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Pacific Lamprey Ammocoete Habitat Utilization in Red River, Idaho

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ABSTRACT The Pacific lamprey *Lampetra tridentata* is a native Snake River basin fish species occupying a unique ecological niche. The recent decline in numbers of returning Pacific lamprey adults to the Snake River basin has focused attention on the species. In 2000–2002, we employed electrofishing surveys to determine habitat utilization and distribution of Pacific lamprey ammocoetes in Red River, South Fork Clearwater River drainage, Idaho. Ammocoete average densities were 25.7/100 m^2 in scour pools, 4.4/100 m^2 in riffles, 2.1/100 m^2 in rapids, and 253.3/100 m^2 in the one alcove sampled. Ammocoetes were found in water depths ranging from 1.0 cm to 1.0 m; however, the two greatest densities were observed in habitat units with maximum depths greater than 0.50 m. Pacific lamprey ammocoete density decreased with increased velocity and coarse substrate, and increased with fine and medium substrates and riparian shade.

Pacific lamprey *Lampetra tridentata* are considered primitive and have an ancestry dating back at least 400 million years (Bond 1996). Pacific lamprey are anadromous and parasitic during their ocean phase. Pacific lamprey spawn and rear in coastal and inland streams from northern Baja California to Alaska (Scott and Crossman 1998; Simpson and Wallace 1982). Ammocoetes (larvae) occupy freshwater stream substrates for 4 to 7 years (Beamish and Levings 1991) where they filter-feed on plant and animal detritus (likely desmids, diatoms, and protozoa; Creaser and Hann 1929; Richards and Beamish 1981). Ammocoetes undergo transformation (Richards and Beamish 1981) into macropthalmia (juveniles) and migrate to the ocean to begin a parasitic phase. Following 1 to 2 years parasitically feeding on a variety of fish species and potentially mammals (Scott and Crossman 1998) in the ocean, Pacific lamprey adults return to spawn in freshwater (Beamish and Levings 1991), surviving only a short time after spawning.

Pacific lamprey were historically abundant in the Columbia River basin (Close et al. 1995), perhaps numbering in the millions. Hydroelectric impacts and alteration of rearing habitat are considered two major factors contributing to Pacific lamprey decline in the Columbia River basin and Snake River subbasin (Jackson et al. 1996). Hydroelectric projects hinder upstream adult passage and downstream ammocoete and macropthalmia outmigrations and delay downstream movement through slack water areas. Significant habitat alteration to spawning and rearing streams since 1850 has potentially resulted in reduced production in the Columbia River basin and Snake River subbasin as well. Jackson et al. (1996) cited mining, logging, irrigation practices, agricultural activities, and streamside riparian habitat destruction as having potential negative impacts affecting ammocoete rearing conditions.

Little is known about ammocoete rearing habitat requirements and utilization in the Columbia River basin. Hammond (1979), however, provides

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documentation of ammocoete habitat for selected sites in the Potlatch River, Idaho. Pletcher (1963) provided extensive information on lamprey life history in the Salmon River, British Columbia, including documentation of selected stream habitats where ammocoetes were captured. The Clearwater River drainage and Red River in north-central Idaho currently support a population of Pacific lamprey. Determination of life history and habitat utilization required extensive examination of the subbasin's stream habitats. The objective of this study was to determine habitat utilization of Pacific lamprey ammocoetes in response to six stream parameters: habitat type, habitat unit flow velocity, depth, substrate, temperature, and riparian canopy in Red River.

Study Area

Red River is a fourth-order tributary watershed consisting of approximately 42,000 ha in the South Fork Clearwater River drainage (300,440 ha) in north-central Idaho (Figure 1). Red River joins American River 8.0 km west of Elk City to form the South Fork Clearwater River at river kilometer (rkm) 83.0. Red River is the largest tributary to the South Fork Clearwater River and contributes approximately one-third of the flow of the South Fork Clearwater River. Average maximum flow of 31.9 m^3/s occurs in May and average minimum flow of 1.6 m^3/s occurs in September at rkm 80.0 in the South Fork Clearwater River. Land use in the South Fork Clearwater River drainage is predominantly forestry related in the upper basin with livestock grazing in the middle and lower reaches. Historically, mining was centered in the upper reaches. Widespread mining from the 1860s to the mid-1900s occurred in four tributaries: Crooked River, Red River, American River, and Newsome Creek. In the early 1900s, bucket dredge mining occurred in the upper drainage and the Red River subbasin (U.S. Forest Service 1998). Dredging impacted numerous stream reaches by confining the channel, reducing habitat diversity, eliminating riparian canopy, and directly discharging sediment into Red River.

