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SYSTEM-WIDE SIGNIFICANCE OF PREDATION ON JUVENILE SALMONIDS IN COLUMBIA AND SNAKE RIVER RESERVOIRS AND EVALUATION OF PREDATION CONTROL MEASURES

ANNUAL REPORT 1993

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

This document is the 1993 annual report of progress for the Bonneville Power Administration (BPA) research Project No. 90-078 conducted by the National Biological Survey (NBS).

This project had three major goals. The first was to assist the Oregon Department of Fish and Wildlife with predation indexing as part of an effort to estimate the relative magnitude of juvenile salmonid losses to northern squawfish *Ptvchocheilus oresonensis* in reservoirs throughout the Columbia River Basin. The results of our work (i.e. consumption indexing in John Day Reservoir) are included in the draft report by Mark P. Zimmerman, Chris Knutsen, David L. Ward, and Kent Anderson. 1994. "Development of a System-Wide Predator Control Program: Indexing and Fisheries Evaluation." *In* C.F. Willis and D.L. Ward, editors. Development of a system-wide predator control program: stepwise implementation of a predation index, predator control fisheries, and evaluation plan in the Columbia River Basin. 1993 Annual report. Contract DE-BI79-90BP07084, Bonneville Power Administration, Portland.

The second goal was to evaluate the northern squawfish control program and test critical assumptions about mid-reservoir predation processes. Progress towards this goal is presented as an abstract only; in lieu of an annual progress report, a manuscript will be.published in late 1994 or early 1995 in Transactions of the American Fisheries Society.

The final goal was to determine mechanisms underlying northern squawfish recruitment and factors affecting year-class strength. The results of the first year of this study (1992) are presented as a progress report.

The following point summary gives the major results on each of the major project objectives and tasks:

(1) Relative abundance of northern squawfish and consumption of juvenile salmonids was estimated by ODFW in Bonneville Dam tailrace, and Bonneville, The Dalles, John Day, and McNary reservoirs. Relative abundance in 1993 was similar to or slightly less than in 1990, and relative consumption was considerably lower in 1993 than 1990 in most locations (see report cited above: Zimmerman et al. 1994).

(2) Predation losses of juvenile salmonids migrating through Columbia River reservoirs were previously estimated with the assumption that one or two homogenous areas existed per reservoir. It has been shown, however, that predation rate and predator density vary greatly between near-dam and mid-reservoir areas, suggesting that reservoirs in the Columbia River should be divided into at least three or four areas for estimating salmonid losses. When this was done for the

John Day Reservoir, estimated numbers of salmonids eaten annually by northern squawfish decreased from 2.9 million to 1.4 million.

(3) Sampling was conducted for larval and young-of-the-year juvenile northern squawfi'sh primarily during June-August 1992 in The Dalles Pool, the upper Bonneville Pool, and the lower Deschutes River. Diel sampling indicated that larval squawfish drift from spawning areas primarily at night. Larval and juvenile squawfish rearing in shallow shoreline areas were collected in highest abundances in the lower Dalles Pool and in the Deschutes river in locations with fine sediment/sand substrates and seasonally heavy amounts of vegetation. Sampling during 1993 was expanded to the upper John Day Pool and additional nighttime sampling was conducted; these results are not yet available because data entry and analysis have not been completed.

Report 1

The Importance of Spatial Pattern in Estimating Predation on Juvenile Salmonids in the Columbia River

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Abstract. -- The impact of piscivores in aquatic systems is often estimated by assuming that predation rate and predator density can be characterized as means throughout large, homogenous areas. Predation losses of juvenile Pacific salmonids *Oncorhynchus* spp. migrating through Columbia River reservoirs were previously estimated with the assumption that one or two homogenous areas existed per reservoir. Data from the John Day Reservoir and throughout the river system showed that predation rate and predator density vary greatly between near-dam and mid-reservoir areas, suggesting that reservoirs in the Columbia River should be divided into at least three or four areas for estimating salmonid losses. For example, the estimated number of salmonids annually eaten by northern squawfish *Ptychocheilus oregonensis* in John Day Reservoir decreased from 2.9 million when all samples in the reservoir were pooled into one area, to 1.4 million when samples were partitioned among four areas. Variance about the estimates also decreased steadily with finer partitioning. Mortality of juvenile salmon from predation was

substantial with any type of partitioning; however, spatial variation in predation rates, and other density-dependent processes, may be especially important in river models of migrating juvenile salmon that repeatedly apply predation rates in a series of reservoirs or river reaches.

Report 2

Reproduction and early life history of northern squawfish *Ptvchocheilus oresonensis* in the Columbia River

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Abstract. -- The northern squawfish *Ptvchocheilus oresonensis* is an important endemic predator in Columbia River reservoirs. Despite this, little published information exists on squawfish reproduction and early life history in the Columbia River Basin. Thus, we initiated a field study to investigate squawfish reproduction and early life history in two Columbia River reservoirs and in the lower Deschutes River. Our objectives were to locate spawning areas, describe larval drift, and characterize larval and juvenile rearing habitats. We conducted weekly ichthyoplankton sampling from late May through mid- September, 1992. Shoreline sampling to assess larval and juvenile use of shallow littoral habitats was conducted with a manually pulled sled primarily from June through September. We sampled at four locations: 1) the upper Dalles Pool; 2) the lower Dalles Pool; 3) the upper Bonneville Pool; and 4) the mouth of the Deschutes River. Larval and juvenile squawfish were collected in highest abundances in shallow shoreline areas with fine sediment/sand substrates and seasonally heavy amounts of cover in the form of instream'vegetation. Highest abundances of larval and juvenile squawfish were collected at sled sites in the lower Dalles Pool and in the Deschutes River. Information on spawning locations and larval drift is limited since few larval squawfish were

collected during daytime plankton tows. Diel studies conducted in the upper Dalles Pool during 1992 indicated that larval squawfish may exhibit increased nighttime drift. In response to this we intensified nocturnal sampling during 1993; these results will be presented in a later report. This information should allow us to further define squawfish early life history in the Columbia and Deschutes Rivers.

INTRODUCTION

Anadromous salmonids are a valuable socioeconomic resource in the Columbia River Basin. In recent history their abundance has declined sharply (Reiman and Beamesderfer 1990). Reasons for decline are complex and multifaceted; one important factor contributing to this decline is predation by resident fishes (Raymond 1979; Gray and Rondorf 1986). The northern squawfish Ptvchocheilus oresonensis is an endemic predator that accounts for a large percentage of the juvenile salmonids lost to predation (Poe et al. 1991; Reiman et al. 1991). Because of this, a variety of squawfish control measures have been initiated. Basic information on the early life history and factors affecting recruitment of northern squawfish could aid attempts to manage squawfish populations.

Very little published information exists on reproduction and early life history of the northern squawfish, particularly in Columbia River reservoirs. However, some information on squawfish ecology is available from other areas in western North America (Jeppson and Platts 1959; Patten and Rodman 1969; Beamesderfer 1992). Northern squawfish are found in a variety of habitats in both still and running waters. Spawning occurs in streams, lakes, and reservoirs (Stewart 1966; Patten and Rodman 1969; Beamesderfer 1992). Spawning congregations ranging in size from a few hundred to several thousand fish have been observed in other systems (Patten and Rodman 1969; Beamesderfer 1992). However, spawning aggregations have not been documented in

Columbia River reservoirs. During spawning, benthic adhesive eggs are broadcast over substrates ranging in size from gravel to rubble at various water depths (Jeppson 1957; Casey 1962; Patten and Rodman 1969; Beamesderfer 1992). Larval and young juvenile northern squawfish rear in shallow, low-velocity, shoreline areas (Casey 1962; Olney 1975; Beamesderfer 1992). Older juveniles use slightly deeper and more variable offshore habitats (Beamesderfer 1992).

In 1992 we initiated a field study to learn more about the early life history of northern squawfish in the Columbia and lower Deschutes Rivers. We sampled in the upper Bonneville Pool, the upper and lower Dalles Pool, and the lower Deschutes River. Our objectives 'were to locate spawning sites, describe larval and juvenile rearing areas,- and describe larval drift between these locations. Environmental parameters were measured or estimated concurrent with fish sampling to determine how physical factors might influence the survival and distribution of squawfish larvae and juveniles.

In 1993 we expanded sampling to the upper John Day Pool for comparison with previous studies (Hjort et al. 1981; Poe et al. 1988) and discontinued sampling in the upper Bonneville Pool due to time constraints. Additional nighttime sampling was added in 1993 because low numbers of cyprinid larvae were collected during daytime ichthyoplankton sampling in 1992. Because sample processing and data entry for 1993 have not been completed, only results from the 1992 field season will be presented.

METHODS

Sample Collection

1992 Overview.-Sample areas were chosen based on substrate type and to compare main stem to tributary areas. The upper Bonneville and upper Dalles Pools contain sites with large proportions of potential northern squawfish spawning habitat (gravel/rubble/cobble), identified by cartographic modeling with a geographic information system (GIS) (Gadomski and Murphy 1991). For comparison, we also sampled in the lower Dalles Pool, an area with little potential northern squawfish spawning substrate.

