy 1976). If a similar pattern occurred in the Columbia River, as would be expected, the mixing of larger juveniles from upstream rearing grounds and smaller juveniles from the lower river may account for the constancy in mean size between the two sites.

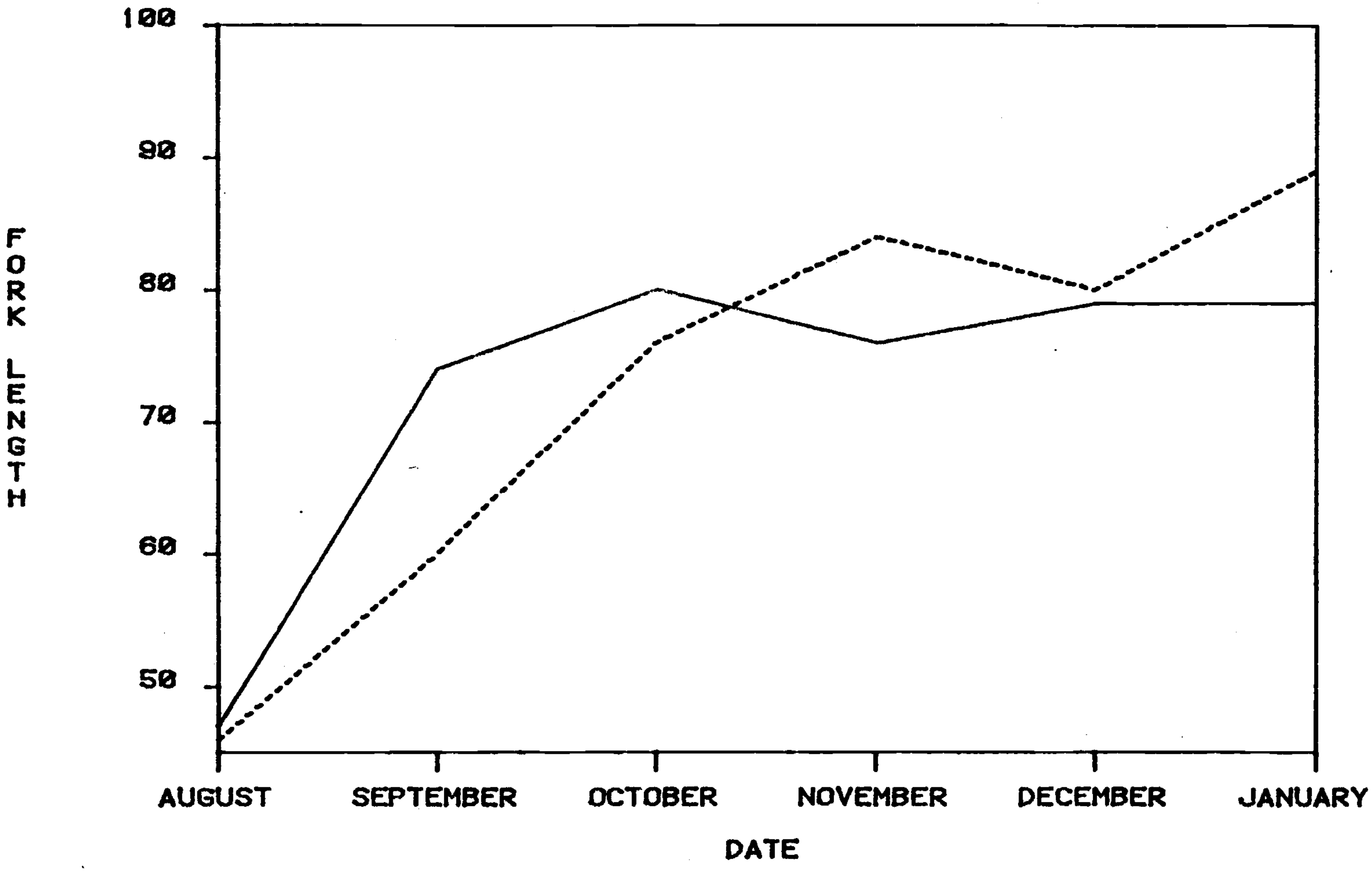

Figure 14. Mean fork length (mm) of juvenile American shad from gatewell dipping at John Day Dam (-) and estuary sampling (----) in 1980. Estuary lengths derived from Hammann (1982).

The length of juvenile shad at migration may be related to the initial demands of the marine migration and the shad's swimming ability (Leggett 1977b): the larger juveniles of the population being able to meet these demands and migrate to ocean feeding grounds. The constant migration of the larger individuals out of the river system would give the impression of no growth in the estuary shad population. The relationship between length and marine migration demands may also explain why some juvenile shad over-winter in the estuary as Hammann (1982) reported.

Predators

Young-of-the-year shad became available to the predator species during mid-July in 1980 and 1981 as larvae disseminated into the backwater areas of each reservoir zone. Shad remained available as a prey item throughout the fall. The diet of each predator species was divided into two time periods for comparison based on the presence of yoy shad: before shad were available (April 1-July 14) and during the presence of shad (July 15-November 20, 1980 and October 3, 1981). The first identifiable shad were recorded in predator stomachs collected in the last week of July in both years.