Information pertaining to anadromous species populations, including Pacific lamprey, in the South Fork Clearwater River drainage before 1900 is limited. In 1910, Grangeville Electric Light and Power Company constructed Harpster Dam at rkm 32.0 on the main South Fork Clearwater River. Adult Pacific lamprey migration was likely possible, but restricted, over the dam from 1935 to 1949. High flows destroyed the fishway in 1949 eliminating adult salmonid passage until the dam was removed in 1963 (U.S. Forest Service 1998). The impact to Pacific lamprey upstream migrants is unknown.

Methods

In 2000, we divided the 41-km length of the mainstem Red River into 1-km sections from mouth to headwaters. One-hundred-meter stream reaches were randomly selected from each 1-km section for determination of habitat utilization and ammocoete distribution. In subsequent years, sampling was focused in the lower Red River as no ammocoetes were found above rkm 7.5 even though similar habitat types were found above this point. Stream habitat units were classified as pool, riffle, glide, falls, rapids, cascades, and alcoves using a

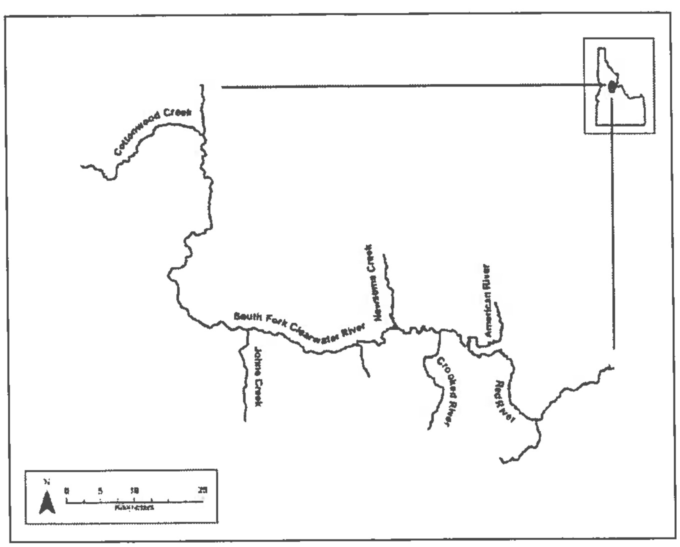

Figure 1. Location of Pacific lamprey ammocoete habitat utilization studies in Red River, Idaho, 2000–2002.

modified version of stream classification methodology utilized in Platts et al. (1983) and Overton et al. (1997). Pools, riffles, and rapids were further classified into subtypes (Table 1). Individual sampling units were defined as a single pool, riffle, glide, falls, rapids, cascades, and alcove. Stream habitat parameters measured in selected habitat units included wetted width, channel width, habitat unit length, maximum depth, average flow velocity, substrate size percent composition, stream temperature, and percent riparian canopy cover.

The substrates within habitat units were visually classified using Platts et al. (1983) size classification (Table 2). Water velocities were measured with a General Oceanics blade type flowmeter 1.0 cm above the substrate (Hammond 1979) at 25% of distance from left bank, 25% of distance from right bank, and at center distance in a habitat unit to obtain average and focal velocities. In instances where a habitat unit failed to span the entire stream width, velocities were measured at the same proportional distances within the width of that habitat unit. The three measurements within a habitat unit were averaged. Maximum depth was recorded in individual habitat units. Individual water velocity and site depth measurements were taken over substrates where Pacific lamprey ammocoetes were captured on emergence. Individual site emergence flow velocity measurements for each unit were averaged. Substrates yielding Pacific lamprey ammocoetes were documented. Stream canopy cover (shade) values expressed as percentages were obtained using a standard concave forestry densiometer. Stream temperatures were measured at each individual habitat unit location with a hand-held mercury thermometer positioned 2.0 cm below the water surface. Single point location substrate temperatures were measured for 10 Red River sites (rkm 1.0 to rkm 10.0) in finer substrates at a depth of 10 cm on 9 August 2001. Additional stream temperature data were obtained at rkm 5.0 utilizing an Onset Computer Corporation HOBO temperature logger.

Table 1.
Habitat unit classification for sampling sites in Red River, Idaho.

Habitat type	*Subtype*
Falls	
Cascades	
Rapids	
	Typical
	Boulder
	Bedrock
Riffles	
	Typical
	Pocket-water
Glide	
Pool	
	Lateral scour
	Straight scour
	Plunge
	Dammed
Alcove	

Table 2.
Substrate classification for sampling sites in Red River, Idaho.