Samples were collected weekly from late May through mid-September 1992 at four locations (Figure 1): 1) the upper Dalles Pool (river miles (RM) 211.25-216.25); 2) the lower Dalles Pool (RM 194-199); 3) the upper Bonneville Pool (RM 186.25-191.25); and 4) the mouth of the Deschutes River. Because of high winds and rough water conditions, not all locations could be sampled every week. Limited sampling at the Deschutes River continued through November 1992. Sampling was conducted during daylight hours, except for some night sampling at the upper Dalles Pool for diel comparisons. Most sampling was conducted with boat-towed plankton nets and a manually pulled shoreline sled. Some samples were collected with dipnets or drift nets. Samples were fixed in 10% formalin buffered with sodium borate and lightly stained with phyloxine B.

Plankton Sampling.-Plankton samples were collected with 0.5 m diameter (2.5 m length, 500 μm mesh) conical plankton nets with bridleless frames (Nester 1987). A net was suspended from a winch situated on each side of a 5.8 m aluminum boat; two nets were towed simultaneously resulting in paired (port and starboard) samples. A General Oceanics Model 2030 digital flowmeter was suspended off-center in the mouth opening of each net to measure water volume filtered. Each net was held at depth by a 5 kg depressor plate. Nets were towed upriver at a wire angle of 65". Actual distance traveled (in relation to the shoreline) varied depending on river current. Tows were stepped-oblique for a total of 9 min: initially 3 min at mid-water depth (based on water depth at the tow starting point), then 3 min at quarter-water depth, and finally 3 min at the surface. Maximum initial net depth was 12 m. In shallow water areas, tows were essentially at the surface.

Each week at the upper and lower Dalles Pool and at the upper Bonneville Pool, we conducted five or six paired plankton tows, three or four tows at fixed sites and two tows at random sites. (At the upper Dalles Pool we collected additional samples which will be described below.) Two fixed sites were sampled in the main stem at a north shore and a mid-channel location, and one fixed site was in a backwater (Table 1). In the upper Dalles Pool, an additional fixed sampling site was established on the south shore (Table 1). Main stem fixed sites were chosen in areas previously identified as having potential northern. squawfish spawning habitat (Gadomski and Murphy 1991). In addition, we sampled two randomly chosen sites at each of the three main stem study areas. Each five-mile long study area was subdivided into 20 quarter-mile intervals. A random number chart was used to determine which quarter-mile would be the starting point of two paired tows. One random tow was conducted in the mid-channel, and one along either the Oregon or the Washington shore. (chosen by a coin toss).

Two paired plankton tows were also conducted weekly in the mouth of the Deschutes River, one each on the east and west shores of the river (Table 1). Because of shallow water and limited distances, tows were at the surface and ranged in duration from about 3 to 8 min.

Additional sampling was conducted in the upper Dalles Pool to determine diel differences in larval abundance. On six occasions, June 29-30, July 15, July 28, August 6, August 11, and August 24, paired plankton tows were conducted at the three main-stem fixed sites (Table 1) during daylight, dusk (2000-2150), and darkness (2330-0030).

Limited sampling was also conducted in the upper Dalles Pool to compare bottom to surface larval distributions. Samples were collected during daylight hours on July 15, July 21, August 11, August 24, and September 9. Two sites were sampled, off the Washington shore at RM 215.25 and at RM 215.50. These areas were shallow (3-7 m), with gravel/cobble substrates and relatively high water velocities (0.7-1.5 m/s). Sampling was conducted for

9 min at each site. The starboard plankton net was maintained with its lower edge touching 'the bottom, and the port plankton net was at the surface. We towed against the current at a speed where we maintained position or only slowly moved upriver.

Sled.-Shoreline locations were sampled weekly for larvae and juveniles with a manually towed net built from a design by LaBolle et al. (1985). The net was a 1.5 m long conical design constructed of 500 μm mesh dyed brown and mounted on a frame with side skids and a front roller bar. The mouth was 1.5 m wide and could be vertically adjusted for depth, although we maintained mouth depth at 10 cm. Bridles were attached on each side of the mouth opening so the sled could be pulled by two persons.

To conduct a tow, we positioned the sled offshore in a water depth just covering the mouth opening, usually about 30 cm. Water depth and distance to shore were measured from the frame center. We waited about a minute for fish to adjust to any disturbances, and then towed the net parallel to the shore . against the current at about 0.75 m/s. Tow distance was usually 50 m. The sample was then washed into the end of the net and removed through a quick-release cod end for preservation. Water volume filtered (usually 7.5 m^3) was calculated by multiplying mouth area by distance towed.

Two or three fixed sled sites were selected at each main stem sampling location, one or two on the main stem, and one in a backwater (Table 2). In the Deschutes River, a sled tow was conducted on each shore (Table 2), although on the east shore the distance towed was only 15 m because of uneven bottom terrain. Sled sites were chosen to represent the range of conditions found in shallow littoral areas of the study locations. Our gear type and towing methods, however, dictated that we sample areas with gentle gradients and even terrain. This type of site was rare in our sampling locations. For example, the upper Dalles Pool is characterized by steep-sided channel walls with shoreline substrates consisting primarily of basaltic cliffs and boulder fields.

Dipnet.- High abundances of larval or juvenile fishes were sometimes observed in very shallow areas of sled sample sites. These areas were not accessible to sled tows; thus, we used a l-mm mesh dipnet to capture a minimum of 30 larvae and juveniles per site. One site on the west shore of the Deschutes River could only be sampled by dipnet. This site consisted of shallow (l-20 cm) pools of water on bedrock overlain by fine sediment with moderate to heavy amounts of instream vegetation. Because dipnet sampling is non-quantitative, numbers of fish larvae and juveniles collected were summarized as percent composition of catch.

Drift Nets.- Larval drift samples were collected weekly at the east side of the Deschutes River 750 m from the confluence with the Columbia River. The substrate in this area was bedrock and boulders with little instream vegetation. Two 0.5 m diameter (2.5 m length, 500 μm mesh) conical plankton nets were attached side-by-side to shoreline vegetation in waters 0.6-0.7 m deep. Current velocity in this area was about 0.3-0.6 m/s. Nets were set for an hour during daylight. A General Oceanics Model 2030 digital flowmeter was suspended off-center in the mouth opening of each net to measure water volume filtered.

Environmental Parameters.- At each sample site we measured temperature, turbidity, and current velocity at the starting point of a tow. Water temperature was measured at the surface with a handheld thermometer and at 2 m with a Yellow Springs Instrument tele-thermometer. Turbidity was measured with a Hach model 16800 Turbidimeter. Mean water column velocity (an average of the velocity measured at 0.2 and 0.8 of the total depth, or at 0.6 of the depth in waters < 0.75 m) was measured with a cable-suspended Price type "AA" sensor connected to a Swoffer Instruments Model 2200 direct reading current velocity meter. Current velocity was not measured at all sites every week because of rough waters or time constraints.

At shoreline sites we also evaluated substrate, gradient, and vegetation. Substrate categories were based upon Platts et al. (1983), and ranged from fine sediment or sand to gravel/cobble, boulders, or bedrock. Gradients were classified as flat (1-10°), gentle (10-20°), steep (20-45°) or very steep (45°-vertical). Vegetation was indexed from absent (1) to heavy (4).

Sample Processing

Sorting.- Fish eggs, larvae and juveniles, were sorted from samples using a magnifying lamp. Larvae and juveniles were placed in vials of 4% formalin buffered with sodium borate for later identification. Fish eggs were enumerated and preserved in 4% unbuffered formalin to prevent chorion collapse (Markle 1984). To ensure quality control, about 15% of the samples were resorted to confirm that no fish or eggs were missed in the original sort.

Composition and volume of each sample were determined. Macrophytes and large pieces of debris such as twigs and leaves were noted and removed. Relative proportions of major groups of invertebrates and plants in the remaining sample were estimated. A measurement of wet volume, determined by displacement, was made for each sample after the removal of fish, eggs, macrophytes and large debris (Kramer et al. 1972; Smith and Richardson 1977).

Larval and Juvenile Fish Identification.- Larval and juvenile fishes were identified, enumerated, and assigned developmental stages (yolk-sac larva, larva, and juvenile). Non-cyprinids were usually identified to family and cyprinids were identified to the lowest possible taxonomic level.

Larvae of northern squawfish and chiselmouth *Acrocheilus alutaceus* have not been adequately described to separate early stages (< about 12 mm standard length (SL), prior to pelvic fin formation); thus we grouped some specimens into a combined northern squawfish/chiselmouth category. Peamouth *Mvlocheilus caurinus* larvae were separated from other cyprinids based on the presence of a median thoracic stripe of melanophores (Miura 1962; Hjort et al. 1981.), although some early yolk-sac cyprinid larvae, lacking diagnostic pigmentation, were identified only to family. Identification criteria'of larger northern squawfish, peamouth, and chiselmouth larvae included position of the dorsal fin relative to the pelvic and anal fins, along with other characters described in Miura (1962) and Mundy (1980).

Specimens'of northern squawfish, northern squawfish/chiselmouth, and unidentified cyprinids, were measured for standard length (SL). Standard length (preflexion and flexion) = snout tip to the end of the notochord, while standard length (postflexion) = snout tip to the posterior margin of the hypural bones (Ahlstrom and Moser 1976).

1993 Overview.-In 1993, sampling was discontinued in the upper Bonneville Pool. New sites were added in the upper John Day Pool for comparison with historical data (Hjort et al. 1981; Poe et al. 1988). Samples were collected weekly from early June through late August, 1993, at four fixed locations: 1) the upper John Day Pool (RM 282.5-290.0); 2) the upper Dalles Pool (RM 211.75-215.5); 3) the lower Dalles Pool (RM 197.25-197.75); and 4) the mouth of the Deschutes River. Occasionally weekly samples were not collected at each location because of high winds, severe weather, or equipment failure.

