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John J. Winkowski, Eric J. Walther, and Mara S. Zimmerman

Fish Science Division, Washington Department of Fish and Wildlife, Olympia, WA

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Executive Summary

Habitat, temperature, and fish distribution patterns of the Chehalis River tributaries were identified as data gaps by the Aquatic Species Enhancement Plan Technical Committee of the Chehalis Basin Strategy (Aquatic Species Enhancement Plan Technical Committee, 2014). This information is needed to address questions pertaining to the development of flood reduction strategies, including a proposed dam, and to anticipate fish responses to the combined effects of future restoration actions and climate change, both of which may further influence fish habitat through changes in the physical, hydrological, and thermal environment. The South Fork Newaukum River, a tributary in the Chehalis River watershed, was selected for study due to the regional interest in pursuing habitat restoration projects in this river basin.

The primary objectives of this study were to 1) describe the landscape and habitat characteristics of five delineated reaches, 2) describe spatial and temporal summer stream temperature patterns, 3) describe spatial and temporal summer fish species distributions, and 4) describe the direction and timing of juvenile salmonid movements. With these data, we explored how juvenile salmon and steelhead distributions and movements were associated with physical habitat and landscape characteristics, stream temperature, and native cyprinid fish distributions throughout the summer rearing period.

The study area was a continuous 37.5 km section of the main stem South Fork Newaukum from elevation 264.9 m (river km 56.6) downstream to the confluence with the North Fork Newaukum River at elevation 81.6 m (river km 19.1). We collected continuous temperature data at 12 locations throughout the survey area and collected spatially continuous habitat and fish data throughout the survey area. Fish data were collected by four snorkel surveys that occurred between May and September 2016. The study area was partitioned into five study reaches that represented variability in landscape characteristics of the basin. Five passive integrated transponder (PIT) detection arrays framed each reach to collect broad scale movement patterns of juvenile salmonids across the survey area. We captured and PIT tagged juvenile Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*) and steelhead (*Oncorhynchus mykiss*) from locations within each study reach that were 2.2 – 4.0 km from the nearest PIT detection array.

The study area was characterized by an upstream-downstream pattern of valley confinement, gradient, and land cover. Upstream reaches were characterized by relatively confined valley walls, higher gradient, and land cover dominated by forest compared to downstream reaches which were characterized by less valley confinement, lower gradient, and cultivated land cover. Habitat characteristics among reaches were minimally variable compared to landscape and temperature features however we detected some variability in large woody debris and pool frequency among the five reaches.

We documented an upstream-downstream pattern in temperature that changed over time. Upstream locations were consistently cold and downstream locations were consistently warm with the month of August having the warmest temperatures. Central locations of the study area had a greater daily range of temperature relative to extreme upstream and downstream extents.

We documented an upstream-downstream pattern in summer fish distribution that changed over time. Juvenile salmonids consistently dominated upstream locations (colder) whereas cyprinids consistently dominated downstream locations (warmer). In the downstream-most reach, juvenile salmonids occurred in low densities throughout the study period. In the adjacent reach (second-most downstream), juvenile salmonid densities decreased sharply from July to August concurrent with increasing temperatures and increases in densities of cyprinid species and hatchery-origin juvenile steelhead in this reach. We conclude that the combination of warm temperatures and competing or predatory native fish species may contribute to declining densities of wild juvenile salmon and steelhead in the downstream reaches of the South Fork Newaukum over the summer months**.**

We observed extensive summer movements of juvenile coho and steelhead, and the directionality of movements changed over time. In total, 24.1% and 18.3% of the PIT tagged coho and steelhead, respectively, were detected at least once, demonstrating movements at least ~2-4 km during the study period. In the summer months (July, August), coho and steelhead had a higher proportion of upstream movements in downstream than upstream reaches. This movement pattern likely contributed to the observed upstream shifts in fish distribution during summer months. However, disproportional mortality among reaches is also possible and may confound this interpretation. In the early fall (September), the majority of movements for coho, and to a lesser extent steelhead, were downstream.

We observed several anthropogenic influences that may conflict with restoration goals to increase productivity of wild fish populations. For example, construction of man-made obstructions (e.g., 'rock dams') were encountered throughout the survey area. Rock dams may inhibit fish movements, especially during summer base flows. In addition, residualized hatchery steelhead had substantial overlap with wild juvenile salmonids, and this overlap is higher in reaches with the highest potential for future restoration actions. In the reach with greatest spatial overlap, residualized hatchery steelhead were approximately to one in every three juvenile steelhead encountered.

Based on results of our study, we offer the following recommendations for restoration planning for juvenile salmon and steelhead summer rearing habitat in the South Fork Newaukum River:

- The upstream most reaches (R3.4, R4.5, and R5) may be good candidate areas for protection of existing riparian and stream conditions,
- The downstream most reaches (R1.2 and R2.3) may be good candidates for habitat enhancement focused on reducing summer stream temperatures. A watershed analysis currently in process will diagnose potential to improve stream temperatures through habitat enhancement in these reaches,
- Restoration would benefit from a combination of education and enforcement actions that minimize construction of man-made obstructions (e.g., 'rock dams') which inhibit fish movements during summer base flows, and
- Managers should review current hatchery practices in the Newaukum River in order to develop strategies to reduce the residualization of hatchery steelhead and minimize ecological interactions between wild and hatchery steelhead.

Introduction

Our study focused on identifying factors contributing to summer distributions of juvenile salmon (*Oncorhynchus kisutch, O. tshawytscha)* and steelhead (*O. mykiss*) in the South Fork Newaukum River in southwestern Washington State. Results from this study are intended to inform future habitat restoration actions within the study area (i.e., Newaukum River), but the principles of our findings should be more broadly applicable to restoration planning in low-gradient coastal rivers with rain dominant hydrology and where summer stream temperatures are near upper thermal tolerances of juvenile salmon and steelhead.

Pacific salmonid distributions can be described according to different spatial and temporal scales. For example, from a very broad geologic perspective, geographic distributions of pacific salmonids reflect their evolution with a dynamic landscape characterized by tectonic uplift, basalt lava flows, glaciation, and megaflood events (Waples et al. 2008). From a contemporary perspective, fish distributions can be studied within watersheds along river reaches and among seasons by species and life stage. For example, salmon and steelhead distribution within a watershed can be described in the context of habitat that supports summer rearing of juveniles. Distributions of fish at any life stage likely reflect a combination of abundance and distribution of the previous life stage, landscape characteristics, habitat features, and environmental conditions such as stream flow and temperature (Burnett et al. 2007; Flitcroft et al. 2014; Winkowski et al. 2018). Contemporary fish distributions are also influenced by anthropogenic impacts that range from instream habitat alterations (e.g., channelization, dams) to landscape level factors (e.g., agriculture, floodplain development) and systemic impacts such as climate change (Burnett et al. 2007; Mantua et al. 2010; Pess et al. 2003; Waples et al. 2009).

Salmon and trout are ectotherms and occupy thermal niches in river systems that follow broad scale temperature gradients (Dunham et al. 2001; Isaak et al. 2017; Torgersen et al. 2006). In rain dominated river systems of the Pacific Northwest, low stream flows and warm temperatures during summer months effectively limit the spatial availability of suitable habitat for rearing salmon and steelhead (Bjornn and Reiser 1991; Reeves et al. 1989). For example, the warmest tributaries occupied by juvenile coho salmon in a northwestern California river were characterized by mean weekly maximum temperatures of 18℃ during summer months (Welsh Jr et al. 2001). In the Chehalis River in coastal Washington, summer rearing distributions for juvenile salmon and steelhead are restricted to upstream locations where mean daily August temperatures rarely exceed 18°C (Winkowski et al. 2018). Taken together, these examples demonstrate that at a basin-wide scale, the spatial distribution of juvenile salmon and steelhead summer rearing is limited by broad scale temperature patterns.

Biological interactions among fish species further influence distribution patterns in river systems and these interactions are often temperature mediated. For example, a temperature-dependent competitive dominance structure exists between brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), and creek chub (*Semotilus atromaculatus*) which is reflected in their distribution patterns in nature, e.g., brook trout are replaced by brown trout and finally by creek chub as temperatures increase from high (cool) to low (warm) elevation in Rocky Mountain streams (Taniguchi et al. 1998). In multiple sub basins of the Chehalis River, summer fish assemblages can be generally described as juvenile salmonids in high elevation (cool) locations replaced by cyprinid species in lower elevation (warm) locations (mean daily August temperatures >18°C) and finally by non-native centrarchid species in even lower elevation warmer locations (Winkowski et al. 2018). Competitive interactions between salmonids and cyprinids are temperature mediated, e.g., juvenile steelhead outcompete redside shiner and pikeminnow in cool temperatures but the opposite outcome occurs in warm temperatures (Reese and Harvey 2002; Reeves et al. 1987). Therefore, the spatial locations in the Chehalis River where salmonids are replaced by cyprinids, or the downstream distribution edge of juvenile salmonids, may be sensitive to seasonal variation in temperature.

Summer habitat use and spatial distribution may also be affected by movement patterns that are further influenced by temperature. For example, in an Alaskan river system with relatively cold temperature conditions, juvenile coho salmon undertake daily movements up to 1 km during summer months between metabolically unfavorable (cold) but rich feeding areas and warmer metabolically favorable locations for assimilation (Armstrong and Schindler 2013). In a Québec river where temperatures reach or exceed thermal tolerance levels, juvenile Atlantic salmon (*Salmo salar*) undertake movements to avoid thermally unfavorable locations and seek patches of cool water refugia during summer months (Dugdale et al. 2015). In some locations of the Chehalis River, juvenile salmon and steelhead must cope with stream temperatures approaching or exceeding suitable levels during summer months. Movements into more thermally and ecologically favorable locations may be a strategy taken by juvenile salmon and steelhead in the Chehalis River and these movements may contribute to their distribution patterns during summer months. Furthermore, a general understanding of behavioral responses of cold-water fishes to high temperatures is relevant to management and planning of restoration activities in watersheds such as the Chehalis River where current summer temperatures can reach or exceed suitable levels and where issues with summer stream temperatures may be exasperated via anthropogenic impacts and climate change (Mantua et al. 2010; Waples et al. 2009).

The primary goal of this study was to investigate how juvenile salmon and steelhead distributions are associated with physical habitat and landscape characteristics, stream temperature, native cyprinid fish distributions, and fish movements throughout the summer rearing period in the South Fork Newaukum River main stem. The South Fork Newaukum River, a tributary in the Chehalis River watershed, was selected for study due to the regional interest in pursuing habitat restoration projects in this river basin. To achieve our primary goal of the study, our objectives were to 1) describe the landscape and habitat characteristics of five delineated reaches, 2) describe spatial and temporal stream temperature patterns, 3) describe spatial and temporal patterns in fish species distributions, and 4) describe the direction and timing of juvenile salmonid movements. We anticipate that the results of this study can be used to inform future habitat restoration actions within the South Fork Newaukum River and that the principles of our findings will be more broadly applicable.

Methods

Study Area

The South Fork Newaukum River (406 km^2) is one of three major tributaries of the Newaukum River, a major sub basin of the Chehalis River watershed in southwest Washington State (Figure 1). The river flows west from its headwaters in the foothills of the Cascade mountain range, and joins the North Fork Newaukum River to form the main stem Newaukum River roughly 19.1 km upstream from its confluence with the Chehalis River main stem. The hydrology of the basin is rain dominated, which results in high flows during winter months (November to March) and extended low flows during summer months (July to September). For example, average stream flows during winter months were over twenty times higher than those during summer months in 2016 (Table 1).

The study area was a continuous 37.5 km section of the South Fork Newaukum from elevation 264.9 m (river kilometer "rkm" 56.6) downstream to the confluence with the North Fork Newaukum River at elevation 81.6 m (rkm 19.1) (Figure 1). During the survey period, stream flows were highest during spring months (May and June), decreased in July, were lowest in August, and increased slightly in early fall (September, Table 1). Additional data on daily variation in flows during the study period are provided in Appendix A.

Table 1. Mean (± one standard deviation, SD) stream flow by month (cubic feet per second) in 2016 measured from USGS 12025000 at Newaukum River rkm 8.0, roughly 11 km downstream of the lower extent of the study area. Approximately half of the stream flow measured at this gage comes from the South Fork Newaukum River. Bold indicates months during the study period.

Month	Flow (cfs)
January	1123.6 (±540.4)
February	1090.9 (±430.0)
March	1213.5 (±472.6)
April	319.3 (±90.8)
May	**126.8 (±23.9)**
June	**133.6 (±55.5)**
July	**90.2 (±25.2)**
August	**47.0 (±11.8)**
September	**56.5 (±17.0)**
October	607.5 (±513.3)
November	1139.9 (±756.6)
December	1031.1 (±432.0)

The study area was partitioned into five study reaches, framed by five passive integrated transponder (PIT) detection arrays. Reaches (and PIT detection arrays) were positioned to partition the study area based on the landscape characteristics (Table 2). Reaches between the PIT detection arrays were named in reference to the detection arrays that framed them (e.g., R4.5

was the reach between detection array A4 and A5 and R5 was the reach upstream of detection array A5). The study area was characterized by upstream-downstream patterns of valley confinement, gradient, and land cover (Table 2). The upstream reaches (R3.4, R4.5, R5) were characterized by confined valley walls (valley width index 2.7-10.6), relatively higher gradient (0.7-1.4%) and land cover dominated by forest (44.7-48.4%; evergreen, deciduous, and mixed), shrubland (16.5-37%; generally trees or shrubs less than 5m tall), and herbaceous cover (9.6-17.2%; dominated by gramanoid or herbaceous vegetation) (Table 2). The downstream reaches (R2.3 and R1.2) were characterized by a wider valley (valley width index 27.0-36.1), lower gradient (0.4-0.7%), and cultivated land (42.2-43.6%) and with less forest cover (<17%) compared to upstream reaches (Table 2). R1.2 was the only reach with a dominant land cover classified as wetlands (19.2%). The transition in landscape and land cover observed in the South Fork Newaukum River study area is characteristic of multiple sub-basins within the Chehalis River watershed (Winkowski et al. 2018).

Table 2. Mean (± SD) landscape characteristics and dominant land cover of five study reaches in the South Fork Newaukum River (rkm 19.1 – 56.6).

Reach	River kilometer	Gradient[a]	Valley Width Index[a]	Dominant Land Cover[b]
1.2	19.1-36.9	0.4% (±0.2)	27.0 (±24.4)	Cultivated (42.2%), Wetlands (19.2%), Forest (13.5%)
2.3	36.9-42.2	0.6% (±0.5)	36.1 (±40.6)	Cultivated (43.6%), Forest (16.6%), Developed (15.1%)
3.4	42.2-50.4	0.7% (±0.3)	10.6 (±7.6)	Forest (46.4%), Shrubland (16.5%), Herbaceous (10.2%)
4.5	50.4-54.9	0.9% (±0.3)	7.5 (±5.0)	Forest (48.4%), Shrubland (20.6%), Herbaceous (17.2%)
5	54.9-56.6	1.4% (±0.5)	2.7 (±1.3)	Forest (44.7%), Shrubland (37%), Herbaceous (9.6%)

[a] Gradient and valley width index were derived from the Terrain Works database. Valley width index is the ratio of valley floor to active channel width (Burnett et al. 2007).
[b] Land cover was calculated as proportions of total area of 250 m buffers surrounding each study reach from the National Land Cover Database (NLCD) in ArcGIS 10.4.1 and the top three land cover categories in each reach are reported. "Cultivated" includes hay, pasture, and crops; "Wetlands" includes woody and emergent herbaceous; "Forest" includes evergreen, deciduous, and mixed; "Developed" includes open space, low intensity, and medium intensity; "Shrubland" includes shrub/scrub forests; and "Herbaceous" includes grasslands.

The study area was further partitioned into survey segments approximately 200m in length which was the scale at which habitat and fish data were collected. Segment lengths were approximated in the field using a laser range finder (TruPulse 200X, Laser Technology Inc.) during the first snorkel survey (described below) and upper and lower extents of each segment were georeferenced with a handheld GPS unit (Garmin 60CSx). Waypoints were converted to shapefiles in ArcGIS 10.4.1 and linear referencing was completed on the main stem river polyline created with reference to the National Agriculture Imagery Program (NAIP) 2015. The main stem river polyline provided consistent spatial reference among data types.

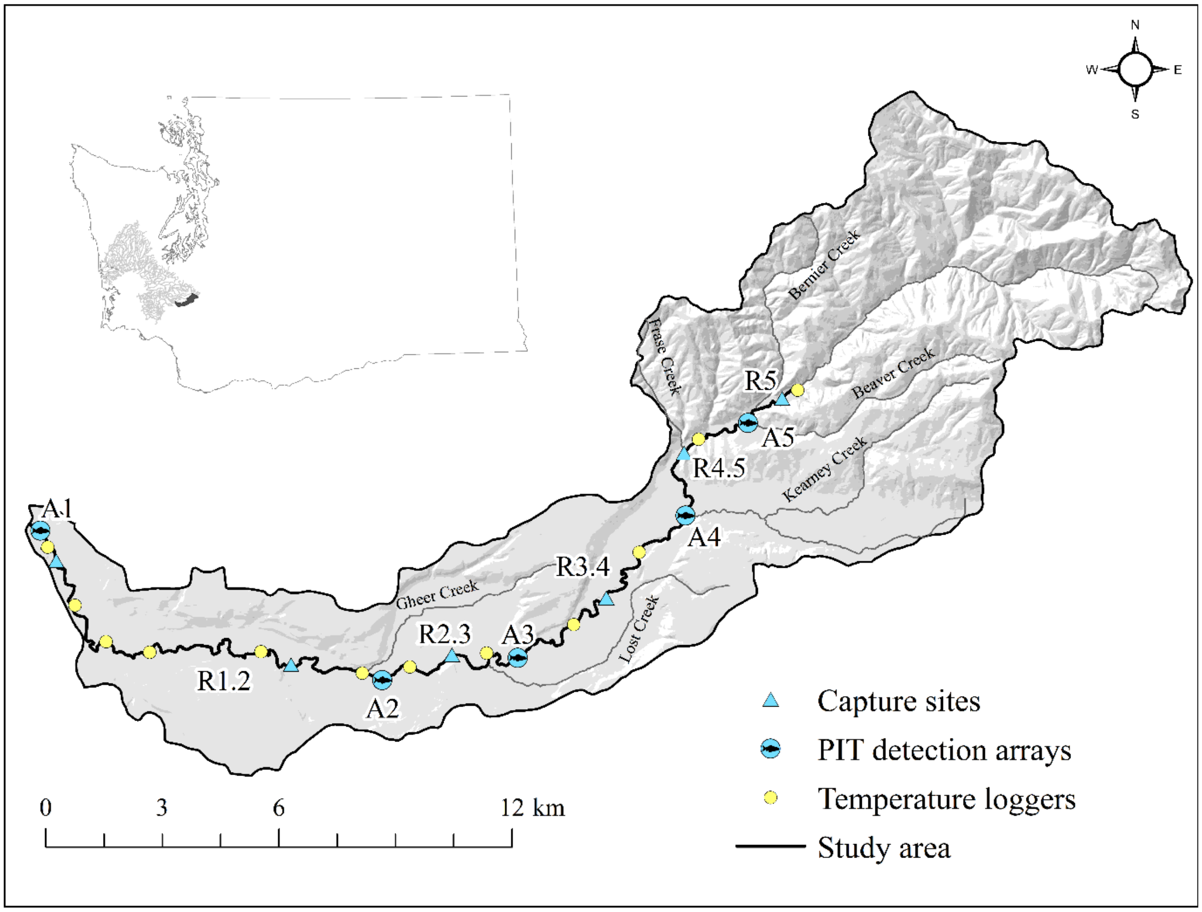

Figure 1. Study area in the South Fork Newaukum River including the location of five delineated reaches, PIT detection arrays, PIT tagging capture sites, and temperature loggers at fixed location monitoring sites. Reaches (labelled R1.2 – R5) are framed by PIT detection arrays (labelled A1-A5).

Temperature Monitoring

To describe spatial and temporal patterns in stream temperatures across summer months, we collected stream temperature information using data loggers (Onset Hobo Pendant Logger 64K UA-001-64) at 12 fixed location monitoring sites (Figure 1). Distances between temperature monitoring sites ranged from 1.5 - 4.7 river kilometers (mean: 3.3; SD: ±1.1). Temperature data were collected at 30-minute intervals between April 19 and October 6, 2016. Loggers were anchored by cable and secured in perforated plastic vinyl chloride (PVC) housing which allowed flowing water to contact the logger but shielded the logger from direct sunlight. Logger positioning in the river was based on three criteria: 1) well-mixed and flowing water, 2) shade, and 3) enough depth for loggers to remain submerged for the summer low flow period. Prior to field deployment and upon retrieval, temperature loggers were calibrated by comparing logger temperature values to values from a National Institute of Standards and Technology (NIST) reference thermometer in cold and warm conditions (roughly 1-21℃) over a 48-hour period. In order for a logger to be deployed in the river, differences between logger and NIST recordings were required to be $\leq$ 0.5℃, which is the precision error reported by the manufacturer for the model of loggers used in our study. Situations including logger positioning becoming unfavorable (e.g., out of flowing, well mixed water or completely dewatered) or tampering could bias temperature values collected at any site. Therefore, we used three levels of screening to remove erroneous stream temperature data from analysis: 1) loggers were routinely inspected in the field to ensure they met our three criteria for logger positioning in the river (i.e., well-mixed flowing water, shade, depth), 2) data were plotted by time and visually inspected for outliers or abnormalities compared to neighboring loggers, and 3) data were flagged as erroneous if the rate of hourly change exceeded 2.5ºC, which likely indicated that the logger was dewatered during that time (Rieman and Chandler 1999). All temperature data from the study period of May through September were screened and no erroneous data were detected.

We summarized stream temperature data in two ways. First, we described spatial and temporal patterns in stream temperatures over the duration of the study (May – September) by summarizing data collected at all temperature monitoring sites in the study area. Second, we described spatial patterns in the stream temperatures across the five study reaches during August only, which was the month of warmest temperatures and lowest flows. To summarize reach temperatures, we derived temperature metrics for each survey segment within the five study reaches by interpolating from linear regressions between the closest upstream and downstream loggers to each segment. Interpolation followed the methods described by Winkowski and Zimmerman (2017) and Winkowski et al. (2018) where this technique was validated with data specific to the South Fork Newaukum in 2016. Five temperature metrics were calculated for both analyses: mean daily temperature, maximum daily temperature, minimum daily temperature, range of daily temperature, and the proportion of time temperature exceeded or was equal to

18ºC. We selected 18ºC as a threshold to represent unfavorable juvenile salmonid rearing conditions based on previous work with juvenile rainbow trout and coho salmon (Hokanson et al. 1977; Welsh et al. 2001; Madej et al. 2006) as well as our current work demonstrating fish temperature associations in sub basins of the Chehalis River (Winkowski et al. 2018). Mean daily temperature was calculated as the mean of mean daily temperatures; maximum daily temperature was calculated as the mean of maximum daily temperatures; minimum daily temperature was calculated as the mean of minimum daily temperatures; and range of daily temperature was calculated as the mean of differences between daily maximum and minimum temperature. The proportion of time stream temperatures exceeded or equaled 18.0ºC was calculated using all recorded temperature measurements during each day.

Habitat Surveys

We collected habitat data between August 2 and August 24, 2016 in accordance with methods described by Winkowski et al. (2018). Data were collected by one to three ground surveyors for each 200 m segment along the survey area (Table 3). Segment lengths (and widths) were approximated in the field using a laser range finder (TruPulse 200X Laser Technologies) and were separated by habitat unit breaks (e.g., between a pool and riffle). Each segment was assigned a channel type (Montgomery and Buffington 1997). Two measures of bankfull width, wetted width, and thalweg depth were measured at the 50m and 150m interval of the segment. Maximum depth was measured in the deepest area of the segment. Depths were measured with a stadia rod (maximum measure = 4 meters). Dominant substrate (>50% of wetted area) was determined visually using substrate criteria developed by Cummins (1962). Surveyors enumerated large woody debris (LWD) and pools for each segment.

Table 3. Habitat measurements collected in each survey reach.

Name	Definition	Source
Wetted width	Measured at 50m downstream from start of reach	
Lower wetted width	Measured at 150m downstream from start of reach	
Upper bankfull width	Measured at 50m downstream from start of reach	
Lower bankfull Width	Measured at 150m downstream from start of reach	
Pool count	Number of depressions at summer low flow expected to retain water in the absence of stream flow (longer than wide, > 0.5m depth)	
Maximum depth	Maximum depth in reach	
Channel Type	Cascade, Step-Pool, Plane Bed , Forced Pool-Riffle, Pool-Riffle, Dune ripple, Canyon, Spring-fed headwaters[a]	(Montgomery and Buffington 1997)
Dominant Substrate	Primary substrate characterizing wetted area in reach (Silt, Sand, Gravel, Cobble, Boulder, Bedrock)	(Cummins 1962)
Large woody debris (LWD)	The number of logs greater than 30cm in diameter and greater than 2m in length occurring in (or suspended ≤ 0.5 meter directly above) the wetted area of the segment	(Garwood and Ricker 2013)

[a] "Spring-fed headwaters" channel type was added in addition to channel types referenced in Montgomery & Buffington 1997, but this channel type was not observed in the South Fork Newaukum River.

Seven habitat metrics were calculated to describe each study reach (Table 4). Using values from segments within each reach, we calculated the proportion of segments classified as pool-riffle channel type, mean wetted widths and maximum depths, large woody debris (LWD) and pool counts per 100m, mean dominant substrate value from a ranking of five ordinal values by substrate coarseness (1= silt, 2 = sand, 3 = gravel, 4 = cobble, 5 = boulder), and the proportion of segments with substrate characterized as bedrock-dominant.

Table 4. Habitat metrics calculated for each survey reach.

Name	Calculation
Proportion pool riffle	Ratio of pool-riffle segments to total segments in reach
Wetted width	Average calculated from all measures in reach
Maximum depth	Average calculated from all measures in reach
Large Woody Debris Density	Average LWD frequency per 100 m of all segments in reach
Pool Density	Average pool frequency per 100 m of all segments in reach
Dominant substrate	Average of ordinal substrate ranking of all segments in reach (1= silt, 2 = sand, 3 = gravel, 4 = cobble, 5 = boulder)
Proportion bedrock substrate	Ratio of segments with bedrock as the dominant substrate to total segments in reach

Fish Surveys

To describe spatial and temporal patterns in fish distribution, fish count data were collected over four discrete spatially continuous snorkel surveys from the upper to lower extent of the study area between May and September 2016. The four survey periods were selected to represent seasonal environmental conditions reflective of late spring (May 2-17) characterized by relatively higher stream flows and cooler temperatures, summer (June 30 to July 19; August 2-17) characterized by flows at or near annual base levels and warmer temperatures, and early fall (September 8-22) characterized by increasing flows and cooler temperatures (Table 5). Hereafter, we will refer to the survey periods as “May,” “July,” “August,” and “September.”

Table 5. Survey periods, dates, and mean (±SD) stream flow (cubic feet per second, "cfs"), 2016. Stream flow measured from USGS 12025000 at Newaukum River rkm 8.0, roughly 11 km downstream of the lower extent of the study area. Approximately half of the stream flow measured at this gage comes from the South Fork Newaukum River. Additional detail on flows during the survey period is provided in Appendix A.

Survey Period	Dates	Stream Flow (cfs)
May	May 2 – 17	134.8 (±20.3)
July	June 30 – July 19	105.5 (±20.2)
August	August 2 – 17	55.2 (±10.6)
September	September 8 - 22	57.0 (±19.7)

For each survey, two snorkelers moved downstream through each of the 200 m segments (in which habitat data were collected) collecting fish counts on wrist-mounted dive slates. All fish were identified to species and size category. Salmon and trout were further identified to origin based on the presence (wild) or absence (hatchery) of an adipose fin. Assignment to size categories was based on calibration to length on a snorkeler's hand or arm and was necessarily approximate. If origin could not be determined, the salmonid was recorded as unknown origin and the ratio of marked to unmarked salmonids within the survey segment was partitioned to the unknown counts to create an adjusted count value. If a ratio was not obtainable within the segment, the proportion was calculated by averaging the proportion of marked to unmarked salmonids from the adjacent upstream and downstream segments. All counts reported in the results refer to the adjusted count value.

Due to the timing and duration of our study, some age class assignments were based on both fork length and survey period (Appendix B). Across surveys, all juvenile salmon were considered subyearlings based on observed fork lengths (FL) less than 90 mm and were classified as "Coho 0+," and "Chinook 0+." The exception to this was juvenile coho observed in the May snorkel which were close to 90 mm but displayed clear signs of smoltification, e.g., silver appearance and fading or no parr marks. These fish were classified as coho 1+ smolts. In the field, juvenile trout were not identified to species due to difficulty distinguishing between juvenile steelhead and cutthroat (*O. clarkii*) underwater. However, supplemental seine and electrofishing efforts indicated that trout within the study area were primarily *O. mykiss*, therefore from hereafter we refer to juvenile trout observations as steelhead, acknowledging that we don't fully know their disposition (resident, anadromous) at the juvenile life stage. Trout observations were classified as "Steelhead 0+" and "Steelhead 1+" based on length and survey period. In each survey there were noticeably two size categories of trout parr and we used this observation in addition to life history information and summer growth considerations to classify trout by size across the study period. For example, some Steelhead 1+ in the May snorkel survey could be similar in size to steelhead 0+ in September (Appendix B). Emergent trout fry (< 45mm FL) predominantly occupy shallow margin habitat early in ontogeny, which coincided with our late spring and to a lesser extent summer snorkel surveys, and were not enumerated because such habitat is not conducive to snorkel techniques. Trout longer than 300 mm (but less than 500 mm) were assumed to be resident (i.e., non-anadromous) life histories. Trout in this category were identified to species underwater when possible and included both rainbow and cutthroat; however, resident trout are reported as a single category in this report.

In addition to salmon and steelhead, fish count data were collected for native fish species including redside shiner (*Richardsonius balteatus*), speckled dace (*Rhininchthys osculus*), longnose dace (*R. cataractae*), northern pikeminnow (*Ptychocheilus oregonensis*), mountain whitefish (*Prosopium williamsoni*), threespine stickleback (*Gasterosteus aculeatus*), and largescale sucker (*Catostomus platyrhynchus*). Speckled dace and longnose dace were combined into a single category ("dace") because of challenges distinguishing these species when snorkeling. Counts of "juvenile northern pikeminnow" included both juvenile (45 - 300mm) and fry (< 45mm) sized individuals. Additionally, juvenile northern pikeminnow fry may have included peamouth (*Mylocheilus caurinus*) as this species could not be distinguished from pikeminnow at this size via snorkeling. Native freshwater mussels including western pearlshell (*Margaritifera falcata*) were present in the South Fork Newaukum River and we recorded presence of mussels for each survey segment but we did not identify species or attempt enumeration. Lastly, fish count data were also collected for non-native centrarchid species encountered and referenced as "bass" and "sunfish." Observations of fish species other than juvenile salmonids and cyprinids are provided in Appendix C.

To minimize potential sources of error of the snorkeling technique, similar protocols were used as described by Winkowski et al. (2018). For example, snorkelers maintained parallel positions to each other when moving through a segment in order to avoid variable detection rates. Following initial survey efforts, we determined that two snorkelers provided sufficient visual coverage of the wetted width throughout the study area. One snorkeler completed all four surveys. A second snorkeler completed three of the four surveys and a third snorkeler completed one of the four. Prior to the start of surveys, multiple days of side-by-side snorkel efforts were conducted to maximize the accuracy of species identification, assignment of size categories, and precision of the fish counts. During each survey period, horizontal visibility was quantified at the start and end of each survey day. Visibility measurements were obtained by a snorkeler slowly moving downstream towards a secchi disk until the black and white markings of the disk became distinguishable at which time the distance between the snorkeler and the secchi disk were measured with a range finder. Visibility measurements were averaged for each day. We used a linear regression to evaluate whether total daily fish counts were correlated with daily visibility for each survey period. Count data were log-transformed prior to analysis.