Hjort et al. (1981) found water current to be the most important feature in defining utilized habitat of fish species in Lake Umatilla. However, patchy distribution of juvenile fish, seasonal and ontological movements of some species and gear selectivity gave highly variable CPUE results. While information on absolute relative abundances of piscine prey items in specific areas of the reservoir could not be drawn from these data, general trends could be found. The backwater areas of the three zones contained similar species assemblages, primarily consisting of exotic species (Hjort et al. 1981). This similarity allowed predators collected in the backwaters of the different zones to be combined in analysis.

Largemouth bass were found only in the backwater areas of all three zones of the reservoir. Small and localized populations were found in areas containing sparse to dense growths of aquatic vegetation which were far removed from the influences of current. The stomach contents of 62 largemouth bass ranging in size from 132 to 474 mm were examined. Fish constituted the largest proportion of prey in the largemouth bass diets during the entire April to October sampling period (Tables 7 and 8). Yoy shad were found in only 12.1% of the stomachs. Young shad ranging from 16 to 22 mm, accounted for only 8.0% by number and 1.1% by volume of the identifiable fish prey items.

Although project sampling ended on October 3, 1981, with yoy shad still in the reservoir and available to the predator species, predation on shad by largemouth bass would have been expected to decrease after this date due to size selectivity. The largemouth bass was the only predator species in this study to demonstrate a size selectivity toward prey items (Fig. 15). The mean length of juvenile shad in the backwater areas of Lake Umatilla was 64 mm on October 3, 1981. Therefore, based on the predator-prey length relationship, largemouth bass greater than 240 mm were expected to prey upon yoy shad after sampling ended. Bass larger than 240 mm constituted less

Table 7. Food of the largemouth bass in Lake Umatilla, April 1-July 14, 1981. All backwater habitats and predator sizes combined. N = 16.

Prey item	% Occurrence	% Total volume	% Total number	I.R.I. value
FISH	100.0	96.9	90.9	18780
Catostomus macrocheilus	16.7	48.7	9.0	964
Cottus asper	50.0	34.2	36.4	3530
Unidentifiable fish	66.7	14.0	45.5	3969
INVERTEBRATES	16.7	3.1	9.1	204
Decapoda (_Pacifastacus_ sp.)	16.7	3.1	9.1	204
EMPTY	62.5			

Table 8. Food of the largemouth bass in Lake Umatilla, July 15-October 3, 1981. All backwater habitats and predator sizes combined. N = 46.

Prey item	% Occurrence	% Total volume	% Total number	I.R.I. value
FISH	97.0	98.6	94.4	18721
Alosa sapidissima	12.1	1.0	5.6	80
Salmonidae	3.0	+	0.8	2
Cyprinidae	18.1	20.2	5.6	91
Cyprinus carpio	6.1	0.3	1.6	12
Carassius auratus	3.0	19.5	0.8	61
Ptychocheilus oregonensis	3.0	0.2	0.8	3
Catostomidae	9.1	2.5	2.4	21
Catostomus columbianus	3.0	0.9	0.8	5
Ictaluridae	21.3	11.1	50.8	416
Ictalurus melas	6.1	10.8	4.0	351
Centrarchidae	3.0	0.5	0.8	4
Unidentifiable fish	72.7	10.9	25.4	2639
INVERTEBRATES	12.1	0.3	3.2	42
Annelida	3.0	0.2	0.8	3
Decapoda (*Pacifasticus* sp.)	3.0	0.1	0.8	3
Diptera (Chironomidae)	6.1	+	1.6	10
VEGETATION (*Potamogeton*)	9.1	1.1	2.4	32
EMPTY	28.3			

+ denotes less than 0.1%.