During limited diel sampling in 1992, more northern squawfish larvae and squawfish/chiselmouth larvae were collected at night. In response to this, we expanded our nighttime sampling program in 1993. During each sampling date, we conducted daytime and nighttime sampling with boat-towed plankton nets. At the Deschutes River, diel sampling was also conducted with drift nets. Random plankton tows were discontinued due to time and logistical constraints. Sled tows were primarily conducted during daylight hours, although some samples were collected at night for diel comparisons. Dipnet sampling was eliminated in 1993 because species composition in 1992 samples did not differ considerably from sled tows taken at the same locations and because dipnet sampling does not yield quantitative data. Sampling protocols in 1993 generally followed those established in 1992. More details will be presented in a subsequent report.

RESULTS

Overview

Only results from the 1992 field season will be presented. Results for both fixed and random plankton tows were pooled for all main stem locations.

During the 1993 field season, 865 plankton net, drift net, and sled samples were collected. Due to time constraints, sample processing is incomplete. Therefore, results from the 1993 field season will be presented and discussed in subsequent reports.

Larval and Juvenile Fishes

Upper Dalles Pool.-During plankton tows in the main stem, a total of 1,862 larvae was collected in 18,198 m^3 of water filtered (a density of 10.2 larvae per 100 m^3). In the backwater area, larvae were somewhat less abundant (Table 3). Sculpin (Cottidae, probably *Cottus asper*) larvae dominated the samples. Two northern squawfish/chiselmouth larvae were collected, both in the main stem.

Diel plankton net sampling resulted in higher total fish abundances during daylight hours (Table 4). More juveniles were captured during dusk and night than day, possibly due to less net avoidance. At all time periods, the most abundant larvae were sculpins. Larval shad *Alosa sapidissima* were most abundant during daylight hours. One northern squawfish juvenile and eight northern squawfish/chiselmouth larvae were collected. All nine specimens were captured in late June or mid- July during dusk and night, suggesting a nocturnal pattern of abundance.

No larval or juvenile fishes were collected during surface and benthic plankton tow sampling in the upper Dalles Pool.

Few larvae and juveniles (N = 21) were collected in shoreline areas of the upper Dalles Pool with the sled in 281 m^3 of water filtered (Table 5). One northern squawfish juvenile and one squawfish/chiselmouth larva were captured at the main stem island site.

Lower Dalles Pool.-Overall fish densities were greater in plankton tows at backwater and main stem sites of the lower Dalles Pool than in tows conducted in the upper pool (Table 3). Species occurrence was similar between the upper and lower Pool. However, densities of some groups differed between the two areas. For example, cottid densities were greater in the lower Dalles Pool.

In the lower Dalles Pool, backwater fish densities were lower than main stem densities (Table 3). Sculpins were the most abundant group in the lower Dalles Pool plankton samples (Table 3). Fewer species were collected at the lower Pool backwater site than in the main stem and all taxa encountered in backwater samples were also present in main stem samples. One squawfish/chiselmouth larva was collected in late July and three unidentified cyprinid larvae were collected in late May during main stem plankton tows. Common carp were the only cyprinids collected in backwater plankton tows.

Shoreline samples from all three sled sites in the lower Dalles Pool contained 265 larvae and juveniles (Table 5); water volume filtered was 319.5 m^3 (a density of 8.3 fish per 10 m^3). Only three fish, a juvenile cottid and two catostomid larvae, were collected at the downstream Browns Island sled site. Northern squawfish larvae and juveniles were collected in greatest abundance at the upstream Browns Island sled site; squawfish densities were lower in backwater sled samples (Table 5). No squawfish were collected at the downstream Browns Island sample site.

Squawfish/chiselmouth larvae were'first collected in lower Dalles Pool sled samples during-mid- June (Figure 2A, B). Peak larval and juvenile squawfish abundance occurred in July; although some juvenile squawfish, probably from the 1991 cohort, were collected at the backwater site in early June (Figure 2B). No squawfish were collected after late July.

Mean standard length of squawfish/chiselmouth larvae collected in sled samples in the lower Dalles Pool during June and July was 10.2 mm (N = 7; SD = 0.46). In June, we also collected juvenile squawfish from the 1991 **year** class (Figure 4A). Mean standard length of these fish was 41.5 mm (**N** = 11; SD = 5.01). Squawfish lengths during the last two weeks of July when last collected in lower Dalles Pool sled samples ranged from 10.1 to 27.5 mm with a mean of 16.7 mm (N = 27; SD = 4.17).

Dipnet samples collected at the backwater and upstream Browns Island sled sites contained 621 larvae and juveniles. The 'downstream Browns Island site was not sampled with the dipnet since fish were rarely observed in shallow waters along the sampling transect. Species occurrence was similar between dipnet and sled samples (Figure 3A, B). However, some differences existed in size and catch composition between the two gear types. Dipnet samples had higher percentages of squawfish larvae, indicating larval squawfish used shallower habitats than juveniles.

Upper Bonneville Pool.-Main stem fish densities in the upper Bonneville Pool were intermediate to densities in main stem tows in'the upper and lower Dalles Pool locations (Table 3). Backwater plankton tow densities were the lowest of the three Columbia River locations.

One northern squawfish larva was collected in late July backwater plankton tows and three unidentified yolk-sac cyprinid larvae were collected during early June main stem tows. Cottid larvae were the most abundant taxon at main stem and backwater sites (Table 3). Species composition was similar to other locations; however, species diversity in the backwater was somewhat greater than in other backwaters sampled.

Seventeen sled samples from two sites in the upper Bonneville Pool contained 137 larvae and juveniles in 128 m^3 of water filtered; a density of 10.7 fish per 10 m^3. Larval squawfish/chiselmouth and larval and juvenile squawfish densities were highest at the main stem sled site (Table 5). Overall densities of larval and juvenile squawfish from both sites combined were lower than combined densities from the three lower

Dalles Pool sites; densities of squawfish/chiselmouth larvae, however, were higher at the upper Bonneville location. Species composition was similar to other locations except suckers comprised a greater proportion of samples.

Deschutes River.-Plankton tows in Deschutes River collected only sucker larvae (Catostomidae); 44 larvae were captured in 4153 m^3 of water filtered. In all drift net samples (5107 m^3 of water filtered), a total of six sucker larvae, one sucker juvenile, and one sculpin juvenile was collected.

Fish densities were generally higher in Deschutes River sled samples than in Columbia River sled samples (Tables 5, 6). During 33 sled tows conducted at two Deschutes River sites, 1087 larvae and juveniles were collected in 163.5 m^3 of water filtered (a density of 66.5 fish per 10 m^3). Larval and juvenile squawfish densities were higher at the east shore sled site than at any other Deschutes or Columbia River sample sites. Only the upstream Browns Island site in the lower Dalles Pool had comparable larval squawfish densities (Table 5). Squawfish/chiselmouth larvae, however, were collected at comparable or higher densities at the lower Dalles Pool backwater sled site and at both upper Bonneville Pool sled sites (Tables 5, 6).

Temporal appearance of northern squawfish larvae and juveniles in Deschutes River sled samples was similar to main stem locations (Figure 2). Squawfish/chiselmouth larvae were first collected in the Deschutes River in late June and peak larval squawfish abundance occurred in mid- July (Figure 2C). Peak juvenile abundance lasted from late July through early September. Juveniles were collected into early November at the east shore location.

Late July size composition of larval and juvenile northern squawfish in the Deschutes River shoreline areas was similar to late July size composition of squawfish in the lower Dalles Pool shoreline areas (Figure 4). During the last two weeks of July, standard lengths of squawfish in Deschutes River sled samples ranged from 13.4 to 28.2 mm with a mean of 21.2 mm (N = 59; SD = 3.96). Mean standard length of squawfish captured in sleds during early November was 31.9 mm (N = 7; SD = 9.56). Late fall size comparisons can not be made with squawfish in the lower Dalles Pool since none were collected there after late July.

Species composition in Deschutes River sled samples differed from Columbia River samples. Except for one cottid larva, Deschutes River samples consisted entirely of catostomids and cyprinids (Figure 3C, D). Dipnet samples generally contained similar species but slightly higher percentages of squawfish larvae. Dipnet samples from the upstream west shore site that was too shallow for sled sampling were dominated by catostomids (79%) and contained few larval and juvenile squawfish.

Environmental Parameters

Temperatures at Columbia River main stem and backwater plankton tow sites were similar between sample locations. Temperatures ranged from 16-17°C in early June to a high of about 22-23°C in late July and August, and then declined in September (Figure 5A, B, C). Backwater locations occasionally had slightly higher temperatures, probably due to less water exchange and shallower depths in these locations. Temperatures measured at main stem and backwater shoreline sled and dipnet sites were generally somewhat higher and more variable than those at plankton tow sites (Figure 6A, B, C).

Turbidities at Columbia River main stem and backwater plankton tow sites were similar between the lower Dalles Pool and upper Bonneville Pool locations, peaking at 4-5 NTU in June and then stabilizing (range 1.5-3.0 NTU) for the remainder of the field season (Figure 7B, C). Turbidities at the upper Dalles Pool location were more variable with peaks measured in mid- June in the main stem and in mid- July in the backwater area (Figure 7A).