Fish assemblages were summarized by survey period for the two major taxonomic groups of focus: salmonid and cyprinid. The proportion of total counts within each survey segment was calculated for each taxonomic group. Species and size class categories included in the salmonid counts included: steelhead 0+, steelhead 1+, coho 0+, and Chinook 0+. Species and size classes included in the cyprinid counts included: adult dace, adult redside shiner, and adult and juvenile pikeminnow. Adult salmon and steelhead were not included in this analysis; their counts were several orders of magnitude lower than the juvenile salmonid counts and their distribution in the study reaches was likely to be influenced by migrating, holding, or spawning behavior rather than rearing and competition. Cyprinid fry (dace, redside shiner) were also excluded from this analysis. Although cyprinid fry counts provided valuable information about rearing locations for these species, the fry counts were extremely high, skewing the interpretations of spatial patterns in the survey area. Furthermore, cyprinid fry were too small (majority < 35 mm) to ecologically compete with the species and size classes of fish in this part of the analysis.

To compare fish assemblages among surveys, we assigned each 200 m segment to one of three categories - low ($\leq$ 24.9 %), medium (25.0 – 75%), and high proportions ($\geq$75.1%) of juvenile salmonids (versus cyprinids). The proportion of segments in each fish assemblage category was compared among survey periods in four color-coded maps of the study area and was compared among reaches and survey periods using a bar plot. A summary of the location (mean, standard deviation of river kilometers) of segments assigned to each fish assemblage category in each survey period is provided in Appendix D.

We conducted separate analyses to evaluate whether fish assemblages in each survey reach differed among survey periods and whether fish assemblages in each survey period differed among survey reaches. For each survey period, we used a chi-square test to evaluate whether the fish assemblages (i.e., counts of low, medium, and high segments) differed among reaches. For each survey reach, we used a chi-square test to evaluate whether the fish assemblages (i.e., counts of low, medium, and high segments) differed among survey periods. For each analysis, if no segments were assigned to a specific fish assemblage category, that category was omitted and the other two categories were compared. If no segments were assigned to two of the three categories (e.g., a reach was characterized by 100% high salmonid category across survey periods), no analysis was performed.

Fish densities (count per 100 m) of salmonid (juveniles) and cyprinid species were calculated for all survey segments and averaged for each reach and survey period. We used a generalized linear mixed effects model to test whether fish densities differed by survey reach and survey period (Zuur et al. 2009). Survey reach, survey period, and a reach by survey period interaction were included as fixed factors and segment was included as a random effect. Fish density was the response variable and each species was included in a separate analysis. We used a negative binomial distribution because the data were overdispersed when fit with a Poisson distribution. Mixed effects model analyses were conducted using the lme4 package (Bates et al. 2014) and the dispersion metric was calculated the blmeco package (Korner-Nievergelt et al. 2015) in R v. 3.4.0 (R Core Team, 2017).

Movements of Juvenile Salmon and Steelhead

We monitored movements of juvenile salmon and steelhead at five stationary PIT detection arrays throughout the summer and early fall (Figure 1). Fish were captured, tagged, and released from six capture sites within the study area (Figure 1). Capture sites in reach R2.3, R3.4, and R4.5 were located roughly in the center of each respective reach, approximately 2.2 - 4 km from the nearest PIT detection array. Due to the larger spatial extent of reach R1.2, two capture sites were selected in upstream and downstream locations of the reach and the center of each site was approximately 3 km from closest PIT detection array. Because of the smaller spatial extent of R5, the capture site in R5 was 1 kilometer upstream from the upper most PIT detection array. Fish collection efforts extended up to 500 m upstream and downstream from each capture site location in effort to maximize sample sizes in each reach.

Juvenile coho, steelhead, and Chinook were collected via a combination of seine-netting and backpack electrofishing. Tagging events occurred over a two-week period from June 30 to July 13, 2016. Two additional tagging events occurred on July 25 in R2.3 and July 27 in R4.5 to increase sample sizes of tagged steelhead and coho, respectively, in those study reaches. All captured salmonids ≥ 65 mm showing no adverse signs from capture or previous injuries were anaesthetized with tricaine methanesulfonate (MS222), measured for fork length (mm) and weight (g), and implanted with a PIT tag (12.5mm, 134.2 kHrz; Biomark Inc) in the peritoneal cavity (Winkowski and Zimmerman 2017). Tagged fish were carefully placed in a perforated live-well in a well-shaded location within the stream and held until recovered (approximately 30-60 minutes). Tagged fish were released in close proximity to their location of capture.

PIT detection arrays were installed between June 13 and June 20, 2016 in accordance with the methods and equipment described by Winkowski and Zimmerman (2017). All PIT detection array sites consisted of two rows of antenna separated by roughly 3-5 m which allowed the direction of fish movement to be assigned (Figure 2). All PIT detection arrays were powered by solar. The configuration of PIT detection array sites A1-A4 consisted of two rows of 2-3 antenna each spanning the width of the channel and connected to a Biomark IS1001-24V antenna control node [ACN], and a Biomark IS1001-MST master controller. The initial PIT detection array configuration at A5 consisted of rows of two antenna connected to RM310 reader boards and a QST QuBE Antenna Multiplexing Controller/Datalogger. Technical complications with the configuration prompted a transition to an ACN PIT detection array system, similar to the other four arrays, on July 26, 2017. Damaged CAN Bus cable at PIT detection array A2 resulted in failure of two of the six antennas between August 7 and August 11.

After selecting the general locations for PIT detection arrays to delineate study reaches by landscape characteristics, final site selection was necessarily determined by landowner access, adequate sun exposure for solar power, and physical stream characteristics. Stream characteristics included homogenous gravel substrate, homogenous depth cross section (< 1.0 m), and a wetted width less than 18 m. If the wetted width was wider than the antenna rows, boulders or sandbags were used to deter movement around the antennas. Fence panels were installed at the edges of the A5 PIT detection array to direct fish over the antennas. Lastly, we selected locations which appeared to be relatively featureless with respect to habitat complexity, e.g., no large woody debris or other cover, to reduce the likelihood of extended fish use surrounding the PIT detection arrays.

Figure 2. Passive integrated transponder (PIT) detection array (A1) in South Fork Newaukum River.

Operation of PIT detection array sites commenced between June 23 and July 11, 2016 and arrays were in continuous operation until removal, which occurred between September 23 and September 29, 2016. The start of data collection for each PIT detection array was defined as the day following tagging events in the adjacent reaches and the end of data collection occurred during the last week of September upon the conclusion of the study (average of 79 ±3.7 days). To ensure continuous functionality of PIT detection array systems, weekly inspections were conducted which included assessment of battery charge, detection range of each antenna, and cleaning of debris. Detection range varied from 0.3 - 0.7 m among PIT detection arrays and generally extended above the water surface at each site. In addition, a virtual test tag (VTT) was programmed to communicate an electronic signal from the master controller to each antenna at continuous one-hour intervals. A successful VTT 'detection' indicates antennas are functioning properly to detect tags.

Data obtained from each PIT detection array included individual tag numbers with date and time of detection. Each detection was categorized as either a complete detection (direction of movement could be assigned) or a partial detection (fish detected but direction of movement could not be assigned). Direction of movement (i.e., upstream and downstream) was assigned based on two criteria: 1) a tagged individual must be detected at both antenna rows at a given detection array within 60 minutes, and 2) a tagged individual must not record a partial or complete directional movement back to its original location at the same PIT detection array within 60 minutes from previous directional detection (Winkowski and Zimmerman 2017).

We calculated detection efficiency (*DE*) from the number of detected and missed tags at each PIT detection array site (Connolly et al. 2008). Missed tags (*M*) were tagged fish with a known location on either side of a PIT detection array site (based on tagging location or previous detection) and detected at another PIT detection array without being detected at the array site in question. For each PIT detection array site (*i*), the detection efficiency was the number of detected tags (D) divided by the sum of the detected and missed tags over the study period:

(1) $$DE_i = \left(D_i^{up} + D_i^{down}\right) \Big/ \left(D_i^{up} + M_i^{up} + D_i^{down} + M_i^{down}\right)$$

We used a chi-square test to evaluate whether the ratios of detected to missed tags differed among PIT detection array sites. If these ratios did not differ among PIT detection array sites ($\alpha = 0.05$), the data were combined to estimate an overall detection efficiency for the entire system of five PIT detection arrays.

We summarized movement data in terms of general movement patterns, movements by location, and directional movements by season and location. General movement patterns included the proportion of fish detected at least one day, the proportion fish detected on multiple days, and the number of days each tagged fish was detected. Additional general movements were summarized by four categories: 1) detection period, 2) maximum displacement, 3) total displacement, and 4) net displacement. Detection period is defined as the number of days between first and last detection of an individual fish. Maximum displacement is defined as the maximum distance between the capture site and detection on one of the five PIT detection arrays. Total displacement is defined as the cumulative distance traveled based on capture site and detection history among PIT detection array sites. Net displacement was a binary variable; individuals were scored based on whether the last detection for that fish was a movement into (0) or out of (1) the study reach where the fish was originally tagged. Individuals needed to be detected at a minimum of one antenna at a PIT detection array to be included in the summary of general movement behaviors.

For coho and steelhead, we compared movements among locations in terms of the proportion of fish detected versus undetected from each capture site and the proportion of days of which a fish was detected at each PIT detection array. For the first analysis, we used separate chi-square tests for each species to determine whether the observed ratios of detected to undetected fish differed among the five capture sites (combining both capture sites in R1.2). For the second analysis, we used separate chi-square tests for each species to determine whether the ratio of the total number of days with and without detections differed among PIT detection array sites ("detection activity"). A minimum of one fish detection was needed for a day to be included in this analysis.

Finally, we compared directional movements by season (i.e., summer : July and August, early fall: September) and location. Seasonal time frames were assigned based on the similar warm stream temperatures and day lengths in July and August and cooler stream temperatures and shorter day lengths observed in September. There was minimal difference observed in stream flows during these three months (Table 1). The first analysis compared upstream and downstream movements between seasons throughout the entire survey area. For each species, movements were combined over the entire survey area (all PIT detection arrays combined) and a chi-square test determined whether the ratio of upstream versus downstream movements differed between summer and early fall. The second analysis compared upstream versus downstream movements among locations in each seasonal time frame. For each species and season (summer, early fall), a chi-square test was used to determine whether the ratios of observed upstream versus downstream movements differed among the five PIT detection array sites.

Results

Stream Temperatures

We observed spatial and temporal patterns of stream temperatures in our study area (Figure 3). In all months, we observed an upstream–downstream gradient in mean, maximum, and minimum daily temperature, and the proportion of time temperatures were ≥ 18°C. The coolest mean temperatures occurred in upstream locations and warmest mean temperatures in downstream locations (Figure 3 A-D). Spatial patterns were consistent across months however the warmest months were August and July and the coolest were May, June, and September. In June, July, and August, the proportion of time temperatures were ≥ 18°C was greatest in downstream reaches and minimal in upstream reaches (Figure 3D). In July and August, temperatures throughout the survey area were ≥ 18°C more frequently than all other months, except in the upstream most reach (R5) where temperatures never exceeded 18°C throughout the duration of the study. In May and September, temperatures across the entire study area rarely exceeded 18°C.

Spatial patterns observed for the range in daily temperatures differed from the other temperature metrics (Figure 3E). The narrowest daily temperature ranges were observed in the upper (R5 and R4.5) and lower (downstream extent of R1.2) reaches of the study area and the widest daily temperature ranges were observed in downstream to central locations of the study area (R2.3 and upstream portions of R1.2). The spatial pattern was consistent across months but in September mean daily ranges decreased by 1-1.5°C across the study area. The greatest ranges in daily temperature were observed in August.

August temperatures were variable among the five study reaches and displayed a similar upstream (cold) – downstream (warm) pattern as described above (Table 6). Daily mean, maximum, and minimum temperature varied roughly 1.5 fold and were warmest in R1.2 and coolest in R5. Daily range in temperature varied by 2.1˚C among reaches and was greatest in R2.3 (4.8˚C) and least in R4.5 and R5 (2.7˚C). August stream temperatures never exceeded 18˚C in the two upstream most reaches (R4.5 and R5), rarely exceeded 18˚C in R3.4 (10%), more commonly exceeded 18˚C in R2.3 (30%), and most often exceeded 18℃ in R1.2 (70%).

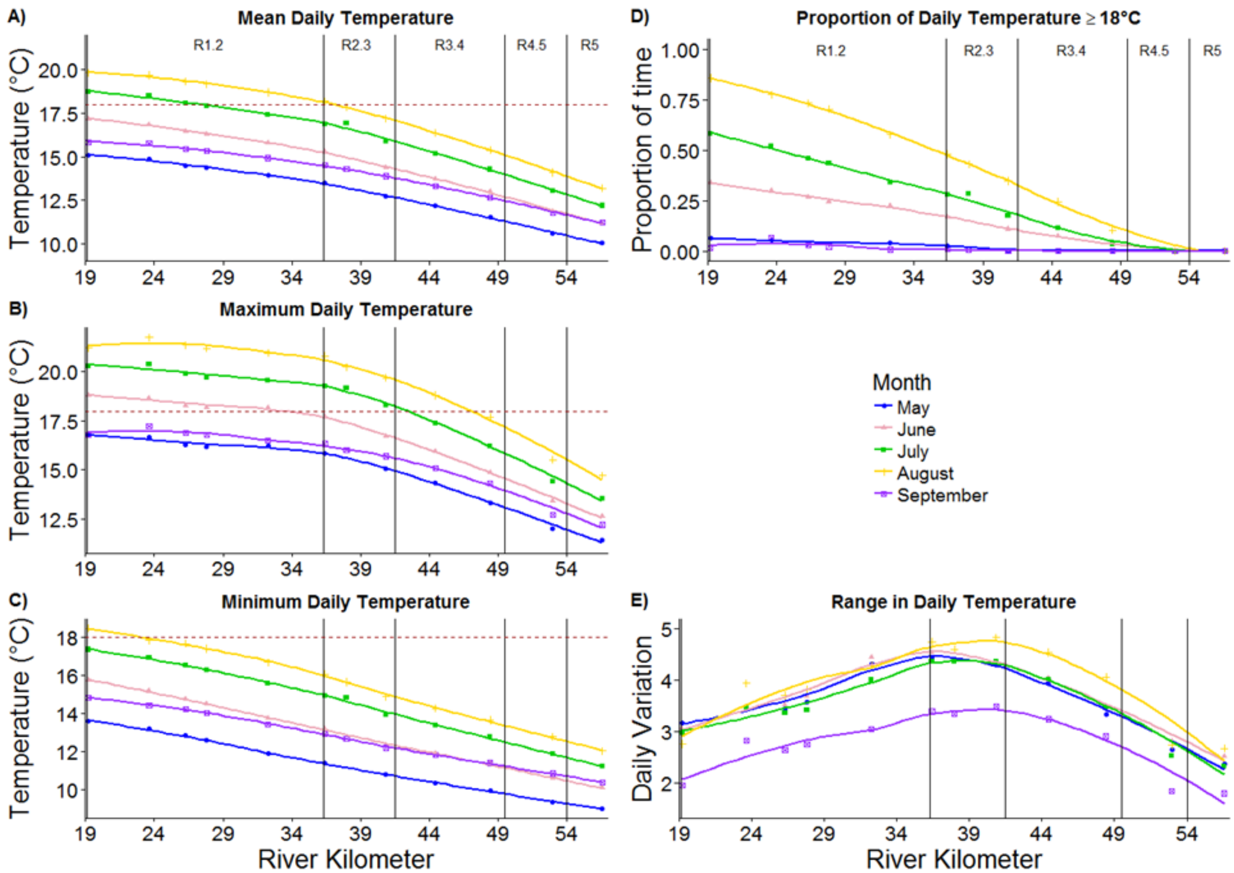

Figure 3. Temperature (˚C) of the South Fork Newaukum River by river kilometer and month, 2016. Temperature metrics displayed include (A) mean daily temperature, (B) maximum daily temperature, (C) minimum daily temperature, (D) proportion of time temperatures were equal to or greater than 18˚C, and (E) daily range in temperature. Vertical lines demarcate study reaches (R1.2, R2.3, R3.4, R4.5, and R5 respectively in an upstream direction). A dashed red horizontal line at 18˚C is displayed as a reference on panels A, B, and C.

Table 6. Mean (± SD) August stream temperature (˚C) in five study reaches of the South Fork Newaukum River, 2016.

Temperature Metric	R1.2	R2.3	R3.4	R4.5	R5
Mean daily	19.2 (±1.3)	17.2 (±1.3)	15.4 (±1.0)	14.1 (±0.9)	13.2 (±0.8)
Mean daily minimum	17.4 (±1.0)	14.9 (±0.9)	13.6 (±0.8)	12.8 (±0.7)	12.0 (±0.6)
Mean daily maximum	21.2 (±1.8)	19.7 (±1.9)	17.7 (±1.7)	15.5 (±1.2)	14.7 (±1.1)
Mean daily range	3.8 (±1.2)	4.8 (±1.6)	4.1 (±1.4)	2.7 (±0.8)	2.7 (±0.8)
Daily proportion ≥18˚C	0.7 (±0.3)	0.3 (±0.2)	0.1 (±0.1)	0.0 (±0.0)	0.0 (±0.0)

Habitat Among Study Reaches

LWD and pool density were variable among the five reaches whereas other metrics were less variable (Table 8). LWD density varied roughly 3-fold among reaches and was least in R2.3 (1.7 LWD per 100 m) and the highest in R4.5 (4.9 LWD per 100 m). Pool density was greatest in R4.5 (1.7 pools per 100 m) and relatively similar across the other four reaches (range 0.9 – 1.2 pools per 100 m). Mean wetted widths were similar among the downstream four reaches (12.1 – 13.2 m) but was narrower in R5 (9.1 m). Average maximum depths were generally similar among reaches (1.2 – 1.7m). Gravel and cobble were the dominant substrates across the study area (88.8% of observations). Substrate in upstream reaches (R4.5 and R5) was slightly coarser compared to downstream reaches. Pool-riffle channel type was exclusively observed in R1.2, R2.3, R3.4, and R4.5 and characterized the majority (87.5%) of R5. Plane bed channel type was observed in R5 only (12.5%).

Table 7. Mean (±SD) habitat metrics in five study reaches of the South Fork Newaukum River, August 2016. Larger dominant substrate ranks correspond to coarser substrate. “Pool-riffle channel type” represents the proportion of segments classified as pool-riffle within each reach.

Habitat Metric	**R1.2**	**R2.3**	**R3.4**	**R4.5**	**R5**
Pool-riffle channel type	100%	100%	100%	100%	87.5%
LWD/100m	4.0 (±5.3)	1.7 (±1.9)	3.8 (±5.5)	4.9 (±5.4)	2.7 (±4.7)
Wetted Width (m)	12.1 (±3.0)	13.2 (±3.7)	12.7 (±3.5)	12.4 (±3.4)	9.1 (±3.8)
Max Depth (m)	1.7 (±0.6)	1.3 (±0.4)	1.4 (±0.4)	1.4 (±0.4)	1.2 (±0.3)
Pool Count/100m	0.9 (±0.5)	1.0 (±0.5)	1.2 (±0.7)	1.7 (±0.6)	1.2 (±0.5)
Dominant substrate rank	2.9 (±1.1)	3.4 (±0.9)	3.2 (±0.4)	3.6 (±0.5)	4.0 (±0.0)

Fish Among Study Reaches

Snorkel Visibility

Daily fish counts and visibility were not correlated in any survey period (all p-values > 0.05, Table 8).

Table 8. Mean (±SD) visibility measurements (m) obtained across four discrete snorkel surveys in the South Fork Newaukum River, 2016. The range is the minimum and maximum mean daily visibility measurements (m) during each survey period. The p-value reported is the result of linear regression analyses between mean daily visibility and log transformed total daily fish counts for each survey period.

Survey Period	Mean Daily Visibility (±SD)	Range	*p-value*
May	3.5 (±0.6)	2.7-4.8	0.22
July	4.1 (±0.9)	2.9-5.5	0.29
August	4.5 (±1.2)	3.2-6.4	0.24
September	4.2 (±1.1)	2.6-6.1	0.47

Salmonid versus Cyprinid Distribution

Across surveys, observations of juvenile salmonids and cyprinids were highest among all species and represented an average of 89.2% (±13.1) of the total counts. Coho 0+ and adult redside shiners were the most numerically dominant species across survey periods followed by dace and steelhead 0+. Occupancy, abundance, and distribution of all observed fish species and age classes are summarized in Appendix C.

We observed spatial patterns in the numerical dominance of salmonid versus cyprinid species throughout the survey area and patterns were relatively consistent across the study period. For all survey periods, upstream segments in the survey area were consistently characterized by ‘high’ proportions of juvenile salmonids (≥75.1%) whereas downstream segments were consistently characterized by ‘low’ (≤24.9%) or ‘medium’ (25-75%) proportions of juvenile salmonids and, conversely a high or medium proportion of cyprinid species, respectively (Figures 4 and 5). Summary statistics for the locations and stream temperatures associated with each fish assemblage category are provided in Appendix D.

For each survey period, the proportion of segments categorized as ‘low’, ‘medium’, and ‘high’ salmonids differed among reaches and these differences were evident when comparing upstream versus downstream reaches (Figure 6). In May, upstream reaches R3.4, R4.5, and R5 were characterized exclusively by ‘high’ salmonid segments, R2.3 was dominated by ‘high’ segments and some ‘medium’ segments, and R1.2 was dominated by ‘medium’ and ‘low’ salmonid segments ($X^2 = 143.4$ and $p < 0.01$). A similar upstream (high salmonid) – downstream (low salmonid) pattern was evident in July, August, and September ($X^2 = 151.2$ and $p < 0.01$, $X^2 = 186.3$ and $p < 0.01$, $X^2 = 160.2$ and $p < 0.01$, respectively).

The proportion of segments categorized as ‘low’, ‘medium’, and ‘high’ salmonids differed among survey periods for the two downstream reaches (R1.2: $X^2 = 53.7$, $p < 0.01$ and R2.3: $X^2 = 23.8$, $p < 0.01$) but not for the other three reaches (Figure 6). In R1.2 from May through September, the proportion of ‘low’ segments increased from 23.3% to 72.1% and the proportion of ‘medium’ segments decreased from 72.1% to 27.9%. ‘High’ salmonid segments were rarely present in R1.2 for any survey period (4.7 and 1.2% of segments in May and July, respectively, and 0% during August and September). In R2.3, the largest difference in the fish assemblage categories occurred from July to August, when ‘medium’ salmonid segments increased from 30.8% to 73.8% and ‘high’ salmonid segments decreased from 69.2% to 27.0%. In R3.4, no ‘low’ salmonid segments were observed across survey periods and ‘high’ salmonid segments dominated compared to ‘medium’ salmonid segments in all survey periods ($X^2 = 6.0$ and $p = 0.11$). ‘High’ salmonid segments characterized the entirety of R4.5 and R5 for all survey periods.

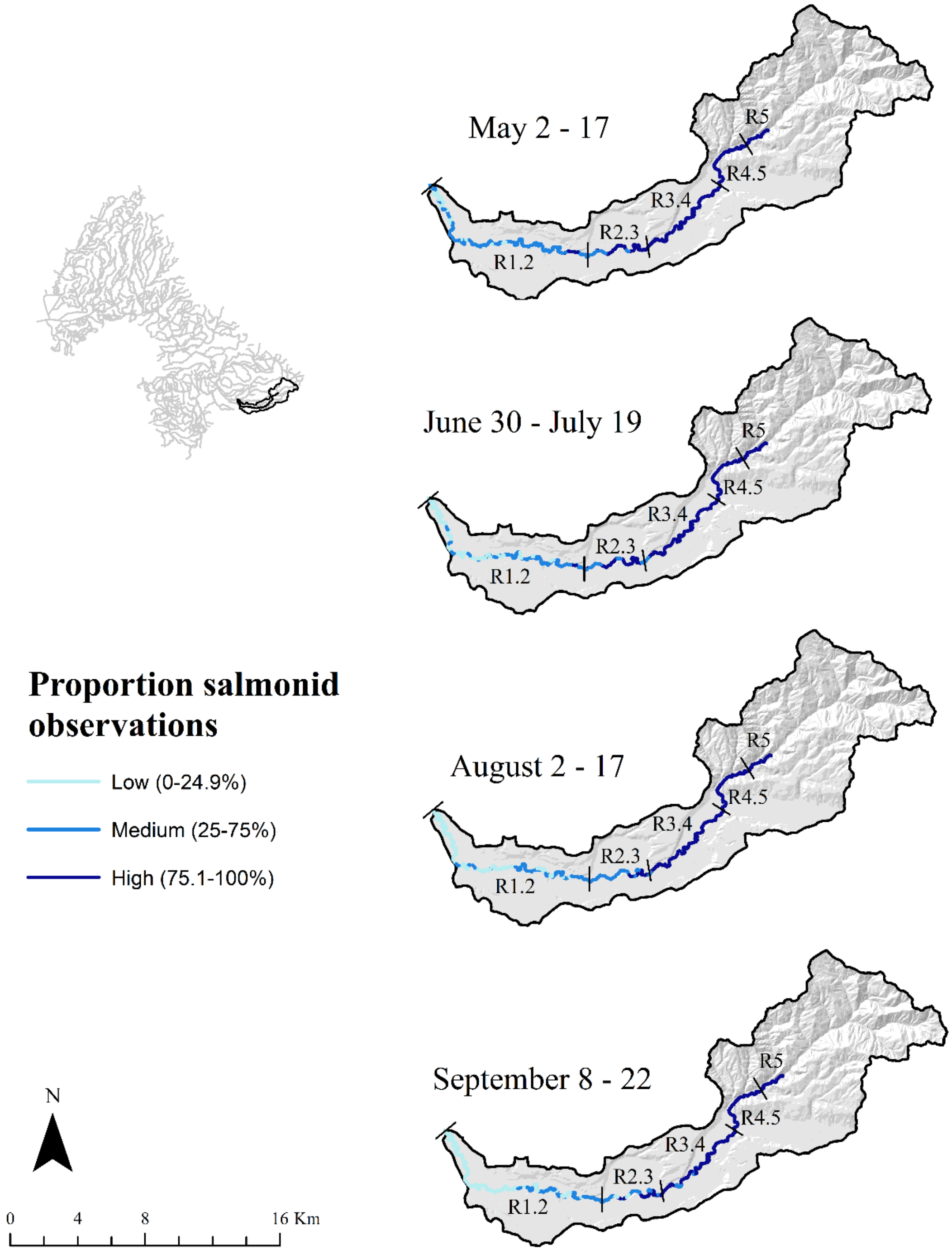

Figure 4. Proportion of salmonids in 200-m segments across four survey periods in the South Fork Newaukum River, May – September 2016. Study reaches are labelled and denoted by intersecting black lines along the survey area.

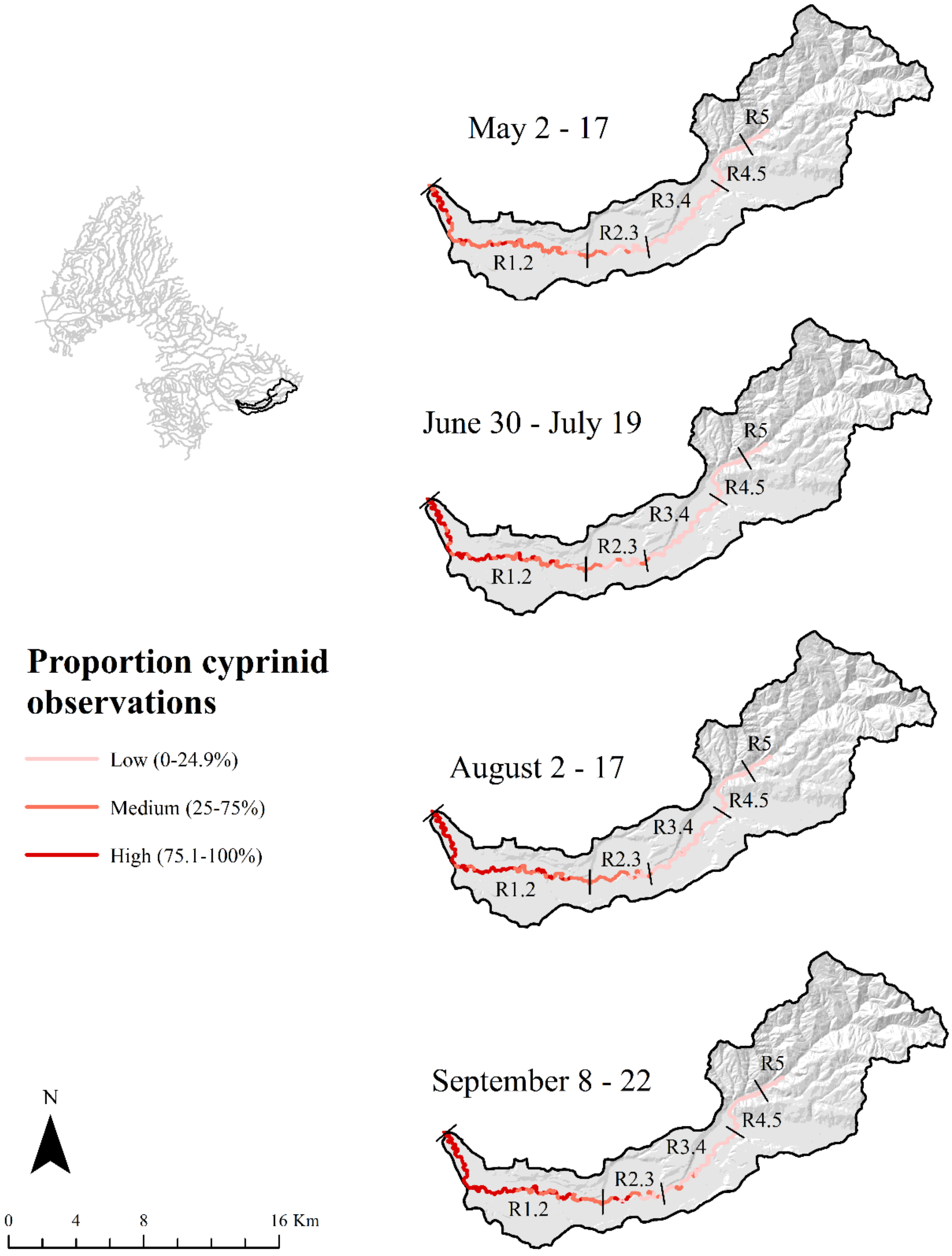

Figure 5. Proportion of cyprinids in 200-m segments across four survey periods in the South Fork Newaukum River, May – September 2016. Study reaches are labelled and denoted by intersecting black lines along the survey area.

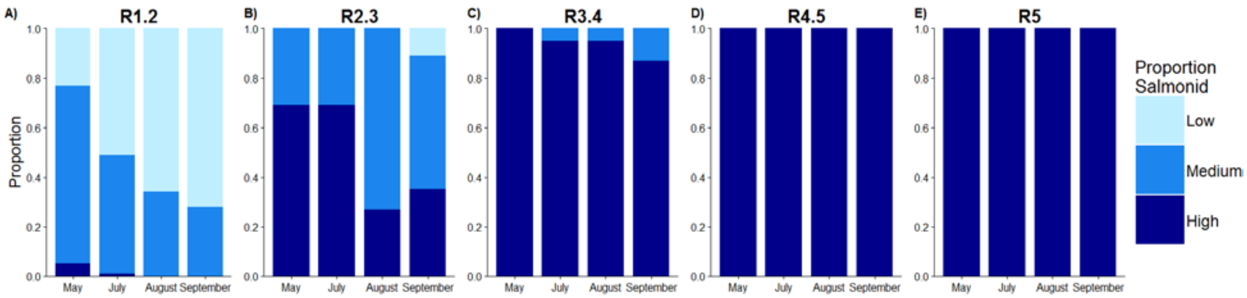

Figure 6. Proportion of 200-m segments categorized as low (0.0-24.9%), medium (25.0-75.0%), and high (75.1-100.0%) proportion salmonids by survey period and study reach (panels A-E) of the South Fork Newaukum River, 2016. R1.2 is the downstream most reach and R5 is the upstream most reach.