Substrate type	*Size (mm)*
Silt/organic	0.004–0.062
Fine sand	0.062–0.50
Coarse sand	0.50–2.0
Fine gravel	2.0–8.0
Medium gravel	8.0–16.0
Coarse gravel	16.0–64.0
Cobble	64.0–256.0
Small boulder	256.0–512.0
Large boulder	>512.0

Habitat types in the randomly selected 100-m reaches were electroshocked systematically with an Engineering Technical Services ABP-2 electroshocker. However, in some instances, not all habitat units in a randomly selected stream reach were sampled due to logistics or weather conditions. Habitat units were electroshocked from bank to bank working upstream from the lowermost point of the habitat unit to the upstream end to ensure complete coverage of the unit. Due to their rarity and the fact that 100-m sections were randomly selected, no falls, cascades, typical rapids, rapids with bedrock, plunge pools, dammed pools, or glides were selected for sampling. Effective electrofisher settings were optimized, recorded, and repeated throughout units electrofished to standardize effort. Initially, we conducted several test samplings with multiple passes, but few if any additional ammocoetes were captured after the first pass. Thereafter, we utilized a one pass technique moving at a slow rate (1.1–3.0 m/min) to maximize catch. Pacific lamprey ammocoete abundance, expressed as ammocoetes/100 m^2, was estimated by the number of ammocoetes captured by the area electroshocked.

Pacific lamprey ammocoete habitat preferences were determined by analysis of variance (ANOVA). The natural log average density values for individual habitat types were analyzed to determine if mean densities were different. The density values in lateral scour pool and straight scour pool habitats were analyzed as a single habitat type (scour pool) due to similarity in the structure of the two habitats. Similarly, the typical riffle and riffle with pocket water ammocoete densities were combined and analyzed as "riffles." The single alcove habitat unit density was not included in the ammocoete density and habitat type relationship because ANOVA requires an average value.

The ammocoete density relationship to stream habitat unit parameters (water velocity, maximum depth, canopy shade, and substrate type) were assessed through linear regression and modeled with best fit stepwise multiple regression. Linear and multiple regression F-tests ($\alpha = 0.05$) were utilized to determine the strength of the relationship between ammocoete density and stream parameters. Due to minimal sample size (1), the densities obtained in alcove habitat and an irregular ammocoete density of one outlier scour pool were excluded from linear and multiple regressions of the velocity, substrate, maximum depth, and canopy cover parameters.

Initial sampling in Red River indicated ammocoete density differences were minimal when comparing individual substrate size-classes (Table 2); therefore, substrates were combined into three classifications: "coarse" (large boulder, small boulder, cobble), "medium" (course gravel, medium gravel, fine gravel), and "fine" (coarse sand, fine sand, silt/organic), and analyzed in relationship to ammocoete densities in the corresponding units.

Results

Pacific lamprey ammocoetes were captured across the entire range of Red River habitat types sampled. The greatest density was observed in alcove habitat type (Table 3), and the greatest total number of ammocoetes was captured in scour pools. Ammocoete densities averaged 952% and 690% greater in

Table 3.
Habitat utilization of Pacific lamprey ammocoetes in randomly sampled units, Red River and selected units in the South Fork Clearwater River, Idaho, 2000–2002.

Habitat type	*Total lamprey captured*	*Total area fished m^2*	*Total time fished (min)*	*Density (Lamprey/100 m^2)*	*Catch per unit of effort (Lamprey/min)*
Scour pools ($n = 9$)	342	1,283.4	1461	25.7 (±87.7)	0.20 (±0.65)
Riffle ($n = 4$)	15	603.5	726	4.3 (±11.3)	0.05 (±0.13)
Riffle with pockets ($n = 5$)	57	1,269.8	825	4.5 (±12.2)	0.06 (±0.15)
Rapids with boulders ($n = 3$)	10	357.3	305	2.1 (±3.6)	0.03 (±0.04)
Alcove ($n = 1$)	19	7.5	20	253.3 (na)	0.95 (na)
Totals	443	3,521.5	3,337	–	–
Average				12.6	0.13

scour pool habitat than in rapids and riffle habitats, respectively. Scour pool densities ranged from 0.8 to 152.3 ammocoetes/100 m^2, riffle densities from 0.0 to 14.9 ammocoetes/100 m^2, and the rapids from 0.0 to 3.3 ammocoetes/100 m^2.

Although alcove habitat is rare in Red River (0.56% of total stream habitat from rkm 0.0 to rkm 7.0), ammocoete density was greater than in other habitat types. The single alcove sampled at rkm 0.9 yielded a density of 253.3 ammocoetes/100 m^2.

Ammocoete densities were similar for comparable velocity habitat types (Figure 2). Average velocities ranged from 0.47 m/s in riffle habitat to 0.050 m/s in the alcove habitat unit (Table 4). Ammocoete density decreased with increasing stream flow velocity in units sampled (R^2 = 0.477; Figure 3). The inability to identify exact individual emergence locations prevented calculation of site of emergence flow velocity. Maximum depths for sampled units averaged from 0.77 m in scour pool habitat to 0.40 m in the alcove habitat. The relationship between ammocoete density and depth was not significant (Figure 4). Coarse substrate averages ranged from 69.5% in rapids habitats to 32.0% in alcove habitat (Table 4). Medium substrate ranged from 29.3% in riffle habitat to 10.0% in alcove habitat. Fine substrate averaged from 58.0% in alcove habitat to 10.5% in rapids habitat. The greatest average canopy shade measured was 33.0% for the alcove habitat, and the minimum was 9.8% in riffle habitat (Table 4).