Turbidities at Columbia River sled sites (Figure 8A, B, C) varied more than turbidities at plankton tow sites (Figure 7A, B, C). Suspended sediment loads tend to be higher in waters along shallow shorelines since they are often more exposed to wind-induced waves. Some locations, however, such as the upper Dalles Pool island and lower Dalles Pool backwater sites, were more protected and had lower turbidities (Figure 8A, B).

Weekly temperatures at Deschutes River plankton tow and drift net sites fluctuated more and were slightly lower than those in the Columbia River, ranging from 13°C in mid- June to 20°C in August (Figure 5). The Deschutes River is probably more directly influenced by local weather and runoff conditions than the Columbia River.

Temperatures at Deschutes River sled and dipnet sites were more variable than mid-river temperatures taken at plankton tow and drift net sites (Figures 6D, 7D). The shallow upstream dipnet site was usually warmer than other sites. Higher temperatures probably occurred at this site because it was shallow and underlain by dark basaltic bedrock, and had little direct exchange with main stem flows.

Turbidities at Deschutes River plankton tow and drift net sites were fairly constant and low (Figure 7D). In contrast, turbidity measurements at sled sites were more variable and often high due to shoreline disturbances caused by wave action (Figure 8D).

DISCUSSION

Beamesderfer (1992) found that suitable riverine rearing habitat for juvenile northern squawfish consisted of shallow, sandy, low-velocity, shoreline margins. In our study, overall larval and juvenile squawfish densities were highest at the east shore sled site in the Deschutes River and at the lower Dalles Pool upstream island sled site (Tables 5, 6). Both of these sites were characterized by fine sediment/sand substrates and seasonally heavy amounts of cover in the form of instream vegetation. In contrast, sites in the upper and lower Dalles Pool with gravel/cobble substrates and little vegetative cover supported few fish. This habitat type probably does not provide optimal rearing conditions for larval and juvenile squawfish.

Peak weekly densities of squawfish larvae in sled samples occurred in July at the Deschutes River east shore and upstream Browns Island sled sites (Figure 2A, C). LaBolle et al. (1985) reported much higher (290 per 10 m^3) late July squawfish/chiselmouth larval densities in littoral habitats of the John Day Pool during July, 1982. Comparisons should be valid since both studies used nearly identical gear and protocol. Perhaps 1992 was a poor year for squawfish reproduction or the locations we sampled did not provide optimal rearing habitats for northern squawfish.

Growth of larval and juvenile squawfish in the Deschutes and Columbia Rivers was similar to that reported in other studies. Mean standard length of squawfish/chiselmouth larvae collected during 1992 in lower Dalles Pool sled samples was 10.2 mm. Casey (1962) and Beamesderfer (1992) reported that squawfish larvae first appeared in shoreline rearing areas when they were about 10.0 mm long. During early November 1992, mean standard length of squawfish captured in Deschutes River sleds was 31.9 mm. Similarly, mean standard length of age 0 squawfish in Cascade Reservoir, Idaho was 32.0 mm (Casey 1962).

Information on timing and location of northern squawfish spawning is limited because few northern squawfish larvae were collected during plankton tows at Columbia River locations, and only cottids and catostomids were collected in Deschutes River plankton tow and drift net samples. We do not know if squawfish spawned in the Deschutes River or if larval squawfish immigrated from the Columbia River. Few squawfish in plankton and drift samples could indicate that 1992 was a year with limited squawfish spawning or poor larval survival, or could simply be due to a temporal or spatial mismatch of our sampling with squawfish larval distributions.

Nighttime drift is reported for many larval fishes (Gale and Mohr 1978; Snyder 1983). This-may explain the low numbers of squawfish larvae in our daytime plankton samples. Results from limited diel sampling in the upper Dalles Pool support this since all squawfish/chiselmouth **larvae** were captured at dusk or night (Table 4). In contrast, Muth and Schmulbach (1984) did not find increased nighttime drift of cyprinid larvae in a prairie stream. They sampled almost the entire water column and felt that many reports of diel periodicity in larval fishes were instead a function of diel shifts in vertical distribution. We do not know the vertical distribution of northern squawfish **larvae** because no fish were collected during daytime sampling to compare surface to benthic distributions in the upper Dalles pool. This may have 'been due to spatiotemporal problems associated with limited sampling conducted at only one location.

Another possibility for low numbers of squawfish larvae in plankton samples is that our sampling did not coincide with seasonal patterns of squawfish spawning. This is unlikely, however, based on other studies and on temperature information. Hjort et al. (1981) estimated that spawning by squawfish in the Columbia River extended from June to August. In Idaho, Beamesderfer (1992) observed spawning from late June through July **at** temperatures ranging from 12 to 18°C. We sampled from late May through mid- September when temperatures ranged from about 16.5 to 22.5°C. All squawfish/chiselmouth larvae and squawfish larvae in plankton samples were collected between late June and the end of July when temperatures ranged from 19 to 23°C.

Presently we can conclude that northern squawfish larvae and YOY juveniles **rear** in tributary and main **stem areas.** Information on spawning in 1992 is limited, possibly because inadequate numbers of samples were collected at night. In 1993 we greatly expanded our nighttime sampling program at Deschutes and Columbia River locations. Although 1993 sample processing is not complete, preliminary data indicate **that** more cyprinid larvae were collected during night than day plankton tows. This information should provide further insight on the reproduction and early life history of northern squawfish in the Columbia and Deschutes Rivers.

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Table 1. Descriptions of fixed plankton tow sites in the upper Dalles Pool, the lower Dalles Pool, the upper Bonneville Pool, and the Deschutes River.. RM = river miles. At the Deschutes River, M = the distance upriver from the confluence of the Deschutes with the Columbia River (measured in meters).

LOCATION	RM	SUBSTRATE-GRADIENT	DEPTH (M)	WATER 'VELOCITY (M/S)
Upper Dalles				
mainstem north shore	215.25	gravel/cobble-gentle	3-7	0.7-1.5
mainstem mid-channel	215.25	--	l-10	0.4-1.1
mainstem south shore.	215.25	bedrock/boulder steep	10-21	0.2-0.9
backwater	211.75	gravel/cobble-gentle/moderate	7-9	< 0.3
Lower Dalles				
mainstem north shore	194.00	bedrock/boulder-vertical	0.6-18	0.2-0.5
mainstem mid-channel	194.00	--	8.5-82.5	O-3-0.6
backwater	197.25	bedrock/boulder-vertical	6-11	0.1-0.2
Upper Bonneville				
mainstem north shore	190.00	large boulder-vertical	4-16.5	0.2-1.0
mainstem mid-channel	190.00	--	1.5-25	0.5-1.4
backwater	190.25	sand/cobble/bedrock-gentle/moderate/steep	l-13	0.1-0.3
Deschutes	M			
east shore	250	fine sediment/sand-steep	0.5-2.5	0.3-0.5
west shore	175	fine sediment/sand-gentle	0.5-2.5	0.4-0.9

Table 2. Descriptions of sled sites in the upper Dalles Pool, the lower Dalles Pool, the upper Bonneville Pool, and the Deschutes River. RM = river miles. At the Deschutes River, M = the distance upriver from the confluence of the Deschutes with the Columbia River (measured in meters). All sled sites had gentle gradients and negligible water velocities. Vegetation was often seasonally variable.

LOCATION	RM	SUBSTRATE	VEGETATION
Upper Dalles			
mainstem south shore	212.25	gravel/cobble	absent
mainstem island	215.50	gravel/cobble	absent
backwater	212.25	fine sediment/ cobble	light
Lower Dalles			
north shore Browns Island (upstream)	197.75	fine sediment	absent-heavy
north shore Browns Island (downstream)	197.75	gravel/cobble	absent-light
backwater	197.50	fine sediment	moderate
Upper Bonneville			
mainstem south 'shore	190.00	fine sediment/ sand	light-heavy
backwater	190.75	fine sediment/ sand	absent-moderate
Deschutes	M		
east shore	900	fine sediment	moderate-heavy
west shore	250	fine sediment/ sand	light-heavy

Table 3. Mean densities (number per 100 m^3) of larvae and juveniles collected during daytime plankton tows in the upper Dalles Pool, the lower Dalles pool, and the upper Bonneville Pool during late May through early September 1992.

	UPPER DALLES POOL		LOWER DALLES POOL		UPPER BONNEVILLE POOL	
	mainstem	backwater	mainstem	backwater	mainstem	backwater
Total number of fish collected:	1,862	259	3,494	438	1,777	97
Total water volume sampled (m^3):	18,198	3,331	13,851	3,216	13,593	3,349
Density (number per 100 m^3):	10.23	7.75	25.23	13.62	13.07	2.90
TAXON						
Petromyzontidae (lampreys)						
Undetermined spp.						
larvae	0.02	0	0	0	0.01	0
Clupeidae (herring)						
Alosa sapidissma						
larvae	6.35	0	0.06	0	0.05	0
Cyprinidae (minnows, carp)						
Cyprinus carpio						
larvae	0.02	0.06	0.48	0.03	0.32	0.11
Mylocheilus caurinus						
larvae	<0.01	0	0.01	0	0.04	0
Ptychocheilus oregonensis						
larvae	0	0	0	0	0	0.03
Ptychocheilus oregonensis/ *Acrocheilus alutaceus*						
larvae	0.01	0	0.01	0	0	0
Undetermined spp.						
larvae	0	0	0.02	0	0.02	0
Catostomidae (suckers)						
Undetermined spp.						
larvae	0.05	0	0.06	0	0.03	0.11
Centrarchidae (sunfishes)						
Micropterus spp.						
juveniles	0	0	0	0	0	0.03
Undetermined spp.						
larvae	0	0.27	0.02	0	0	0.03
Percidae (perches)						
Perca flavescens						
larvae	0	0	0.01	0	0	0
Cottidae (sculpins)						
Undetermined spp. (probably *Cottus asper*)						
larvae	8.17	6.98	23.18	13.99	11.78	2.24
juveniles	0	0	0.03	0	0	0
Undetermined spp. (damaged)						
larvae	0	0	0.10	0.01	0.06	0.05

Table 4. Mean densities (number per 100 m^3) of larvae and juveniles collected in plankton tows conducted in the upper Dalles Pool during day, dusk, and night on June 29-30, July 15, July 28, August 6, August 11, and August 24, 1992.