Salmonid versus Cyprinid Densities

Coho 0+ densities differed among survey reaches (reach effect, $p << 0.001$) and survey periods (survey period effect, $p << 0.001$), and the pattern among reaches differed over time (reach by survey period interaction, $p << 0.001$). In May, the highest coho 0+ densities were observed in R2.3, R3.4, and R4.5 whereas in July, August, and September, the highest coho 0+ densities were observed in R3.4 and R4.5 (Figure 7). Across survey periods, the lowest coho 0+ densities were observed in R1.2. Coho 0+ densities were similar between July and August in the three upstream-most reaches (R3.4, R4.5, and R5) but decreased between July and August in the two downstream-most reaches (R1.2 and R2.3). From August to September, coho 0+ densities decreased 0.7 to 3.2-fold across reaches.

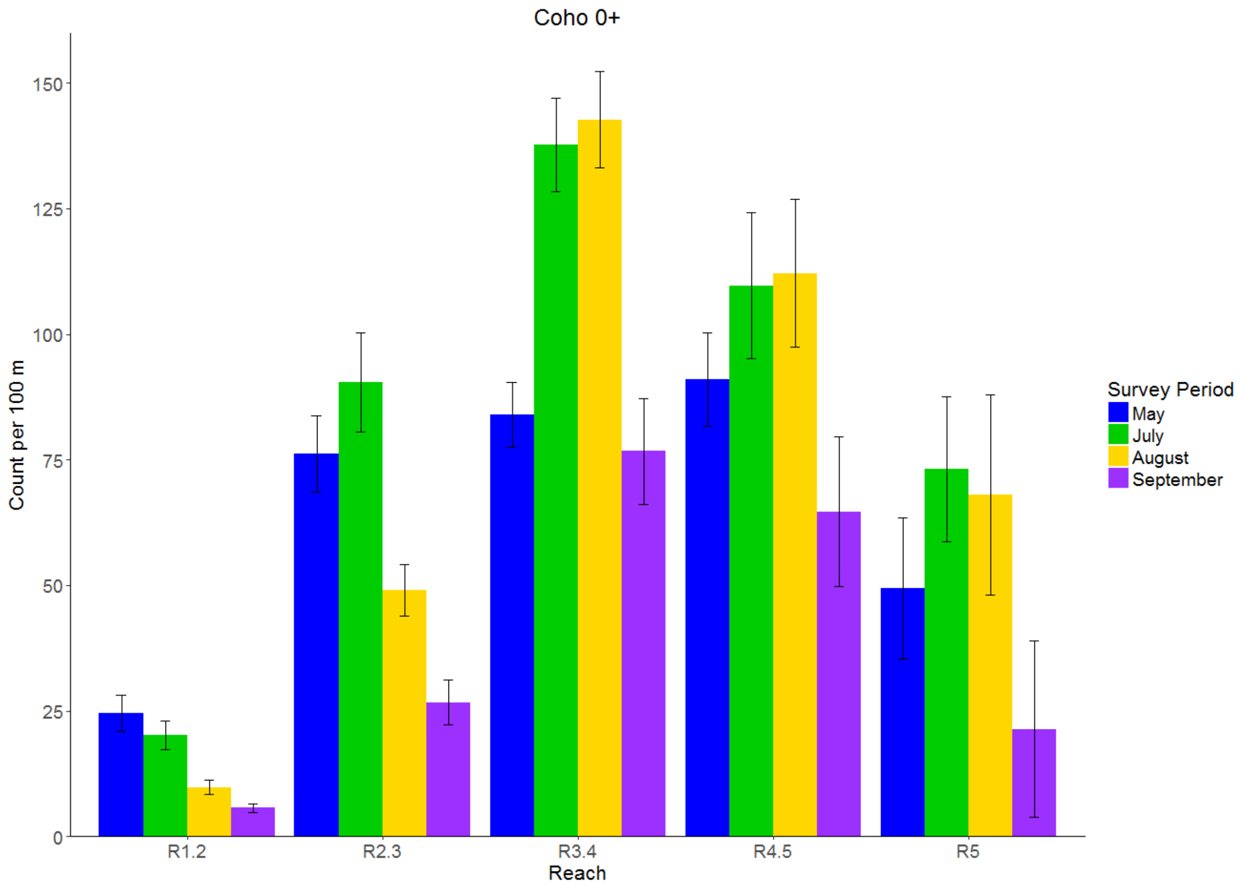

Figure 7. Mean (± SD) juvenile coho densities (fish count per 100 m) by study reach and survey period in the South Fork Newaukum River, 2016 (values provided in Appendix E).

Steelhead 0+ densities differed among survey reaches (reach effect, $p = 0.0003$) and survey period (survey period effect, $p = 0.02$), and the pattern among reaches differed over time (reach by survey period interaction, $p << 0.001$). In May, steelhead 0+ were rare and only observed in R1.2 and R2.3 (Figure 8). In July and August, the highest densities of steelhead 0+ were observed in R2.3. In September, the highest densities of steelhead 0+ were observed in R3.4 and R5. Overall, steelhead 0+ densities increased between May and July in all reaches. From August to September, steelhead 0+ densities decreased by 1.3-2.7 fold across reaches except in R5 where no decrease was observed.

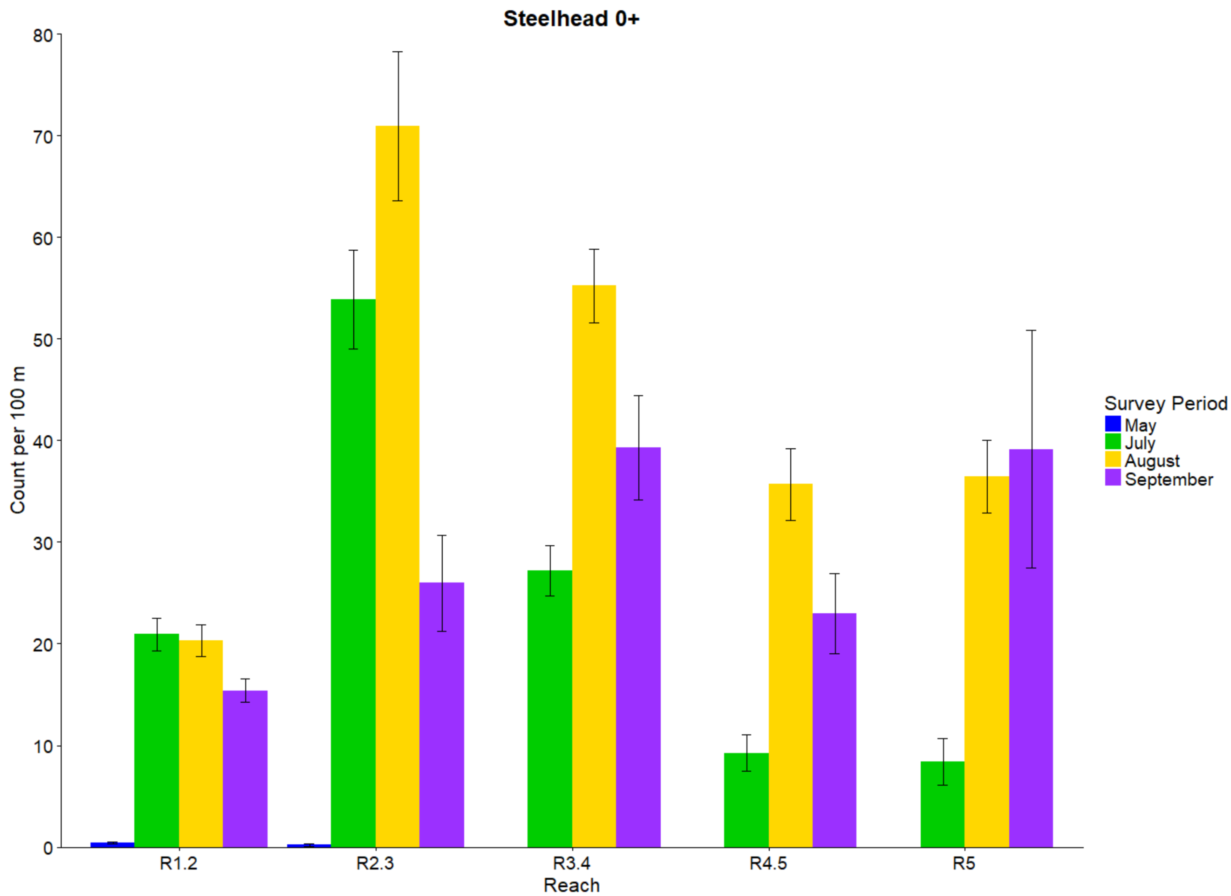

Figure 8. Mean (± SD) juvenile steelhead 0+ densities (fish count per 100 m) by study reach and survey period in the South Fork Newaukum River, 2016 (values provided in Appendix E).

Steelhead 1+ densities differed among survey reaches over time (reach by period interaction, p = 0.006) and among survey periods (survey period effect, $p << 0.001$) but no additional differences among reaches were detected after accounting for the reach by survey period interaction (reach effect, p = 0.4). In May, the highest steelhead 1+ densities were observed in R1.2 and R2.3 (Figure 9). In July, the highest steelhead 1+ densities were observed in R2.3, R3.4, and R4.5. In August, the highest steelhead 1+ densities were observed in R4.5 and R5. In September, steelhead 1+ densities were similar across reaches. From August to September, steelhead 1+ densities generally decreased throughout the survey area except in R1.2 where densities were similar between months.

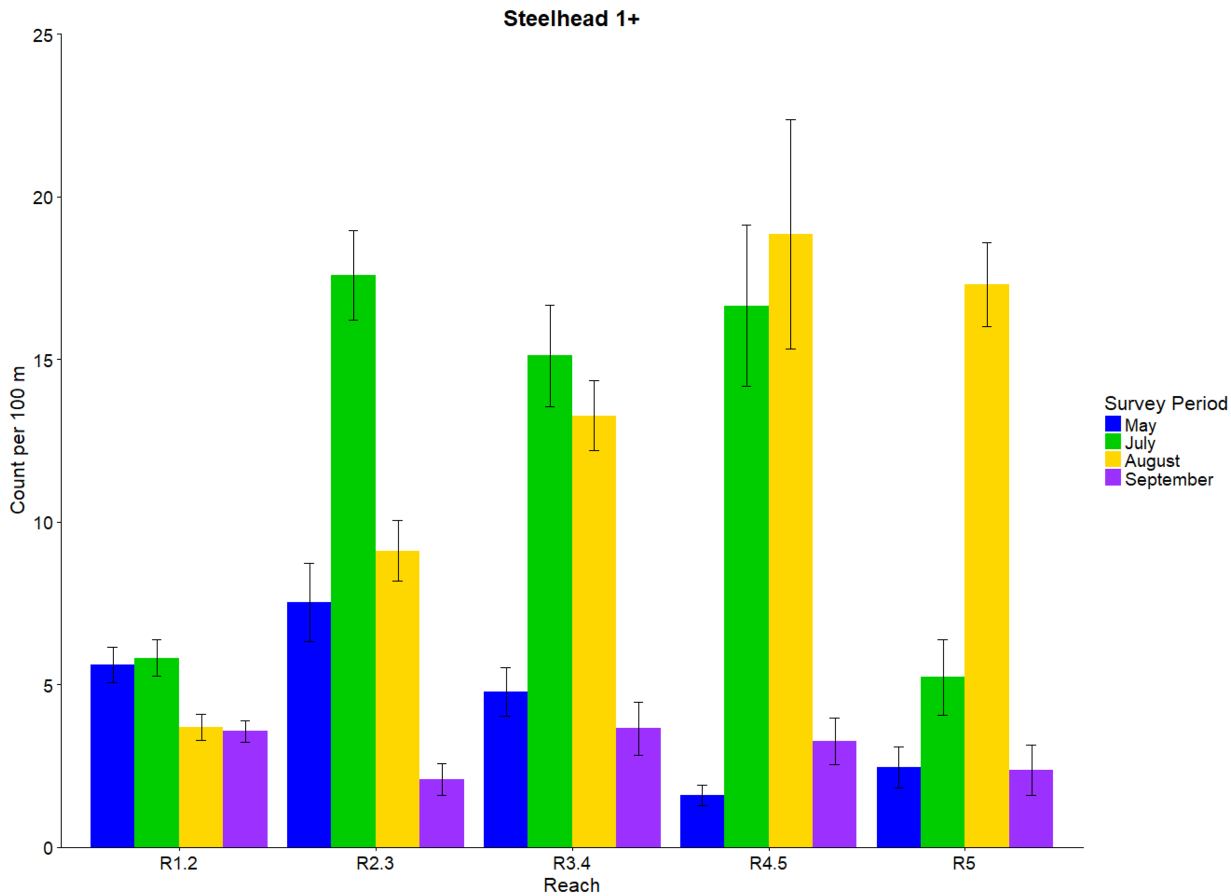

Figure 9. Mean (± SD) juvenile steelhead 1+ densities (fish count per 100 m) by study reach and survey period in the South Fork Newaukum River, 2016 (values provided in Appendix E).

Redside shiner densities differed among survey reaches (reach effect, $p << 0.001$) and survey periods (survey period effect, $p << 0.001$), and the pattern among reaches differed over time (reach by survey period interaction, $p << 0.001$). R4.5 and R5 were not included in the analysis because no observations occurred in these reaches during any survey. Across all surveys, redside shiner densities were highest in R1.2 (Figure 10). In R1.2, redside shiner densities were similar in July, August, and September but lower in May. In R2.3, redside shiner densities increased roughly 40-fold from July to August and were similar in August and September. In R3.4, we did not observe redside shiners in May or July but densities of 3.9 and 5.4 fish per 100 m were observed in August and September, respectively.

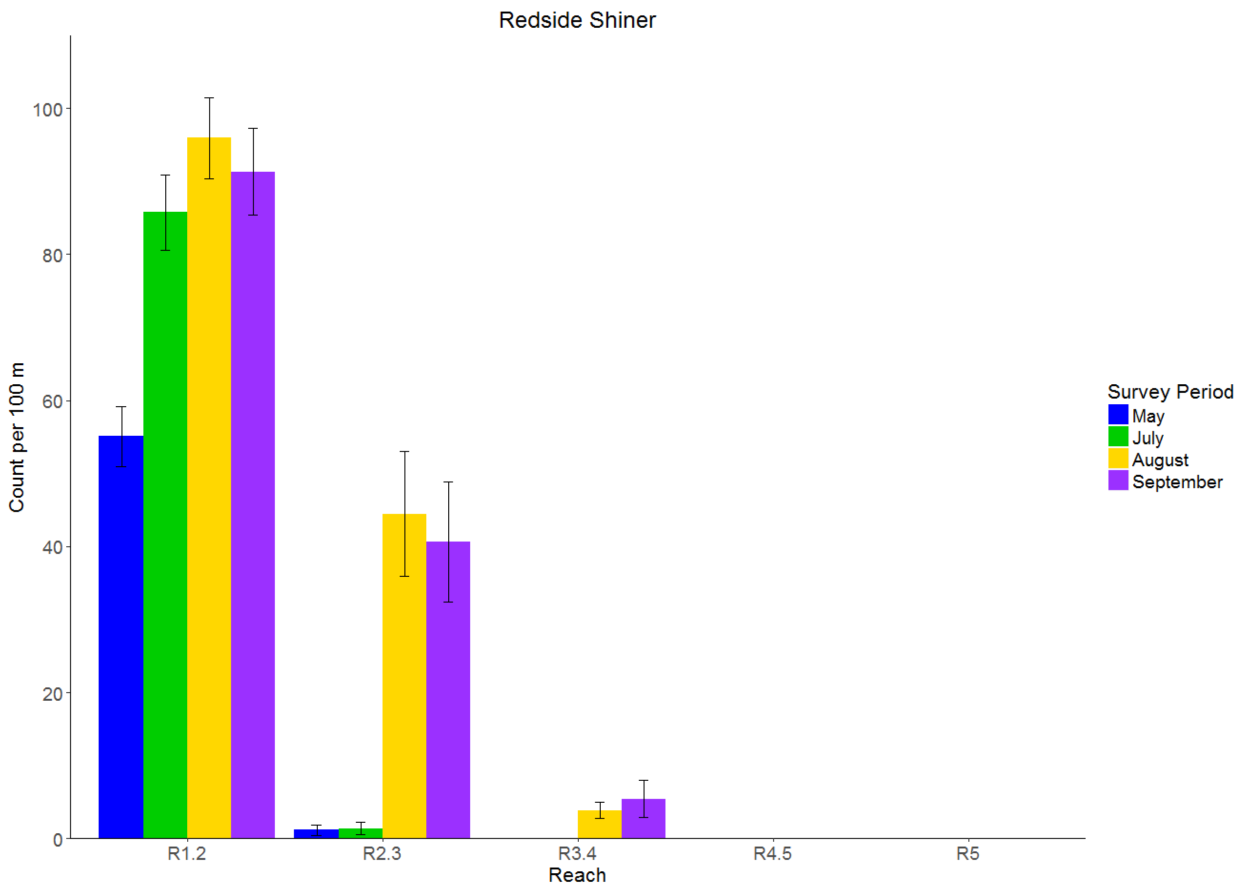

Figure 10. Mean (± SD) redside shiner densities (fish count per 100 m) by study reach and survey period in the South Fork Newaukum River, 2016 (values provided in Appendix E).

Dace densities differed among survey reaches (reach effect, $p << 0.001$) and survey periods (survey period effect, $p = 0.04$), and the pattern among reaches differed over time (reach by survey period interaction, $p << 0.001$). R4.5 and R5 were not included in the analysis as dace were rarely observed in these reaches. In general, dace densities were higher R1.2 and R2.3 compared R3.4 except in September when densities were comparable among R2.3 and R3.4 (Figure 11). Dace densities increased between May and July in R1.2, R2.3, and R3.4 with the greatest increase observed in R3.4 (roughly 5-fold). Dace densities increased in R1.2, R2.3, and R3.4 between July and August, however the magnitude of increase between July and August was smaller (roughly 1 to 2-fold increase in reaches R1.2, R2.3, and R3.4) than that observed between May and July. Dace densities decreased across reaches between August and September with the greatest decrease observed in R2.3 (roughly 4-fold decrease). Although at relatively low densities, dace were observed in R4.5 in August and September (0.3 and 0.1 fish per 100 m, respectively) and R5 in September (0.05 fish per 100 m).

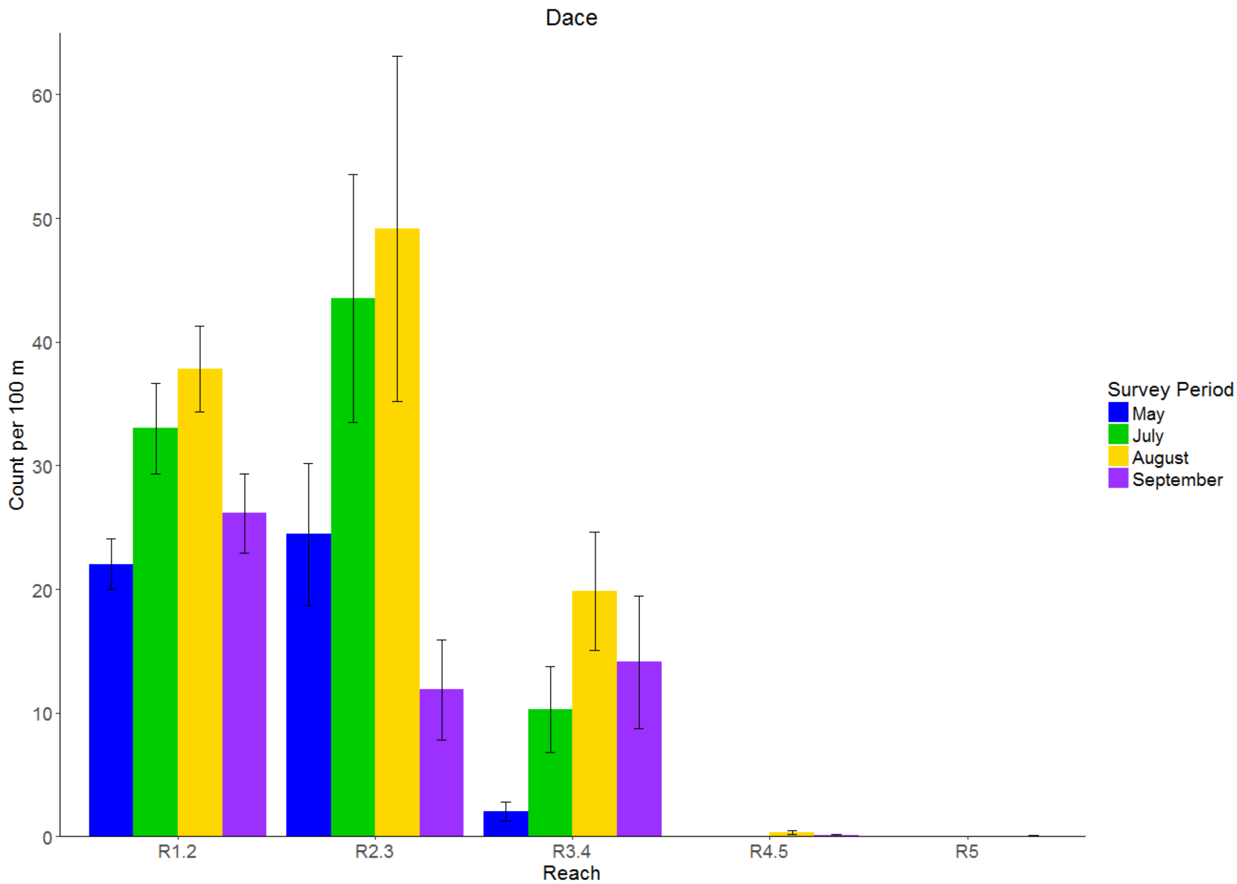

Figure 11. Mean (± SD) dace densities (fish count per 100 m) by study reach and survey period in the South Fork Newaukum River, 2016 (values provided in Appendix E).

Juvenile northern pikeminnow densities differed among survey reaches (reach effect, $p \ll 0.001$) and survey periods (survey period effect, $p \ll 0.001$), and the pattern among reaches differed over time (reach by survey period interaction, $p \ll 0.001$). R4.5 and R5 were not included in the analysis as juvenile pikeminnow were not observed in these reaches. In R1.2, juvenile pikeminnow densities were higher than the other reaches and this result was consistent across survey periods (roughly 1.5 to 8.5-fold higher). In R1.2, densities increased roughly 2-fold between May and July and were similar between the July, August, and September surveys (Figure 12). In R2.3 and R3.4, juvenile pikeminnow were rare or not observed in the May and July surveys but densities in these reaches increased 5 to 6-fold by the August and September surveys.

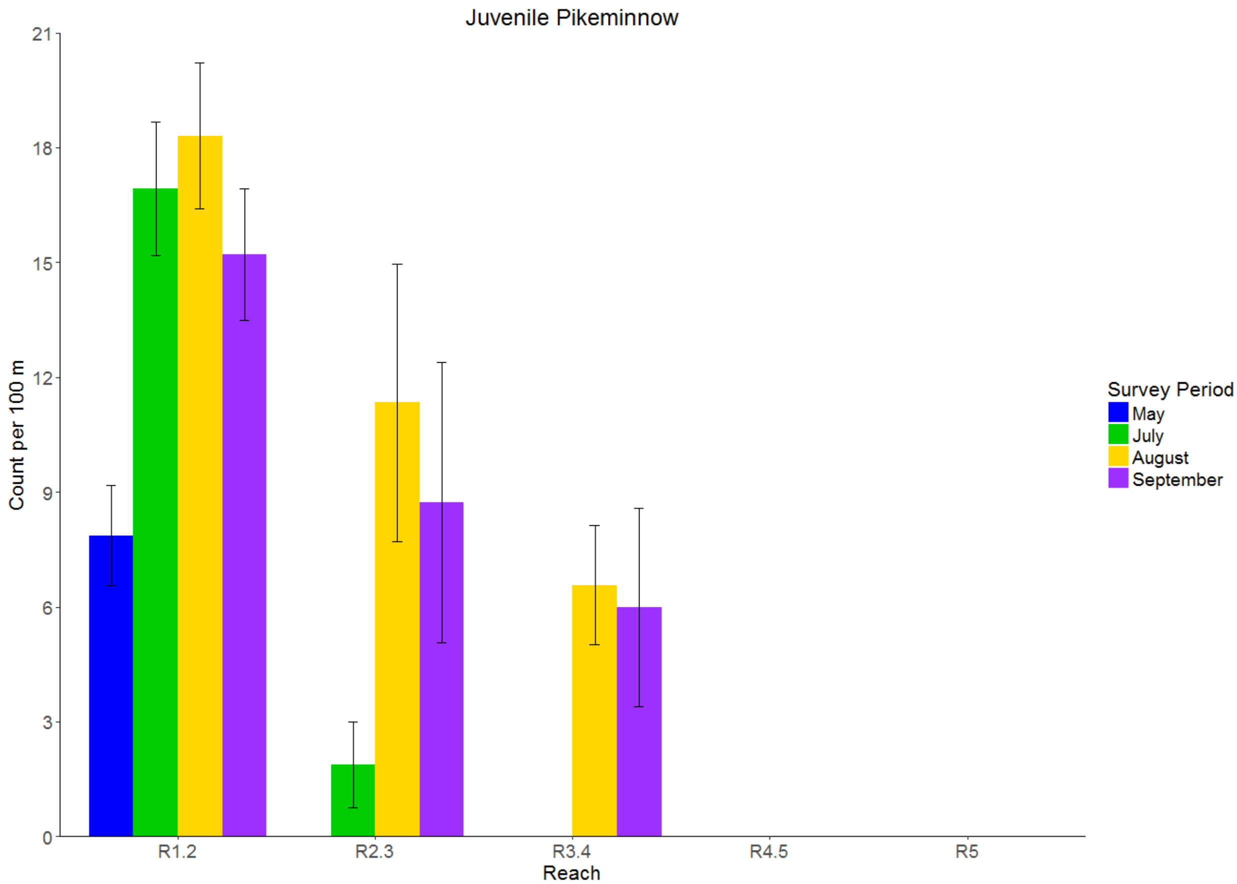

Figure 12. Mean (± SD) juvenile pikeminnow densities (fish count per 100 m) by study reach and survey period in the South Fork Newaukum River, 2016 (values provided in Appendix E).

Adult northern pikeminnow densities differed among survey reaches (reach effect, $p << 0.001$) and between survey periods (survey period effect, $p = 0.004$); differences between the reaches were similar over time (reach by survey period interaction, $p = 0.5$). The three upstream-most reaches (R3.4, R4.5, and R5) were not included in the analysis as adult pikeminnow were rare or not observed in these reaches. Across survey periods, adult pikeminnow densities were 1.5 to 3-fold higher in R1.2 compared R2.3 (Figure 13). In R1.2, adult pikeminnow densities were similar between May and July and between August and September but increased 1.5 fold between July and August. In R2.3, adult pikeminnow were rarely observed in May; however densities increased roughly 1.5-fold between May and July and were then similar between July, August, and September.

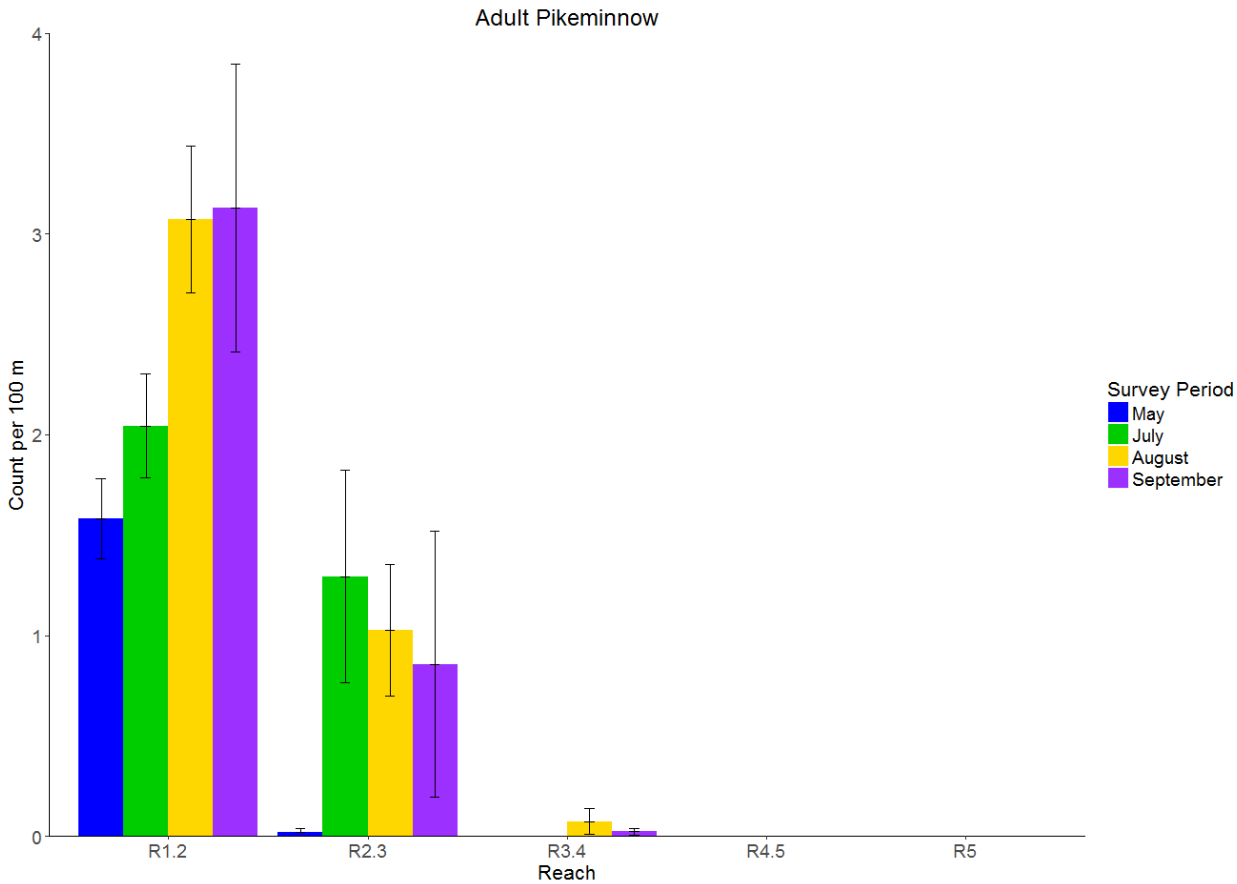

Figure 13. Mean (± SD) adult pikeminnow densities (fish count per 100 m) by study reach and survey period in the South Fork Newaukum River, 2016 (values provided in Appendix E).

Movements of Juvenile Salmon and Steelhead

Tagging Summary

We tagged 1,271 juvenile salmonids between June 30, 2016 and July 27, 2016 at six capture sites (Table 9). Low densities of juvenile salmonids in the downstream most capture site (R1.2) limited the number of individuals captured and tagged in this reach. Of all tagged individuals, coho accounted for 69.1% (n = 878) and ranged in FL from 65-100 mm, steelhead accounted for 30.5% (n = 388) and ranged in FL from 65-275 mm, and Chinook accounted for < 1% (n = 5) and ranged in FL from 85-103 mm.

Table 9. Juvenile salmon and steelhead tagged and released in five survey reaches in the South Fork Newaukum River, 2016. Fish were captured and released in R1.2 on June 30 and July 5; R2.3 on July 6 and July 25; R3.4 on July 7, R4.5 on July 12; and R5 on July 13 and July 27. Mean (± SD) fork length [FL] (mm), weight (g), and Fulton's condition factor ($K = 100 \times W/L^3$) are presented for tagged fish.