Red River substrates within the known ammocoete distribution (rkm

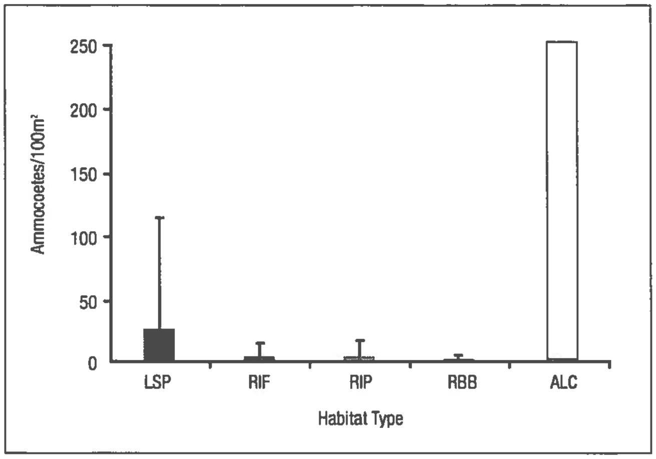

Figure 2. Pacific lamprey ammocoete average densities (95% confidence intervals) in Red River, Idaho, 2000–2002. (LSP = Lateral Scour Pool, RIF = Riffle Typical, RIP = Riffle with Pockets, RBB = Rapids with Boulders, ALC = Alcove, [*n* = 1]).

Table 4.
Pacific lamprey ammocoete density and habitat unit parameter averages (95% confidence intervals in parenthesis), Red River, Idaho, 2000–2002.

Habitat unit	*Density (Lamprey/100 m²)*	*Velocity @ substrate (cm/s)*	*Max. depth (m)*	*Substrate (%) Coarse*	*Substrate (%) Medium*	*Substrate (%) Fine*	*Canopy shade (%)*
Scour pools (*n* = 9)	25.7 (±87.7)	26 (±17)	0.77 (±0.30)	61.4 (±20.5)	22.6 (±15.4)	16.0 (±11.9)	21.3 (± 26.2)
Riffle (*n* = 4)	4.3 (±11.3)	47 (±41)	0.60 (±0.37)	53.4 (±17.8)	29.3 (±14.4)	17.3 (±9.2)	9.8 (±12.4)
Riffle with pockets (*n* = 5)	4.5 (±12.2)	29 (±24)	0.70 (±0.29)	65.1 (±10.5)	21.2 (±10.1)	13.7 (±6.0)	16.1 (±26.2)
Rapids with boulders (*n* = 3)	2.1 (±3.6)	41 (±28)	0.62 (±0.29)	69.5 (±10.4)	20.0 (±9.0)	10.5 (±8.7)	20.3 (±32.4)
Alcove (*n* = 1)	253.3 (na)	5 (na)	0.40 (na)	32.0 (na)	10.0 (na)	58.0 (na)	33.0 (na)

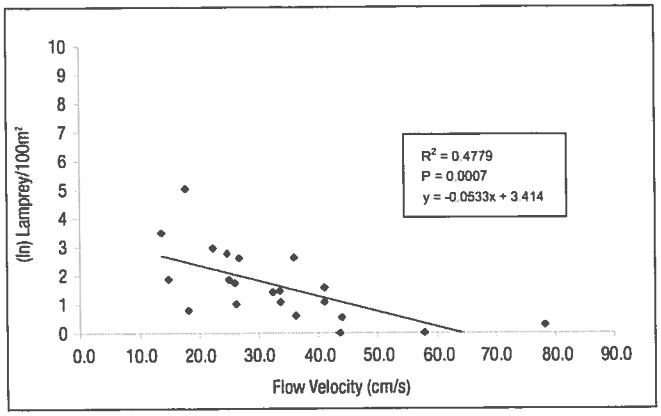

Figure 3. Natural logarithm of Pacific lamprey habitat unit ammocoete densities and average habitat unit flow velocity in Red River, Idaho, 2000–2002.

