2009–2018 Idaho Tributary Monitoring

Comprehensive Project Report

Idaho Tributary Habitat Acquisition and Fishery Enhancement Program,
Appendix A

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December 2022

Doc. No. 2022-0261

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ABSTRACT

Stream fish abundance monitoring surveys have been conducted on 25 Lake Pend Oreille tributaries on a five-year rotational basis since 2009. To date, compiled data from this sampling has not been investigated for changes in population dynamics at the drainage, stream, or reach scale. In this report, we summarized the results of these sampling efforts and made recommendations to guide future sampling efforts. Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi* was the most common species in all of the streams surveyed. Reach-specific densities of Westslope Cutthroat Trout, Bull Trout *Salvelinus confluentus*, Rainbow Trout *O. mykiss*, and Brook Trout *Salvelinus fontinalis* were variable between sample events. However, they remained stable at the basin-wide scale. Size distribution of each species was similar throughout the basin, but specific tributaries did exhibit changes that were likely driven by changes in abundance. Based on relative weight (W_r), Bull Trout were in the highest condition in each creek during both sample events, with Westslope Cutthroat and Rainbow Trout exhibiting reduced but stable levels. Trends in overall fish biomass at the reach scale were stable; however, species composition changed in certain locations depending on site-specific environmental and biological conditions and processes. Evidence also suggests that adfluvial life history forms of Westslope Cutthroat Trout are prevalent throughout the watershed, but the extent is still unknown. Future studies should seek to investigate how site-specific habitat influences species distribution and density at multiple life history stages, investigate the prevalence of adfluvial Westslope Cutthroat Trout, conduct targeted fish tagging, and assess the potential for instream competition when species overlap occurs.

INTRODUCTION

Tributaries to Lake Pend Oreille (LPO) and the Clark Fork River (CFR) support populations of adfluvial Bull Trout *Salvelinus confluentus*, Rainbow Trout *Oncorhynchus mykiss*, and Westslope Cutthroat Trout *O. clarkii lewisi*. These tributaries serve as spawning and rearing habitat for adfluvial life history forms of each species, and as habitat for resident Westslope Cutthroat Trout. The Idaho Tributary Habitat Acquisition and Fishery Enhancement Program, funded through the Clark Fork Settlement Agreement (CFSA), supports ongoing research and monitoring surveys to: (1) evaluate the ongoing efforts in aquatic habitat protection and enhancement of LPO and CFR tributaries; (2) address the impacts and mitigation efforts related to load-following and gas supersaturation by the Clark Fork hydroelectric project; and (3) inform decisions regarding future mitigation efforts.

Lake Pend Oreille (LPO) is Idaho's largest (36,000 surface ha) and deepest (360 m) natural lake. The native salmonid species assemblage consists of Bull Trout, Westslope Cutthroat Trout, Mountain Whitefish *Prosopium williamsoni*, and Pygmy Whitefish *P. coulteri*. Lake Pend Oreille supports one of the strongest remaining adfluvial Bull Trout populations in the United States. It also has a substantial non-native sport fish component including Rainbow Trout, Brown Trout *Salmo trutta*, Lake Trout *S. namaycush*, kokanee *O. nerka*, Smallmouth Bass *Micropterus dolomieu*, Northern Pike *Esox lucius*, Yellow Perch *Perca flavescens*, and Walleye *Sander vitreus*. The lake is well-known for its premier sport fishery for trophy Rainbow Trout, but also supports notable kokanee, Bull Trout, Westslope Cutthroat Trout, and increasingly popular warmwater fisheries. Major tributaries to LPO provide opportunity for shore-based anglers to target large-bodied adfluvial fish like Rainbow Trout and Bull Trout.

Research and monitoring surveys have largely focused on identifying changes in abundance and distribution of salmonids in tributaries, primarily focused on Bull Trout and Westslope Cutthroat Trout; however, Rainbow Trout are an additional species of interest because of the trophy fishery present within the lake. Standardized electrofishing surveys were conducted in 25 LPO tributaries on a five-year rotation and have provided data regarding trends in fish abundance, species composition, and distribution. Acquiring this information enables broad-scale evaluation of the effectiveness of management actions, including aquatic habitat protection and restoration in tributaries, as well as Lake Trout and Walleye suppression, and kokanee enhancement in LPO. In addition, the data collected from these monitoring surveys are used to evaluate the location, purpose, and need for future habitat enhancement projects. All of these management actions are supported through the CFSA.