Species	Reach	Count	FL (SD)	Weight (SD)	Condition (SD)
Coho	R1.2	113	72.0 (±5.0)	4.4 (±1.0)	1.2 (±0.1)
	R2.3	168	73.7 (±6.3)	5.1 (±1.5)	1.2 (±0.1)
	R3.4	220	73.5 (±6.2)	4.8 (±1.4)	1.2 (±0.1)
	R4.5	224	73.3 (±6.1)	4.6 (±1.3)	1.1 (±0.1)
	R5	153	71.2 (±5.2)	4.3 (±1.1)	1.2 (±0.1)
	Total	**878**	**72.9 (±6.0)**	**4.7 (±1.3)**	**1.2 (±0.1)**
Steelhead	R1.2	117	88.7 (±29.7)	11.3 (±13.0)	1.2 (±0.1)
	R2.3	103	102.3 (±31.4)	15.8 (±13.9)	1.2 (±0.1)
	R3.4	69	111.4 (±34.4)	20.0 (±15.7)	1.1 (±0.1)
	R4.5	43	121.0 (±19.5)	21.0 (±9.3)	1.1 (±0.1)
	R5	56	119.7 (±42.3)	26.5 (±32.3)	1.1 (±0.1)
	Total	**388**	**104.4 (±34.5)**	**17.3 (±18.3)**	**1.1 (±0.1)**
Chinook	R1.2	4	91.8 (±6.3)	9.1 (±2.0)	1.2 (±0.1)
	R2.3	1	103.0	12.1	1.1
	R3.4	0	NA	NA	NA
	R4.5	0	NA	NA	NA
	R5	0	NA	NA	NA
	Total	**5**	**94.0 (±7.2)**	**9.7 (±2.1)**	**1.2 (±0.1)**

Detection Efficiency

Detection efficiency was similar among PIT detection array sites ($\chi^2 = 0.26$, $p = 0.99$) and the combined efficiency for all five PIT detection array systems was 75.9% (Table 10).

Table 10. Detection efficiency at five Passive Integrated Transponder (PIT) detection array sites in the South Fork Newaukum River (A1: rkm 19.2; A2: rkm 37.1; A3: rkm 42.2; A4: rkm 50.2; A5: rkm 54.6) based on detections of PIT-tagged juvenile coho and steelhead, July – September 2016.

Array Site	Detection Efficiency	Detected	Missed
A1	63.6%	7	4
A2	78.1%	57	16
A3	75.9%	85	26
A4	72.1%	44	17
A5	78.3%	47	13
Combined:	**75.9%**	**240**	**76**

General Movement Patterns

A total of 24.1% (n = 212) and 18.3% (n = 71) of juvenile coho and steelhead, respectively, were detected at least once (Table 12). Of those that were detected, 34.9% (n = 74) of coho and 40.8% (n = 29) of steelhead were detected more than one day. The majority of coho were detected on one (65.1%) or two (25.5%) days but some fish were detected on eight separate days (1.2%) (Figure 14). The majority of steelhead were detected on one (59.2%) or two (23.9%) days but some fish were detected on twelve separate days (1.4%) (Figure 14). We tagged very few juvenile Chinook at capture sites in R2.3 (n = 1) and R1.2 (n = 4) and detected three individuals moving downstream at PIT detection arrays A1 and A2 between July 7 and 11th. Due to low sample size, no additional analyses were conducted with Chinook.

Individual movement behaviors were variable for coho and steelhead (Table 11). Average detection periods for coho and steelhead were 6.5 and 4.2 days, respectively. Average maximum displacement for coho and steelhead was 4.5 and 5.5 km, respectively. Average total displacement for coho and steelhead was 5.2 and 7.3 km, respectively. Average net displacement outside the reach of original capture was 71.2 and 54.9% for coho and steelhead respectively.

Table 11. Summary of individual movement behavior for juvenile coho and steelhead in the South Fork Newaukum River, July to September 2016. Total count of detected fish and mean (±SD) detection period (days), maximum displacement (m), total displacement (m), and net displacement from the original study reach (%) are summarized for each species.

Species	Count	Detection Period	Maximum	Total	Net Displacement
Coho	212	6.5 (±12.4)	4.5 (±5.2)	5.2 (±7.5)	71.2%
Steelhead	71	4.2 (±8.2)	5.5 (±5.6)	7.3 (±9.6)	54.9%

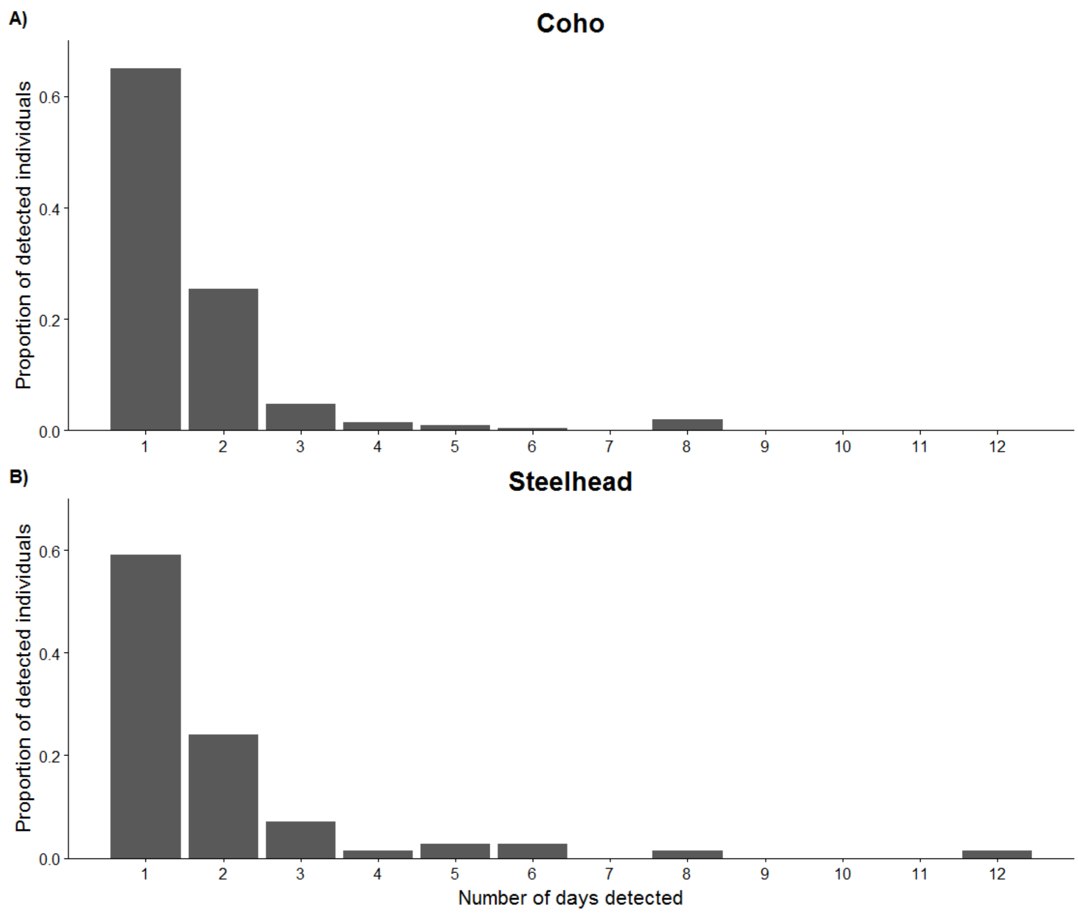

Figure 14. Number of days that tagged juvenile coho salmon (A) and steelhead trout (B) were detected at PIT array sites in the South Fork Newaukum River, June – September 2016.

Movements by Location

For both coho and steelhead, the ratio of detected and undetected fish differed among capture sites (coho: $\chi^2 = 15.3$, $p < 0.01$; steelhead: $\chi^2 = 23.2$, $p < 0.01$, Figure 15). Higher proportions of coho were detected from capture sites in the two upstream reaches (R4.5 = 24.1%, R5 = 56.2%) compared to downstream reaches (R1.2 = 4.4%, R2.3 = 19.6%, and R3.4 = 15.5%). Higher proportions of steelhead were detected from capture sites in the lower to central reaches (R2.3 = 31.1%, R3.4 = 24.6%) compared to captures sites in the most downstream and upstream reaches (R1.2 = 6.0%, R4.5 = 11.6%, R5 = 17.9%).

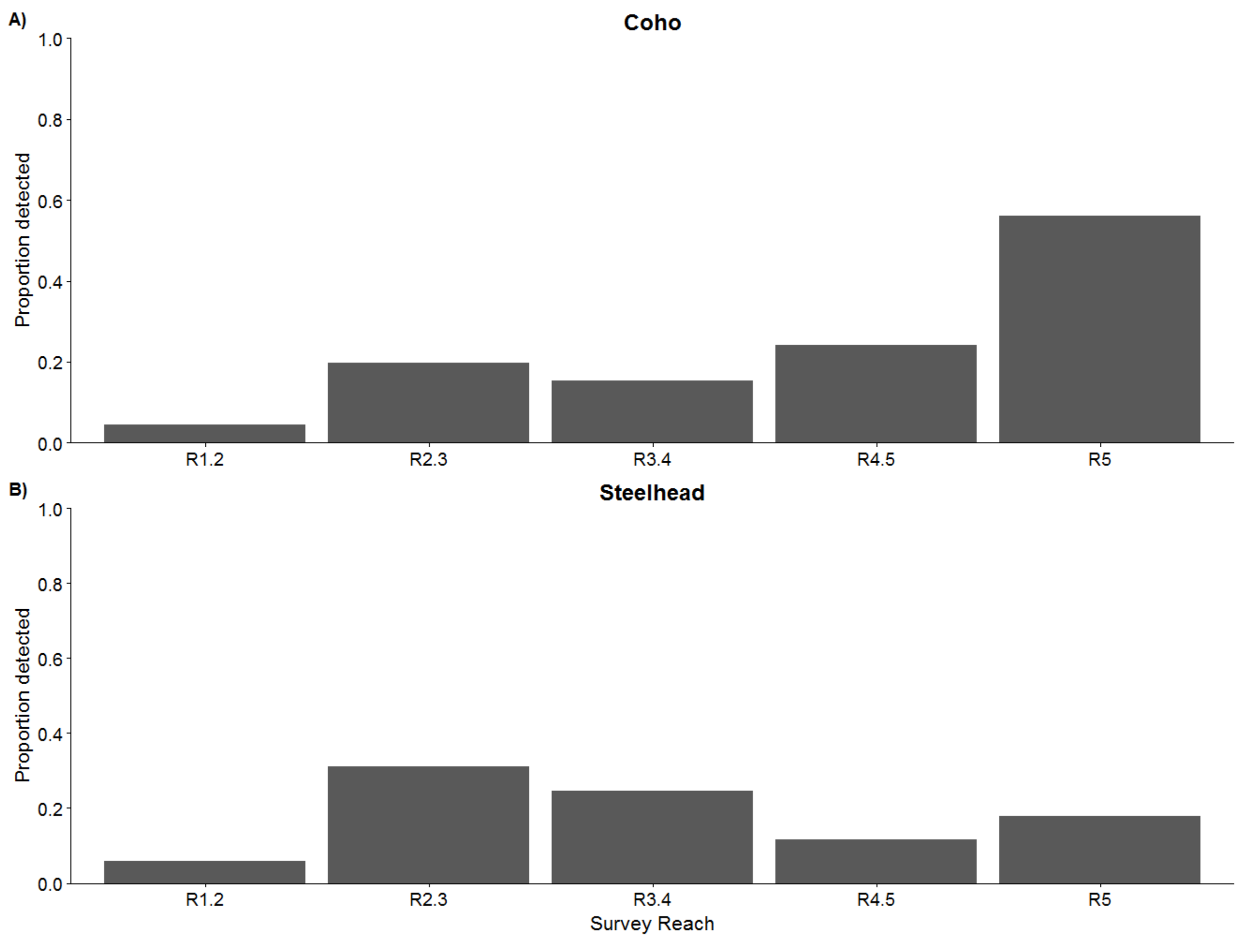

Figure 15. Proportion of tagged coho salmon (A) and steelhead trout (B) from each capture site that were detected at least once at PIT array sites in the South Fork Newaukum River, June – September 2016. R1.2 and R5 are the downstream and upstream survey reaches, respectively.

Detection activity differed among PIT detection array sites for both coho and steelhead (coho: $\chi^2 = 31.2$, $p < 0.01$; steelhead: $\chi^2 = 48.5$, $p < 0.01$) (Figure 16). Coho detection activity was relatively comparable at PIT detection array sites A2 – A5 (34.2-46.3% of days) however less activity was observed at the downstream most array A1 (7.6% of days). Steelhead detection activity was relatively comparable at the two PIT detection arrays central to the study area (A2 and A3 with 36.9 and 41.5% of days, respectively) but less activity was observed at upstream PIT detection arrays of A4 (21.1% of days) and A5 (6.8% of days) and the downstream most array A1 (6.8% of days).

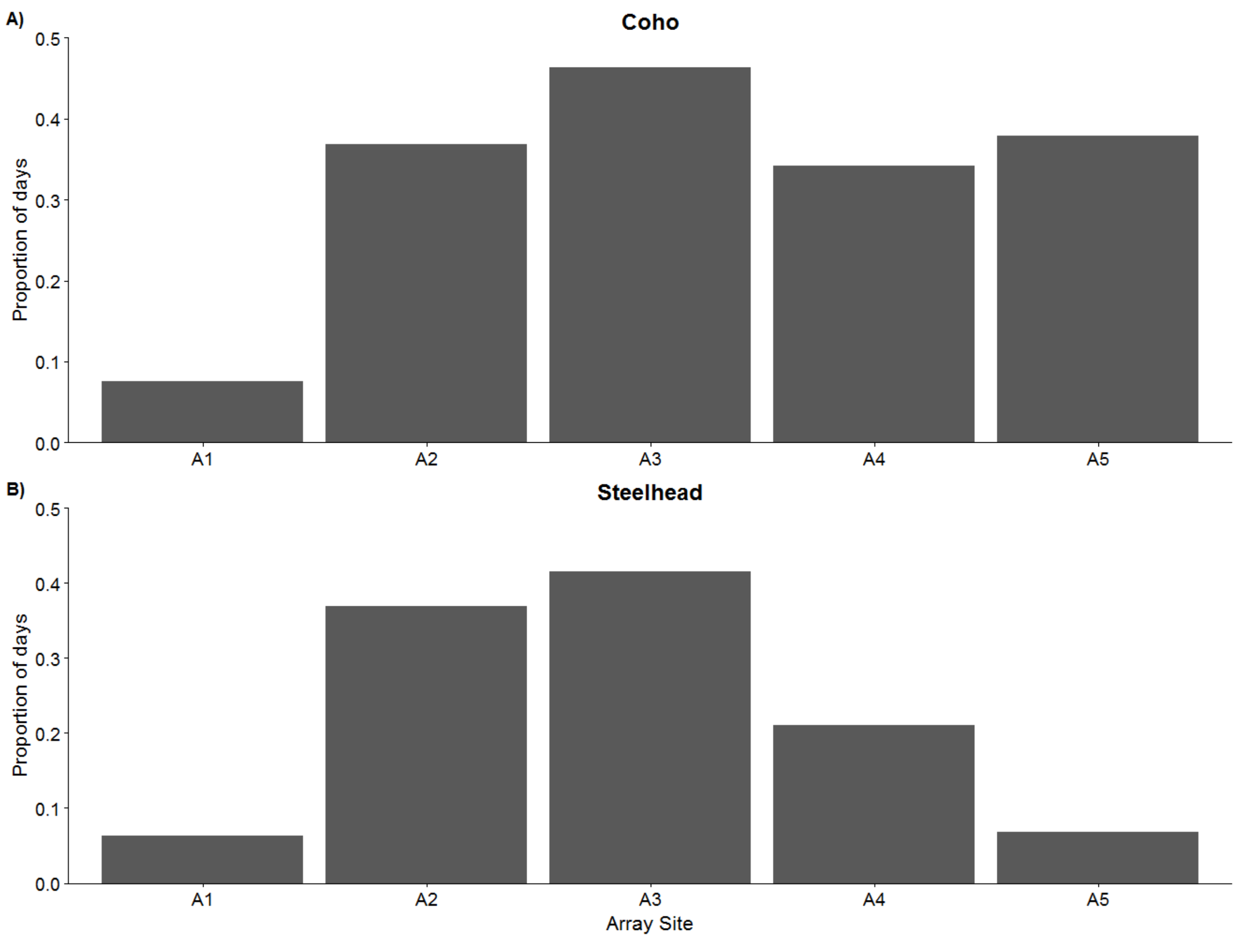

Figure 16. Proportion of days at each PIT array site that tagged juvenile coho salmon (A) and steelhead trout (B) were detected in the South Fork Newaukum River, June – September 2016. A1 was the downstream most array and A5 was the upstream most array.

Directional Movements by Season and Location

For coho, the ratio of upstream and downstream movements were similar between summer and early fall and were dominated by downstream movements in both time periods (summer; 29% upstream and 71% downstream, and early fall; 26.5% upstream and 73.5% downstream) (χ^2 = 0.06, p = 0.81). For steelhead, the ratio of upstream and downstream movements differed between summer and early fall and were disproportionately upstream in the summer (62.1% upstream and 37.9% downstream) and downstream in the early fall (44.4% upstream and 55.6% downstream) (χ^2 = 5.60, p = 0.02).

During the summer time period, the ratio of upstream to downstream coho movements differed among PIT detection array sites (χ^2 =112.1, $p < 0.01$). Coho summer movements were disproportionately downstream at A1 (100% downstream), A2 (64% downstream), and A5 (92.1% downstream) (Figure 17, Appendix Table F-1), but more evenly distributed at PIT detection array sites A3 (54.3% upstream, 45.7% downstream) and A4 (47.4% upstream, 52.6% downstream). During the early fall time period, the ratio of upstream to downstream coho movements differed among PIT detection array sites (χ^2 =182.82, $p < 0.01$). However, downstream movements were most prevalent at all sites during early fall (except for A1 where only one total directional movement was observed) (Figure 17, Appendix Table F-1).

During the summer time period, the ratio of upstream to downstream steelhead movements differed among PIT detection array sites (χ^2 = 215.49, $p < 0.01$). Steelhead summer movements were disproportionately upstream at A3 (65.5% upstream) and A4 (66.7% upstream) (Figure 17, Appendix Table F-1), but more evenly distributed at PIT detection array site A2 (52.9% upstream, 47.1% downstream) (Figure 17, Appendix Table F-1) and rarely recorded at A1 (n = 2 upstream movements) and A5 (n = 1 downstream movement). During the early fall time period, the ratio of upstream to downstream steelhead movements also differed among PIT detection array sites (χ^2 = 148.73, $p < 0.01$) (Figure 17, Appendix Table F-1). Steelhead early fall movements were disproportionately downstream at A3 (83.3% downstream) but more evenly distributed at PIT detection array sites A2 (46.7% upstream and 53.3% downstream), A4 (40% upstream and 60% downstream), and A5 (50% upstream and 50% downstream). Steelhead early fall movements were rarely recorded at A1 (n = 2 upstream movements).

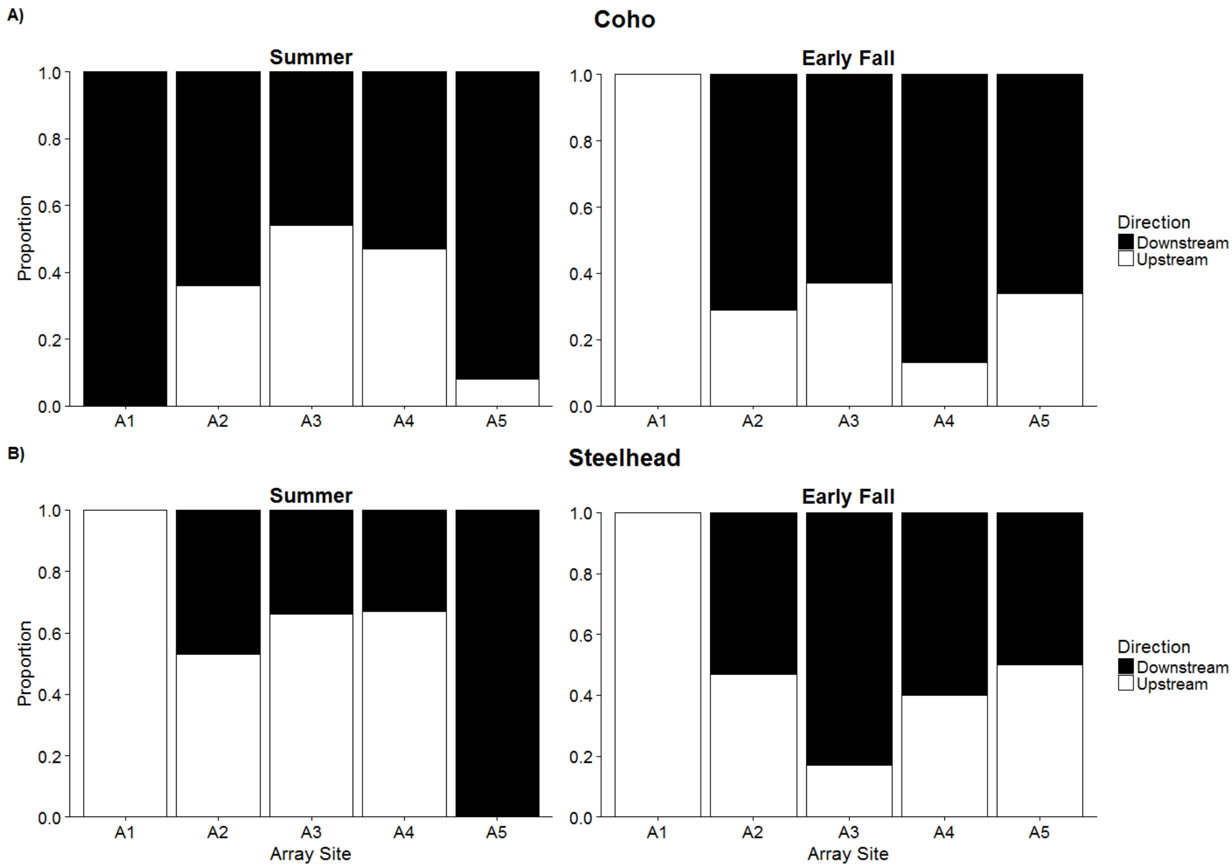

Figure 17. Upstream and downstream movements at each PIT array site of tagged juvenile coho salmon (A) and steelhead trout (B) in the South Fork Newaukum River, June – September 2016. Data are organized into summer (July and August) and early fall (September) time frames. A1 was the downstream most array and A5 was the upstream most array. Data are provided in Appendix F.

Discussion

In this study, we used a combination of riverscape survey and fish tagging methods to gain a temporal perspective on summer rearing habitat for juvenile salmon and steelhead. Spatially continuous "riverscape" surveys provide a broad scale view but a momentary snapshot of fish distributions (Fausch et al. 2002) and we replicated this snapshot four times between the months of May and September in order to put the broad scale view of fish distributions into a seasonal perspective. The results of our study demonstrate that juvenile coho salmon and steelhead distributions are not static throughout summer months and are associated with a combination of the physical environment, other fish species in the stream community, and movements among stream reaches.

Information on temperature, cyprinid species, and fish movements were collectively important in describing patterns of juvenile coho salmon and steelhead distributions across summer months. Temperature was a general organizing factor for fish distributions in that upstream cooler locations were consistently a salmonid dominated fish assemblage while downstream warmer locations were consistently cyprinid dominated. The downstream extent of the salmonid distribution was centrally located in the survey area early in the summer months (R2.3) and shifted further upstream from July to August. The upstream shift in juvenile salmonids was concurrent with increases in both summer stream temperatures and observed densities of cyprinids and hatchery-origin juvenile steelhead in these locations. Cyprinids observed were predominantly redside shiner and juvenile pikeminnow, both of which compete with juvenile salmonids and are more successful competitors under warmer temperature conditions (Reeves et al. 1987, Reese and Harvey 2002). Directional fish movements also provide some explanation for the shifts in juvenile salmonid distribution over the study period. The upstream shift in salmonid distribution occurred at the location (between R2.3 and R3.4) and time (between July and August) that movements were directionally upstream for both juvenile coho salmon and steelhead. Furthermore, as temperatures began to cool in September, an overall downstream shift in the salmonid spatial distribution occurred simultaneous in time with movements that were directionally downstream for both juvenile coho salmon and steelhead.

Our results have implications for both protection and restoration strategies associated with summer rearing habitat in the Newaukum River. We identified specific locations within the 37.5 km study area that consistently supported a juvenile salmonid dominated fish assemblage with high juvenile salmonid densities throughout summer months and other locations that were generally dominated by cyprinids and had consistently low or declining juvenile salmonid densities throughout the summer. Specifically, R3.4, R4.5, and R5 may be good candidate reaches for protection of existing stream habitat as these reaches had high and consistent densities of juvenile coho salmon and steelhead, indicating they are currently important summer rearing locations. In addition, R1.2 and R2.3 may be good candidate reaches for restoration actions focused on reducing summer stream temperatures. R1.2 was consistently dominated by cyprinid species with low densities of juvenile salmonids. R2.3 was increasingly dominated by cyprinid species during the warmest months of the summer; juvenile salmonid densities in this reach were relatively high in late spring (May survey) and early fall (September survey) but notably lower in the months of July and August.

Our results also highlight that connectivity among stream segments is an important component of summer rearing habitat. Results from this study and elsewhere (Winkowski and Zimmerman 2017) demonstrate that movements over multiple kilometers are common behaviors of juvenile coho and steelhead during summer base flows in the Chehalis River basin. The purpose of these movements are not fully understood, although they may provide access to cool water refugia and additional feeding opportunities. Connectivity associated with culverts and other fish passage barriers are often major restoration opportunities in smaller tributary streams. However, in the main stem of the South Fork Newaukum River, the major improvement to connectivity will be the elimination of man-made obstructions such as 'rock dams' that are constructed for recreational use but unintentionally inhibit fish movements. A combination of education and enforcement actions are recommended to address this issue.

Below we discuss some additional findings and caveats to the results of this study.

Landscape, Habitat, and Temperature Description of Study Area

From a landscape perspective, our study area transitioned from upstream extents where the river flowed through relatively confined valley walls with a constricted channel and higher gradient reaches to downstream extents characterized by a less confined valley, less constricted channel, and lower gradient reaches. A major landscape transition occurs between R3.4 and R2.3, where the valley widens roughly 3-fold and remains unconfined downstream through R1.2. Additionally, as the valley widens in a downstream direction, land cover transitions were apparent; land cover was predominantly forested in upstream extents (44.7-48.4% of land cover surrounding reaches R3.4, R4.5, and R5) and cultivated in downstream extents (42.2-43.6% of land cover surrounding reaches R1.2 and R2.3). These shifts in the landscape are significant because our results suggest that the lower reaches (R1.2 and R2.3) may have some of the best restoration potential within the South Fork Newaukum River but they are also the reaches that currently have the most overlap with ongoing human activities and are different in terms of geomorphology compared to upstream reaches. Therefore, restoration planning for these reaches would need to consider the protections of river processes offered by enforcing existing laws, the voluntary willingness of landowners to manage the landscape in a way that will enhance natural river processes, and how potential restoration actions may function within distinct geomorphic locations in the watershed.

Despite notable transitions in the surrounding landscape, we detected relatively minor differences in habitat characteristics among reaches. The majority of channel type in the study area was pool-riffle, which is commonly associated with juvenile salmon and steelhead rearing and is expected for stream gradients found in our study area (Montgomery and Buffington 1997). Generally, pool frequencies were slightly higher and substrate slightly coarser in upstream reaches. Higher pool frequencies in the upstream reaches might be expected due to more wood found in R4.5 and a narrower channel observed in R5. With the exception of R5, the widths of all other reaches were comparable amongst each other although the depth increased in the lower reaches. Large woody debris was variable across reaches and was notably highest in R4.5 and least in R2.3.

We observed strong spatial and temporal patterns of stream temperature in the South Fork Newaukum River over summer months. Overall, we observed an upstream (cool)-downstream (warm) summer temperature gradient. Upstream-downstream summer temperature gradients are common in rivers with no glacial or minimal snow-melt influence, such as the South Fork Newaukum, as upstream extents are closer in proximity to cool groundwater river sources and processes of heat energy exchange occur as water flows downstream (Caissie 2006; Poole and Berman 2001). Shade provided by riparian forests can buffer stream temperatures from solar radiation and air temperatures as rivers flow farther from headwaters (Poole and Berman 2001). However, downstream areas of our study area may be particularly vulnerable to elevated summer stream temperatures due to reduced riparian cover (less than 17% in R1.2 and R2.3 versus more than 44% in the upstream reaches). Additionally, R2.3 had the largest variations in daily stream temperature (daily range of 3 – 4.5˚C), which may also reflect limited riparian cover and less buffering capacity from atmospheric influences. The benefits of restoring riparian cover in the South Fork Newaukum River are currently being addressed through a holistic watershed assessment model that includes both natural and anthropogenic drivers of temperatures in this sub-basin (T. Beechie, Northwest Fisheries Science Center, personal communication).

Juvenile Salmonid Summer Habitat

The South Fork Newaukum River summer fish community was dominated by juvenile salmonids and adult and juvenile cyprinids. Additionally, we observed a diverse assemblage of other species and age classes and this information is presented in Appendix C. In this section of the discussion, we discuss patterns of summer rearing distributions of juvenile salmon and steelhead in the context of physical stream characteristics, cyprinid species, and fish movements and how these observations might inform restoration.

Upstream reaches in our study area were important summer rearing locations for juvenile coho salmon. In the summer and early fall surveys, the highest coho densities were observed in upstream reaches R3.4 and R4.5. Reaches R3.4 and R4.5 were characterized by mean valley width indices of 10.6 and 7.5 and gradients of 0.7 and 0.9, respectively, which are consistent with intrinsic potential models for high quality rearing habitat of juvenile coho salmon (Burnett et al. 2007). While the mean valley width indices and gradients of reaches R1.2 and R2.3 are within the range of high quality rearing habitat for juvenile coho salmon (see Burnett et al. 2007), densities in R1.2 were consistently low relative to other reaches and densities declined substantially in R2.3 from July to August. We did not detect fish exiting the survey area during this time period, so a combination of movement into tributaries, upstream movements, and mortality may explain declining densities. Nevertheless, we hypothesize that temperature conditions during summer months in these downstream reaches limits the spatial availability of suitable habitat for juvenile coho salmon. Therefore, we suggest that R1.2 and R2.3 are strong candidates for restoration of cooler summer stream temperatures.

Restoration goals of cooler summer stream temperatures in R1.2 and R2.3 would likely also benefit yearling steelhead. In general, locations of relatively high yearling steelhead densities shifted concurrently with temperature patterns. When temperatures were cooler across the study area in May and September, densities were more evenly distributed throughout the study area. As temperatures increased into July and August, densities were highest in central to upstream reaches where stream temperatures were relatively coolest. These observations demonstrate 1) juvenile steelhead distributions are associated with temperature, 2) upstream locations appear to be important rearing areas during July and August, and 3) yearling steelhead use the majority of our study area from May - September. Yearling steelhead densities in R1.2, the most downstream reach, were consistently low relative to other reaches and in R2.3 densities declined substantially from July to August (similar to observations of juvenile coho densities). We hypothesize these observations are a result of interactions of unsuitable stream temperatures, competing and or predatory cyprinids, fish movements, and mortality. At the scale of analyses presented here, all reaches were outside of optimal stream gradients and only the two upstream reaches were within optimal valley width indices according to intrinsic potential models for high quality rearing habitat of juvenile steelhead (Burnett et al. 2007). Nonetheless, our data suggest the South Fork Newaukum River is an important sub basin for winter steelhead in the Chehalis River watershed and juveniles would likely benefit from restoration of cooler summer stream conditions in downstream reaches.