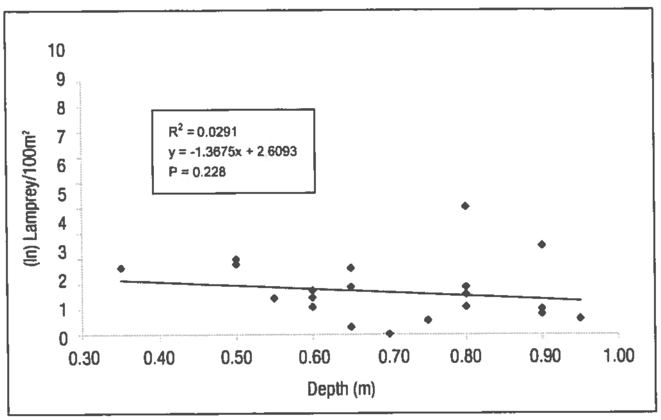

Figure 4. Natural logarithm of Pacific lamprey ammocoete densities and habitat unit maximum depth, Red River, Idaho, 2000–2002.

0.0–7.5) are largely boulder and cobble (Table 2). The ammocoete density decreased with increasing coarse substrate (R^2 = 0.263), increased with increasing medium substrate (R^2 = 0.333), and increased with increasing fine substrate percentage (R^2 = 0.157; Figures 5, 6, and 7).

Red River drains in a northwesterly direction from Red Horse Creek (rkm 9.0) to the mouth. The solar input reaching the riparian and upslope canopy in the Red River stream section rkm 0.0–7.5 is comparable throughout due to streamflow direction (NNW) and similar upslope topography. Therefore, the resultant relative solar input to the stream is primarily a function of riparian canopy. Ammocoete density in Red River increased with increasing habitat unit canopy shade percentage (Figure 8).

Analysis of variance of ammocoete densities in pool, riffle, and rapids habitat in sampled units was insignificant (F = 2.83; P = 0.0854). However, analysis of the habitat unit (pool, riffle, and rapids) mean densities with Fisher's least significant difference indicated the scour pool mean was modestly different from the riffle mean (P = 0.0616) and the rapids mean (P = 0.0709).

A linear regression of ammocoete densities by habitat unit with average flow velocity yielded a significant response (P = 0.0007; Table 5). Linear regression of ammocoete density and canopy cover (shade) was also significant (P = 0.0280; Table 5). The coarse substrate and medium substrate ammocoete density responses were significant as well (P = 0.0208, P = 0.0070), respectively (Table 5). Multiple regression of ammocoete densities and stream parameters produced a best fit model with velocity, coarse substrate, and canopy cover (P = 0.0080, P = 0.0350, and P = 0.0400 respectively; Table 6).

Temperatures in Red River commonly reach 20.0°C or higher during the summer (Figure 9). Maximum stream temperature obtained at rkm 5.0 in 2000 was 26.7°C. Substrate temperatures were an average of 2.2°C (P < 0.05) cooler than stream temperatures when measured 9 August 2001. Stream temperature increased with distance from the source. However, daily stream temperatures in the rkm 0.0–7.5 reach during August and September were comparable, with slightly higher temperatures near the mouth. The inability to isolate ammocoetes in reaches with different temperatures precluded analysis of ammocoete densities and stream temperature relationship.

Discussion

Red River substrates (rkm 0.0–7.5) were predominantly boulder and cobble in the lower reach; how-

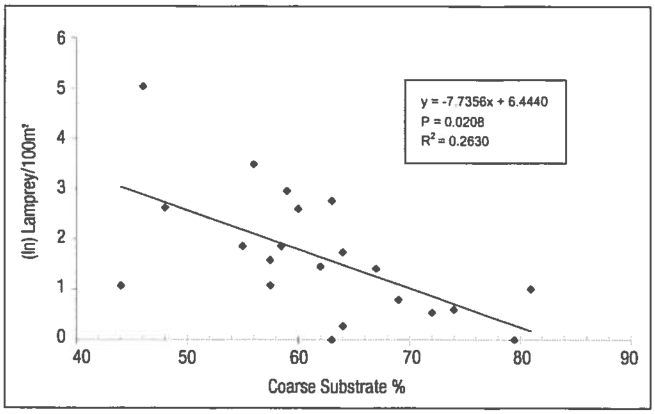

Figure 5. Natural logarithm of Pacific lamprey ammocoete densities and percentage of stream habitat unit coarse substrate (large boulder, small boulder, and cobble), Red River, Idaho, 2000–2002. All sites contain at least 42% coarse substrate.

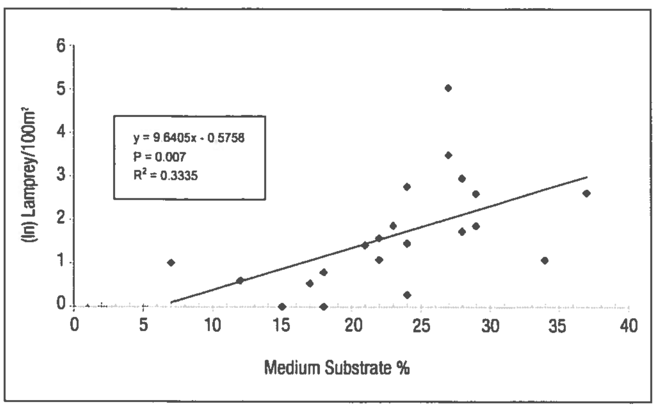

Figure 6. Natural logarithm of Pacific lamprey ammocoete densities and percentage of stream habitat unit medium substrate (coarse gravel, medium gravel, and fine gravel) in Red River, Idaho, 2000–2002.