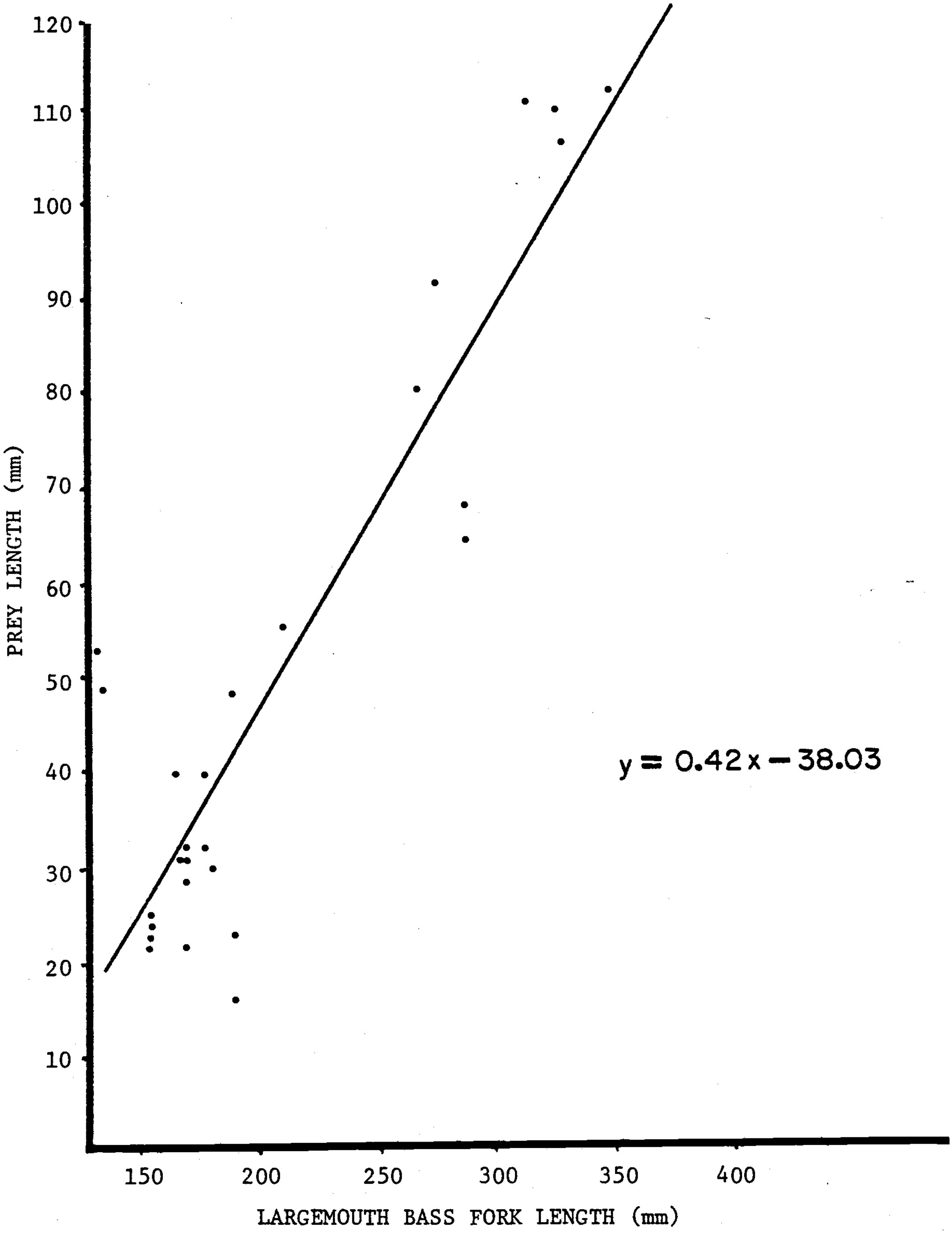

Figure 15. Fork length of largemouth bass captured in Lake Umatilla, 1981 versus prey length.

than 30% of the population in Lake Umatilla. As shad continued to grow, the proportion of largemouth bass utilizing shad should continue to decrease. Added to this was the continual decrease in shad abundance brought about by out-migration.

A notable feature of the largemouth bass summer diet was the heavy reliance on introduced fish species which accounted for approximately 82% by number of the identifiable fish prey items.

Smallmouth bass were more widely distributed throughout the reservoir than the largemouth bass. The capture of smallmouth bass in the main channel of the island and forebay zones indicated a greater tolerance to current by smallmouth than largemouth bass. There was less of an association with vegetation by smallmouth bass than by the largemouth species, and this led to a more ubiquitous distribution of smallmouth bass in the backwater areas of all three zones.

A total of 230 smallmouth bass stomachs were sampled over the two years; fish size ranged from 132 to 424 mm and prey lengths ranged from <1 to 136 mm. The differences in habitat and fish species assemblages between backwater and main channel areas (Hjort et al. 1981) necessitated a separate analysis of smallmouth bass stomachs collected in the two different macrohabitats. Chi-square analysis of the pre-shad diets of 1980 and 1981 showed the two years were not significantly different ($P < 0.05$) therefore, the results were combined (Tables 9 and 10).

The pre-shad diets of smallmouth bass from the main channel and backwaters were remarkably similar and were dominated by prickly sculpin (Cottus asper). The most notable discrepancy between the

Table 9. Food of the smallmouth bass in backwater habitats of Lake Umatilla, April 1-July 14, 1980 and 1981. All predator sizes combined. N = 93.

Prey item	% Occurrence	% Total volume	% Total number	I.R.I. value
FISH	88.0	92.0	45.1	12065
Salmonidae	2.0	+	0.8	2
Cyprinidae	10.0	18.4	5.3	237
Mylocheilus caurinus	2.0	+	1.5	3
Acrocheilus alutaceus	4.0	15.6	2.3	72
Catostomidae	6.0	12.8	2.3	91
Catostomus macrocheilus	2.0	3.5	0.8	9
Cottus asper	30.0	42.6	17.3	1797
Unidentifiable fish	50.0	18.8	18.8	1880
INVERTEBRATES	46.0	7.7	53.4	2811
Annelida	2.0	+	0.8	2
Amphipoda (Gammaridae)	4.0	+	3.8	15
Decapoda (*Pacifastacus* sp.)	16.0	6.4	6.0	198
Ephemeroptera (Ephermeridae)	2.0	+	0.8	2
Diptera (Chironomidae)	6.0	+	7.5	415
Unidentifiable insects	22.0	1.1	38.3	867
VEGETATION	4.0	0.4	1.6	8
Wood	2.0	0.4	0.8	2
Unidentifiable vegetation	2.0	+	0.8	2
EMPTY	46.2			

+ denotes less than 0.1%.

Table 10. Food of the smallmouth bass in main channel habitats of Lake Umatilla, April 1-July 14, 1980 and 1981. All predator sizes combined. N = 19.