Life history information and our sampling technique should be considered when interpreting patterns observed for subyearling steelhead. We rarely detected steelhead 0+ in May, which is within winter steelhead spawn timing in the Chehalis River basin. Therefore, some juvenile steelhead had yet to emerge from the gravel and those that had recently emerged likely occupied shallow margin habitat which is difficult to survey via snorkeling (Wydoski & Whitney 2003). Foot surveyors anecdotally observed steelhead fry in shallow margin habitat during May, July, and to a lesser extent August. As temperature increases throughout summer months, steelhead fry grow to parr stage and recruit from shallow margin habitat to cooler, swifter thalweg habitat (Everest & Chapman 1972). In all reaches, subyearling steelhead densities increased from May to July and again from July to August (except in R1.2). We hypothesize this result is at least in part reflective of recruitment from margin to thalweg habitat where snorkelers could collect fish counts. As a result, our subyearling steelhead data should provide a relatively accurate assessment of spatial occupancy but are not adequate in representing spatial patterns of relative density across the summer months.

The fish assemblage structure and spatial temperature patterns observed in our study suggest temperature conditions are most suitable for cyprinids in downstream reaches during summer months. The influence of stream temperatures on spatial distributions of salmonid versus cyprinids is further supported by laboratory experiments demonstrating that cyprinid species have a competitive advantage over juvenile salmonids in warm water conditions. For example, in water temperatures from 19-23°C redside shiner and juvenile pikeminnow outcompeted juvenile steelhead for space and food, resulting in reductions in steelhead growth and altered habitat use (Reeves et al. 1987; Reese and Harvey 2002). However, in cooler conditions (<18°C), juvenile steelhead growth and habitat use were unaffected in the presence of competing cyprinid species (Reeves et al. 1987; Reese and Harvey 2002). In our study area, stream temperatures at which cyprinids displayed competitive dominance over juvenile steelhead were more spatially available during July and August, specifically in R1.2 and R2.3. Therefore, the combination of temperature and cyprinid species could contribute to consistently low densities of juvenile salmon and steelhead in R1.2 and sharply declining densities in R2.3 from July to August. Under current conditions, therefore, juvenile salmonids rearing in R2.3 are likely to be particularly sensitive to land use activities that disrupt stream temperatures regulating processes (e.g., removal of riparian cover) and these factors further point towards R2.3 as a good candidate for restoration of these natural processes.

Interestingly, we did not observe clear associations between juvenile salmon and steelhead densities and reach scale habitat characteristics, such as LWD, wetted widths, depths, pool counts, and substrate. However, the lack of fish-habitat associations presented here does not mean that habitat characteristics are unimportant for fish species in the South Fork Newaukum River but rather, fish-habitat relationships are sometimes better informed by considering multiple scales of analyses (Fausch et al. 1994). An example is evident in relationships between fish assemblages, temperature and channel morphology in the Middle Fork and North Fork John Day River of eastern Oregon, where temperature was an overarching factor shaping fish assemblages at large spatial scales and channel morphology was important at smaller spatial scales (Torgersen et al. 2006). This example demonstrates that broad scale temperature patterns structure fish assemblages along a river gradient and that at finer spatial scales within temperature zones, other physical habitat features help to explain variability in fish distribution. In this study, habitat metrics were averaged across relatively large reaches (mean of 7.5 km) which is a spatial scale of which fish assemblages may be more appropriately viewed through the lens of broad scale temperature patterns.

Spatial Overlap With Hatchery Steelhead

In addition to native cyprinid species, our results demonstrate that ecological interactions with hatchery salmonids are likely to influence wild juvenile salmon and steelhead during the summer rearing period. Hatchery steelhead are currently released into the South Fork Newaukum River as mitigation for habitat loss from the construction of Skookumchuck Dam and contribute to a local steelhead fishery within the Newaukum sub-basin. Hatchery steelhead are currently reared to the yearling life stage for release into Carlisle Lake through an educational program with the Onalaska school system. Carlisle Lake is an impoundment of Gheer Creek which is connected to the South Fork Newaukum River at approximately rkm 36. In 2016, approximately 5,000 yearling steelhead smolts were released into Carlisle Lake in the month of April and an additional 25,000 subyearling steelhead were released directly into the South Fork Newaukum in the month of October (WDFW 2015 and 2016 Future Brood Document, https://wdfw.wa.gov/hatcheries/future_brood.html). Although the future brood document indicates that the release of subyearlings would occur in the month of October, our snorkel observations indicate that this release occurred slightly earlier than planned in 2016.

Hatchery steelhead observed in our snorkel surveys are those fish that failed to emigrate to salt water (i.e., residualized in freshwater) after release. Residualized hatchery salmonids compete with wild fish and typically make minimal contributions to the intended fishery (Kostow 2009; Naish et al. 2007; Snow et al. 2013). Hatchery-reared coho smolts and rainbow trout are also released into Carlisle Lake each spring; however, neither of these groups were observed in the South Fork Newaukum River during our surveys. Hatchery reared rainbow trout have intact adipose fins that differentiate them from hatchery steelhead smolts and are different enough in appearance from wild juvenile steelhead that they would likely have been distinguishable in our counts.

Residualized hatchery-origin juvenile steelhead add to current ecological stresses (e.g., warm stream temperatures and high densities of cyprinids) on wild juvenile salmon and steelhead during summer rearing. Densities of residualized hatchery steelhead were particularly high in the reaches proposed to be good candidates for restoration (R2.3 and R1.2). Due to the two releases (i.e., spring yearling smolts, fall subyearlings), we encountered two ages classes of hatchery steelhead in our surveys. Occupancy of hatchery steelhead yearlings increased from two study reaches (R1.2 and R2.3) in July to three study reaches (R1.2, R2.3, and R3.4) in August. Densities of hatchery steelhead yearlings doubled in reach R2.3 from July to August. As a result, the mean ratio of hatchery:wild steelhead yearlings in this reach increased from 0.15 to 0.28 during this time frame. We also observed hatchery steelhead subyearlings but in a narrower spatial and temporal extent relative to hatchery steelhead yearlings. Hatchery steelhead subyearlings were observed in downstream segments of R2.3 and upstream segments of R1.2 during September only, occupying an area roughly 800 m upstream to 3 km downstream from the outlet of Carlisle Lake.

In contrast to the influence of temperature on native cyprinid distribution, the spatial distribution of hatchery fish appears to be influenced by the location of their release and the propensity of the release group to residualize in freshwater. Also in contrast to the effects of native cyprinids, the influence of hatchery steelhead on wild fish can be influenced by human action. Decision makers will need to consider the fishery benefits and societal value of these particular hatchery programs against the ecological effects that residualized fish have on wild populations targeted by the restoration actions. Further, additional consideration should be given to the hatchery rearing practices as restoration plans for the South Fork Newaukum develop. For example, adjustments to hatchery rearing practices have potential to decrease residualization (Sharpe et al. 2007; Snow et al. 2013; Viola and Schuck 1995) which should reduce the extent to which hatchery steelhead interact with wild steelhead rearing in the lower reaches of the South Fork Newaukum River.

Other Considerations

Juvenile salmonid summer distributions and densities are influenced by additional abiotic and biotic factors not measured in this study and therefore our results should be interpreted in this context. Such factors include the abundance and distribution of parental spawners which would determine broad scale patterns of early rearing distribution for offspring. Environmental factors including stream flows and temperature would influence both spawning distributions and timing of adults in addition to the rearing environment of offspring. Our study area was not inclusive of the entirety of spawning and rearing habitat for salmon and steelhead in the South Fork Newaukum and therefore, recruitment from outside of the study area was likely. Summer rearing is a strong bottleneck during the salmon and steelhead life stage and therefore mortality likely explains some of the variability observed in our data. Nevertheless, while we would expect to observe annual variability in juvenile salmonid densities, we would also expect the broad-scale upstream-downstream summer fish assemblage patterns to be relatively consistent across years (see Winkowski et al. 2018).

In the main stem of the South Fork Newaukum River, juvenile salmonids in downstream reaches are most susceptible to effects of warm stream temperatures and predation relative to upstream locations. Mean maximum daily temperatures in August were approximately 20-21℃ and observations of adult pikeminnow densities were highest in these locations. A combination of factors can lead to mortality of juvenile salmon and steelhead during summer rearing (Sauter et al. 2001; Sullivan et al. 2000), and we presume a combination of stressful stream temperatures and predation likely lead to elevated levels of mortality in downstream locations of the study area.

Non-native Fish Observations

Non-native sunfish were observed in August and September surveys and bass were observed in the September survey. The most upstream observation of sunfish was roughly 10 km upstream from the confluence with the North Fork Newaukum River. In September, all observations of sunfish occurred in one survey segment roughly 4 km upstream from the confluence with the North Fork Newaukum River. We observed only one bass approximately 1.6 km upstream from the confluence with the North Fork Newaukum River. Non-native fishes were observed in habitat units with dense aquatic vegetation and algal growth. Aquatic vegetation sometimes reduced the field of vision of snorkelers which subsequently influenced abilities to detect fish as effectively compared to the open-water thalweg where most of the salmonid and cyprinid species were observed.

In a previous study, bass and sunfish were prevalent in the Chehalis River main stem from Rainbow Falls to the confluence with the Newaukum main stem and were observed in the North Fork Newaukum River in a summer survey in 2014 (Winkowski et al. 2018). Observations of non-native fish species in this study were low, suggesting ecological impacts on native fish in these locations may be currently limited. However, the presence of non-native fish in our study area in combination with other observations in the Chehalis basin in close proximity is concerning especially when considering the limited rearing habitat currently available for juvenile salmonids during summer months (Winkowski et al. 2018). Furthermore, upstream distributions of non-native fish may be currently limited by cool temperatures however these limitations may be reduced as stream temperatures are projected to increase as a result of climate change (Carey et al. 2011; Lawrence et al. 2014). Restoration and protection planning would benefit from future summer surveys throughout the Chehalis River basin to better understand spatial distribution patterns of non-native fishes.

Conclusions

Developing well-informed protection or restoration strategies in a given river system requires a broad understanding of fish distributions and a holistic watershed analysis to understand mechanisms altering natural processes and limiting fish populations (Beechie et al. 2010; Roni and Beechie 2012). Results presented here provide broad scale context for the protection and restoration of juvenile salmon and steelhead summer rearing habitat in the South Fork Newaukum River. Our study suggests upstream reaches R3.4, R4.5, and R5 may currently be the most important main stem summer rearing habitat for juvenile salmon and steelhead (within our study area). Current conditions in downstream reaches (R2.3 and R1.2) are less suitable for juvenile salmon and steelhead specifically during July and August and would be good candidates for planning restoration actions in terms of cooler summer stream temperatures and reducing spatial and temporal overlap with hatchery fish.

Developing a better understanding of relationships between the river temperature and surrounding landscape may provide additional insight into factors driving fish distributions across the summer rearing period. For example, land cover surrounding R1.2 and R2.3 is predominantly cultivated land with minimal forest cover, which may contribute to elevated stream temperatures observed during summer months. In the process of restoration planning, decision makers should explore the willingness of landowners to assess and manage land use practices in a manner that minimizes negative impacts on stream fishes by addressing issues such as riparian cover, water withdrawals, and run-off as well as other impacts on physical stream characteristics and stream biota. A watershed assessment currently in progress (T. Beechie, Northwest Fisheries Science Center, personal communication) may better identify the potential to regulate temperature patterns and results from this assessment are important to identify whether changes to current conditions in R1.2 and R2.3 could indeed improve and spatially expand suitable summer stream reaches for juvenile salmon and steelhead. Besides stream temperature, less is known about spatial and temporal patterns of other characteristics of water quality in the river such as dissolved oxygen which may influence juvenile salmon and steelhead summer rearing patterns.

Our study suggests summer movements of juvenile salmon and steelhead of several kilometers are relatively common and were associated with shifts in distribution across summer months.

Maintaining connectivity in the river during summer months is important for allowing juvenile salmon and steelhead to undergo such movements. We anecdotally observed human constructed ‘rock dams’ in multiple locations of the South Fork Newaukum River main stem. Rock dams may inhibit juvenile salmonid movements and are prohibited by Washington State law. However, the regulations and the negative impacts to fish may not be widely understood among citizens who construct the dams with recreational purposes in mind. In the restoration planning process, we recommend that decision makers include an effort to educate landowners on existing laws pertaining to alteration of stream habitats and develop improved mechanisms to enforce these laws.

The presence of hatchery and non-native fish is concerning in the context of current and future impacts on wild juvenile salmonids. Managers should review current hatchery practices in the Newaukum River in order to develop strategies to reduce residualization of hatchery steelhead and minimize interactions between wild and hatchery steelhead. Currently, our data suggest non-native fish may be limited to downstream locations during summer months and this limitation is likely temperature related. However, climate change projections of increasing stream temperatures may facilitate colonization of upstream habitat leading to increasing spatial overlap and ecological interactions (e.g., predation, competition) with native fish including juvenile salmon and steelhead.

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Appendices

Appendix A. Stream Flow Conditions During the Study Period.

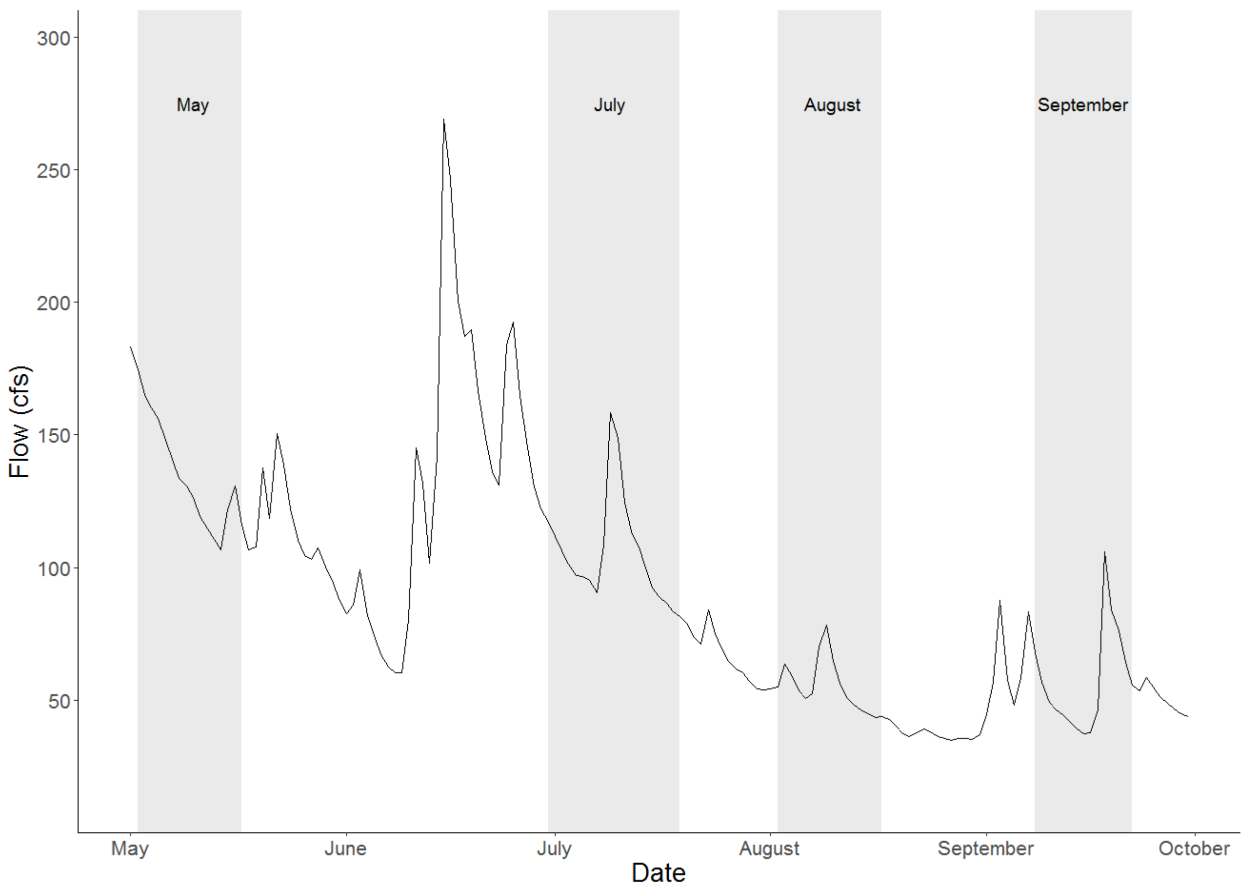

Figure A-1. Mean daily stream flows (cubic feet per second) of the Newaukum River collected from USGS gauge 12025000 (46.620028, -122.945167; rkm 8.0) from May 1 – September 30, 2016. Shaded regions represent the four survey periods (May: May 2-17; July: June 30-July 19; August: August 2-17; September: September 8-22).

Appendix B. Length-Date Criteria for Species and Age Class Assignments

Species/Life Stage	Time period	Fork length (mm)	Notes
Coho 0+[a]	May – September	< 100	Parr with no signs of smoltification
Coho smolt 1+	May – July	> 90	Signs of smoltification including coloration of body and fins
Chinook 0+	May – September	< 100	
Chinook (Adult)	May – September	> 300	Adult spring Chinook salmon
Steelhead 0+ [a]	May – September	45 - 90	Parr with no signs of smoltification
Steelhead 1+[a]	May – September	91 – 300	Parr with no signs of smoltification
Steelhead smolt 1+	May-July	91 - 300	Signs of smoltification including coloration of body and fins
Resident trout	May – September	300-500	Traits typical of resident trout including coloration and spotting
Steelhead (Adult)	May – September	> 500	
Redside Shiner (Adult)[a]	May – September	> 45	
Redside Shiner (Juvenile)	May – September	< 45	Includes fry
Dace (Adult) [a]	May – September	> 45	
Dace (Juvenile)	May – September	< 45	Includes fry
Pikeminnow (Adult) [a]	May – September	> 250	
Pikeminnow (Juvenile) [a]	May – September	< 250	Includes fry, may include peamouth
Mountain Whitefish (Adult)	May – September	> 250	No parr marks
Mountain Whitefish (Juvenile)	May – September	< 249	Parr marks visible
Largescale Sucker (Adult)	May – September	> 250	Adult sucker
Largescale Sucker (Juvenile)	May – September	< 250	Includes fry
Threespine stickleback	May – September	All sizes	
Smallmouth Bass[b]	May – September	All sizes	
Largemouth Bass[b]	May – September	All sizes	
Sunfish[b]	May – September	All sizes	Includes bluegill, pumpkinseed

[a] Denotes species and life stage used in fish assemblage analysis. [b] Species is not native to the Chehalis River.

Appendix C. Fish Species Occupancy, Densities, and Distribution

Although the focus of this study was the summer ecology of juvenile salmon and steelhead, we collected distribution and density information from a much broader suite of fish species within the South Fork Newaukum River. In this Appendix, we summarize the occupancy, relative abundance, and density in each survey period for all fish species across the survey area. The presentation of these results is organized by species included in the fish assemblage analysis, other salmonid species and life stages, other native fish species and life stages, and non-native fishes. Occupancy was the proportion of 200-m segments where the species was present. Relative abundance was the total counts across all segments. Density (fish count per 100 m) was the mean and standard deviation across all segments. Distribution of species and age classes in each survey period was visualized with a boxplot. Boxplots display the median, 25% and 75% quartiles, and range of observations across the study area.

We observed 25 fish species-life stage-origin combinations (Table C-1). In all surveys, the densities of juvenile salmonids and cyprinids were the most numerous and represented an average of 89.2% (±13.1) of the total counts among segments. Coho 0+ and adult redside shiners were the most numerically dominant species across survey periods followed by counts of dace and steelhead 0+. In the latter three surveys (June, August, and September), the occupancy of steelhead 0+ was consistently highest among all species and life stages (> 98% of survey segments), although steelhead 0+ were rarely observed in the May survey.

Table C-1. Fish occupancy (Occ.), total counts (Total), density (fish count per 100 m) by survey period in the South Fork Newaukum River, May – September 2016. Density values are the mean (± SD). All fish and life stage groups are wild origin unless elsewise indicated.

	May			July			August			September		
Species/ Life Stage	**Occ.**	**Total**	**Density**	**Occ.**	**Total**	**Density**	**Occ.**	**Total**	**Density**	**Occ.**	**Total**	**Density**
Coho 0+[a]	98.3%	20118	53.5 (±46.6)	91.6%	25817	68.4 (±65.8)	88.3%	22226	58.5 (±67.4)	87.7%	12207	31.5 (±49.8)
Coho smolt 1+	40.8%	419	1.1 (±2.8)	0.0%	0	0.0 (±0.0)	0.0%	0	0.0 (±0.0)	0.0%	0	0.0 (±0.0)
Chinook 0+	64.8%	3150	8.6 (±10.7)	3.4%	7	0.0 (±0.1)	0.6%	1	0.0 (±0.0)	0.0%	0	0.0 (±0.0)
Chinook (Adult)	1.7%	4	0.0 (±0.1)	8.9%	17	0.0 (±0.2)	8.4%	28	0.1 (±0.3)	19.0%	78	0.2 (±0.8)
Trout 0+ [a]	18.4%	87	0.2 (±0.6)	100.0%	9290	25.2 (±20.4)	100.0%	14111	37.7 (±28.4)	98.9%	8947	24.0 (±22.9)
Trout 1+ [a]	91.6%	1888	5.1 (±5.0)	96.1%	3995	10.7 (±9.0)	91.1%	3367	8.9 (±8.8)	84.9%	1210	3.3 (±3.5)
Steelhead smolt	5.0%	9	0.0 (±0.1)	0.0%	0	0.0 (±0.0)	0.0%	0	0.0 (±0.0)	0.0%	0	0.0 (±0.0)
Resident trout	20.7%	43	0.1 (±0.2)	27.9%	85	0.2 (±0.5)	25.7%	73	0.2 (±0.4)	29.1%	89	0.2 (±0.5)
Steelhead (Adult, wild)	8.4%	17	0.0 (±0.1)	0.0%	0	0.0 (±0.0)	0.0%	0	0.0 (±0.0)	0.0%	0	0.0 (±0.0)
Steelhead (Adult, unk)	0.6%	1	0.0 (±0.0)	0.0%	0	0.0 (±0.0)	0.0%	0	0.0 (±0.0)	0.0%	0	0.0 (±0.0)
Trout 0+ (Hatchery)	0.0%	0	0.0 (±0.0)	0.0%	0	0.0 (±0.0)	0.0%	0	0.0 (±0.0)	10.6%	216	0.6 (±2.4)
Trout 1+ (Hatchery)	0.0%	0	0.0 (±0.0)	20.7%	110	0.3 (±0.8)	25.1%	141	0.4 (±1.0)	11.7%	24	0.1 (±0.2)
Redside shiner (Adult) [a]	48.6%	9752	26.6 (±38.0)	51.4%	15097	41.4 (±53.8)	69.3%	19535	53.4 (±58.3)	65.9%	18940	50.9 (±58.3)
Redside shiner (Juv)	0.0%	0	0.0 (±0.0)	10.1%	2232	5.9 (±21.6)	24.6%	5191	13.9 (±40.7)	20.1%	2640	7.0 (±18.6)
Dace (Adult) [a]	68.7%	5384	14.6 (±20.1)	73.7%	8944	24.4 (±35.3)	79.9%	10948	29.7 (±40.4)	71.5%	6410	17.4 (±28.4)
Dace (Juv)	0.0%	0	0.0 (±0.0)	8.4%	153	0.4 (±1.8)	26.3%	590	1.5 (±4.3)	39.1%	1258	3.4 (±7.8)
Pikeminnow (Adult) [a]	35.8%	284	0.8 (±1.5)	43.6%	427	1.2 (±2.1)	43.6%	596	1.6 (±2.8)	31.8%	609	1.6 (±5.0)
Pikeminnow (Juv) [a]	15.1%	1375	3.8(+9.3)	45.8%	3110	8.4(+14.0)	68.7%	4399	11.9 (+16.2)	59.2%	3792	9.9 (+16.0)
Whitefish (Adult)	36.9%	176	0.5 (±0.8)	41.3%	292	0.8 (±1.4)	31.8%	309	0.8 (±2.0)	22.3%	260	0.6 (±2.0)
Whitefish (Juv)	2.2%	7	0.0 (±0.1)	24.0%	151	0.4 (±1.0)	35.2%	178	0.5 (±1.1)	35.8%	249	0.7 (±1.5)
Largescale sucker (Adult)	59.2%	1083	3.0 (±4.0)	36.3%	546	1.5 (±3.5)	24.0%	763	2.1 (±7.2)	17.9%	753	2.1 (±9.4)
Largescale sucker (Juv)	6.1%	50	0.1 (±1.1)	12.3%	194	0.5 (±3.4)	16.8%	148	0.4 (±1.2)	19.6%	278	0.8 (±2.6)
Threespine stickleback	0.0%	0	0.0 (±0.0)	1.1%	161	0.4 (±5.9)	3.4%	167	0.5 (±5.5)	1.1%	113	0.3 (±4.0)
Bass[b]	0.0%	0	0.0 (±0.0)	0.0%	0	0.0 (±0.0)	0.0%	0	0.0 (±0.0)	0.6%	1	0.0 (±0.0)
Sunfish[b]	0.0%	0	0.0 (±0.0)	0.0%	0	0.0 (±0.0)	1.7%	3	0.0 (±0.1)	0.6%	5	0.0 (±0.1)

[a] Denotes species and life stage used in fish assemblage analysis. [b] Species is not native to the Chehalis River.

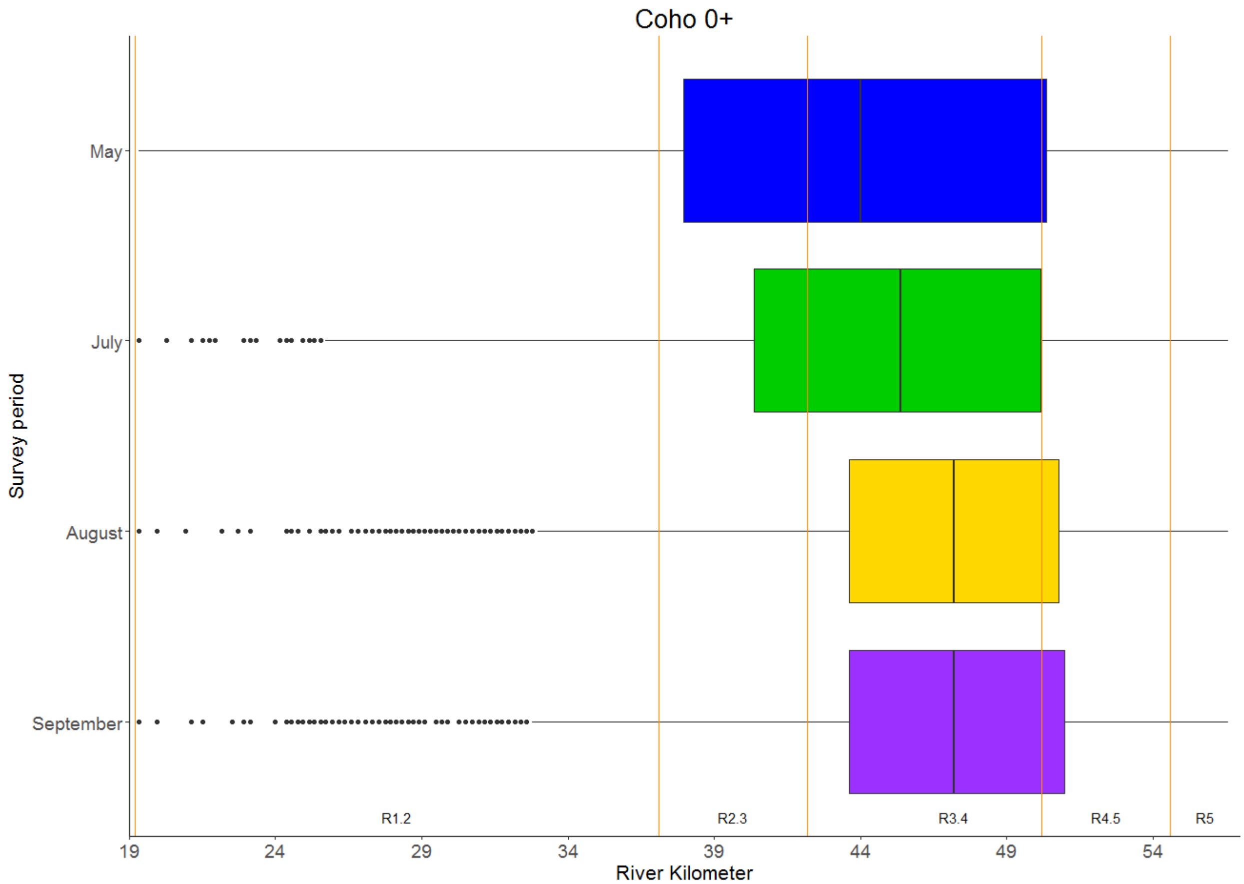

Figure C-1. Distribution of coho salmon 0+ by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25th and 75th quartile, and range of observations. Red vertical lines represent reach breaks (PIT detection arrays). Reaches are annotated along the lower portion of the figure.

Coho 0+ were observed across all survey periods (Table C-1). The overall median location of coho 0+ observations varied by 3.2 rkm among surveys and was located most downstream in May (rkm 44) and most upstream in August and September (rkm 47.2) (Figure C-1).

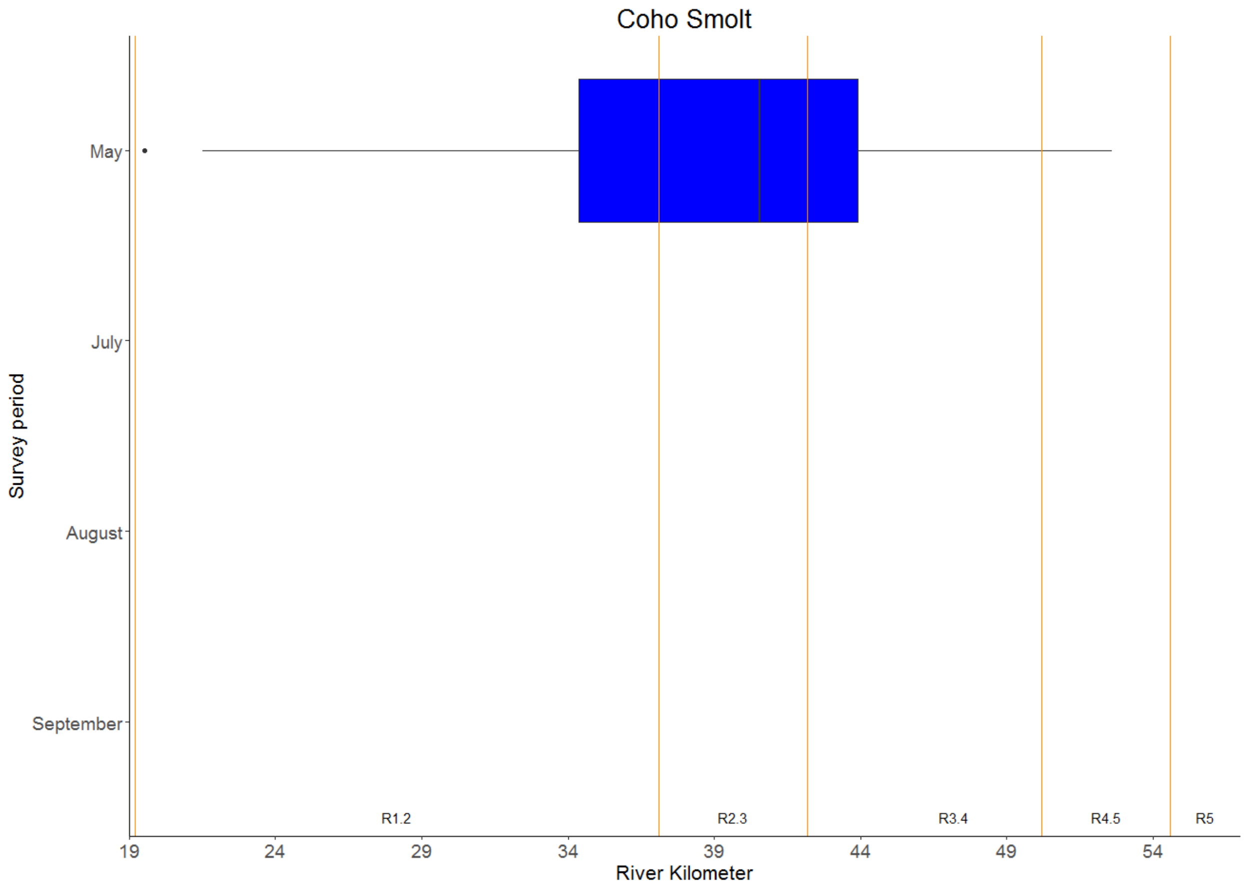

Figure C-2. Distribution of coho salmon smolts by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25th and 75th quartile, and range of observations. Red vertical lines represent reach breaks (PIT detection arrays). Reaches are annotated along the lower portion of the figure.