	DAY	DUSK	NIGHT
Total number of fish collected:	161	146	118
Total water volume sampled (m^3):	4,377	4,875	4,446
Density (number per 100 m^3):	3.68	2.99	2.65
TAXON			
Petromyzontidae (lampreys)			
Undetermined spp.			
larvae	0.05	0	0
Clupeidae (herring)			
Alosa sapidissma			
larvae	1.23	0.26	0.20
juveniles	0	0.23	0.16
Cyprinidae (minnows, carp)			
Cyprinus carpio			
larvae	0.02	0.02	0
Ptvchocheilus oresonensis			
juveniles	0	0.02	0
Ptvchocheilus oregonensis/ *Acrocheilus alutaceus*			
larvae	0	0.04	0.13
Catostomidae (suckers)			
Undetermined spp.			
larvae	0.13	0.12	0.04
Cottidae (sculpins)			
Undetermined spp. (probably *Cottus asper*)			
larvae	1.63	2.23	**1.94**
juveniles	0	0.02	0.04

Table 5. Mean densities (number per 10 m^3) of larvae and juveniles collected during sled tows in the upper Dalles Pool, the lower Dalles Pool, and the upper Bonneville Pool during late May through early October 1992.

	UPPER DALLES POOL			LOWER DALLES POOL			UPPER BONNEVILLE POOL	
	mainstem		backwater	mainstem-island		backwater	mainstem	backwater
	S shore	island		downstream	upstream			
Total number of fish collected:	6	7	8	3	174	88	100	37
Total water volume sampled (m^3):	98	83	101	113	108	99	60	68
Density (number per 10 m^3):	0.61	0.84	0.79	0.27	16.11	8.88	16.66	5.44
TAXON								
Cyprinidae (minnows, carp)								
Cyprinus carwio								
larvae	0.51	0	0.21	0	0.27	0.75	0.50	0.44
Mylocheilus caurinus								
larvae	0	0	0	0	0.71	0.30	1.50	0.60
juveniles	0	0	0.10	0	2.40	0	0.33	0.15
Ptychocheilus oregonensis								
larvae	0	0	0	0	2.93	0.79	1.67	0.30
juveniles	0	0.12	0	0	3.11	1.74	0.83	0
Ptychocheilus oregonensis/ *Acrocheilus alutaceus*								
larvae	0	0.12	0	0	0.09	0.57	2.17	0.30
Catostomidae (suckers)								
Undetermined spp.								
larvae	0.10	0.36	0.21	0.18	5.62	2.92	9.00	3.70
juveniles	0	0	0	0	0.27	1.65	0	0
Centrarchidae (sunfishes)								
Undetermined spp.								
larvae	0	0.12	0.10	0	0	0	0	0
Cottidae (sculpins)								
Undetermined spp. (probably *Cottus asper*)								
larvae	0	0.12	0	0	0	0	0.67	0
juveniles	0	0	0.21	0.09	0	0	0	0
Undetermined spp. (damaged)								
larvae	0	0	0	0	0.27	0	0	0

Table 6. Mean densities (number per 10 m^3) of larvae and juveniles collected during sled tows in the Deschutes River 27 May - 5 November 1992.

	DESCHUTES RIVER	
	east-shore	west-shore
Total number of fish collected:	549	538
Total water volume sampled (m^3):	36	128
Density (number per 10 m^3):	152.50	42.03
TAXON		
Cyprinidae (minnows, carp)		
Cyprinus carpio		
larvae	0.28	0
Mvlocheilus caurinus		
larvae	0.56	0
Ptvchocheilus oresonensis		
larvae	3.06	0
juveniles	40.00	0.31
Ptvchocheilus oreqonensis/ *Acrocheilus alutaceus*		
larvae	0.28	0
Rhinichthvs spp.		
larvae	14.44	0.16
juveniles	16.11	1.88
Richardsonius balteatus		
larvae	2.50	0.24
juveniles	18.06	0.16
Undetermined spp.		
larvae	1.67	0.31
Catostomidae (suckers)		
Undetermined spp.		
larvae	50.83	38.82
juveniles	4.44	0.31
Cottidae (sculpins)		
Undetermined spp.		
larvae	0.28	0

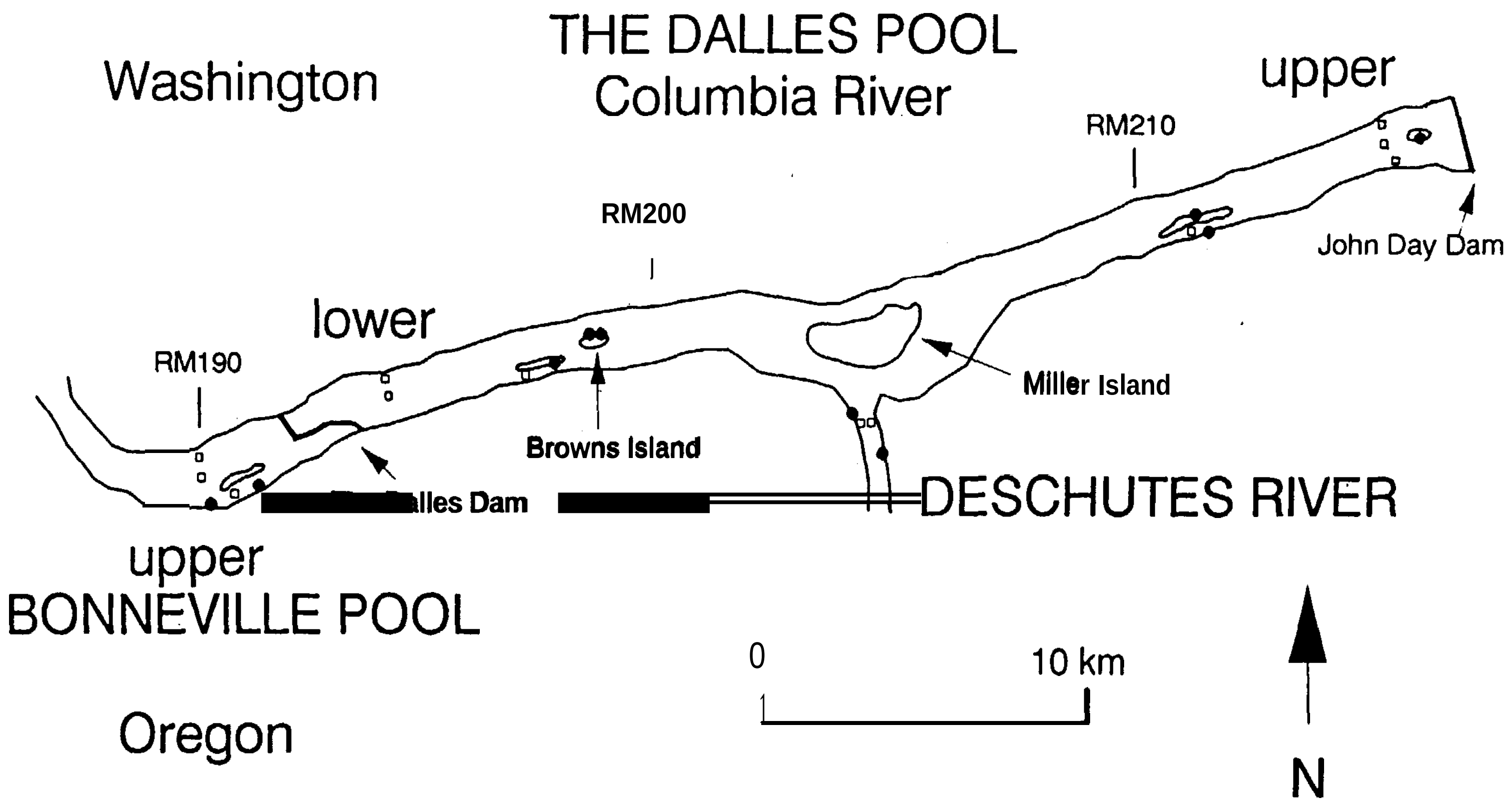

Figure 1. Plankton tow (□) and sled (●) sampling sites in the upper Bonneville Pool, The Dalles Pool, and the Deschutes River. RM = River Mile.