To date, each tributary has been sampled two times, and this report is meant to provide a comprehensive summary of results in a single document. Temporal trends in fish density, age structure, size, and distribution were assessed on a LPO basin-wide scale for the first time, with an additional update scheduled after the next sample round is completed in 2023.

METHODS

Tributary monitoring surveys were conducted on Trestle, Gold, West Gold, Strong, Mosquito, Morris, Wellington, Granite, East Fork Lightning, Johnson, Rattle, Savage, Porcupine, Hellroaring, McCormick, Caribou, Berry, Jeru, Char, Grouse, North Fork Grouse, South Fork Grouse, Rapid Lightning, Spring, and Twin creeks (Figure 1). Specific survey reaches were established on systematic 1-kilometer intervals progressing upstream from the mouth. Typically, a 100 m section was sampled for each kilometer of stream, except on longer streams where sections were sampled every other kilometer. A set of tributaries was selected for sampling each year, and each set was sampled on a five-year rotational basis. Although not always possible, every attempt was made to sample the same stream sections during each year of sampling. The farthest upstream survey site was determined based on whether water was present or fish were suspected to be absent further upstream as a result of no fish being sampled in the adjacent downstream section. In a few instances, the uppermost site was established where past sampling results suggested further surveys would provide low expected variation among additional sample sites. Abundance estimates only included salmonid fish species $\geq$75 mm in total length due to low probability of capture for smaller sizes. Average wetted width of each site was calculated based upon six cross sectional measurements throughout the longitudinal profile of the sample area. Sample sites were closed using block nets at the downstream end of each survey site to prevent escapement during downstream electrofishing passes.