Coho smolts were observed during the May survey only (Table C-1) which is consistent with smolt outmigration timing observed in the main stem Chehalis River as monitored annually at the WDFW smolt trap near Rochester, Washington. The overall median location of coho smolt observations in May occurred at rkm 40.6 (Figure C-2).

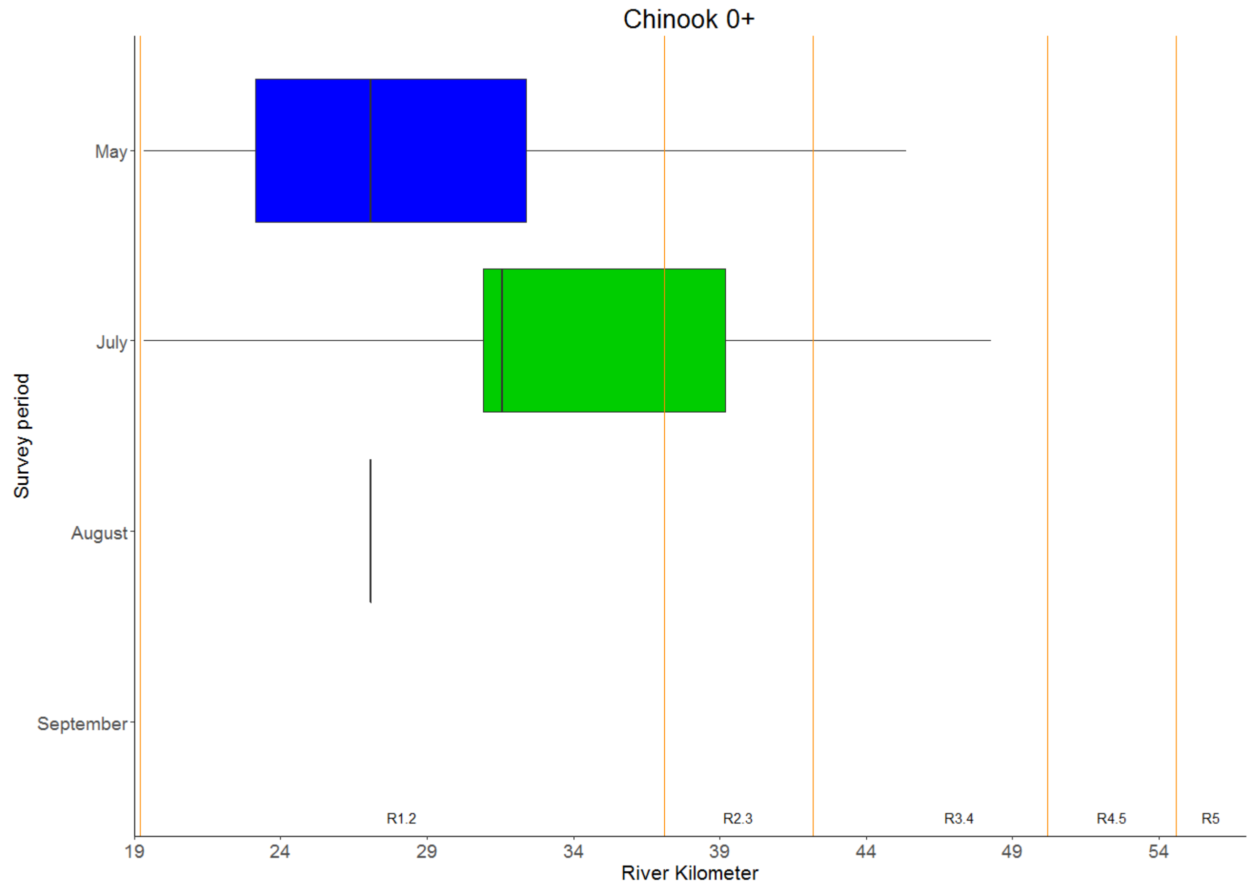

Figure C-3. Distribution of Chinook salmon 0+ by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25th and 75th quartile, and range of observations. Red vertical lines denote reach breaks (PIT detection arrays). Reaches are annotated along the lower portion of the figure.

Chinook 0+ were rarely observed in July (n = 7) and August (n = 1) and were not observed in September (Table C-1). In May, the overall median location of Chinook 0+ observations was rkm 27.1 (Figure C-3).

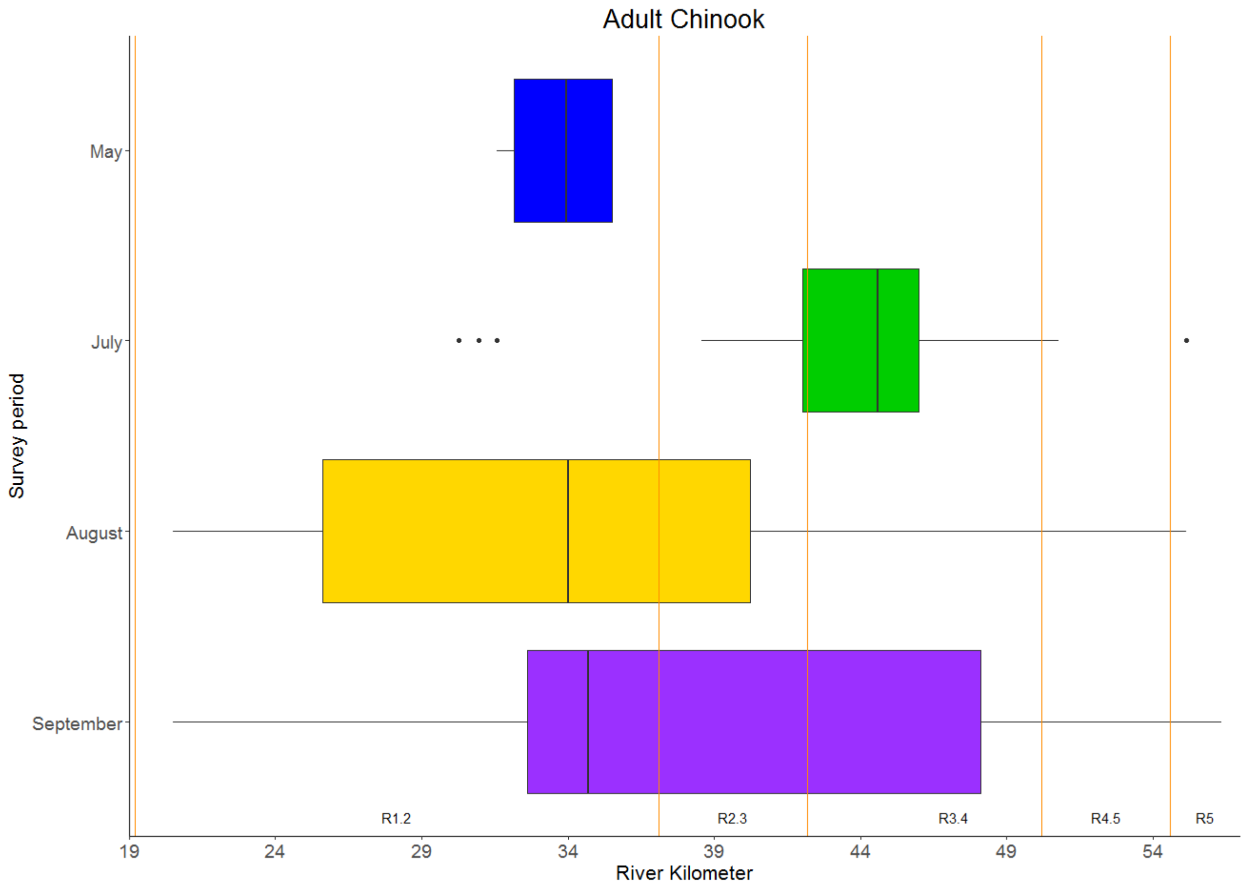

Figure C-4. Distribution of adult Chinook salmon by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25th and 75th quartile, and range of observations. Red vertical lines denote reach breaks (PIT detection arrays). Reaches are annotated along the lower portion of the figure.

Adult Chinook were observed across all survey periods (Table C-1). The overall median location of adult Chinook observations varied by 10.7 km and was located in the most downstream location in May (rkm 33.9), August (rkm 34.0), and September (rkm 34.7) and the most upstream location in July (rkm 44.6) (Figure C-4). The range of adult Chinook was far more constricted in May (rkm 31.6 – 35.5), intermediate in June (rkm 30.3 – 46.0) and more widespread in August and September (rkm 20.5 – 55.1 and 20.5 – 48.1, respectively).

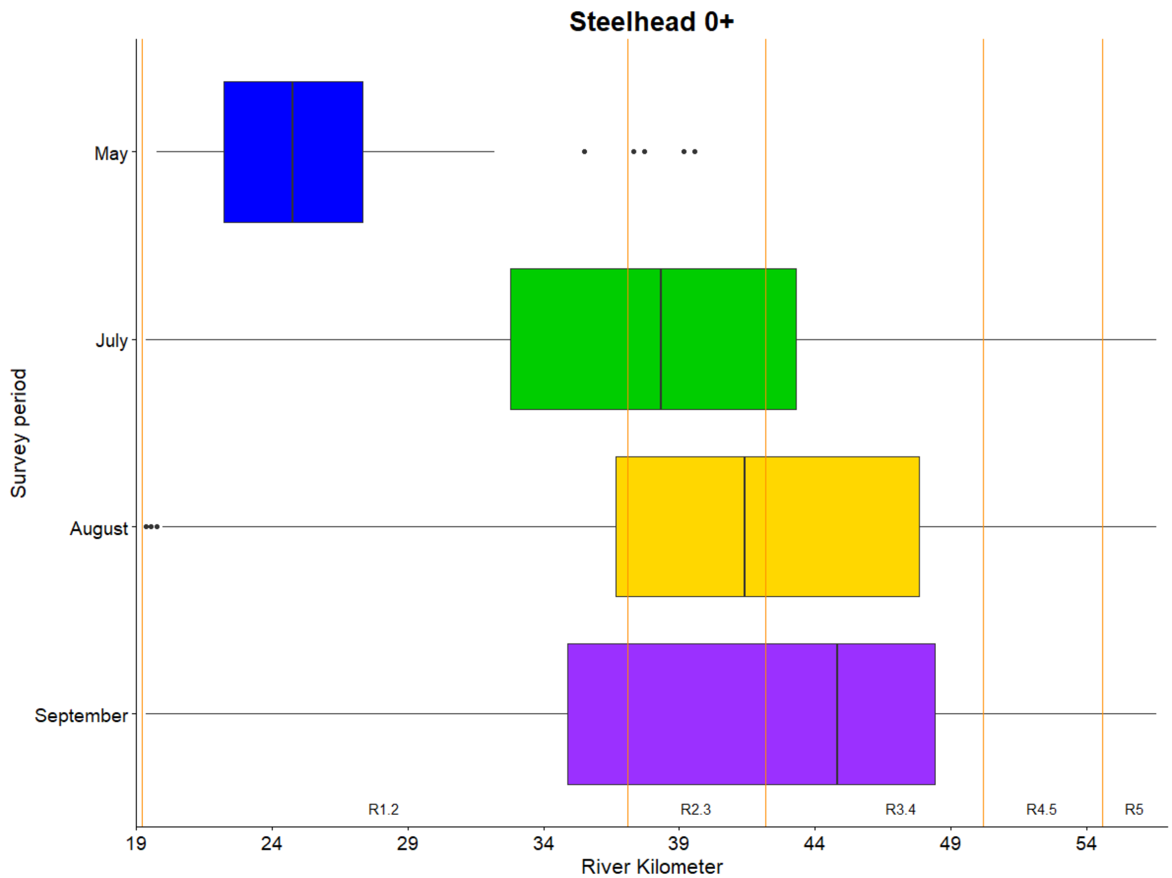

Figure C-5. Distribution of steelhead 0+ by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25th and 75th quartile, and range of observations. Red vertical lines denote reach breaks (PIT detection arrays). Reaches are annotated along the lower portion of the figure.

Steelhead 0+ were observed across all survey periods (Table C-1). Total steelhead 0+ observations were low in May (*n* = 87) which is likely reflective of fish which had yet to emerge from the gravel in addition to recently emerged fish occupying shallow margin habitat not conducive to sampling via snorkel techniques. Excluding May, the overall median location of steelhead 0+ observations varied by 6.5 km among survey periods and was most downstream in July (rkm 38.3) and most upstream location in September (rkm 44.8) (Figure C-5).

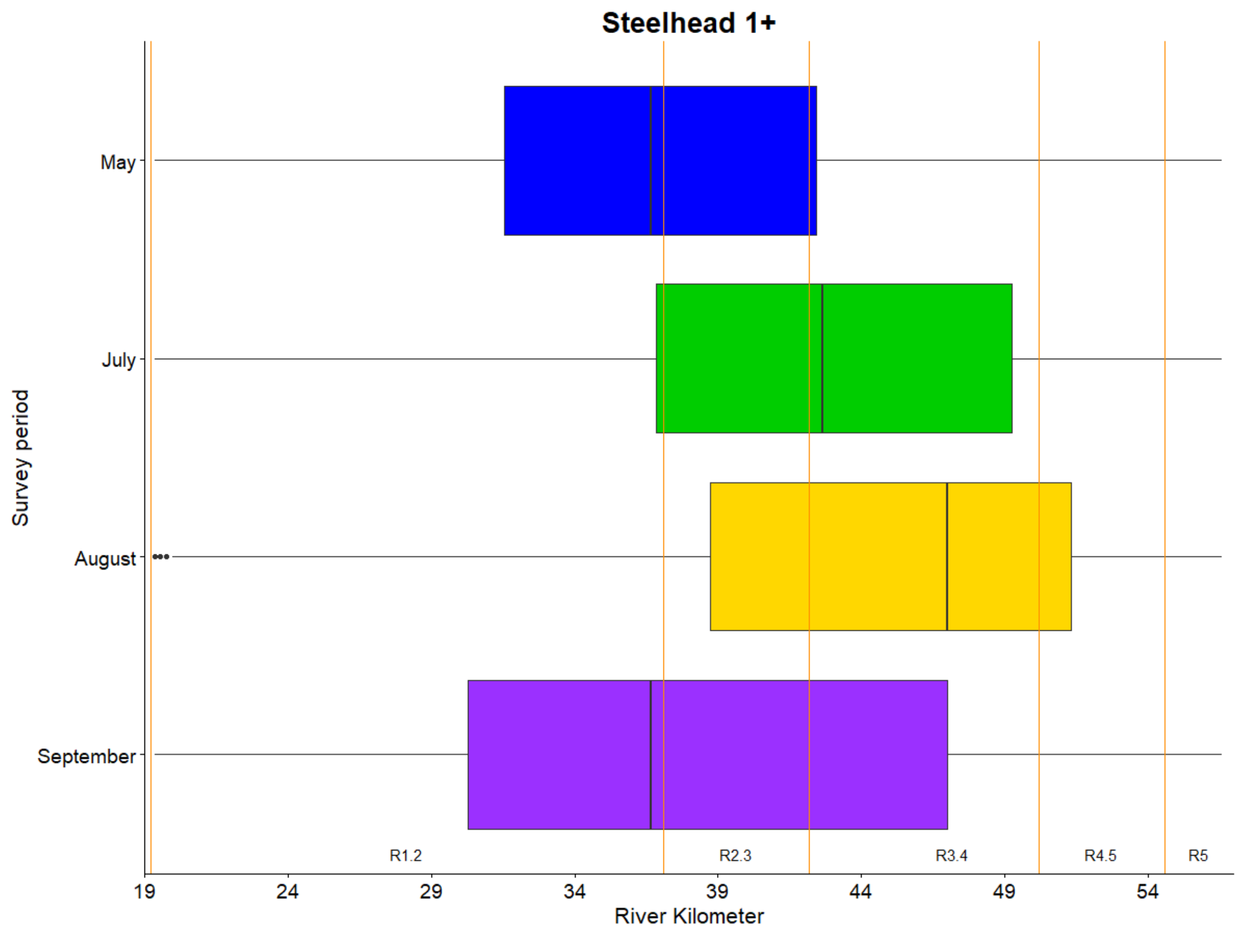

Figure C-6. Distribution of steelhead 1+ by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25th and 75th quartile, and range of observations. Red vertical lines denote reach breaks (PIT detection arrays). Reaches are annotated along the lower portion of the figure.

Steelhead 1+ were observed across all survey periods (Table C-1). The overall median location of steelhead 1+ observations varied by 10.3 km among surveys and was most downstream in May and September (rkm 36.7) and most upstream in August (rkm 47) (Figure C-6).

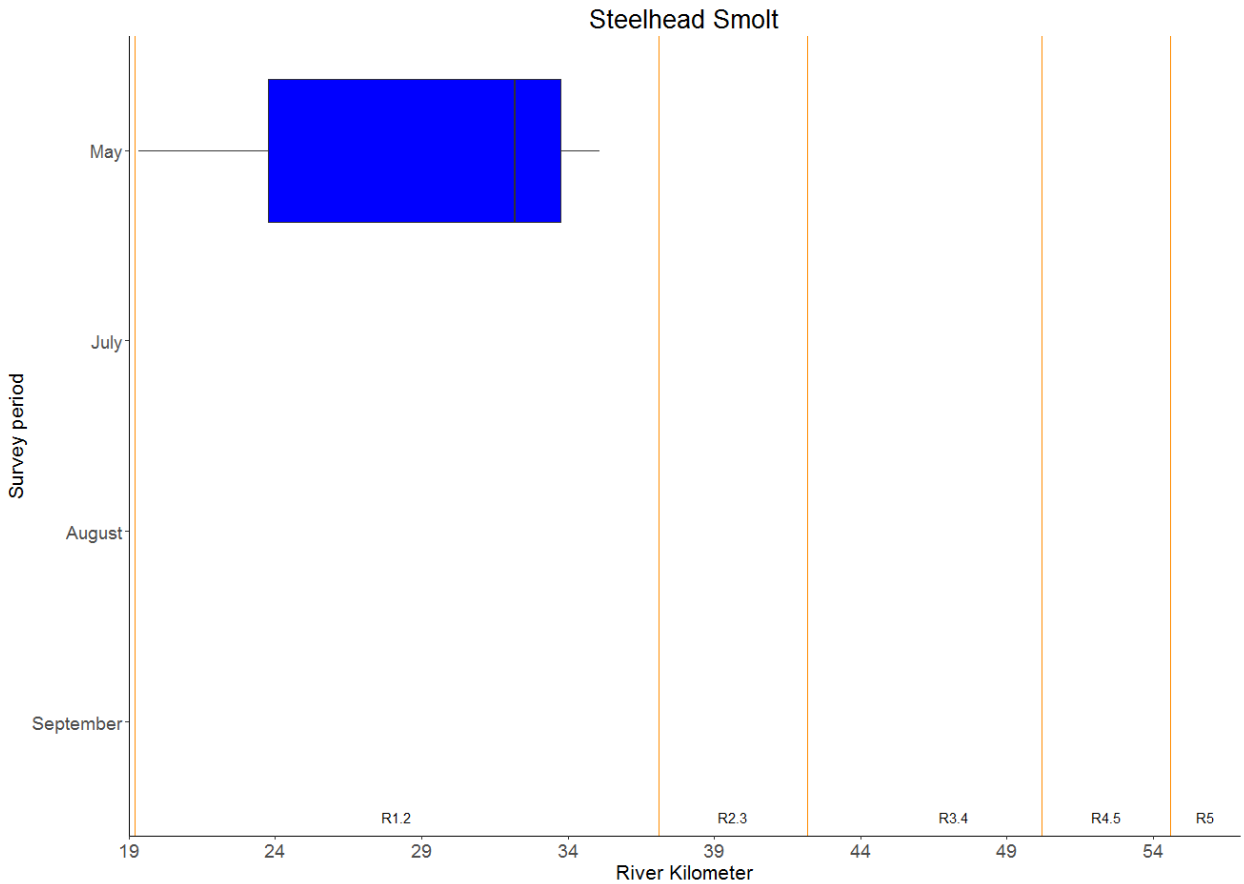

Figure C-7. Distribution of steelhead smolts by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25th and 75th quartile, and range of observations. Red vertical lines denote reach breaks (PIT detection arrays). Reaches are annotated along the lower portion of the figure.

Steelhead smolts were rare and observed in the May survey only (Table C-1) which is consistent with smolt outmigration timing observed in the main stem Chehalis River as monitored annually at the WDFW smolt trap near Rochester, Washington. In May, the overall median location of steelhead smolt observations occurred at rkm 32.2 (Figure C-7).

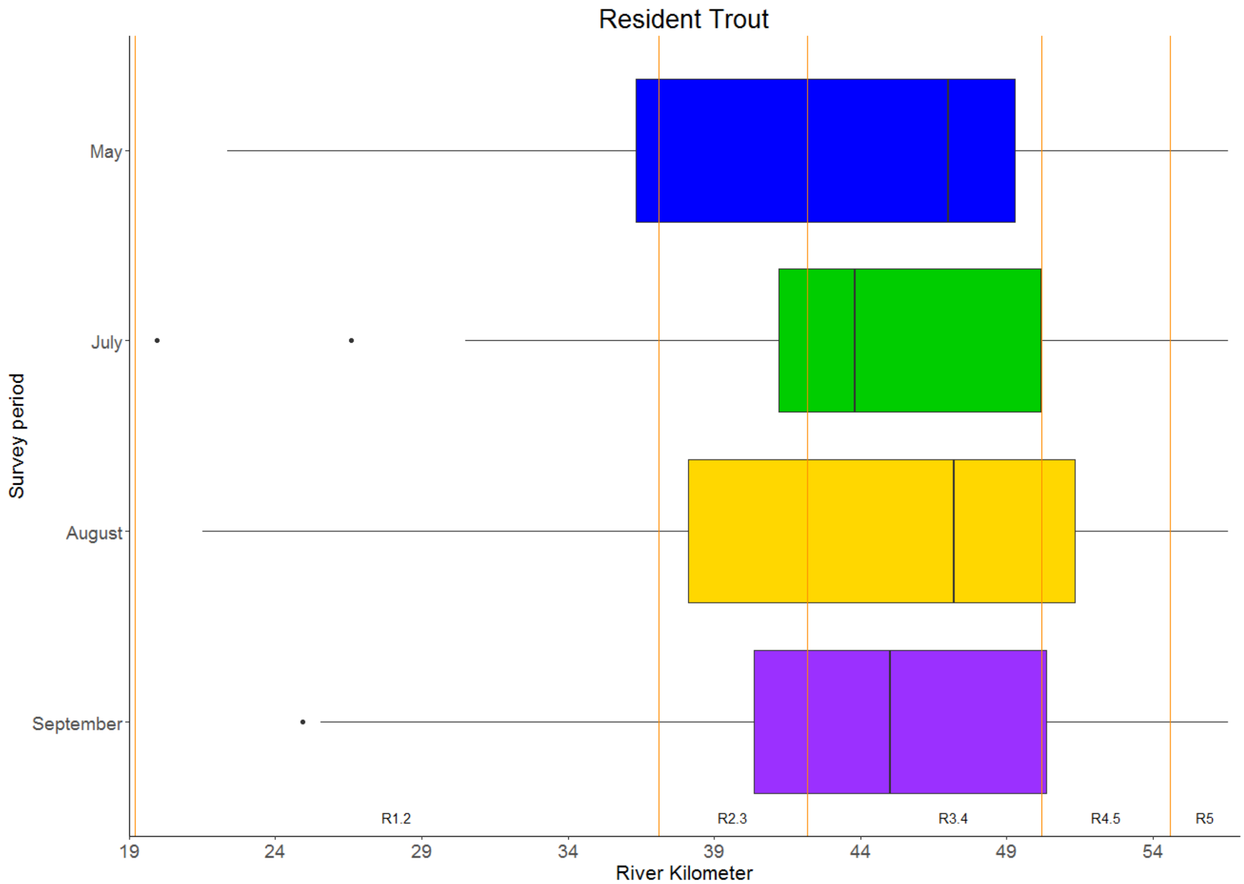

Figure C-8. Distribution of resident trout by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25th and 75th quartile, and range of observations. Red vertical lines denote reach breaks (PIT detection arrays). Reaches are annotated along the lower portion of the figure.

Resident trout were observed across all survey periods (Table C-1). The overall median location of resident trout observations varied by 3.2 km among surveys and was most downstream in July (rkm 43.8) and most upstream in August (rkm 47.2) (Figure C-8).

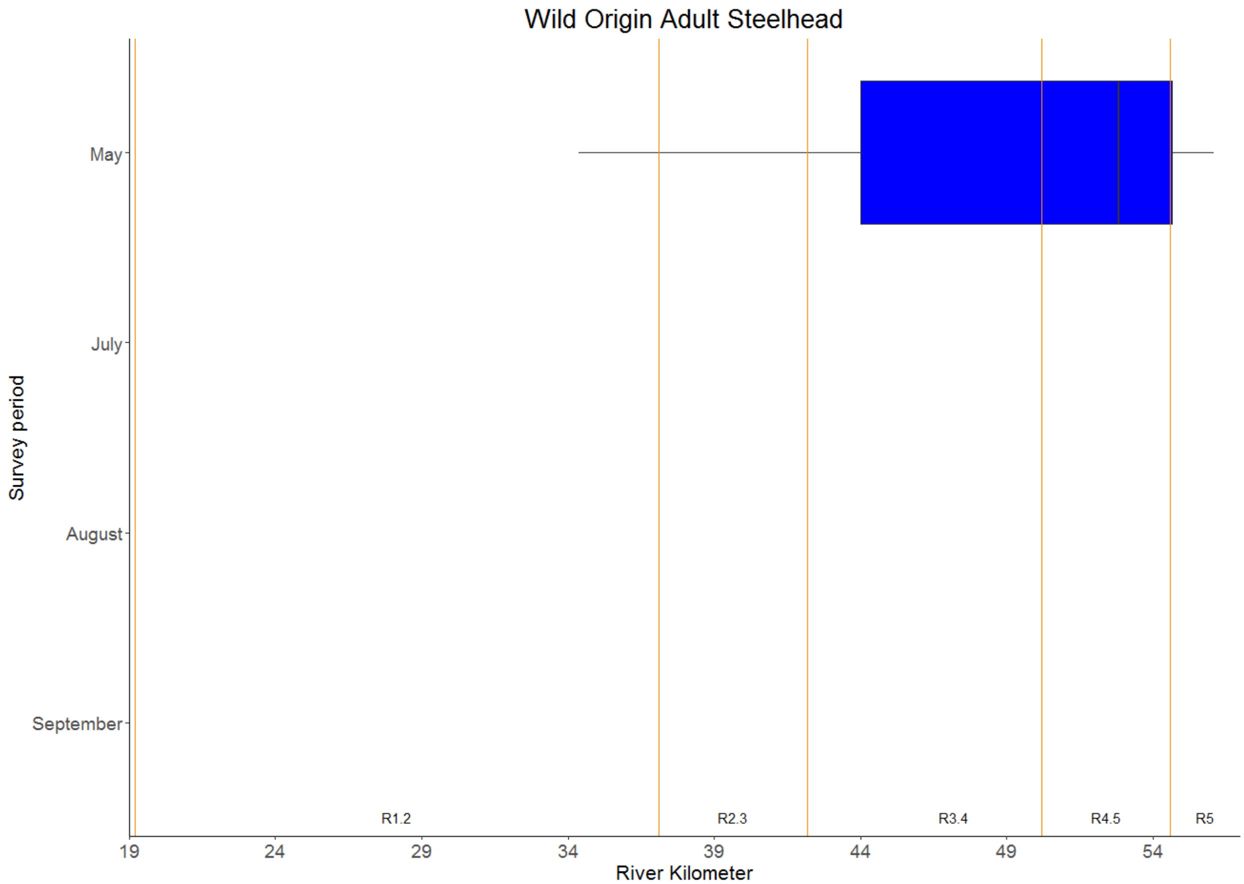

Figure C-9. Distribution of wild adult steelhead by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25th and 75th quartile, and range of observations. Red vertical lines denote reach breaks (PIT detection arrays). Reaches are annotated along the lower portion of the figure.

Wild adult steelhead were observed during the May survey only (Table C-1). In May, the overall median location of adult steelhead occurred at rkm 52.8 and the range of observations occurred between rkm 34.4 – 56.1 (Figure C-9).

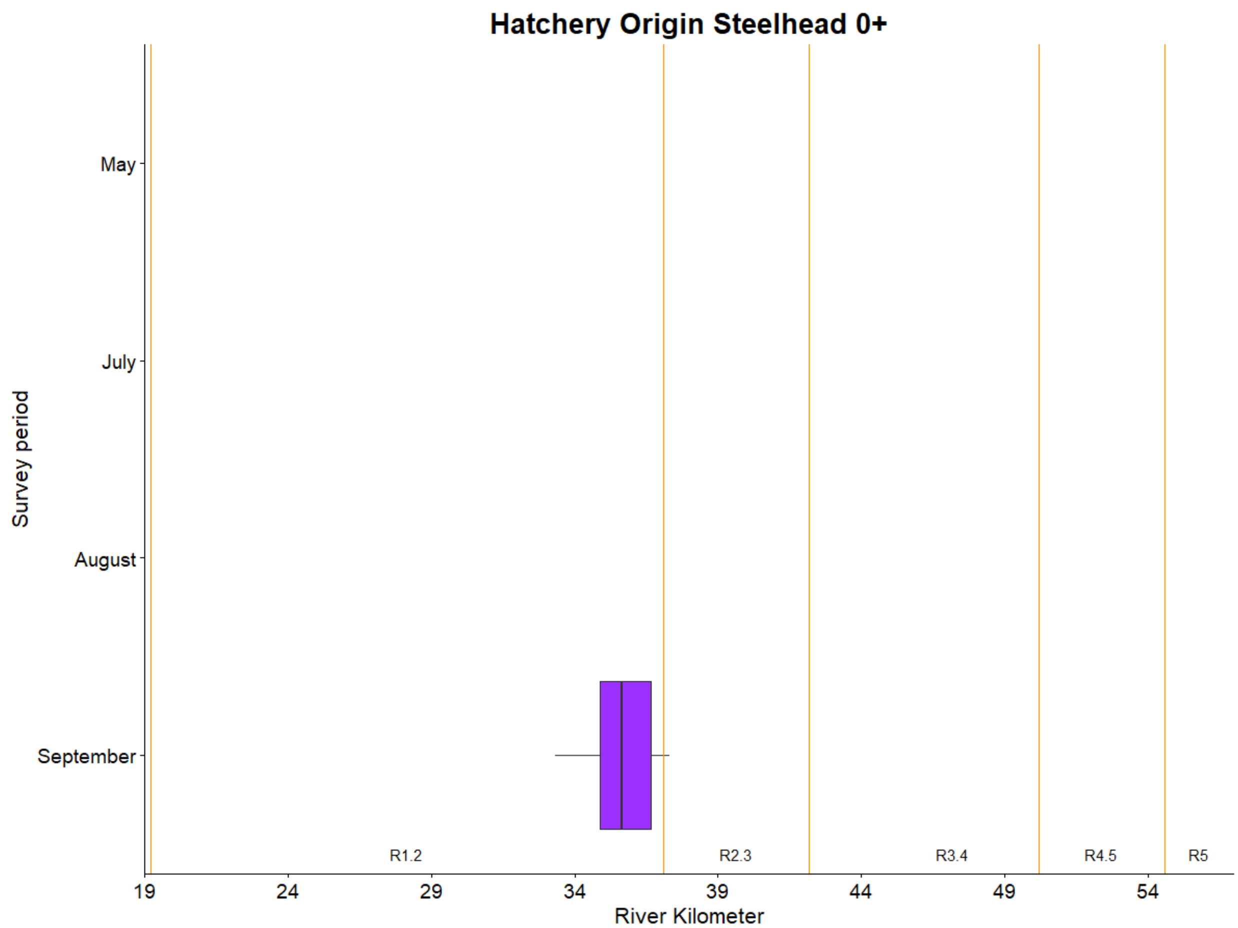

Figure C-10. Distribution of hatchery steelhead 0+ by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25th and 75th quartile, and range of observations. Red vertical lines denote reach breaks (PIT detection arrays). Reaches are annotated along the lower portion of the figure.