Prey item	% Occurrence	% Total volume	% Total number	I.R.I. value
FISH	86.7	91.8	79.4	14843
Oncorhynchus tshawytscha	6.7	0.9	5.9	46
Acrocheilus alutaceus	6.7	3.6	2.9	44
Catostomus macrocheilus	6.7	37.1	2.9	268
Cottus asper	26.7	30.1	20.6	1354
Unidentifiable fish	80.0	20.2	47.1	5384
INVERTEBRATES	26.7	7.7	14.7	298
Decapoda (*Pacifastacus* sp.)	20.0	7.7	8.8	330
Diptera (Chironomidae)	6.7	+	5.9	40
VEGETATION	6.7	0.5	5.9	43
Potamogeton	6.7	0.4	2.9	22
Wood	6.7	0.1	2.9	20
EMPTY	21.1			

+ denotes less than 0.1%.

diets of fish from the two areas was the percentage of empty stomachs, a much higher rate occurred in bass from the backwater areas.

Shad constituted a minor proportion of the smallmouth bass diet in both years. The 1980 diets (Tables 11, 12) contained more shad than those of 1981 (Tables 13, 14), the year of lower relative abundances of shad. The discontinuance of sampling in October, 1981, may have also contributed to the decrease of shad in the diet. Smallmouth bass as small as 175 mm contained fish prey items equal in size to the mean length of juvenile shad in the reservoir at the time sampling ended, meaning shad were still available to approximately 70% of the adult smallmouth bass. The decrease of shad in the diet was offset by increased predation on prickly sculpin in 1981.

Young-of-the-year shad contributed more to the diets of smallmouth bass in main channel habitats than in backwater habitats in both years. This may be due to the presence of yoy shad in the main channel for a slightly longer time than in backwater areas. Another pronounced difference in the diets of smallmouth bass from the two areas was the utilization of invertebrates. The smallmouth bass in backwater areas consumed a wide variety of invertebrates, whereas, crayfish dominated the invertebrate proportion of the main channel bass diets during spring and summer. As in the pre-shad diets, smallmouth bass from the main channel had a lower rate of empty stomachs than those from backwater areas while shad were present.

The distribution of black crappie and white crappie in the reservoir was similar to that of the largemouth bass in that both crappie species were captured only in the backwater areas of the three

Table 11. Food of the smallmouth bass in backwater habitats of Lake Umatilla, July 15-November 20, 1980. All predator sizes combined. N = 26.

Prey item	% Occurrence	% Total volume	% Total number	I.R.I. value
FISH	93.8	99.8	36.7	12804
Alosa sapidissima	12.5	1.7	6.7	105
Cyprinidae	25.0	64.0	7.7	1793
Mylocheilus caurinus	12.5	10.5	4.4	186
Acrocheilus alutaceus	12.5	50.2	2.2	655
Cottus asper	6.3	6.2	4.4	67
Unidentifiable fish	62.5	24.6	17.8	2650
INVERTEBRATES	18.8	0.2	63.4	1196
Cladocera (*Daphnia* sp.)	6.3	+	55.6	350
Unidentifiable insects	12.5	0.2	7.8	150
EMPTY	38.5			

+ denotes less than 0.1%.

Table 12. Food of the smallmouth bass in main channel habitats of Lake Umatilla, July 15-November 20, 1980. All predator sizes combined. N = 14.

Prey item	% Occurrence	% Total volume	% Total number	I.R.I. value
FISH	100.0	76.63	89.3	16590
Alosa sapidissima	22.2	9.8	14.3	535
Salmo gairdneri	11.1	0.5	7.2	86
Mylocheilus caurinus	44.4	13.6	14.3	1239
Catostomidae	22.2	6.1	7.2	295
Catostomus macrocheilus	11.1	3.2	3.6	76
Cottus asper	33.3	22.6	14.3	1229
Unidentifiable fish	66.7	23.9	32.1	3735
INVERTEBRATES	22.2	23.4	10.8	759
Decapoda - *Pacifastacus* sp.				
EMPTY	24.6			

+ denotes less than 0.1%.

Table 13. Food of the smallmouth bass in backwater habitats of Lake Umatilla, July 15-October 3, 1981. All predator sizes combined. N = 69.

Prey item	% Occurrence	% Total volume	% Total number	I.R.I. value
FISH	96.0	94.2	42.2	13094
Alosa sapidissima	6.0	0.6	2.0	16
Salmo gairdneri	4.0	0.5	1.2	7
Acrocheilus alutaceus	6.0	6.2	1.6	47
Catostomidae	10.0	37.1	2.0	391
Catostomus columbianus	2.0	7.5	0.4	16
Catostomus macrocheilus				
Cottus asper	42.0	30.3	15.2	1911
Unidentifiable fish	68.0	19.7	20.1	2706
INVERTEBRATES	38.0	5.3	55.7	2318
Annelida	2.0	+	0.4	1
Amphipoda	6.0	+	10.6	64
Talitridae	2.0	+	4.5	9
Gammaridae	4.0	+	6.1	24
Decapoda (*Pacifastacus* sp.)	4.0	4.8	0.8	22
Ephemeroptera (Baetidae)	2.0	+	0.4	1
Odonata (Coenagriidae)	2.0	+	1.2	2
Diptera (Chironomidae)	10.0	+	18.4	184
Unidentifiable insects	16.0	0.3	23.4	379
VEGETATION	10.0	0.4	2.0	8
Potamogeton	4.0	+	0.8	3
Wood	6.0	0.3	1.2	22
EMPTY	26.1			

+ denotes less than 0.1%.

Table 14. Food of the smallmouth bass in main channel habiatts of Lake Umatilla, July 15-October 3, 1981. All predator sizes combined. N = 18.