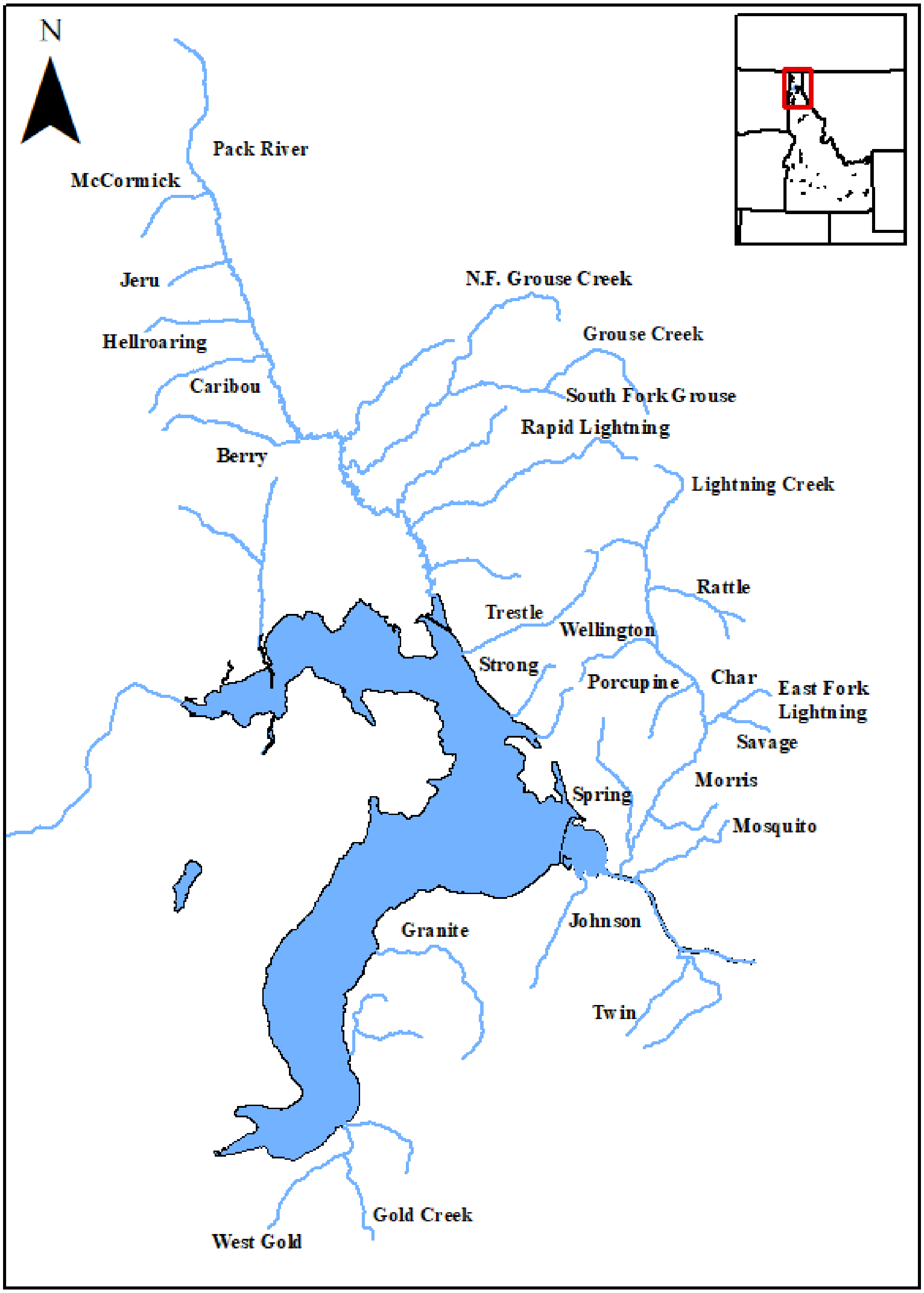


Figure 1. Map of all tributaries to Lake Pend Oreille with sample tributaries and the mainstem Pack River and Lightning Creek identified.

Fish were collected using a Smith-Root backpack electrofishing unit with pulsed DC settings, typically at 40-50 Hz, 2 ms, and 500 to 900 V. All salmonid species were collected, and captured individuals were identified to species, enumerated, weighed (g), and measured for total length (mm). Species and hybrid crosses were identified phenotypically. Characteristics used to identify Westslope Cutthroat Trout (WCT) x Rainbow Trout (RBT) hybrids (WRHY) included throat slashes of light intensity or broken in form and exhibiting heavy spotting below the lateral line and toward the anterior end of the fish. Bull Trout (BLT) x Brook Trout *S. fontinalis* (BRK) hybrids (BBHY) were identified as individuals exhibiting typical BLT form, but with the presence of some vermiculation or irregular spotting on the dorsal fin. Genetic tissue samples were collected, processed, and archived from BLT and all suspected BBHYs. Sagittal otoliths were removed from a subset of individuals identified as RBT and WCT and used for determining age structure. Due to the timing of sampling, migratory spawners were not observed in these surveys, and all fish collected are considered to be juveniles or resident adults.

Multiple-pass removal estimates (Zippin 1958) were conducted in combination with single-pass samples to estimate fish abundance in each tributary. For each stream, a single site was randomly selected to be a multiple-pass estimate. For each multiple-pass sample, additional passes were conducted until fish captures from subsequent passes did not exceed 20% of the total capture by species of the first pass. Typically, two or three passes were necessary to satisfy this criterion. Abundance estimates and associated 95% confidence intervals were derived for two- and three-pass samples using calculations for removal estimates in closed populations (Hayes et al. 2007). The total catch on the first pass was reported as the population estimate when no additional individuals of a particular species were captured on subsequent passes. In cases where the lower limit of a confidence interval was less than the total number of fish captured, the total number of fish captured was reported as the lower limit.

The remaining sections of the stream were sampled using a single pass. This was done to increase the number of possible sample sites visited in a field season, as each single-pass sample required less time to complete than a multiple-pass sample. Linear abundance (fish/m stream length) was estimated from single-pass samples by generating a single multiple-pass regression model of abundance based on first pass collections (Meyer and Schill 1999). The multiple-pass regression model was generated using data collected from all LPO tributary streams sampled between 2009 and 2019 and from all target species combined. Fish density for the reach (fish/m^2) was calculated by dividing the linear abundance by the average width of the reach. Average density (fish/m^2) estimates for each stream were calculated for each species for all sections sampled that contained fish of any target species for comparison between different width streams, and may have included data from sections where a given species was not detected. Year-specific methods are listed in the associated annual reports; however, they did not differ substantially from those already described (Ryan and Jakubowski 2011a, 2011b, 2012, 2013; Ryan et al. 2014, Bouwens and Jakubowski 2015, 2016, 2017; Bouwens et al. 2019a, Frawley et al., 2019).