Hatchery steelhead 0+ were observed in September only (Table C-1). In September, the overall median location of hatchery origin steelhead 0+ observations occurred at rkm 35.7 and the distribution of observations ranged between rkm 33.3 and 37.3 (Figure C-10).

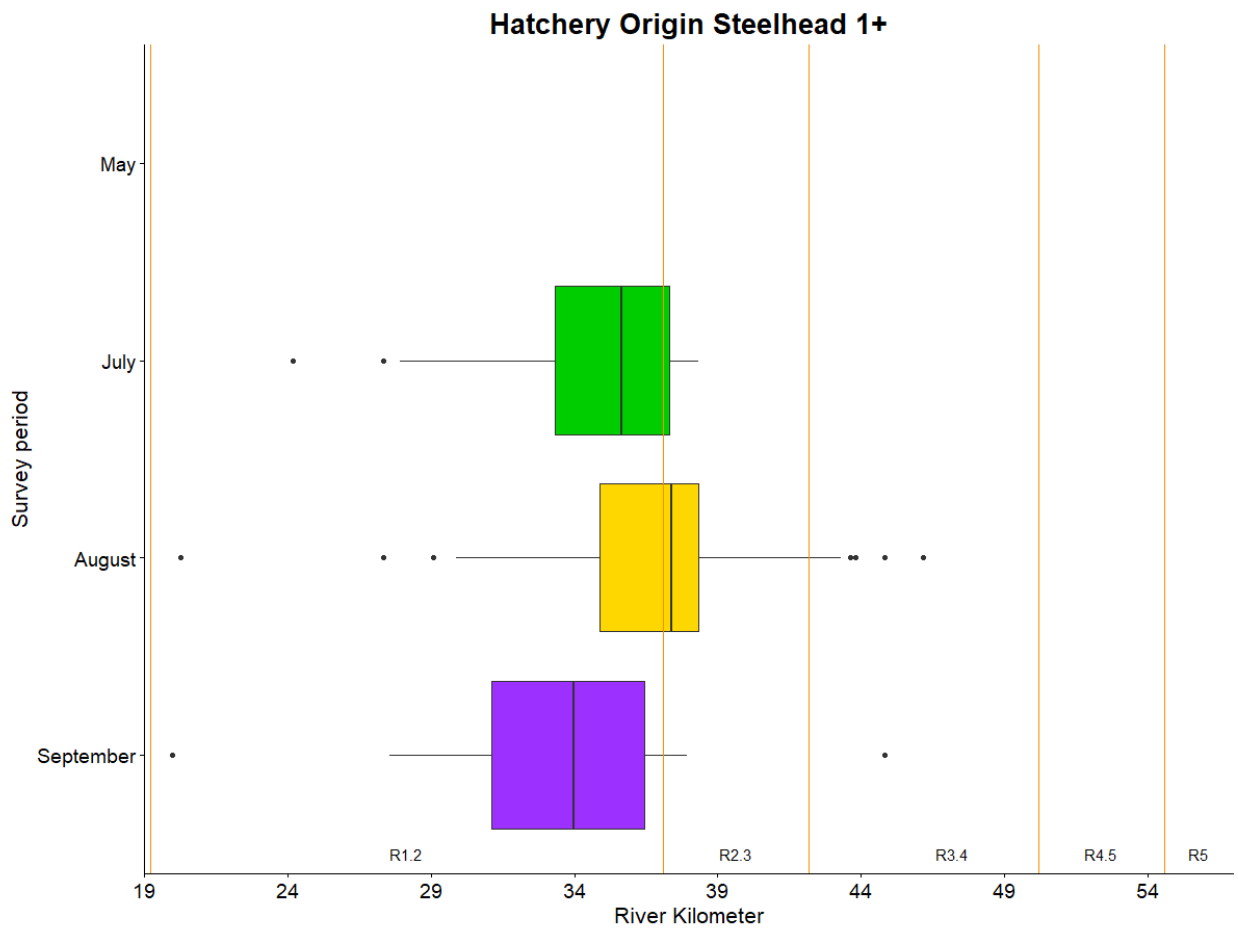

Figure C-11. Distribution of hatchery steelhead 1+ by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25th and 75th quartile, and range of observations. Red vertical lines denote reach breaks (PIT detection arrays). Reaches are annotated along the lower portion of the figure.

Hatchery steelhead 1+ were observed in July, August, and September but not in May (Table C-1). Excluding May, the overall median location of hatchery origin trout 1+ observations varied by 3.4 rkm and was most downstream in September (rkm 34.0) and most upstream in August (rkm 37.4) (Figure C-11).

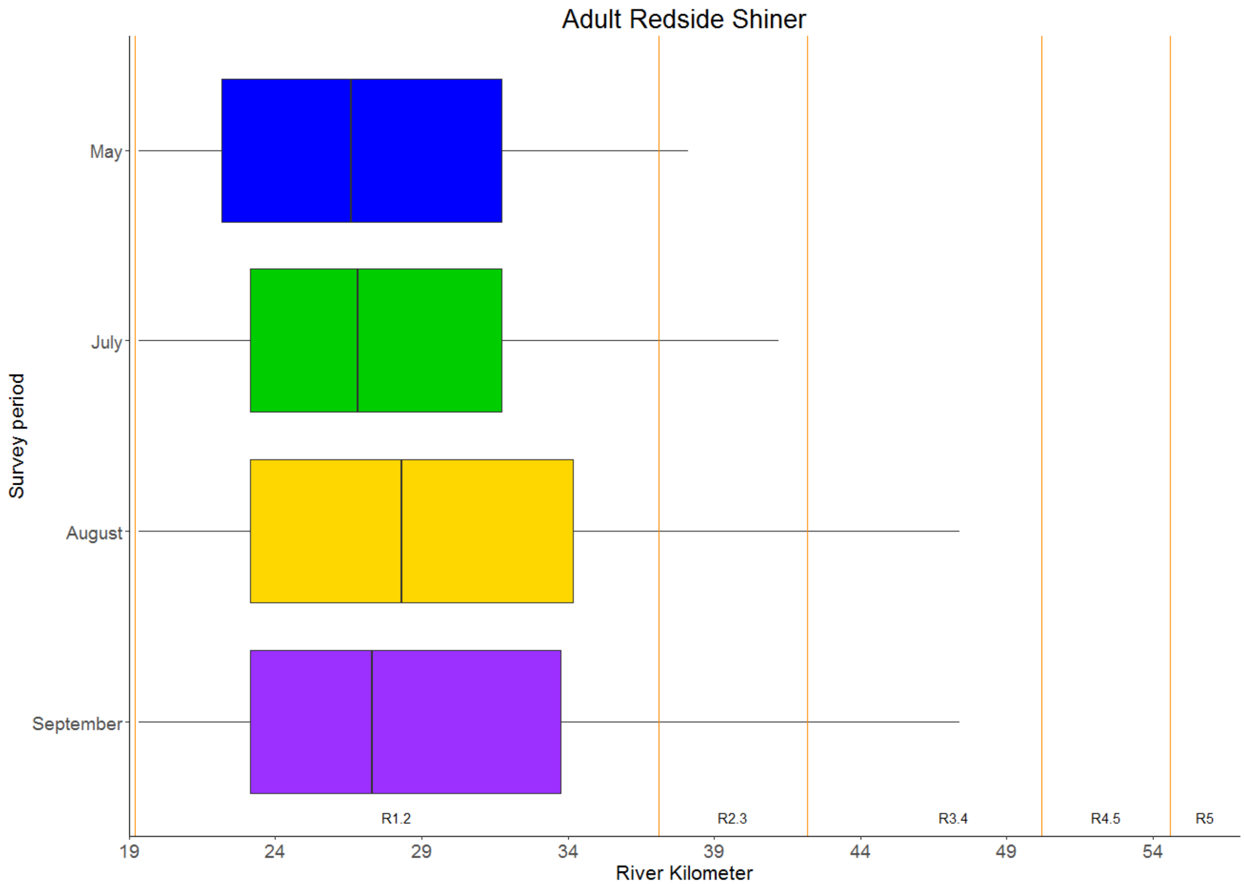

Figure C-12. Distribution of adult redside shiner by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25th and 75th quartile, and range of observations. Red vertical lines denote reach breaks (PIT detection arrays). Reaches are annotated along the lower portion of the figure.

Adult redside shiner were observed across all survey periods (Table C-1). The overall median location of redside shiner observations varied by 1.7 rkm and was most downstream in May (rkm 26.6) and most upstream in August (rkm 28.3) (Figure C-12).

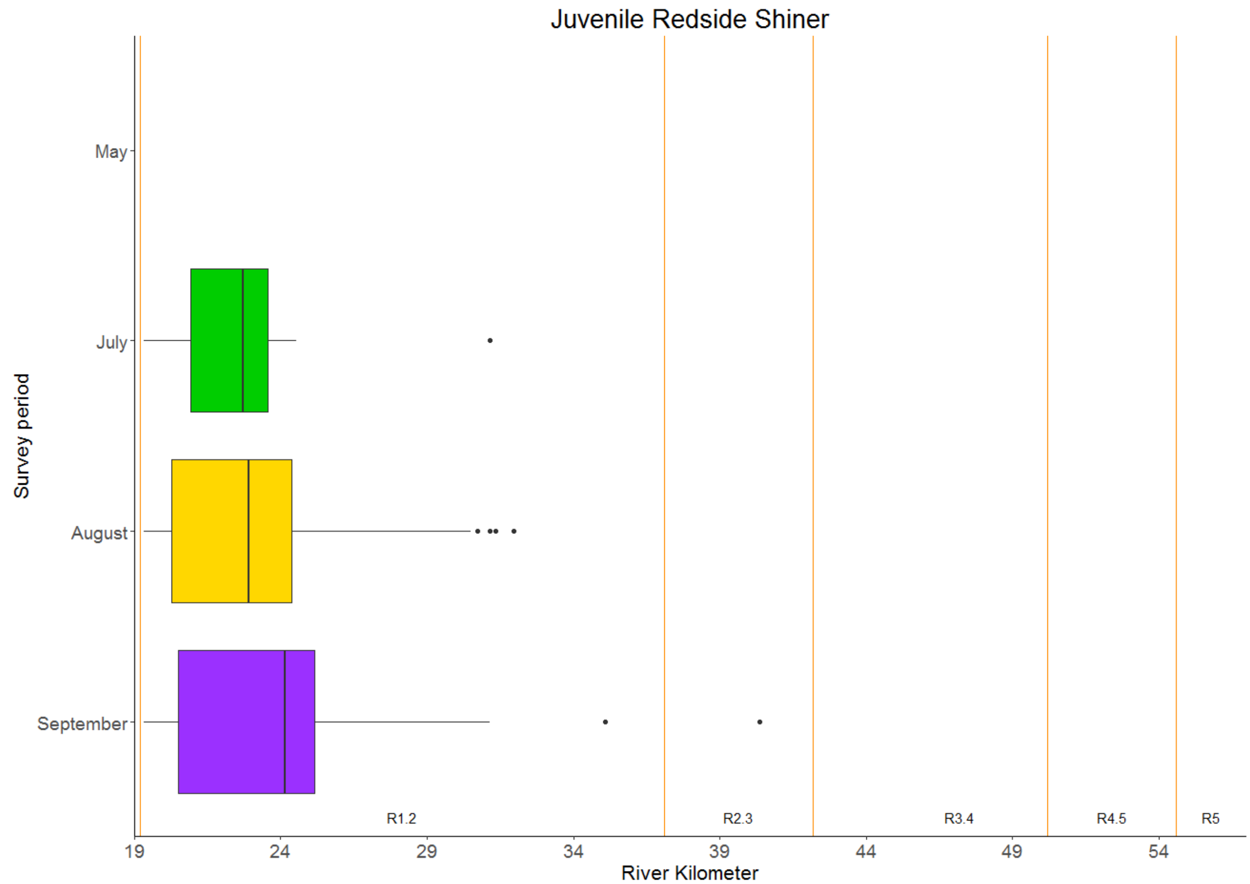

Figure C-13. Distribution of juvenile redside shiner by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25th and 75th quartile, and range of observations. Red vertical lines denote reach breaks (PIT detection arrays) and reaches are annotated on the lower portion of the figure.

Juvenile redside shiner were observed across all survey periods except May (Table C-1). Excluding May, the overall median of juvenile redside shiner observations varied by 1.3 km and was most downstream in July (rkm 22.7) and most upstream in September (rkm 24.2) (Figure C-13).

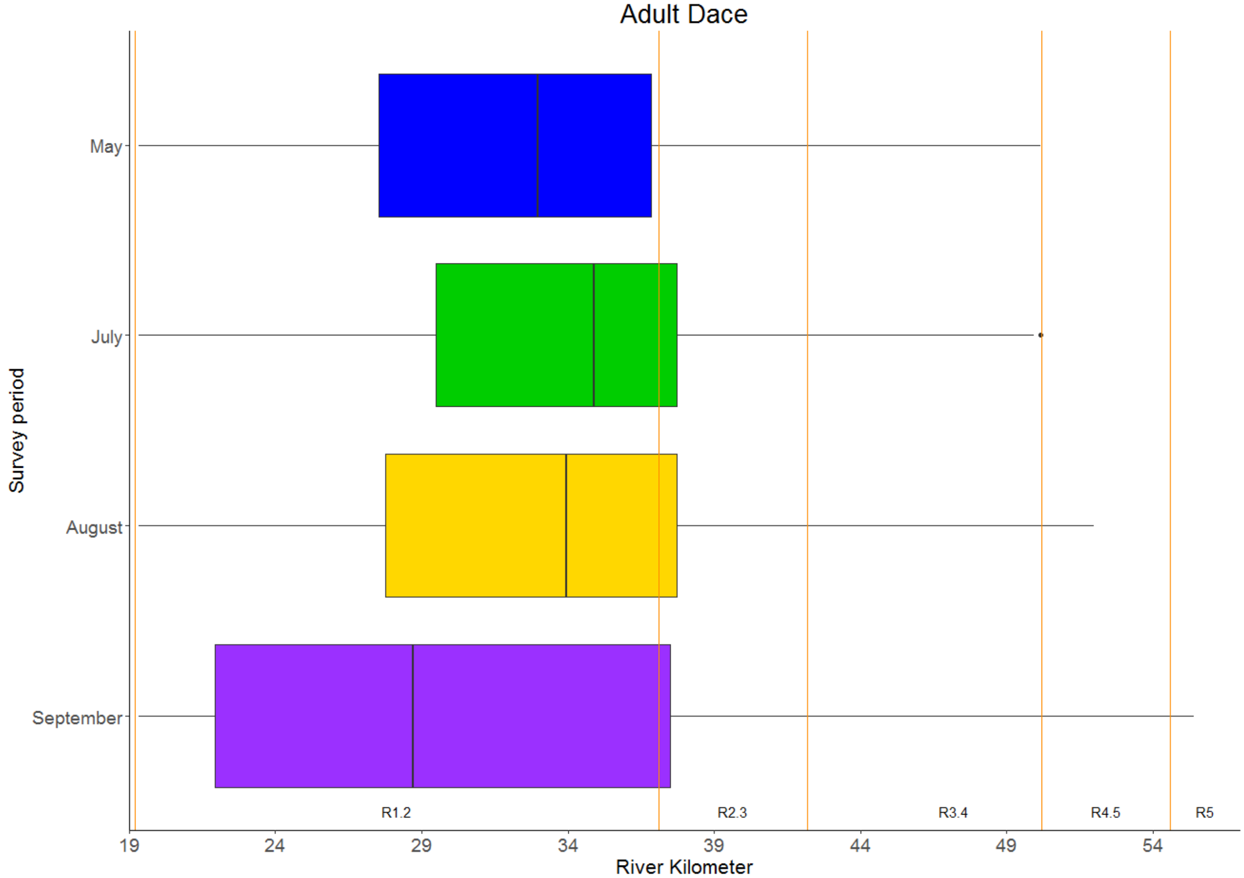

Figure C-14. Distribution of adult dace by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25th and 75th quartile, and range of observations. Red vertical lines denote reach breaks (PIT detection arrays) and reaches are annotated on the lower portion of the figure.

Adult dace were observed across all survey periods (Table C-1). The overall median of dace observations varied by 6.2 km and was most downstream in September (rkm 28.7) and most upstream in July (rkm 34.9) (Figure C-14).

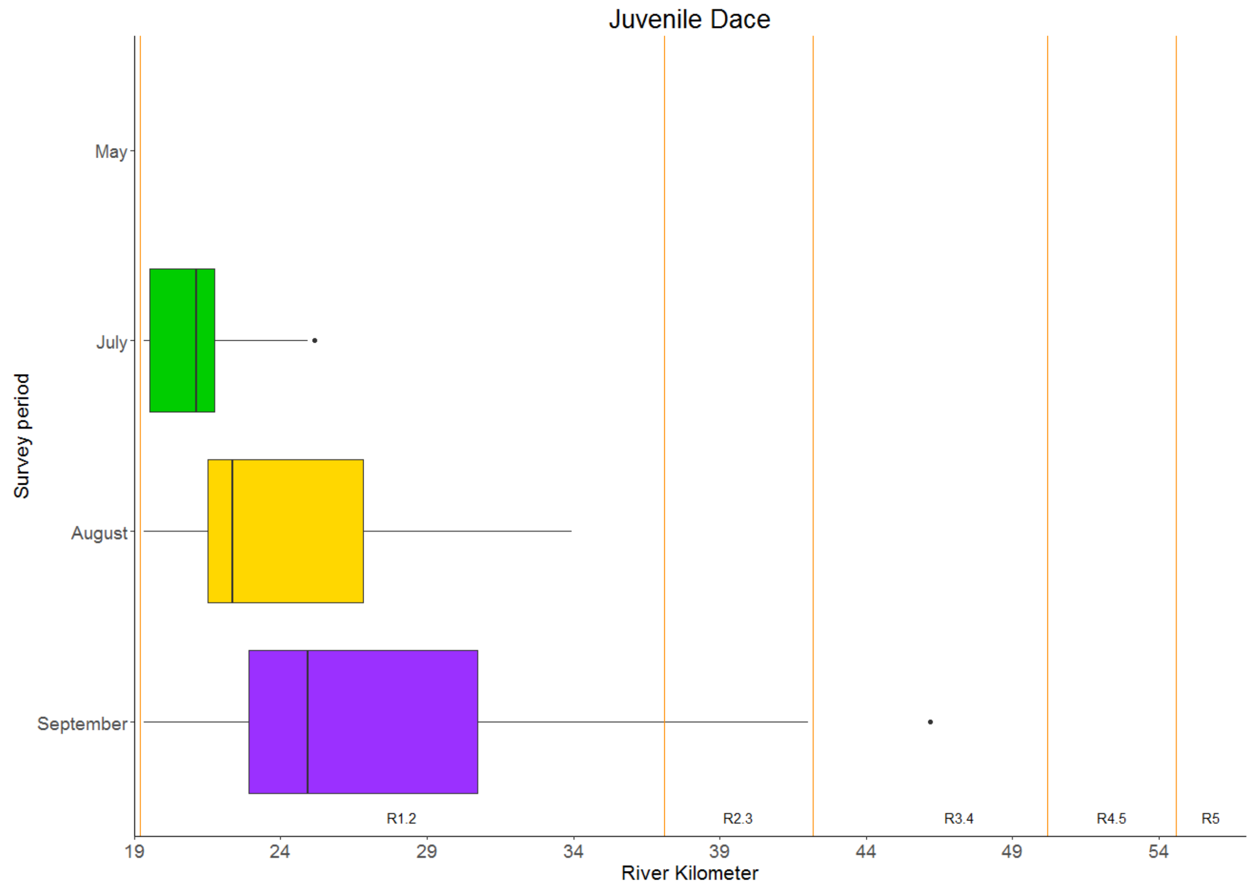

Figure C-15. Distribution of juvenile dace by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25th and 75th quartile, and range of observations. Red vertical lines denote reach breaks (PIT detection arrays) and reaches are annotated on the lower portion of the figure.

Juvenile dace were observed across all survey periods except May (Table C-1). Excluding May, the overall median of juvenile dace observations varied by 3.8 km and was most downstream in July (rkm 21.1) and most upstream in September (rkm 24.9) (Figure C-15).

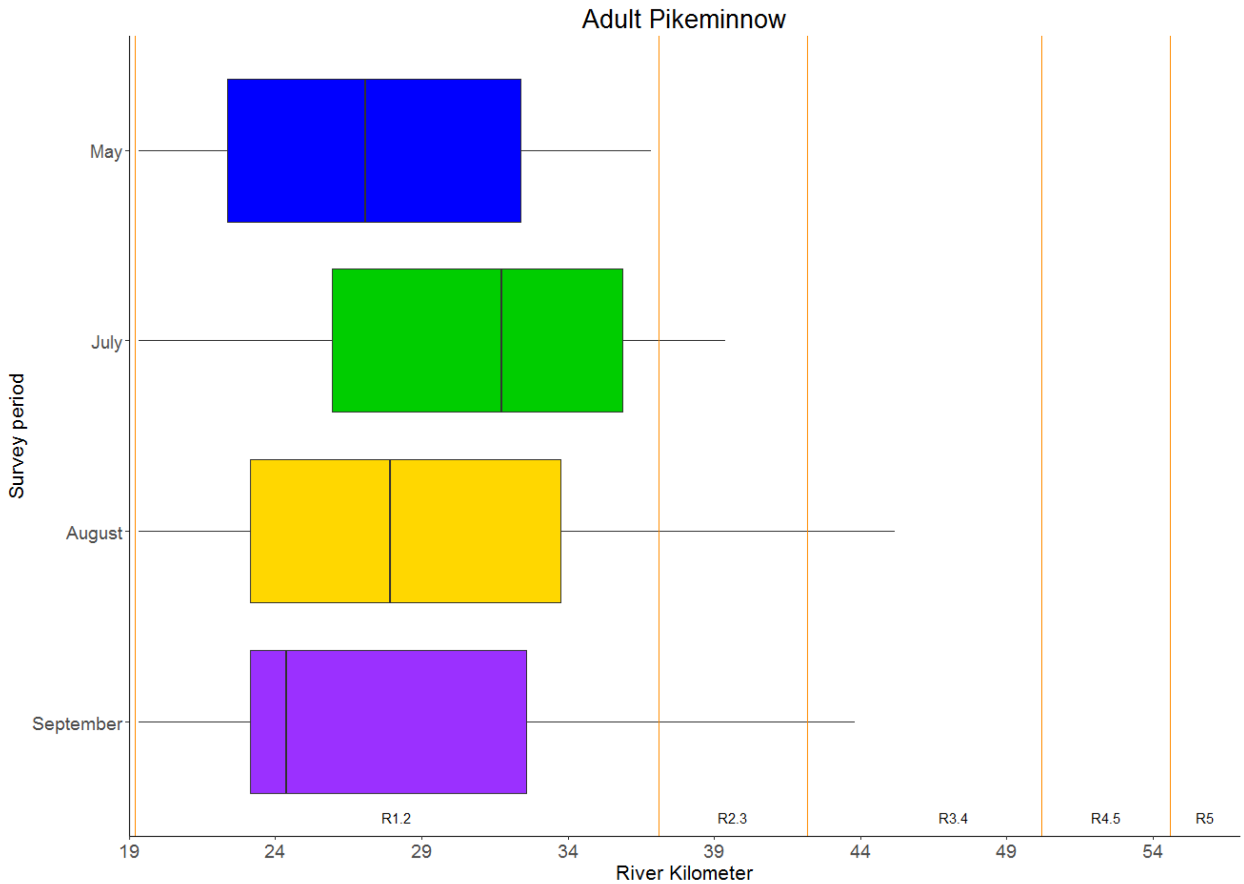

Figure C-16. Distribution of adult pikeminnow by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25^{th} and 75^{th} quartile, and range of observations. Red vertical lines denote reach breaks (PIT detection arrays) and reaches are annotated on the lower portion of the figure.

Adult pikeminnow were observed across all survey periods (Table C-1). The overall median of pikeminnow observations varied by 7.3 km and was most downstream in September (rkm 24.4) and most upstream in July (rkm 31.7) (Figure C-16).

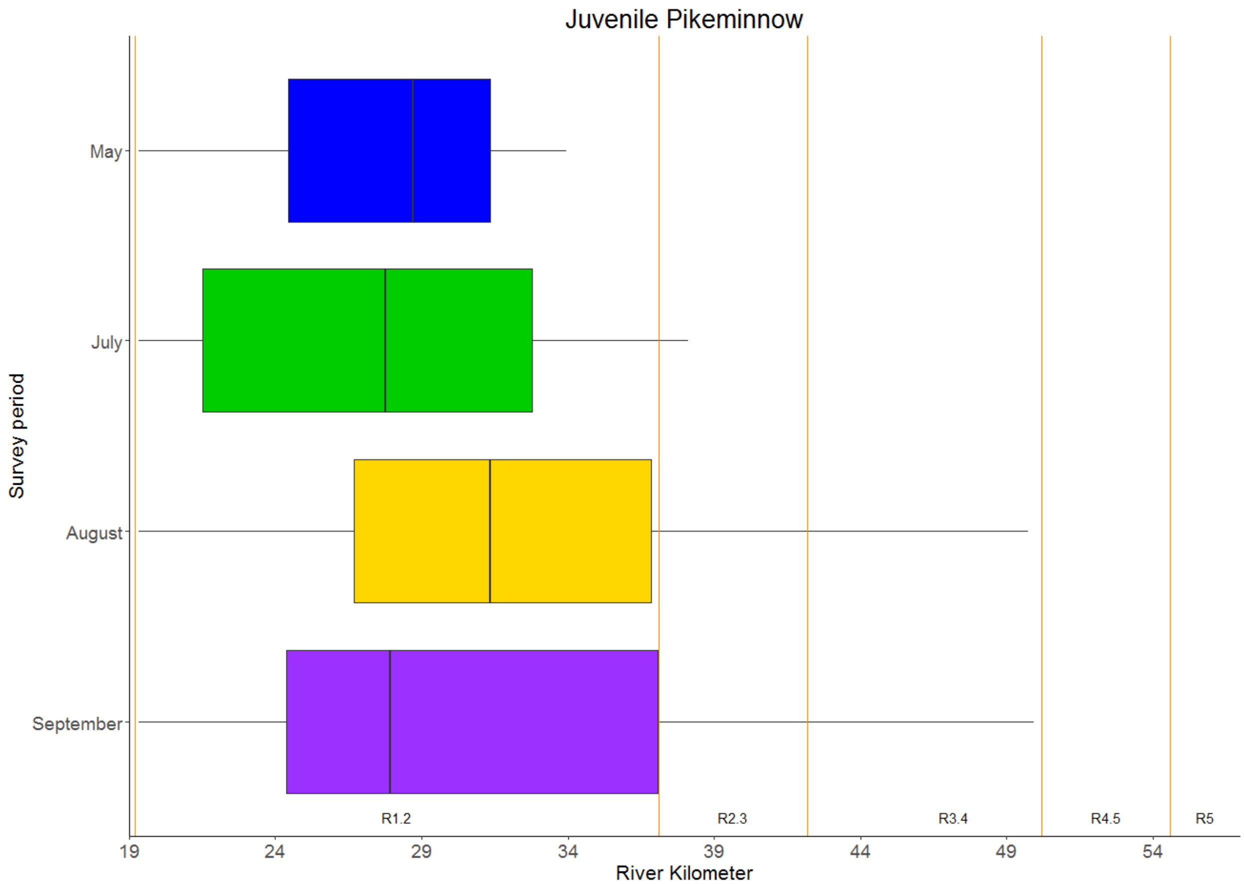

Figure C-17. Distribution of juvenile pikeminnow by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25th and 75th quartile, and range of observations. Red vertical lines denote reach breaks (PIT detection arrays) and reaches are annotated on the lower portion of the figure.

Juvenile pikeminnow were observed across all survey periods (Table C-1). The overall median of juvenile pikeminnow observations varied by 3.7 km and was most downstream in July (rkm 27.8) and most upstream in August (rkm 31.3) (Figure C-17).

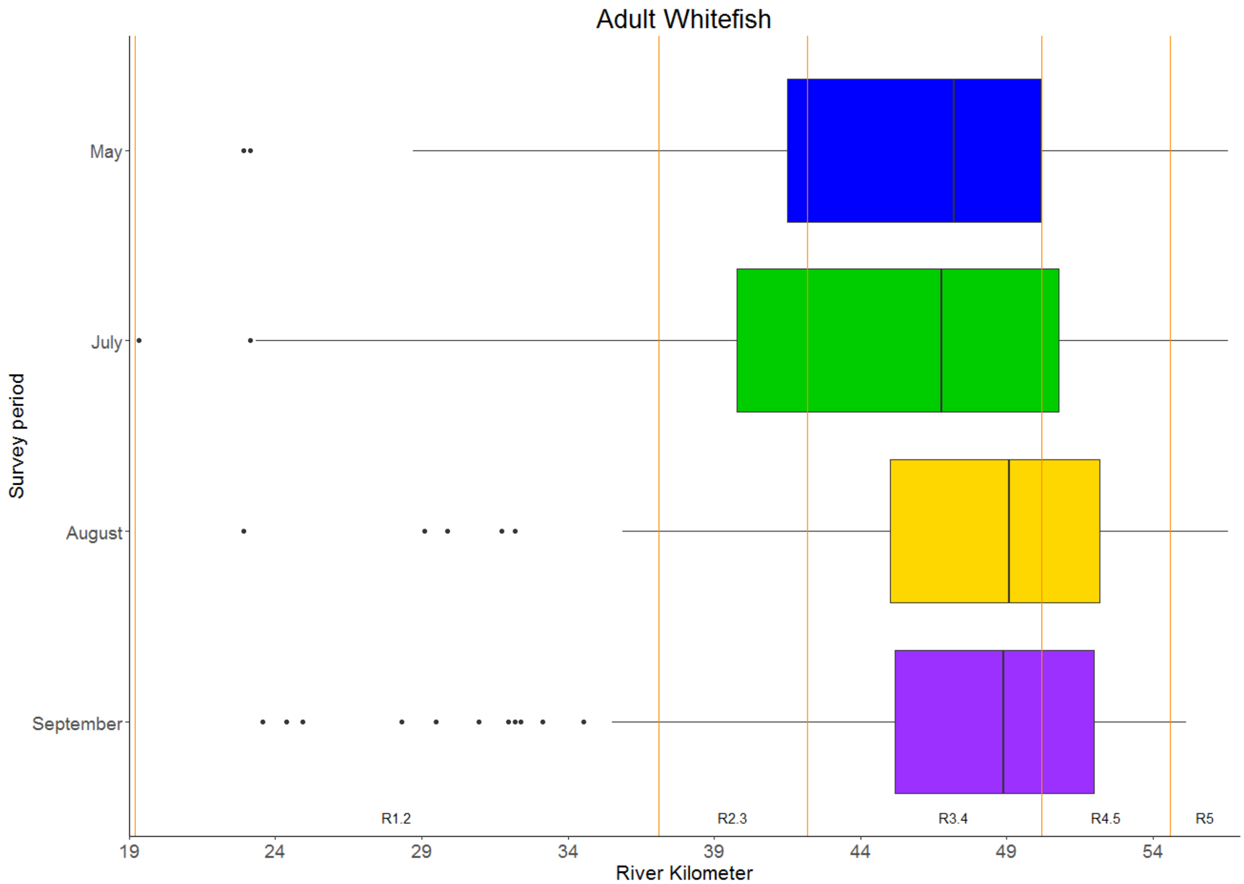

Figure C-18. Distribution of adult whitefish by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25^{th} and 75^{th} quartile, and range of observations. Red vertical lines denote reach breaks (PIT detection arrays) and reaches are annotated on the lower portion of the figure.