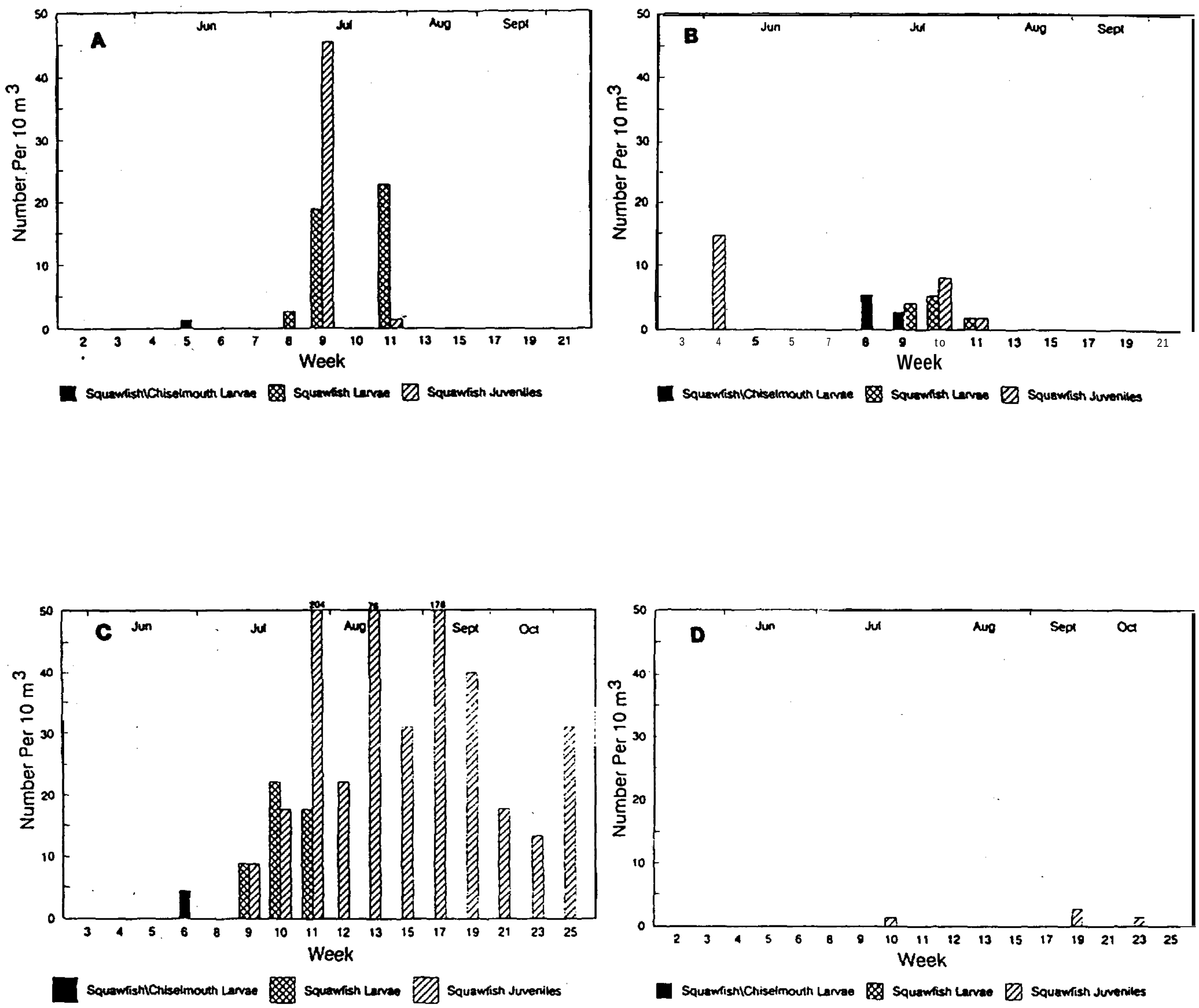

Figure 2. Weekly densities of northern squawfish larvae and juveniles collected in sled samples: A) lower Dalles Pool upstream island site: B) lower Dalles Pool backwater site; C) Deschutes River east shore site: D) Deschutes River west shore site.

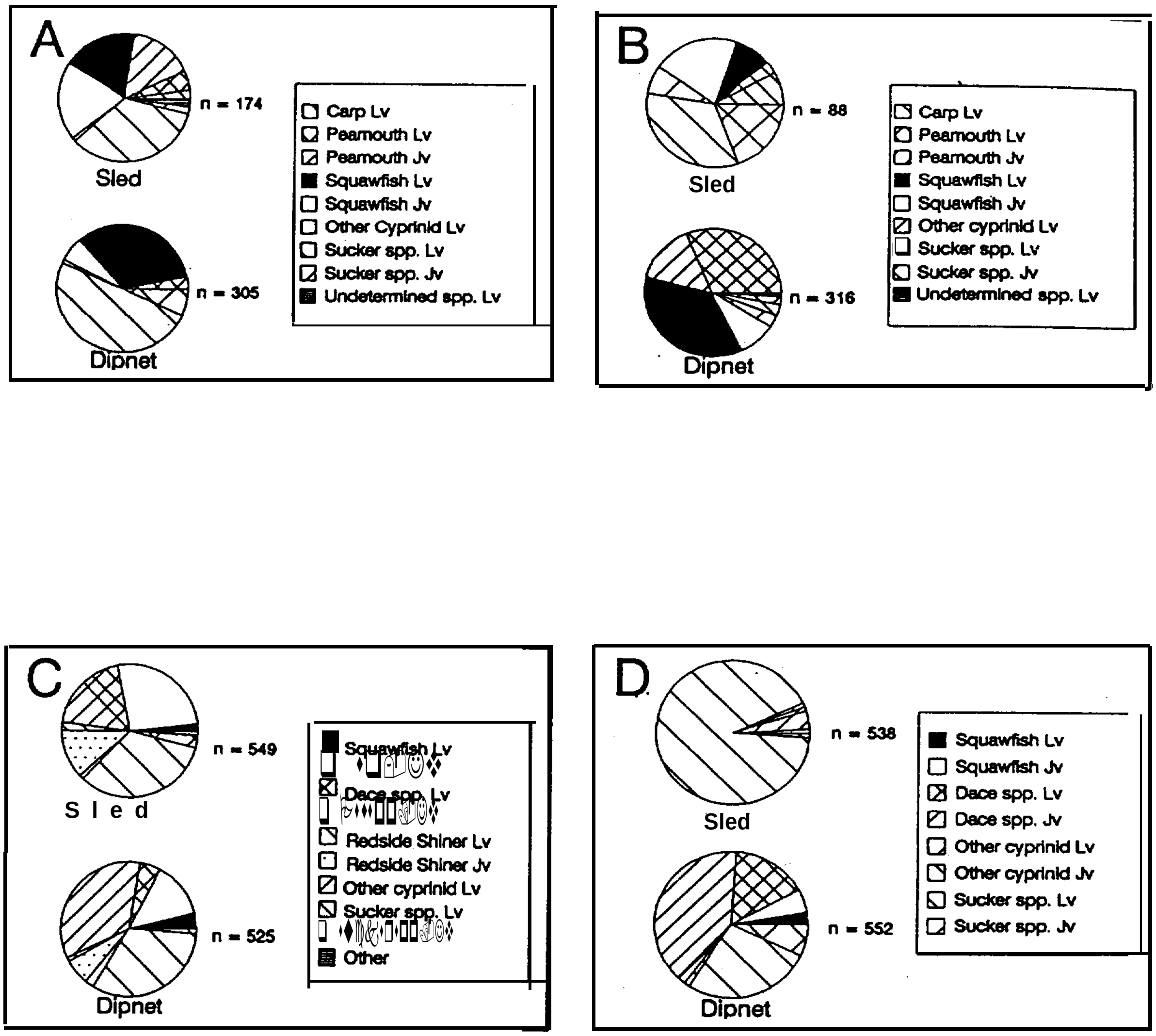

Figure 3. Species composition in sled and dipnet samples: A) lower Dalles Pool upstream island site; B) lower Dalles Pool backwater site: C) Deschutes River east shore site; D) Deschutes River west shore site.