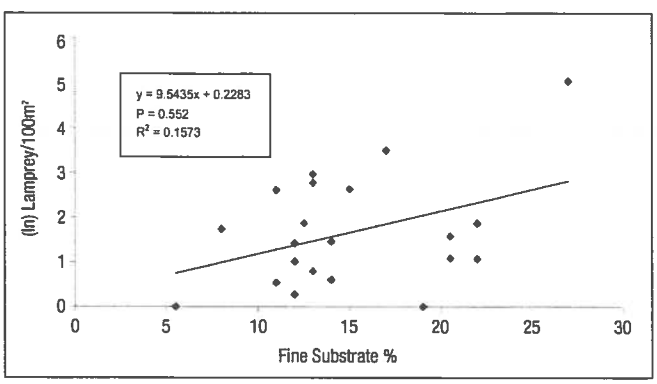

Figure 7. Natural logarithm of Pacific lamprey ammocoete densities and percentage of stream habitat unit fine substrate (coarse sand, fine sand, silt/organic) in Red River, Idaho, 2000–2002.

ever, extensive areas of finer substrates were present. Random selection of samples excluded several fine substrate dominated scour pool habitat units from sampling. It is possible that ammocoete densities in finer substrate dominated reaches of Red River would differ from the randomly sampled sites. In 2002, a pool at rkm 6.0 yielded an ammocoete density of 152.3/100 m^2, which is 480% greater than the maximum pool density obtained in 2000 and 2001.

Studies in the Salmon River of British Columbia and other river systems (Pletcher 1963; Close et al. 1995) have indicated that Pacific lamprey ammocoetes prefer low stream velocity habitat. Ammocoete densities in Red River were greater in pool habitats compared to riffle and rapids habitats, supporting the findings of Pletcher (1963). Even though the ANOVA analysis of ammocoete densities and habitat type relationship was not significant ($P = 0.0854$), the habitat type and densities in Red River are modestly correlated. Ammocoete densities in Red River scour pool habitat ranged from 0.8/100 m^2 to 152.3/100 m^2. The ammocoete densities in other habitats also ranged widely, reducing the potential to obtain statistical significance. Stream parameters of substrate, canopy shade, velocity, and depth were quite variable between and within habitat units, thereby influencing ammocoete density at any sample site.

The range of habitats sampled included scour pools, riffles, rapids, and alcove habitats. Other habitat types (glides, rapids over bedrock, and dammed pools) were present in Red River but were extremely rare and not sampled due to random selection.

Pletcher (1963) indicated the ability of all Pacific lamprey ammocoetes (age 0 or greater) to burrow was impacted at

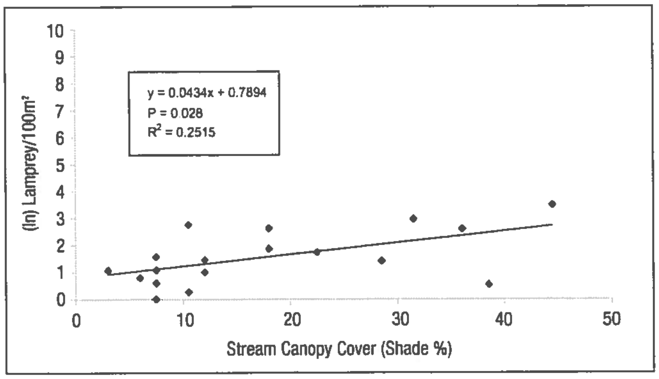

Figure 8. Natural logarithm of Pacific lamprey ammocoete densities and percentage of stream habitat unit riparian canopy shade in Red River, Idaho, 2000–2002.

stream velocities exceeding 31.0 cm/s and burrowing time of ammocoetes increased with increases in water velocity in the Salmon River, British Columbia. He noted the burrowing ability of age-0 ammocoetes was reduced by small increases in velocity (15.0 cm/s) and ammocoetes are believed to seek pools after hatching in response to reduced velocities. Ammocoete densities in Red River decreased with increasing flow velocity. Ammocoetes were captured in stream habitats with greater velocities; however, ammocoetes in these habitats were found in margin pockets where velocity is reduced. Shoreline boulder created calm water pockets in Red River commonly supported higher ammocoete densities.