Prey item	% Occurrence	% Total volume	% Total number	I.R.I. value
FISH	85.7	86.8	71.4	13558
<u>Alosa sapidissima</u>	14.3	0.5	14.3	212
<u>Ptychocheilus oregonensis</u>	14.3	45.7	7.1	755
<u>Cottus asper</u>	28.6	16.8	14.3	870
Unidentifiable fish	57.1	23.9	35.7	3403
INVERTEBRATES	42.9	13.2	28.6	1793
Decapoda (<u>Pacifastacus</u> sp.)	28.6	12.7	21.4	975
Unidentifiable insects	14.3	0.5	7.1	109
EMPTY	12.5			

+ denotes less than 0.1%.

zones. The two species were found widely distributed throughout the backwater areas but were most often associated with areas of light to medium growth of aquatic vegetation. The black crappie was more abundant in Lake Umatilla than the white crappie, a pattern which is found throughout the range of the two species (Scott and Crossman 1973). Combined, the two species accounted for less than 1.0% of the total fish population of the reservoir.

Stomach contents of 105 black crappies and 62 white crappies were examined. The length ranges of sampled fish were similar, 118 to 288 mm and 107 to 287 mm for black and white crappie, respectively. Piscine prey items which ranged in length from 10 to 50 mm were not found in black crappies less than 135 mm; white crappies less than 138 mm did not contain any fish prey items. In white crappie greater than 138 mm, prey fish ranged from 20 to 72 mm.

The similarity of the 1980 and 1981 pre-shad diets of the two species allowed combining of the two year's results (Tables 15 and 16). The two crappie species consumed a higher proportion of invertebrates than the bass species. The difference was probably due to the low abundance of prey fish of suitable size for consumption by crappies. Juveniles of the prey fish species produced in the preceeding year had attained sizes by early spring which were apparently too large to allow predation by the crappies but were still within the size range of prey taken by the two bass species. In addition, the crappie species did not utilize the prickly sculpin, a small-sized prey species, to the extent the basses had.

Table 15. Food of the black crappie in Lake Umatilla, April 1-July 14, 1980 and 1981. All backwater habitats and predator sizes combined. N = 44.

Prey item	% Occurrence	% Total volume	% Total number	I.R.I. value
FISH	23.3	34.0	0.1	795
<u>Oncorhynchus tshawaytscha</u>	3.3	21.2	+	70
<u>Ptychocheilus oregonensis</u>	3.3	1.9	+	6
Unidentifiable fish	20.0	10.9	+	218
INVERTEBRATES	90.0	66.0	99.9	14931
Cladocera (<u>Daphnia</u> sp.)	46.7	6.4	88.8	4446
Amphipoda	30.0	17.9	3.5	642
Talitridae	6.7	0.3	+	4
Gammaridae	6.7	0.6	+	4
<u>Corophium</u> sp.	20.0	16.7	3.4	402
Ephemeroptera	13.3	2.6	+	35
Ephemeridae	10.0	2.6	+	26
Baetidae	3.3	+	+	1
Hemiptera (Corixidae)	3.3	+	+	1
Diptera (Chironomidae)	63.3	18.6	6.3	1576
Unidentifiable insects	40.0	11.5	1.3	512
EMPTY	31.8			

+ denotes less than 0.1%.

Table 16. Food of the white crappie in Lake Umatilla, April 1-July 14, 1980 and 1981. All backwater habitats and predator sizes combined. N = 21.

Prey item	% Occurrence	% Total volume	% Total number	I.R.I. value
FISH	71.4	89.6	1.1	6476
Salmonidae	35.7	62.5	0.1	2246
Oncorhynchus tshawytscha	21.4	55.2	0.2	118
Cyprinidae	28.6	25.8	0.3	747
Mylocheilus caurinus	14.3	4.6	0.2	69
Acrocheilus alutaceus	14.3	21.2	0.1	305
Unidentifiable fish	21.3	1.2	0.3	32
INVERTEBRATES	50.0	10.4	98.9	5465
Cladocera (*Daphnia* sp.)	21.4	0.4	93.2	2003
Amphipoda (*Corophium* sp.)	7.1	0.4	0.1	4
Ephemeroptera (Ephemeridae)	7.1	0.8	+	6
Diptera (Chironomidae)	35.7	8.9	5.1	500
Unidentifiable insects	28.6	+	0.4	11
EMPTY	33.3			

+ denotes less than 0.1%.

The proportion of fish, specifically chinook salmon, which did occur in the spring diets of the black and white crappies is somewhat misleading. The U.S. Fish and Wildlife Service made releases of surplus hatchery salmon into Rock Creek, the sampled backwater area in the forebay zone. Although some young chinook were found in stomachs of crappies captured elsewhere, the bulk of chinook consumed (75%) were found in crappies captured in the Rock Creek backwater area immediately after the release of hatchery fish.

American shad were the most important piscine constituant in the diets of black and white crappies from mid-July through November of 1980 (Tables 17 and 18). Shad accounted for 25.0% by number and 29.8% by volume of the identifiable fish prey items in black crappie stomachs, and 72.7% by number and 73.5% by volume of the identifiable fish prey in white crappie stomachs. The occurrence of shad in black crappie stomachs dropped from 17.6% in 1980 to 3.3% in 1981 and shad made up only 1.9% of the volume of identifiable fish prey items (Table 19). Shad were not found in white crappie stomachs during 1981 (Table 20). Because of juvenile shad length at the time sampling ended in 1981 and the length ranges of fish prey consumed by the two crappie species, minimal predation on shad would have been expected after October 3. Therefore, the reduction of shad in the crappie diet was probably a reflection of the decreased abundance of yoy shad in the reservoir during 1981.