Statistical Analysis

We investigated the potential for change in species composition over time using similarity indices and k-means clustering. Clusters were assigned based on Euclidean distances of relative species abundance at both stream and reach spatial scales. Relative abundances of each species were calculated by dividing the count of each species captured within the stream or reach by the total count of fish captured within the same stream or reach. Results were clustered in order to minimize the Euclidean distance between values within each group. The number of clusters selected for interpretation was determined by model performance. To test for species specific changes in abundance, we conducted paired t-tests ($\alpha = 0.05$) using calculated densities in reaches that were sampled during both rounds of sampling for WCT, RBT, and BLT. Reaches were subsampled to include only those where the target species was documented in at least one of the sample events. Analyses were performed in R using the ‘factoextra’ and ‘cluster’ packages (Kassambara and Mundt 2017; Maechler 2019).

Fish condition for BLT, WCT, and RBT was assessed for each stream and sample event using relative weight (W_r) equations reported in the literature (Hyatt and Hubert 2000; Kruse and Hubert 1997; Simpkins and Hubert 1996). Individuals were removed from analysis if they were below the species-specific size minimum identified by each standardized unit equation. For the purpose of this study, values between 95 and 105 are considered within the range of “normal” condition. Additionally, we estimated total biomass per stream reach (B) using equation $B = (N * w)/ A$, where w is the mean weight of fish sampled, N is the estimated abundance of all species, and A is the total sample area (Hayes et al. 2007). Changes in biomass between sample rounds were assessed using a paired t-test ($\alpha = 0.05$).

Bull Trout spawner escapement surveys occurred in a subset of electrofished streams on an annual basis. We attempted to relate redd density (redds/km) to subsequent juvenile densities (fish/100m^2) in streams where redd counts were conducted. The relationship between redds and juvenile densities was assessed using Pearson’s Correlation Coefficient ($\alpha = 0.05$). Redd densities were lagged from the year of juvenile sampling by two and three years and then averaged because of the occurrence of multiple year classes in our juvenile samples (Downs et al. 2006; Jakubowski and Bouwens 2019).

RESULTS

A total of five salmonid species was sampled during the study; BRK; Brown Trout BRN; BLT; RBT; and WCT, and two hybrids, WRHY and BBHY. The majority of streams exhibited perennial flow and water temperatures typically varied from 6°C to 19°C during the time of sampling. These temperatures were below the lethal limits for most salmonid species (Behnke 1992), so we did not expect to have reduced fish abundance or atypical fish distribution directly resulting from low water or high temperatures.

The multiple-pass data from each stream were added to the cumulative regression model to estimate fish abundance from a single-pass based on the first pass collections of a multiple-pass depletion estimate (Figure 2). Modeling suggests that the first pass collections describe approximately 98% of the variation in estimated abundance from multiple-pass samples after two rounds of sampling ($n = 175$, $p < 0.01$). This strong relationship has been relatively consistent since the first year of sampling in 2009, when the relationship was also 98% comparable between one and three pass estimates (Ryan and Jakubowski 2011). This technique continues to be a valuable tool to reduce sampling effort in each reach, thus allowing sampling to occur at more locations per field season. Abundances of each species ranged widely depending on the stream, but WCT were generally the most abundant throughout (Table 1).