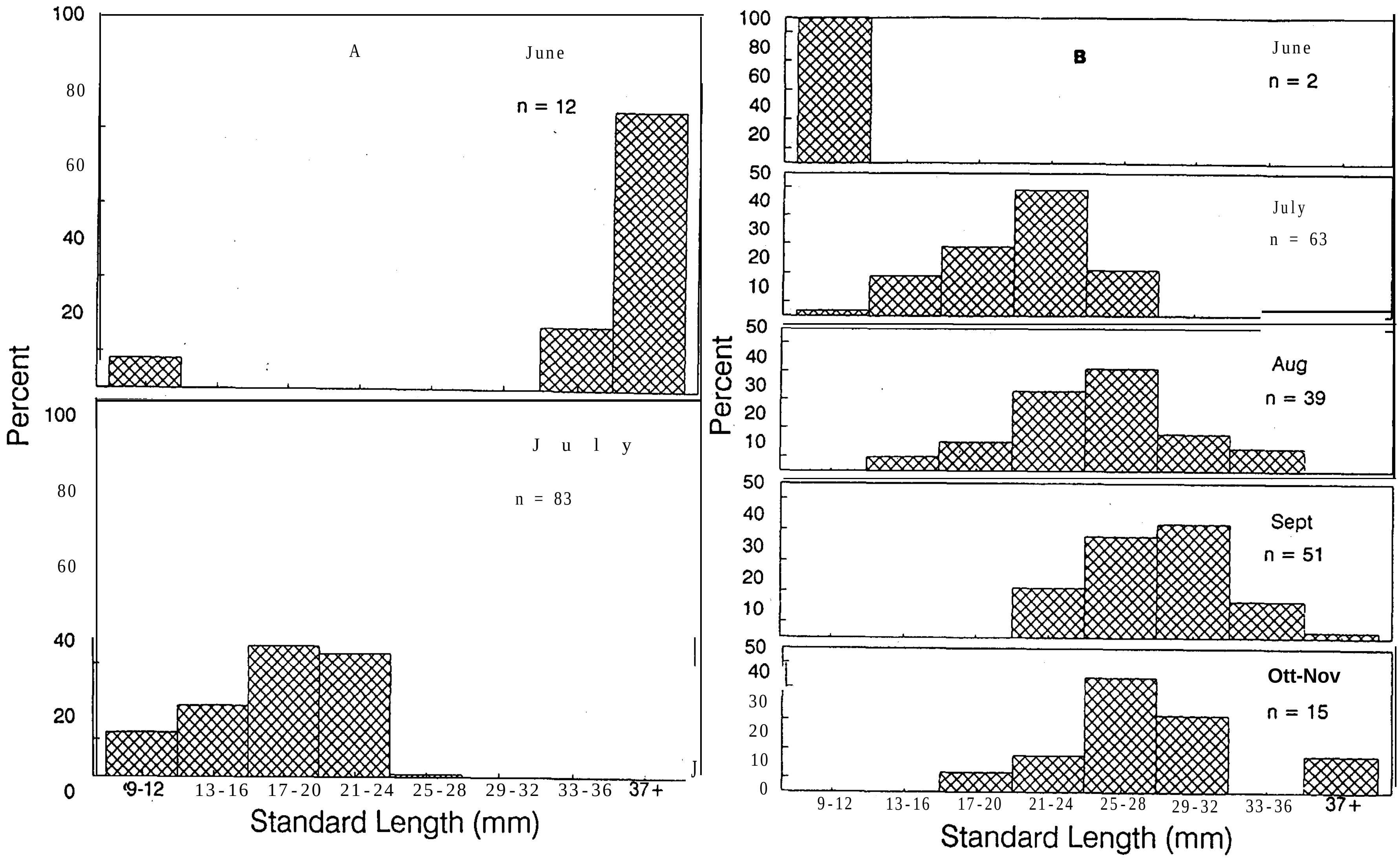

Figure 4. Monthly size composition of northern squawfish and squawfish/chiselmouth collected in sled samples: A) lower Dalles Pool; B) Deschutes River

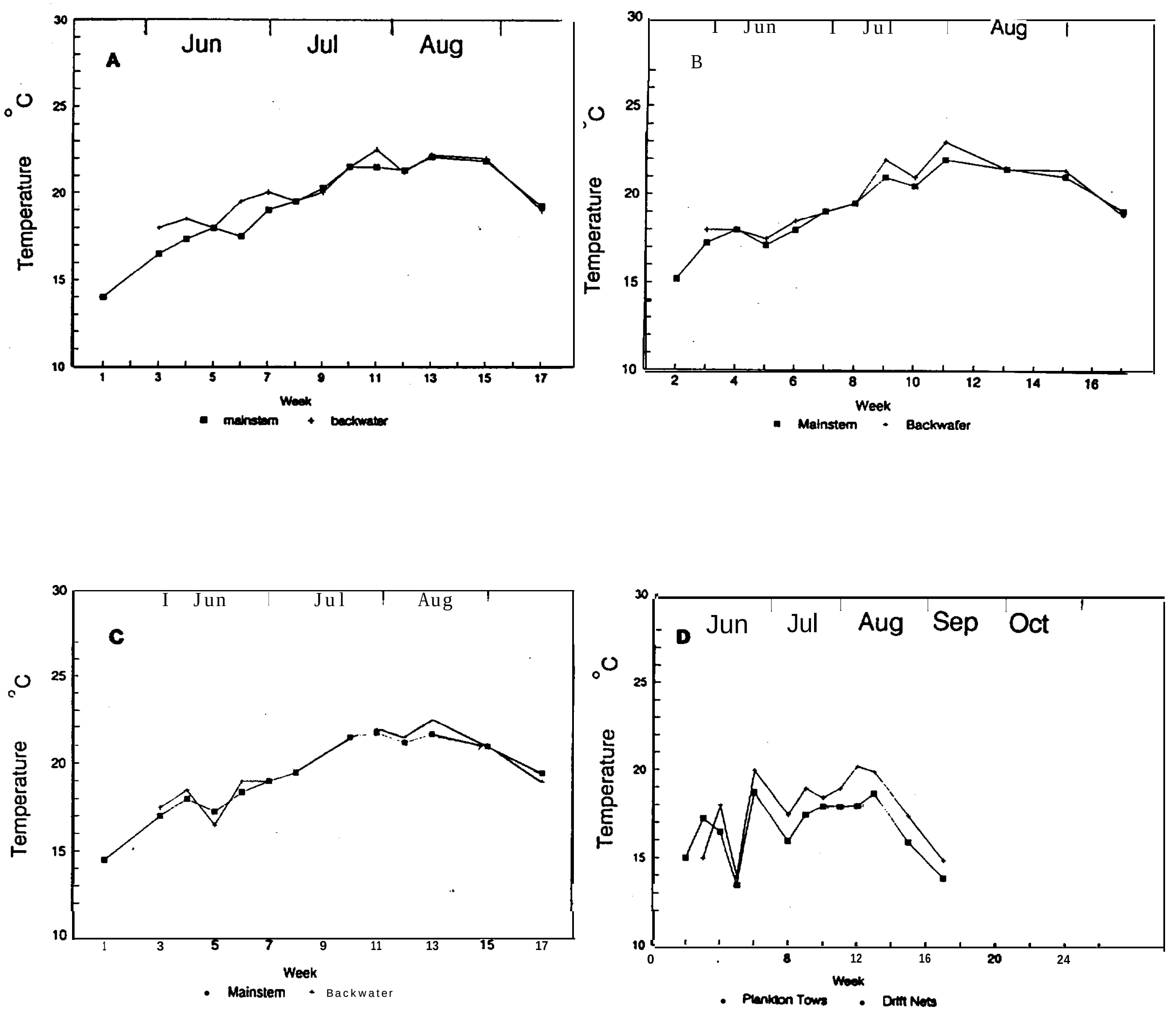

Figure 5. Mean weekly temperatures measured at Columbia River plankton tow sites and Deschutes River plankton tow and drift net sites: A) upper Dalles Pool: B) lower Dalles Pool; C) upper Bonneville Pool: D) Deschutes River.

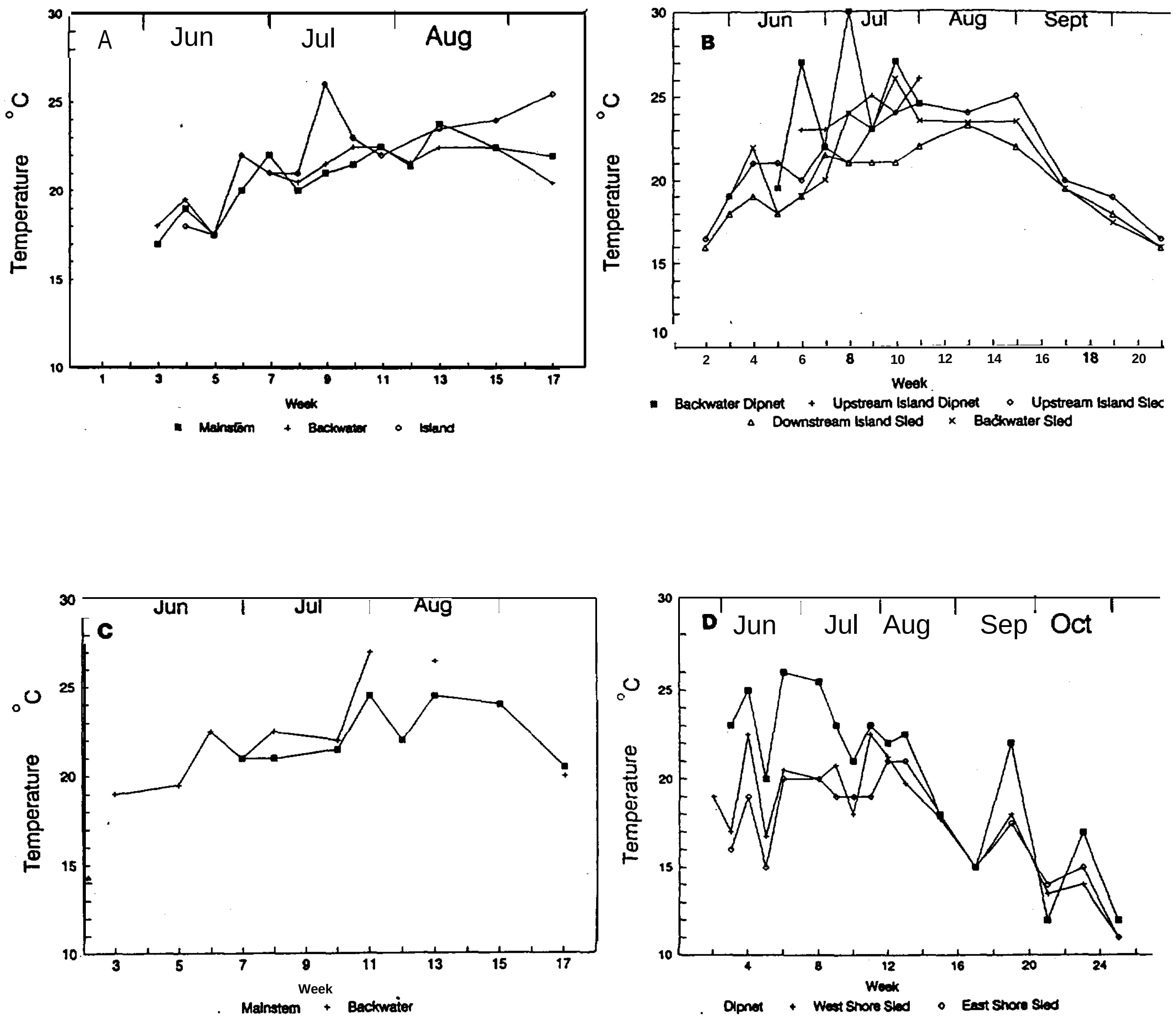

Figure 6. Mean weekly temperatures measured at Columbia and Deschutes River sled and dipnet sites: A) upper Dalles Pool; B) lower Dalles Pool; C) upper Bonneville Pool: D) Deschutes River.