The yoy centrarchid, cyprinid and catostomid species were incorporated into the black and white crappie diets as they became available in late summer-early fall. The relatively high amount of

Table 17. Food of the black crappie in Lake Umatilla, July 15-November 20, 1981. All backwater habitats and predator sizes combined. N = 26.

Prey item	% Occurrence	% Total volume	% Total number	I.R.I. value
FISH	64.7	97.5	2.6	6477
Alosa sapidissima	17.6	13.9	0.3	3 250
Salmo gairdneri	11.8	6.0	0.2	73
Cyprinidae	17.7	14.5	0.3	262
Mylocheilus caurinus	5.9	2.5	0.2	15
Acrocheilus alutaceus	5.9	6.5	0.1	39
Catostomidae	11.8	10.5	0.2	126
Catostomus columbianus	5.9	5.0	0.1	30
C. macrocheilus	5.9	5.5	0.1	33
Centrarchidae	5.9	1.0	0.1	7
Cottus asper	5.9	1.0	0.1	7
Unidentifiable fish	47.1	50.2	1.3	2426
INVERTEBRATES	41.2	2.5	97.4	4116
Cladocera (*Daphnia* spp.)	29.4	2.0	96.4	2893
Amphipoda (*Corophium* spp.)	5.9	+	0.2	2
Diptera (Chironomidae)	11.8	+	0.3	4
Unidentifiable insects	11.8	+	0.5	6
EMPTY	34.6			

+ denotes less than 0.1%.

Table 18. Food of the white crappie in Lake Umatilla, July 15-November 20, 1981. All backwater habitats and predator sizes combined. N = 23.

Prey item	% Occurrence	% Total volume	% Total number	I.R.I. value
FISH	64.7	91.5	1.1	5991
Alosa sapidissima	23.5	35.5	0.4	844
Salmo gairdneri	11.8	8.1	0.1	97
Mylocheilus caurinus	5.9	4.7	+	28
Unidentifiable fish	47.1	43.1	0.6	2058
INVERTEBRATES	52.9	8.5	98.9	5682
Cladocera (*Daphnia* sp.)	23.5	1.9	98.1	2350
Amphipoda (Gammaridae)	5.9	0.5	0.2	4
Coleoptera (Haliplidae)	5.9	0.5	+	3
Diptera (Chironomidae)	35.3	0.5	0.3	28
Unidentifiable insects	17.6	0.5	0.2	12
EMPTY	26.1			

+ denotes less than 0.1%.

Table 19. Food of the black crappie in Lake Umatilla, July 15-October 3, 1981. All backwater habitats and predator sizes combined. N = 35.

Prey item	% Occurrence			% Total volume			% Total number			I.R.I. value		
FISH	83.3			93.5			2.6			8005		
Alosa sapidissima			3.3			0.5			+			2
Salmo gairdneri			3.3			1.4			0.2			5
Cyprinidae		40.0			11.6			1.0		504		
Cyprinus carpio			6.7			2.8			0.1			19
Mylocheilus caurinus			23.3			6.5			0.7			168
Ptychocheilus oregonensis			10.0			2.3			0.2			25
Catostomidae		13.3			9.8			0.5			137	
Cottus asper			6.7			1.4			0.1			10
Unidentifiable fish		66.7			65.0			1.4			4429	
INVERTEBRATES	53.3			6.5			97.4			5538		
Cladocera (*Daphnia* sp.)		13.3			0.9			94.6			1270	
Amphipoda		16.7			1.0			1.0			33	
Talitridae			6.7			0.5			0.2			5
Gammaridae			3.3			+			0.2			1
Corophium sp.			6.7			0.5			0.6			7
Coleoptera (Haliplidae)		3.3			+			+			1	
Diptera		26.6			0.5			1.4			51	
Chironomidae			23.3			0.5			1.2			40
Culicidae			3.3			+			0.2			1
EMPTY	14.3											

+ denotes less than 0.1%.

Table 20. Food of the white crappie in Lake Umatilla, July 15–October 3, 1981. All backwater habitats and predator sizes combined. N = 18.

Prey item	% Occurrence	% Total volume	% Total number	I.R.I. value
FISH	87.5	78.6	43.1	10649
Salmo gairdneri	6.3	1.2	1.7	18
Cyprinidae	25.0	16.8	6.8	590
Cyprinus carpio	6.3	4.8	4.7	41
Mylocheilus caurinus	6.3	6.0	1.7	49
Ptychocheilus oregonensis	12.5	6.0	3.4	118
Centrarchidae	12.5	16.7	3.5	251
Micropterus dolomieui	6.3	2.4	1.7	26
Cottus asper	6.3	15.5	1.7	102
Unidentifiable fish	68.8	28.6	29.3	3984
INVERTEBRATES	43.8	21.4	56.9	3430
Amphipoda (*Corophium* sp.)	12.5	1.2	6.9	101
Ephemeroptera (Ephemeridae)	6.3	14.3	1.7	101
Diptera (Chironomidae)	25.0	6.0	46.6	1315
Unidentifiable insects	6.3	+	1.7	11
EMPTY	11.1			

+ denotes less than 0.1%.

unidentifiable fish among the stomach contents of these two species stemmed from the consumption of larval and early juvenile prey fish, which were rapidly digested beyond recognition. As in the spring diets, the summer-fall diets of the crappies contained less prickly sculpin than the corresponding bass diets and invertebrates remained a substantial part of the crappie diet.