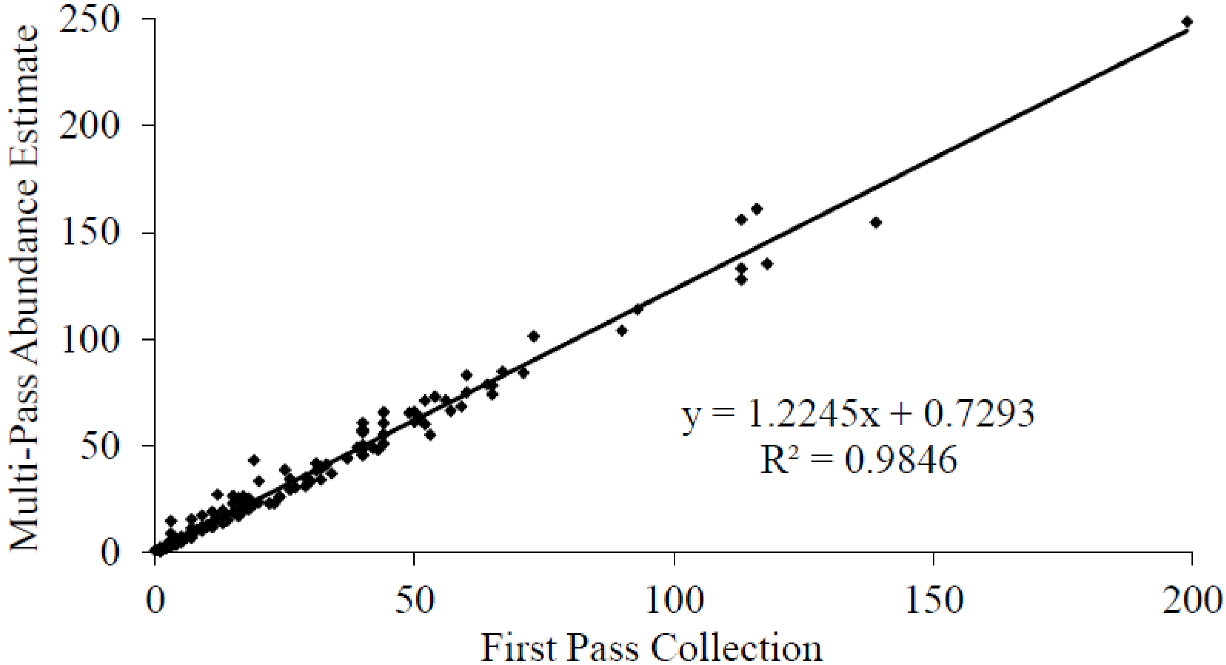


Figure 2. Regression model showing the relationship of estimated salmonid abundance between multiple-pass methods and the number of fish captured on the first pass. Data represent combined 2009–2018 multiple-pass removal efforts for salmonids ≥75 mm total length in tributaries of Lake Pend Oreille, Idaho.

Table 1. Mean density estimates (fish/100 m^2) for all streams (sections combined) where fish were sampled by stream, year, and species 2009–2018.

Stream	Year	BLT	BRK	BRN	RBT	WCT	BBHY	WRHY
Gold Creek	2014	2.5	0.0	0.0	0.0	32.0	0.0	0.2
	2009	4.4	0.0	0.0	0.0	23.6	0.0	<0.1
Granite Creek	2014	6.3	0.0	0.0	0.0	6.4	0.0	<0.1
	2009	4.6	0.0	0.0	0.0	6.7	0.0	0.0
Strong Creek	2014	3.2	0.0	0.0	<0.1	19.0	0.0	<0.1
	2009	0.1	0.0	0.0	0.1	7.2	0.0	0.1
Johnson Creek	2014	1.0	0.0	0.0	0.0	7.0	0.0	0.0
	2009	1.4	0.0	0.0	0.0	5.1	0.0	0.0
Twin Creek	2014	0.1	7.6	0.5	1.3	3.3	0.0	1.4
	2009	0.0	2.7	0.3	2.0	3.8	0.0	0.0
Berry Creek	2018	0.0	0.2	0.0	1.0	11.7	0.0	0.2
	2013	0.0	0.2	0.0	0.5	11.0	0.0	0.8
Jeru Creek	2018	0.0	0.0	0.0	1.4	9.5	0.0	1.1
	2013	0.2	0.0	0.0	0.7	5.6	0.0	3.1
Mosquito Creek	2018	0.0	3.6	0.1	0.3	7.4	0.0	0.5
	2013	0.0	4.9	0.2	0.0	3.4	0.0	0.2
Spring Creek	2018	0.0	3.7	0.1	1.3	0.9	0.0	0.2
	2013	0.0	16.5	0.1	0.2	0.9	0.0	0.3
Char Creek	2018	0.0	0.0	0.0	0.0	25.3	0.0	0.0
	2013	0.0	0.0	0.0	0.0	75.0	0.0	0.0
E.F. Lightning Creek	2017	0.3	0.1	0.0	10.5	2.7	0.0	1.7
	2012	3.1	0.1	0.0	2.8	4.5	0.5	0.4
Porcupine Creek	2017	0.3	3.4	0.0	0.3	12.1	0.0	0.3
	2012	1.0	5.4	0.0	0.0	10.5	0.0	0.9
Rattle Creek	2017	0.8	0.0	0.0	0.3	5.1	0.0	0.1
	2012	4.6	0.0	0.0	0.6	5.8	0.0	0.1
Savage Creek	2017	1.6	0.0	0.0	0.2	9.3	0.0	1.7
	2012	5.1	0.0	0.0	<0.1	3.9	0.0	0.7
Wellington Creek	2017	0.3	0.0	0.0	2.3	12.1	0.0	1.0
	2012	1.3	0.1	0.0	0.5	10.4	0.0	0.4
Caribou Creek	2016	1.8	0.1	0.0	0.8	9.0	0.0	0.2
	2011	3.1	0.3	0.0	1.2	6.1	0.0	0.7
Morris Creek	2016	0.7	0.0	0.0	0.0	11.5	0.0	0.4
	2011	5.8	0.0	0.0	0.0	7.0	0.0	1.8
Trestle Creek	2016	1.5	0.0	0.0	0.0	12.5	0.0	0.0
	2011	1.8	0.0	0.0	<0.1	4.5	0.0	1.0
Hellroaring Creek	2016	0.2	0.0	0.0	7.1	0.1	0.0	0.0
	2012	0.2	<0.1	0.0	4.0	0.0	0.0	0.2
McCormick Creek	2016	0.0	0.0	0.0	0.0	11.3	0.0	0.0
	2012	0.0	0.0	0.0	0.5	1.7	0.0	0.0
Grouse Creek	2015	3.6	0.3	0.0	3.5	1.7	0.2	0.2
	2010	3.5	0.4	0.0	8.2	3.6	0.2	0.3
N.F. Grouse Creek	2015	0.2	2.2	0.0	6.4	4.1	0.0	0.1
	2010	0.0	4.1	0.0	5.0	5.9	0.0	0.3
S.F. Grouse Creek	2015	0.7	2.5	0.0	15.1	0.7	2.5	2.9
	2013	1.3	3.0	0.0	7.6	1.3	0.0	0.0
Rapid Lightning Creek	2015	0.0	3.3	0.0	1.1	6.4	0.0	0.2
	2010	<0.1	3.2	0.0	1.0	5.2	0.0	0.3
West Gold Creek	2015	2.2	0.0	0.0	0.0	50.8	0.0	0.0
	2009	0.1	0.0	0.0	0.0	43.7	0.0	0.0