Pletcher (1963) observed Pacific lamprey ammocoetes using deeper water in summer and shallower water in the winter in the Salmon River of British Columbia, Canada and larger ammocoetes (age 2 or older) used deeper water in one river system. Ammocoete densities

Table 5.
Linear regression of Pacific lamprey habitat unit ammocoete densities
(ln density = ln (density/m² x 1,000 + 1)) and stream habitat parameters, Red River, Idaho, 2000–2002.

Source	*DF*	*Type III SS*	*Mean square*	*F value*	*P value*	*R-square*
Velocity	1	22.84545	22.84545	16.48	0.0007	0.4779
Substrate coarse	1	12.57106	12.57106	6.42	0.0208	0.2630
Substrate medium	1	15.94397	15.94397	9.01	0.0070	0.3335
Canopy shade	1	9.18372	9.18372	5.71	0.0280	0.2515

Table 6.
Stepwise multiple regression of Pacific lamprey habitat unit ammocoete densities (ln density = ln (density/m² x 1,000 + 1)) and stream habitat parameters in Red River, Idaho, 2000–2002.

Source	*DF*	*Type III SS*	*Mean square*	*F, t value*	*P > F, t*	*R-square*
Model	3	23.06964	7.68988	8.58*	0.0015*	0.6319
Error	15	13.44007	0.89600			
Corrected total	18	36.50972				
Velocity	1			3.01**	0.0080**	–
Substrate coarse	1			2.30**	0.0350**	–
Canopy shade	1			2.25**	0.0400**	–

* *F* value.
** *t* value.

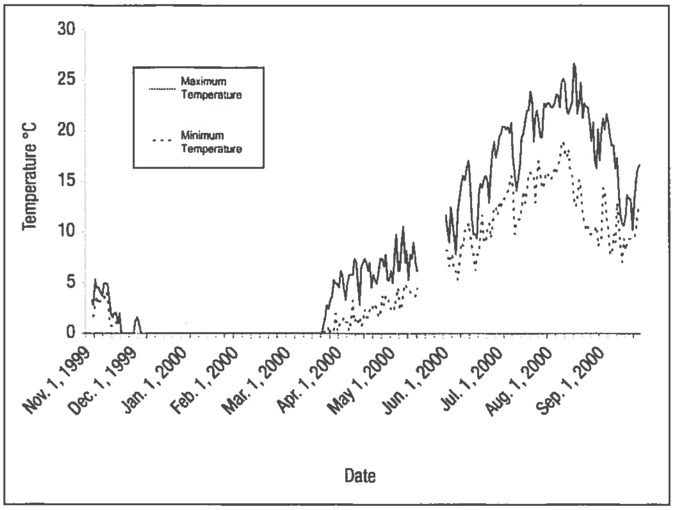

Figure 9. Red River daily maximum/minimum stream temperatures at rkm 5.0 from 5 November 1999 to 14 September 2000, Red River, Idaho. Temperatures ranged from −0.6°C (min) to −0.1°C (max) 21 November 1999 to 15 March 2000. Data logger removed for download 10 May 2000–24 May 2000.

in Red River were greater in depths less than 0.3 m when habitats were sampled in August and September. Ammocoete density and stream depth utilization relationships in Red River during winter months are unknown. Habitat sampling in Red River is restricted to minimum flow, ice free months (primarily July, August, and September). Larger ammocoetes (>120 mm total length) were captured in the range of Red River depths without noticeable patterns. Ammocoete density and habitat unit maximum depth relationship in Red River is generally weak (R^2 = 0.029); however, habitat unit maximum depth reflects the attributes of the entire habitat unit, not the specific locations ammocoetes occupy. The difficulty with visually identifying individual ammocoete emergence sites precluded analysis of single ammocoete depth utilization in Red River.

Substrate preference of Pacific lamprey ammocoetes in the Salmon River, British Columbia was predominantly mud and silt for age-1 ammocoetes (Pletcher 1963). Older ammocoetes were found predominantly in sand and leaf substrates. Hammond (1979) found most ammocoetes in sand, silt, or clay substrates in the Potlatch River, Idaho. Beamish and Lowartz (1996) found that American brook lamprey *L. appendix* density was positively correlated with the amount of medium fine sand and organic matter in the substrate. The substrates in the Red River drainage are predominantly gravels, boulders, and sand with lesser amounts of silt and organic material. Ammocoete densities in Red River were inversely correlated to substrate size. Ammocoete densities noticeably increased in sites with a greater percentage of finer substrates (sand, silt/organic); however, the regression strength with fine substrate was impacted due to the influence of other stream habitat parameters (flow velocity, depth, canopy cover, etc.) on ammocoete habitat selection. Ammocoetes were captured in substrates of all size-classes but were captured in modest numbers from sites with large and small boulders dominating the substrate. Ammocoetes in Red River commonly emerged from substrate gaps in cobble and small boulder areas. Pletcher (1963) indicated that Pacific lamprey ammocoete burrowing ability is impacted by substrate size. Generally finer substrates are considered the preferred Pacific lamprey ammocoete substrate (Close et al. 1995; Pletcher 1963; Hammond 1979). However, if concealment is provided with larger substrates and the interstitial spaces are sufficient for ammocoetes to penetrate, or finer substrate pockets exist in coarse substrate sites, it is likely that they are adequate for limited rearing.