Yellow perch were the most abundant and widely distributed of the five predator species. The species occurred in all sampled habitats of the reservoir. Catch per unit effort data showed higher yellow perch abundances in the backwater areas than in the main channel areas and a progressive increase in both areas downstream by sampling zone (Hjort et al. 1981). The most important factors in determining yellow perch habitat were the presence of vegetation and bottom substrate. Vegetation of any density appeared to be satisfactory and a mud or sandy-mud bottom appeared to be preferred by the species.

The stomach contents of 132 yellow perch from backwater areas, ranging in size from 145 to 236 mm, were analyzed. The number of yellow perch stomachs collected in main channel habitats were insufficient for comparative purposes and were disregarded. The diets of perch less than 155 mm did not include any of the fish prey items, which ranged in length from 8 to 53 mm, that were found in larger perch.

The yellow perch were more omnivorous than the centrarchid predators, not only utilizing invertebrates and vegetation to a greater extent, but including a wider variety of organisms within each of the food groups (Tables 21, 22). Another notable difference was

Table 21. Food of the yellow perch in Lake Umatilla, April 1-July 14, 1981. All backwater habitats and predator sizes combined. N = 54.

Prey item	% Occurrence	% Total volume	% Total number	I.R.I. value
FISH	7.7	52.4	0.1	404
Cottus asper	7.7	52.4	0.1	404
INVERTEBRATES	92.3	45.2	99.7	13374
Cladocera (*Daphina* spp.)	15.4	+	41.3	636
Amphipoda (Gammaridae)	7.7	+	0.1	1
Hydracarina	7.7	+	0.3	2
Ephemeroptera	23.1	11.9	0.5	286
Ephemeridae	15.4	11.9	0.4	189
Baetidae	7.7	+	0.1	1
Hemiptera (Corixidae)	23.1	4.8	1.1	136
Trychoptera (Caddidae)	7.7	+	0.2	23
Diptera	84.6?	9.6	55.3	5491?
Chironomidae	53.9	4.8	9.4	765
Chaoborinae	46.2	48	4539	2342
Gastrapoda	30.8	19.1	0.9	
Lymnaera	23.1	14.3	0.8	349
Pelecypoda (*Corbicula manilensis*)	7.7	+	0.1	1
VEGETATION	23.1	2.5	0.4	67
Potamogeton	15.4	2.4	0.2	40
Wood	15.4	+	0.2	3
EMPTY	75.9			

+ denotes less than 0.1%.

Table 22. Food of the yellow perch in Lake Umatilla, , July 15–October 3, 1981. All backwater habitats and predator sizes combined. N = 78.

Prey item	% Occurrence	% Total volume	% Total number	I.R.I. value
FISH	50.7	72.5	4.4	3899
Alosa sapidissima	3.0	1.4	0.1	5
Cyprinidae	17.5	17.1	0.8	313
Mylocheilus caurinus	3.0	2.6	0.1	8
Ptychocheilus oregonensis	6.0	10.6	0.4	66
Catostomidae	10.5	10.4	0.3	112
Catostomus macrocheilus	1.5	4.3	+	7
Centrarchidae	6.0	12.5	0.5	78
Lepomis macrochirus	1.5	2.6	0.1	4
Pomoxis nigromaculatus	3.0	7.5	0.4	24
Cottus asper	3.0	6.1	0.1	19
Unidentifiable fish	28.4	24.8	2.5	775
INVERTEBRATES	71.6	20.6	94.8	8263
Annelida	1.5	5.7	0.2	9
Amphipoda	10.5	0.4	0.6	11
Talitridae	1.5	+	+	1
Corophium sp.	9.0	0.4	0.6	9
Hydracarina	1.5	+	0.5	1

Table 22. Continued

Prey item	% Occurrence	% Totsl volume	% Total number	I.R.I. value
Ephemeroptera	22.5	1.2	2.3	79
Ephemeridae	7.5	0.6	0.4	8
Baetidae	15.0	0.6	1.9	38
Hemiptera (Corixidae)	1.5	+	0.2	1
Trychoptera (Caddidae)	31.5	3.2	7.2	328
Diptera	62.8	7.6	62.1	4377
Chironomidae	49.3	7.2	48.5	2746
Chaoborinae	15.0	0.4	13.6	210
Unidentifiable insects	3.0	0.2	0.2	1
Gastrapoda	32.9	2.8	3.3	201
Lymnaea	29.9	2.6	3.2	173
VEGETATION	17.9	6.9	0.6	134
Potamogeton	10.5	5.9	0.5	67
Wood	1.5	0.6	+	1
EMPTY	14.1			

+ denotes less than 0.1%.

the large decrease in the percentage of empty yellow perch stomachs from 75.9% in the spring to 14.1% in the summer-fall diet. The centrarchid species showed a decrease in the percentage of empty stomachs between the two periods but not of the magnitude which occurred in the yellow perch.