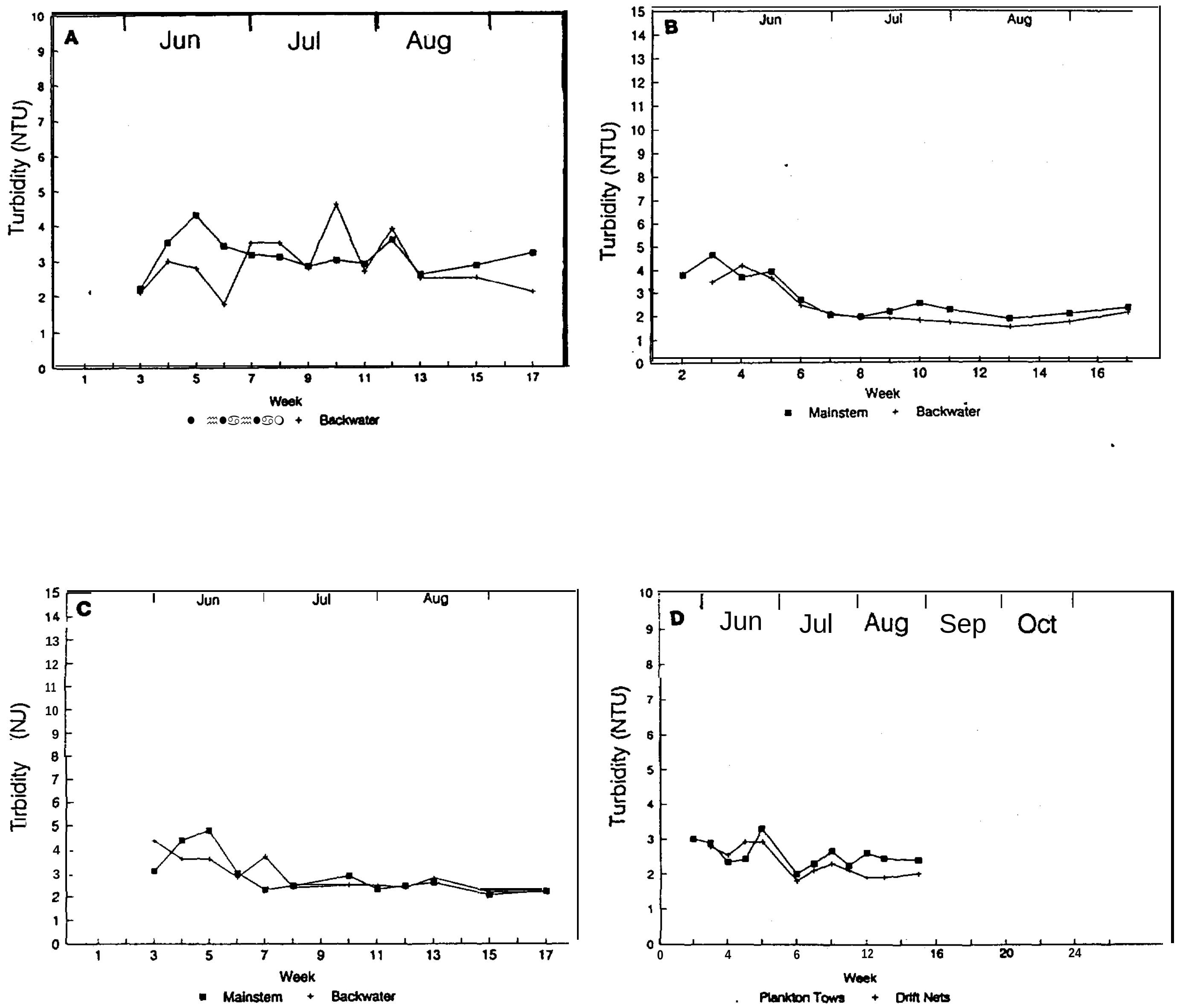

Figure 7. **Mean weekly turbidity measurements at Columbia River plankton tow sites and Deschutes River plankton tow and drift** net sites: **A) upper Dalles Pool; B) lower** Dalles **Pool: C)** upper **Bonneville Pool; D) Deschutes River.**

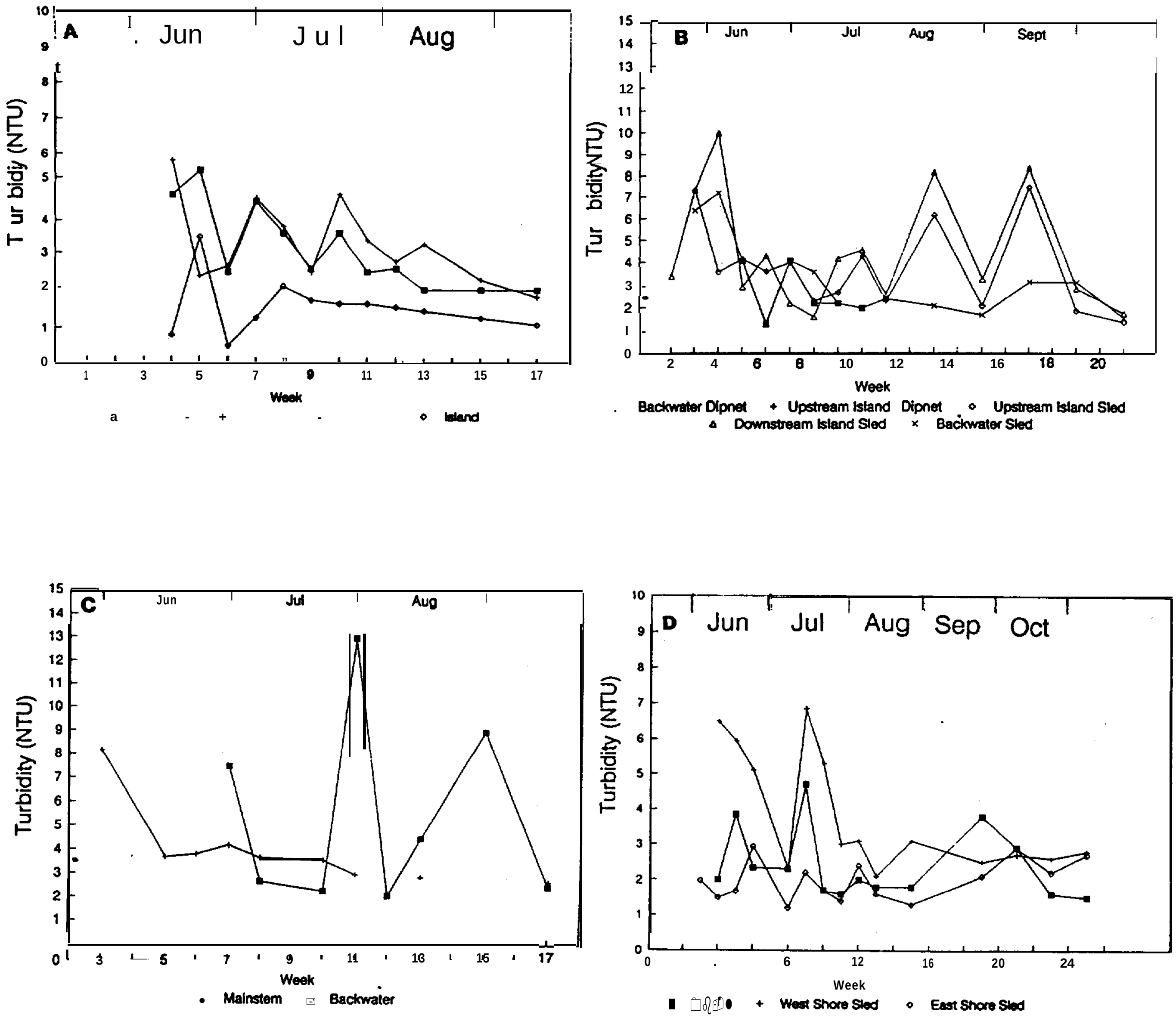

Figure 8. Mean weekly turbidity measurements at Columbia and Deschutes River sled and dipnet sites: A) upper Dalles Pool; B) lower Dalles Pool; C) upper Bonneville Pool; D) Deschutes River.