Pacific lamprey ammocoete rearing temperature requirements are not fully known, but ammocoetes are generally found in cold waters (Close et al. 1995); however, tolerance may exceed 25°C (Mallat 1983). In a laboratory environment, Meeuwig et al. (2005) found significant decreased survival during incubation at water temperature of 22°C than at lower temperatures. They also found that abnormal development is significantly more pronounced at the higher water temperatures in initial stages of larval development. Holmes and Youson (1998) found that the percentage of sea lamprey ammocoetes that metamorphosed was maximized with water temperature of 21.0°C and inhibited with higher temperatures. Red River stream temperatures are known to reach or exceed 26.7°C. Temperature monitoring in the Red River subbasin infers that Pacific lamprey ammocoetes and macropthalmia are capable of surviving with stream temperatures in excess of 20.0°C; however, the duration ammocoetes are able to withstand high stream temperatures is unknown. Red River substrate temperatures commonly exceed sea lamprey metamorphosis temperature preference of 21°C for a limited time period in July and August; however, it is unknown if Pacific lamprey ammocoetes are negatively impacted. Substrate temperatures were cooler than stream temperatures sampled, but it is unclear whether Pacific lamprey benefit.

Limited riparian canopy cover is often cited as a factor impacting stream production (Jackson et al. 1996). Elevated stream temperature due to removal of riparian canopy in coldwater species watersheds results in limited production of a number of native aquatic species (U.S. Forest Service 1998); however, it is unclear if temperature extremes in Red River impact Pacific lamprey population productivity. Ammocoetes are adept at detecting light. Pacific lamprey movements predominantly occurred at night (presumably due to light or predator avoidance) in the Salmon River in British Columbia (Pletcher 1963). Ammocoetes are predominantly captured from dusk to sunrise in the rotary screen smolt traps operated in Red River. Maximum stream temperature tolerances likely limit Pacific lamprey production in watersheds where human removal of riparian canopy results in excessive insolarization of streams (Close et al. 1995; Jackson et al. 1996; Jackson et al. 1997). Low-angle shading was identified as an important parameter for Australian lamprey (also known as pounched lamprey) *Geotria australis* ammocoetes (Potter et al. 1986). The Pacific lamprey ammocoete density and riparian canopy relationship in Red River was stronger ($R^2 = 0.251$) than compared to the maximum depth ($R^2 = 0.029$) and fine substrate relationships ($R^2 = 0.157$). Ammocoetes were captured in greater numbers repeatedly under overhanging hardwood riparian vegetation; however, whether the increased densities were in response to decreased microhabitat temperatures or light intensity is unknown.

Pacific lamprey is a species critically linked to the ecological function of the Snake River and South Fork Clearwater River biological communities. The ecological interaction of Snake River Pacific lamprey populations and other riverine species is thought to contribute to Snake River basin overall aquatic productivity. Pacific lamprey ammocoetes provide Snake River basin white sturgeon *Acipenser transmontanus* populations with an important food source, which potentially contributes to Snake River white sturgeon population productivity (Galbreath 1979). Pacific lamprey adults are a source of marine derived nutrients in the Snake River basin. Aquatic and avian predator utilization of ammocoetes and macropthalmia potentially results in reduced predation impact to out-migrating juvenile salmon and steelhead *Oncorhynchus mykiss* in the lower Snake River migrational corridor. Pacific lamprey, Chinook salmon *O. tshawytscha*, and summer steelhead rear in Snake River basin stream habitats; however, the ecological relationship interactions of the three species in the basin are little known. The decline of Pacific lamprey adult upstream migrants to the Snake River basin is undoubtedly in part a function of instream migration corridor mortality, hydroelectric upstream passage impediments, and rearing stream habitat degradation (Close et al. 1995; Jackson et al. 1996; Vella et al. 1997). Pacific lamprey persistence in the South Fork Clearwater River drainage following the installation of Harpster Dam indicates the resilient and enduring character of the species. Knowledge of Columbia River basin Pacific lamprey population ecology, subbasin distributions, and species habitat requirements is currently limited. Increased Pacific lamprey habitat requirement data will further augment the potential to intensively manage the species. Habitat utilization sampling in the South Fork Clearwater River drainage suggests that maintenance of remaining preferred habitats in the South Fork Clearwater River and its tributaries, including Red River, is paramount to ensure that rearing conditions are adequate for the species to continue to inhabit the drainage.

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