The yellow perch diet after July 15 resembled those of the black crappie and white crappie; fish consumption increased as yoy fish became available, with similar species being utilized as prey and invertebrates still making up a substantial amount of the diet. Young shad were not a major prey item of the yellow perch in Lake Umatilla backwaters, accounting for only 3.0% of the total volume of identifiable fish prey and occurring in only 3.0% of the stomachs collected after July 15. Shad found in yellow perch stomachs ranged in length from 12 to 28 mm, indicating yellow perch captured only larval and very young juvenile shad. The capture of only these life stages may have been the result of the shad's reduced mobility in early development and the opportunistic feeding behavior of the yellow perch.

The three predator species, smallmouth bass, black crappie and white crappie, which were studied during 1980 and 1981 showed a marked decrease in IRI values for shad in 1981 (Table 23). The majority of this decrease can be attributed to the decreased abundance of yoy shad in 1981, because Hjort et al. (1981) did not find a major change in the abundance of any other prey fish in the two years.

The higher IRI values for shad in the diet of main channel smallmouth bass than in the diet of smallmouth bass from backwater

Table 23. Index of Relative Importance values for shad in the diets of five predator species from Lake Umatilla, 1980 and 1981.

	IRI value for y-o-y American shad as a prey item	
Predator species	1980	1981
Largemouth bass	--	80
Smallmouth bass:		
Backwater habitats	105	16
Main channel habitats	535	212
Black crappies	250	2
White crappies	844	0
Yellow perch	--	5

areas would seem to indicate that predator species which primarily inhabit the main channel areas, such as the squawfish (*Ptychocheilus oregonensis*) and walleye (*Stizostedion vitreum vitreum*), may utilize shad as prey to a greater extent. However, Hjort et al. (1981) did not report any identifiable shad in the 1980 and 1981 diets of the squawfish from the tailrace zone. In a concurrent study on the food habits of the walleye, Maule (1982) reported percentage values for shad in the diet which would give IRI values of 92 and >1 in 1980 and 1981, respectively. The low importance of shad in the diet of these two species, in addition to the variation in IRI values for predators from backwater areas, points out that predator species selectivity, as well as shad abundance and spatial separation, affects the amount of predation on shad.

CONCLUSIONS

This study has provided baseline information on the reproductive characteristics of American shad spawning in or above Lake Umatilla in the Columbia River system. These shad demonstrated fecundity and growth similar to northern east coast shad populations and also, a high degree of iteroparity. While this information will be useful for future comparisons, certain limitations of the study must be acknowledged. The basis for adaptation of reproductive characteristics to a specific environment is the inheritability of, and selection for, these reproductive traits (Cole 1954). Due to the major changes brought about by the impoundment of the Columbia River system beginning in 1933 and continuing into the 1970's, it is unlikely that shad have truly adapted to the system as it now exists. Long term, as well as short term, changes in the absolute values of the shad's reproductive characteristics (i.e., percentage of repeat spawning, fecundity and mean age at maturity) are a reasonable expectation. Furthermore, extrapolation of adult shad results from this study to the entire spawning population of the Columbia River system would be inaccurate.

Shad home not only to their natal river system but to their natal tributary within the river system and the life history strategy varies with each tributary or spawning location in the river (Carscadden and Leggett 1975a, b). The numerous tributaries to the Columbia River and the diversity of temperature and flow regimes of each tributary would lead to a variety of life history strategies in the Columbia system.

The area immediately above and below McNary Dam and the main channel of the tailrace zone were the most important shad spawning areas of the reservoir, whereas the island zone was the most important larval and juvenile shad rearing area. The distribution of the egg and early larval stages appeared to be primarily influenced by water current; the distribution of juveniles was apparently a function of intraspecific competition for food and space.

Future water management schemes which alter the river's flow regime during late July-early August may in turn change the distribution of young shad. A high flow during this time period may flush higher numbers of yoy shad into the lower river causing increased competition and ultimately, an alteration in the survival rate. Conversely, a low flow rate would leave more yoy shad nearer the spawning grounds and allow a greater proportion of the river system to be used as rearing grounds.

While water temperature has long been recognized as a regulating factor in the emigration of yoy shad, the results of this study support the contention that juvenile length may be an equally important factor. It was apparent from reservoir and gatewell sampling that the larger juveniles of the shad population emigrated first and that the emigration size, after reaching a plateau, remained relatively constant throughout the fall months. The yearly variation in emigration size appears to be a function of juvenile shad abundance, and water flow and temperature when the yoy shad are present in the reservoir.

The amount of predation on yoy shad by smallmouth bass, largemouth bass, black crappie, white crappie and yellow perch was relatively low. The amount of shad in the predator's stomach contents did not reflect the shad's high abundance relative to other prey species in Lake Umatilla. The differences in the two proportions were apparently due to spatial separation of shad and the predator species and more importantly, selection by the predators for other prey items.

The percentage of shad in the diet of predator species reflected the year class strength of shad in 1980 and 1981. This finding supports Leggett's (1977a) hypothesis that predation during the shad's freshwater phase may function as a density-dependent factor in the regulation of the stock-recruitment relationship. The actual effect that predation would have as a density-dependent factor would in turn be dependent upon predator and other prey item population levels. Alterations in the water management of the Columbia River system which affect recruitment of the centrarchid, cyprinid, catostomid and cottid species will ultimately affect the predator-prey relationships involving shad.

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