Adult whitefish were observed across all survey periods (Table C-1). The overall median of adult whitefish observations varied by 2.3 km and was most downstream in July (rkm 46.8) and most upstream in August (rkm 49.1) (Figure C-18).

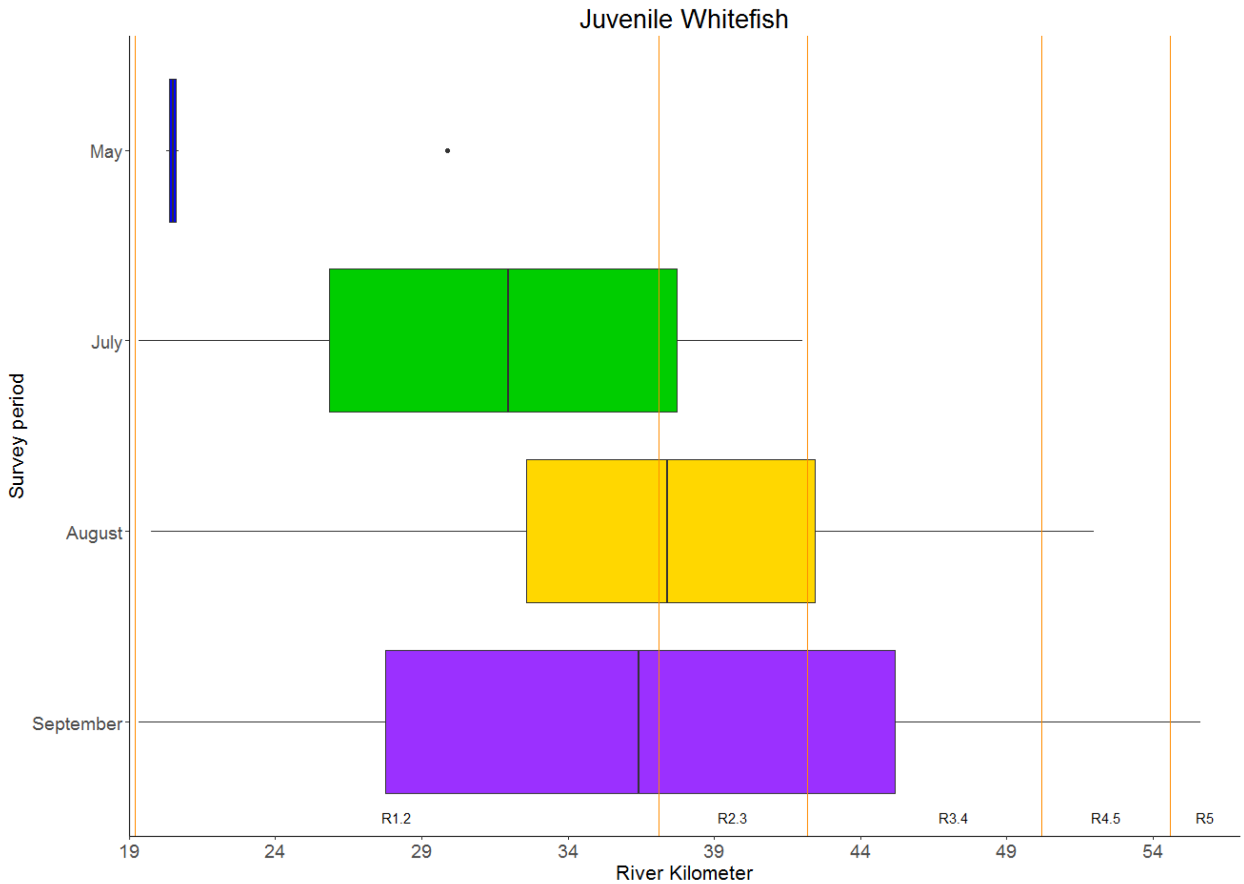

Figure C-19. Distribution of juvenile whitefish by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25th and 75th quartile, and range of observations. Red vertical lines denote reach breaks (PIT detection arrays) and reaches are annotated on the lower portion of the figure.

Juvenile whitefish were observed across all survey periods however observations were rare in May (n = 7) (Table C-1). In the July, August, and September surveys, the overall median of juvenile whitefish observations varied by 5.4 km and was most downstream in July (rkm 32) and most upstream in August (rkm 37.4) (Figure C-19).

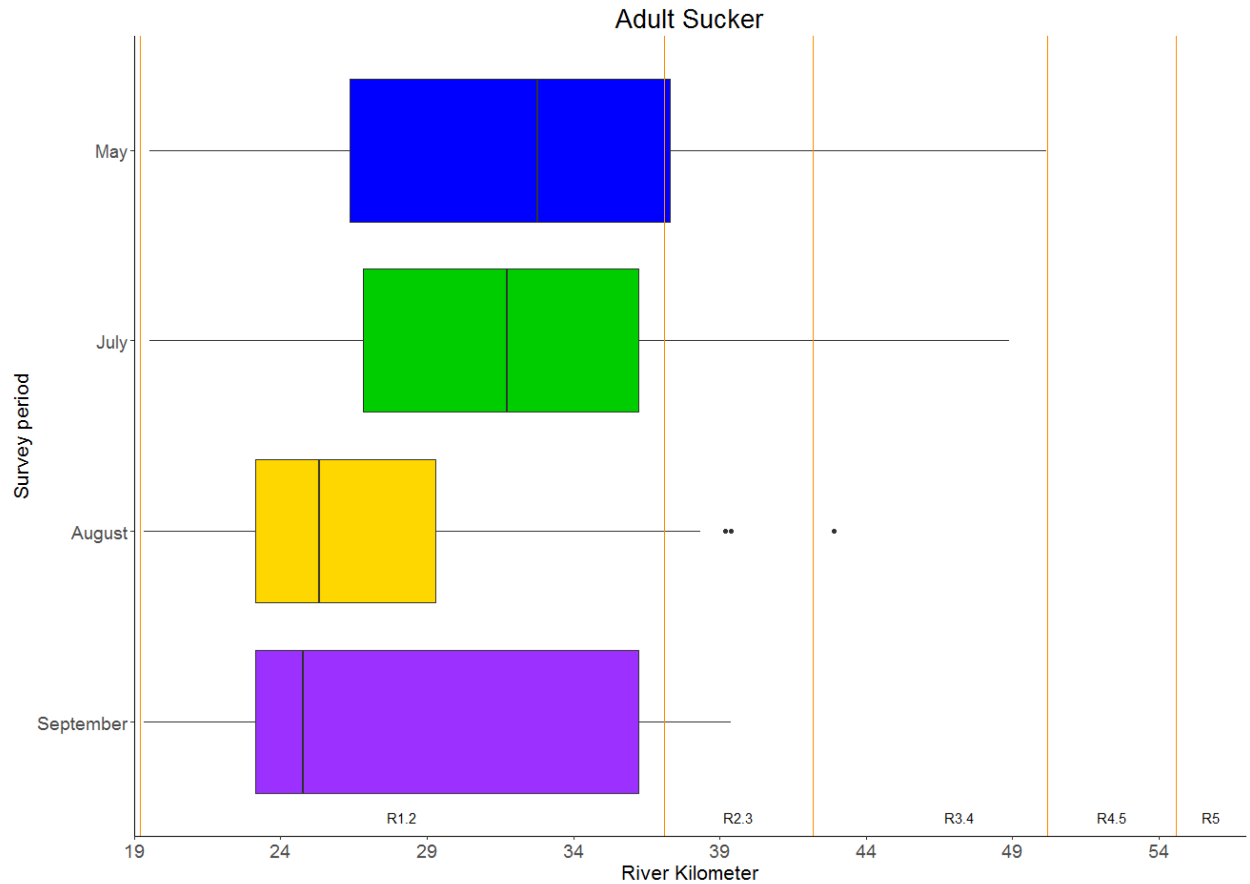

Figure C-20. Distribution of adult largescale sucker by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25th and 75th quartile, and range of observations. Red vertical lines denote reach breaks (PIT detection arrays) and reaches are annotated on the lower portion of the figure.

Adult largescale sucker were observed across all survey periods (Table C-1). The overall median of adult largescale sucker observations varied by 8 km and was most downstream in September (rkm 24.8) and most upstream in May (rkm 32.8) (Figure C-20).

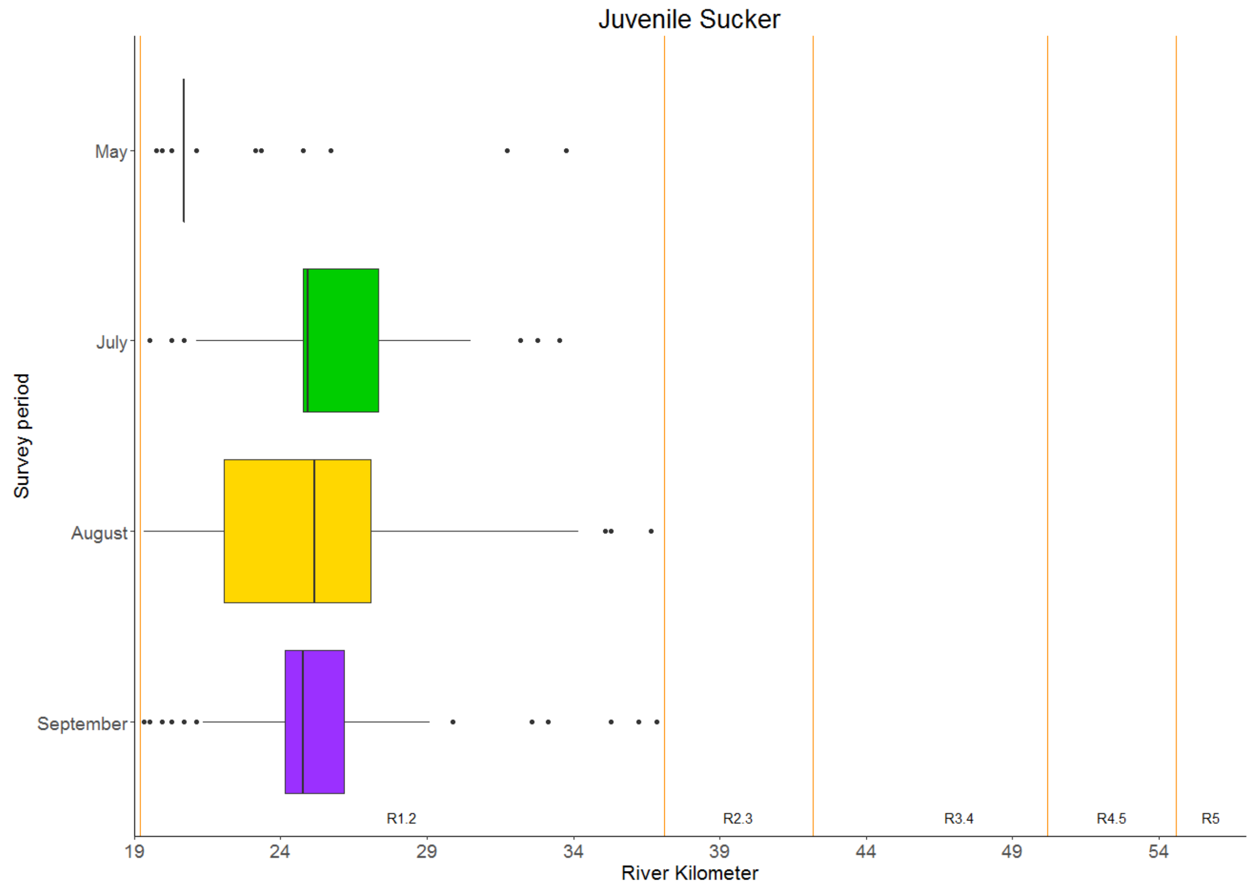

Figure C-21. Distribution of juvenile largescale sucker by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25th and 75th quartile, and range of observations. Red vertical lines denote reach breaks (PIT detection arrays) and reaches are annotated on the lower portion of the figure.

Juvenile largescale sucker were observed across all survey periods (Table C-1). The overall median of juvenile largescale sucker observations in the survey area varied by 4.5 km and was observed in the most downstream location in May (rkm 20.7) and the most upstream location in August (rkm 25.2) (Figure C-21).

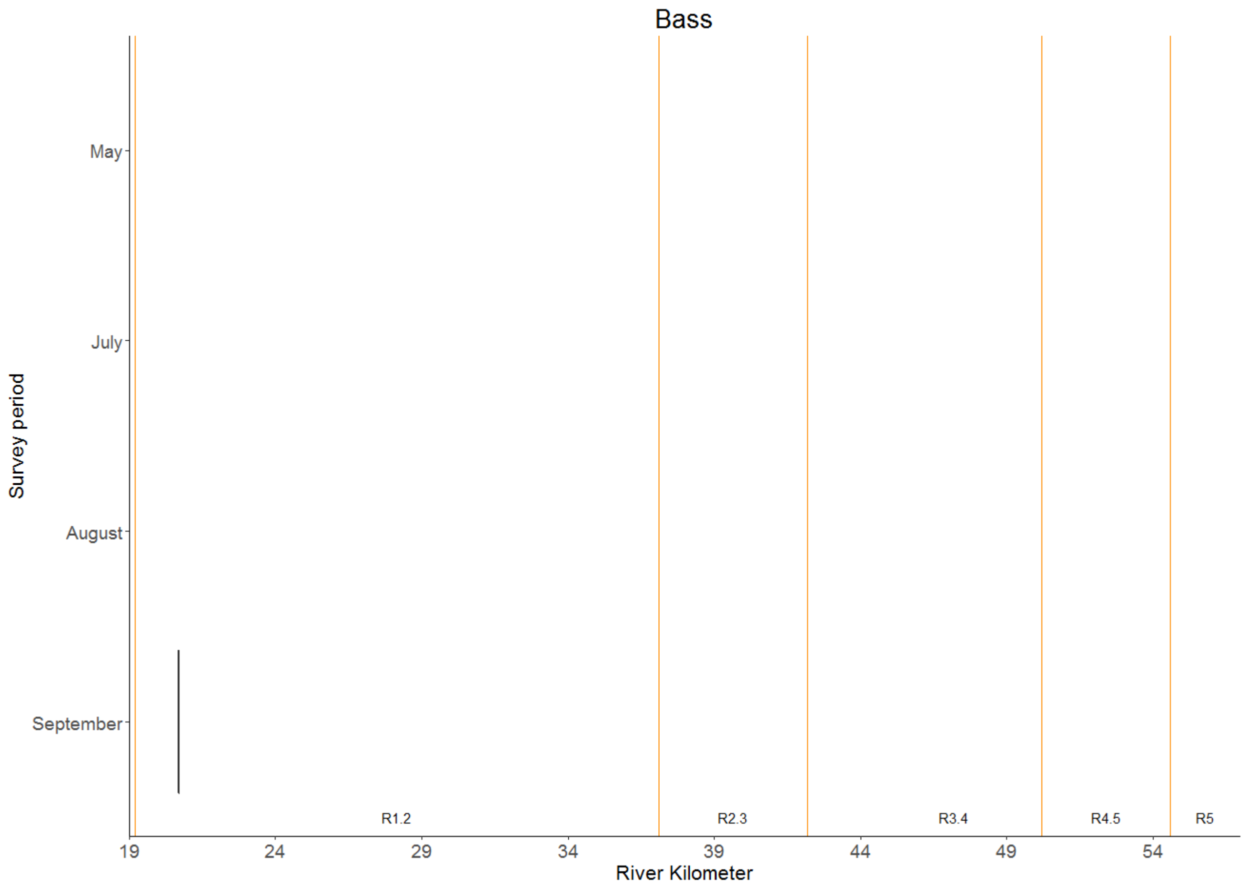

Figure C-22. Distribution of bass by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25th and 75th quartile, and range of observations. Red vertical lines denote reach breaks (PIT detection arrays) and reaches are annotated on the lower portion of the figure.

One bass observation occurred at rkm 20.7 (Table C-1, Figure C-22).

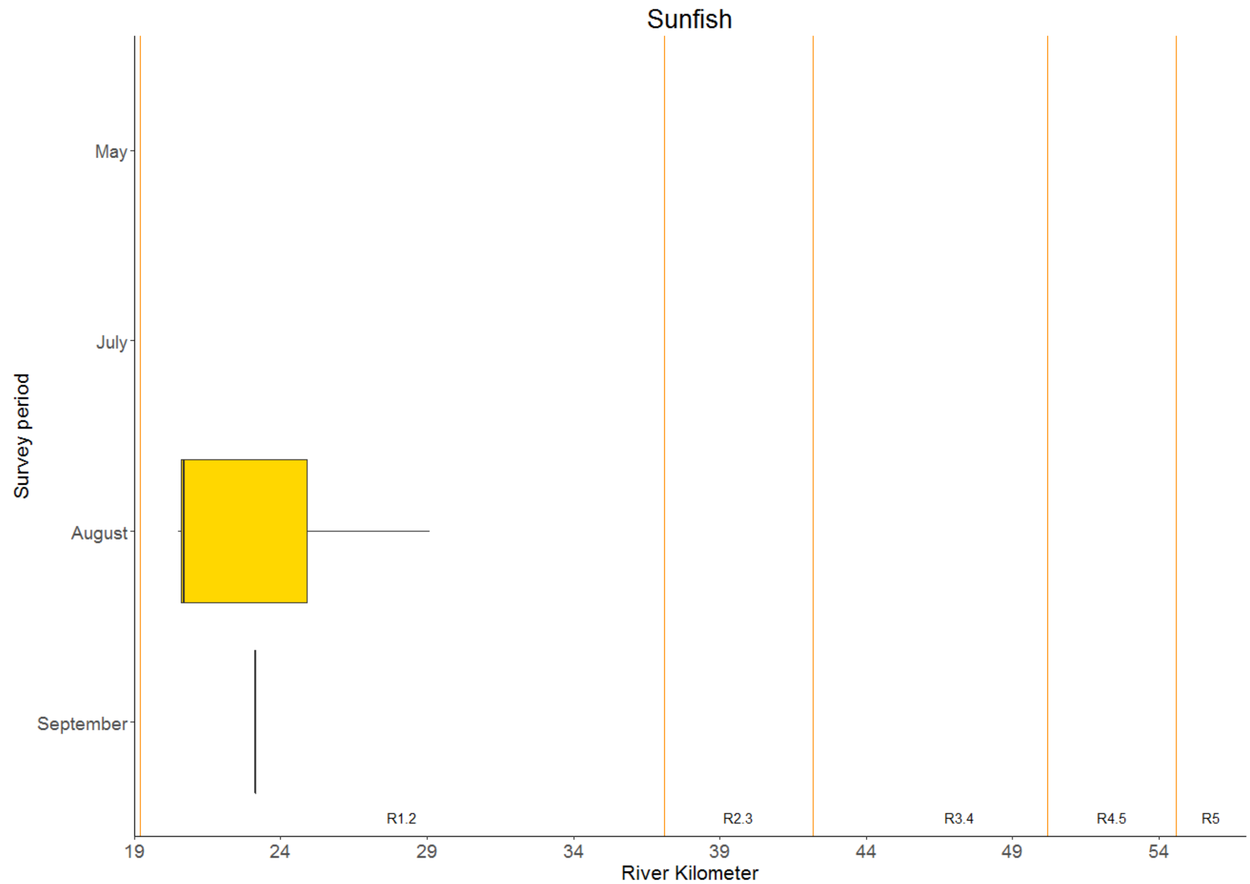

Figure C-23. Distribution of sunfish by river kilometer among four surveys in the South Fork Newaukum River, 2016. Box plots represent median, 25th and 75th quartile, and range of observations. Red vertical lines denote reach breaks (PIT detection arrays) and reaches are annotated on the lower portion of the figure.

Sunfish were observed in August (n = 3) and September (n = 5) (Table C-1). Observations in August ranged from rkm 20.5 – 29.1. All observations in September occurred at rkm 23.2 (Figure C-23).

Appendix D. Location and Stream Temperatures Associated with Salmonid versus Cyprinid Assemblages

The proportion of the survey area characterized by ‘low’ salmonid segments increased roughly three-fold over the four surveys and was lowest in May (0.11) and greatest in September (0.36, Table D-1). In contrast, the proportion of the survey area characterized by ‘medium’ and ‘high’ salmonid segments decreased over the four surveys, and was greatest in May (‘medium’ = 0.38, ‘high’ = 0.51) and lowest in September (‘medium’ = 0.23, ‘high’ = 0.41). The mean location of segments in each fish assemblage category shifted upstream from May to September. ‘High salmonid’ segments shifted upstream by 1.8 km from May through August and then slightly downstream (0.2 km) in September. The most downstream ‘high salmonid’ segment was at rkm 35.5 in May and shifted upstream to rkm 38.3 in August and September. Mean river km of ‘low salmonid’ and ‘medium salmonid’ segments shifted upstream by 2.9 and 6.5 km, respectively, from May to September. The most upstream ‘low salmonid’ segment was at rkm 31.7 and 34.4 in May and July and rkm 35.7 and 39.0 in August and September, respectively.

Temperatures associated with each fish assemblage category varied between survey periods however across all surveys, ‘low’ salmonid segments were consistently warmer than ‘high’ salmonid segments (Table D-2). The greatest contrast in temperature between ‘low’ and ‘high’ salmonid segments was observed in July and August when mean, maximum, and minimum daily temperatures varied up to 4.1℃ between the two categories. During July and August, temperatures were equal to or exceeded 18℃ up to 70% of the time in ‘low’ salmonid segments compared to 0 to 10% of the time in ‘high’ salmonid segments. In all months, temperature characteristics of the ‘medium salmonid’ segments were intermediate to the other two categories but closer in value to those observed in the ‘low salmonid’ segments. Across all survey periods, mean, maximum, and minimum daily temperatures varied 0.5℃ to 1.6℃ between ‘medium’ and ‘low’ salmonid segments whereas temperature characteristics of ‘medium’ and ‘high’ salmonid segments varied 1.5℃ to 3.4℃.

Table D-1. Fish assemblage summarized by survey period in the South Fork Newaukum River, 2016. Fish assemblage is categorized as low salmonid (<25%), medium salmonid (25 – 75%), and high salmonid (>75%). Proportion is the ratio of 200-m segments associated with each category. Mean (± SD) and range of river kilometers (rkm) describe the location of segments associated with each category.

	Low Salmonid-High Cyprinid	**Medium Salmonid-Medium Cyprinid**	**High Salmonid-Low Cyprinid**
May			
Proportion	0.11	0.38	0.51
Mean rkm	23.7 (±3.6)	30.1 (±5.1)	46.8 (±5.6)
Range rkm	19.5-31.7	19.5-42.4	35.5-56.6
July			
Proportion	0.25	0.27	0.48
Mean rkm	24.9 (±3.7)	32.9 (±4.7)	47.2 (±5.4)
Range rkm	19.3-34.4	19.5-42.4	36.2-56.6
August			
Proportion	0.31	0.27	0.42
Mean rkm	25.9 (±4.4)	35.3 (±4.3)	48.6 (±4.6)
Range rkm	19.3-35.7	24.9-45.2	38.3-56.6
September			
Proportion	0.36	0.23	0.41
Mean rkm	26.6 (±4.9)	36.6 (±4.3)	48.4 (±4.9)
Range rkm	19.3-39.0	29.3-46.0	38.3-56.6

Table D-2. Temperature metrics (mean ± SD) of survey segments organized by fish assemblage category (low, medium, and high salmonid) in the South Fork Newaukum River, 2016.

	Low Salmonid-High Cyprinid	**Medium Salmonid-Medium Cyprinid**	**High Salmonid-Low Cyprinid**
May			
Mean Daily Temperature (˚C)	14.8 (±0.3)	14.1 (±0.5)	11.7 (±1.0)
Maximum Daily Temperature (˚C)	16.6 (±0.2)	16.2 (±0.3)	13.6 (±1.3)
Minimum Daily Temperature (˚C)	13.1 (±0.5)	12.3 (±0.7)	10.1 (±0.7)
Proportion ≥ 18 ˚C	0.1 (±0.0)	0.0 (±0.0)	0.0 (±0.0)
July			
Mean Daily Temperature (˚C)	18.3 (±0.4)	17.3 (±0.7)	14.4 (±1.3)
Maximum Daily Temperature (˚C)	20.1 (±0.3)	19.4 (±0.5)	16.4 (±1.7)
Minimum Daily Temperature (˚C)	16.7 (±0.5)	15.4 (±0.8)	12.9 (±0.9)
Proportion ≥ 18 ˚C	0.5 (±0.1)	0.3 (±0.1)	0.1 (±0.1)
August			
Mean Daily Temperature (˚C)	19.4 (±0.4)	18.2 (±0.7)	15.3 (±1.2)
Maximum Daily Temperature (˚C)	21.3 (±0.3)	20.6 (±0.6)	17.3 (±1.6)
Minimum Daily Temperature (˚C)	17.6 (±0.6)	16.1 (±0.8)	13.6 (±0.8)
Proportion ≥ 18 ˚C	0.7 (±0.1)	0.5 (±0.1)	0.1 (±0.1)
September			
Mean Daily Temperature (˚C)	15.4 (±0.4)	14.4 (±0.6)	12.6 (±0.8)
Maximum Daily Temperature (˚C)	16.8 (±0.3)	16.1 (±0.5)	14.1 (±1.2)
Minimum Daily Temperature (˚C)	14.1 (±0.6)	12.9 (±0.6)	11.4 (±0.6)
Proportion ≥ 18 ˚C	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)

Appendix E. Densities of Salmonid and Cyprinid Species Use in Fish Assemblage Analysis

Table E-1. Densities (fish count per 100 m) by study reach and survey period for salmonids and cyprinids in the South Fork Newaukum River, 2016. Data are mean (± SD) among segments within each study reach and survey period. Species included in this table were used in the fish assemblage analysis. Data are shown in graphical format in Figures 7-13.

		Reach				
Species	**Survey**	**R1.2**	**R2.3**	**R3.4**	**R4.5**	**R5**
Coho 0+	May	24.6 (±33.4)	76.1 (±37.8)	84.0 (±39.7)	91.0 (±40.7)	49.4 (±37.3)
	July	20.2 (±25.6)	90.4 (±49.5)	137.7 (±57.5)	109.7 (±63.6)	73.1 (±38.1)
	August	9.8 (±13.1)	49.0 (±25.5)	142.7 (±59.2)	112.1 (±64.2)	68.1 (±52.9)
	September	5.7 (±8.2)	26.7 (±22.5)	76.7 (±64.9)	64.7 (±64.8)	21.4 (±46.3)
Steelhead 0+	May	0.4 (±0.8)	0.2 (±0.5)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)
	July	20.9 (±14.5)	53.9 (±24.5)	27.2 (±15.2)	9.3 (±7.9)	8.4 (±6.0)
	August	20.3 (±14.6)	70.9 (±36.8)	55.2 (±22.1)	35.7 (±15.3)	36.5 (±9.4)
	September	15.4 (±10.5)	26.0 (±23.7)	39.3 (±31.7)	23.0 (±17.1)	39.2 (±31.0)
Steelhead 1+	May	5.6 (±5.0)	7.5 (±6.0)	4.8 (±4.5)	1.6 (±1.4)	2.4 (±1.7)
	July	5.8 (±5.1)	17.6 (±6.9)	15.1 (±9.6)	16.6 (±10.8)	5.2 (±3.0)
	August	3.7 (±3.8)	9.1 (±4.6)	13.3 (±6.6)	18.8 (±15.4)	17.3 (±3.4)
	September	3.6 (±3.0)	2.1 (±2.4)	3.6 (±5.0)	3.3 (±3.2)	2.4 (±2.0)
Redside Shiner (Adult)	May	55.1 (±38.1)	1.2 (±3.4)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)
	July	85.7 (±47.3)	1.4 (±4.1)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)
	August	95.9 (±51.2)	44.5 (±42.6)	3.9 (±7.0)	0.0 (±0.0)	0.0 (±0.0)
	September	91.3 (±54.8)	40.6 (±41.0)	5.4 (±15.8)	0.0 (±0.0)	0.0 (±0.0)
Dace (Adult)	May	22.0 (±18.8)	24.4 (±28.8)	2.0 (±4.9)	0.0 (±0.0)	0.0 (±0.0)
	July	33.0 (±34.0)	43.5 (±50.2)	10.3 (±21.5)	0.0 (±0.0)	0.0 (±0.0)
	August	37.8 (±31.8)	49.2 (±69.9)	19.8 (±29.4)	0.3 (±0.7)	0.0 (±0.0)
	September	26.2 (±29.5)	11.9 (±20.3)	14.1 (±32.9)	0.1 (±0.4)	0.0 (±0.1)
Pikeminnow (Adult)	May	1.6 (+1.8)	0.0 (±0.1)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)
	July	2.0 (+2.4)	1.3 (±2.6)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)
	August	3.1 (+3.4)	1.0 (±1.6)	0.1 (±0.4)	0.0 (±0.0)	0.0 (±0.0)
	September	3.1 (+6.6)	0.9 (±3.3)	0.0 (±0.1)	0.0 (±0.0)	0.0 (±0.0)
Pikeminnow (Juvenile)	May	7.9 (±12.1)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)
	July	16.9 (±16.1)	1.9 (±5.6)	0.0 (±0.0)	0.0 (±0.0)	0.0 (±0.0)
	August	18.3 (±17.5)	11.3 (±18.1)	6.6 (±9.6)	0.0 (±0.0)	0.0 (±0.0)
	September	15.2 (±15.9)	8.7 (± 18.3)	6.0 (±15.9)	0.0 (±0.0)	0.0 (±0.0)

Appendix F. Direction Movements by Season and Location

Table F-1. Directional movements in upstream and downstream direction observed for juvenile coho and steelhead at five PIT detection arrays located in the South Fork Newaukum River, 2016. Movements are organized by summer (July, August) and early fall (September) seasonal time frames. These data are shown in graphical format in Figure 17.

	PIT Detection	**Summer**		**Early Fall**	
Species	**Array**	**Upstream**	**Downstream**	**Upstream**	**Downstream**
Coho	A1	0 (0.0%)	3 (100%)	1 (100%)	0 (0.0%)
	A2	9 (36.0%)	16 (64.0%)	4 (28.6%)	10 (71.4%)
	A3	19 (54.3%)	16 (45.7%)	6 (37.5%)	10 (62.5%)
	A4	9 (47.4%)	10 (52.6%)	5 (12.8%)	34 (87.2%)
	A5	5 (7.9%)	58 (92.1%)	11 (34.4%)	21 (65.6%)
	Total	**42 (29.0%)**	**103 (71.0%)**	**27 (26.5%)**	**75 (73.5%)**
Steelhead	A1	2 (100%)	0 (0.0%)	2 (100%)	0 (0.0%)
	A2	9 (52.9%)	8 (47.1%)	7 (46.7%)	8 (53.3%)
	A3	19 (65.5%)	10 (34.5%)	1 (16.7%)	5 (83.3%)
	A4	6 (66.7%)	3 (33.3%)	2 (40.0%)	3 (60.0%)
	A5	0 (0.0%)	1 (100%)	4 (50.0%)	4 (50.0%)
	Total	**36 (62.1%)**	**22 (37.9%)**	**16 (44.4%)**	**20 (55.6%)**

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