At the tributary-wide spatial scale, clustering analysis identified five distinct species assemblage groups; 1) WCT and BRK dominated; 2) WCT and BLT dominated; 3) RBT dominated; 4) WCT dominated; and 5) BRK dominated (Table 2). A species is considered dominant when it represents a majority (>50%) of the fish captured. Species can be co-dominant when they represent similar percentages of catch that result in the majority observed (e.g., 40% and 40%). Eleven of the 25 streams exhibited a cluster change between sampling rounds. Many changes were driven by a decline in BLT and an increase in WCT or RBT. Twin and Mosquito creeks were largely driven by changes in BRK.

Table 2. Species composition clusters at the stream scale from the first and second rounds of electrofishing sampling.

Stream	Round One	Round Two
Berry	WCT	WCT
Char	WCT	WCT
Jeru	WCT	WCT
Johnson	WCT	WCT
Strong	WCT	WCT
W. Gold	WCT	WCT
Wellington	WCT	WCT
Granite	WCT, BLT	WCT
Caribou	WCT, BLT	WCT
East Fork	WCT, BLT	RBT
Gold	WCT, BLT	WCT
Morris	WCT, BLT	WCT
Rattle	WCT, BLT	WCT
Savage	WCT, BLT	WCT
Trestle	WCT, BLT	WCT
Porcupine	WCT, BRK, RBT	WCT, BRK, RBT
Rapid Lightning	WCT, BRK, RBT	WCT, BRK, RBT
McCormick	WCT, BRK, RBT	WCT
Twin	WCT, BRK, RBT	BRK
North Fork Grouse	WCT, BRK, RBT	RBT
Grouse	RBT	RBT
Hellroaring	RBT	RBT
South Fork Grouse	RBT	RBT
Spring	BRK	BRK
Mosquito	BRK	WCT, BRK, RBT

When clustered at the individual reach or shocking section scale, seven distinct groups were observed; 1) RBT dominant; 2) WCT dominant; 3) BRK dominant; 4) BLT and WCT dominant; 5) BRK and WCT dominant; 6) BLT dominant, WCT abundant; 7) WCT and WRHY dominant, RBT abundant (Figure 3). In this instance, a "dominant" species represents the highest percentage of fish captured, and an "abundant" species are the next highest. However, when two species are within twenty percent of each other, both are considered to be dominant.

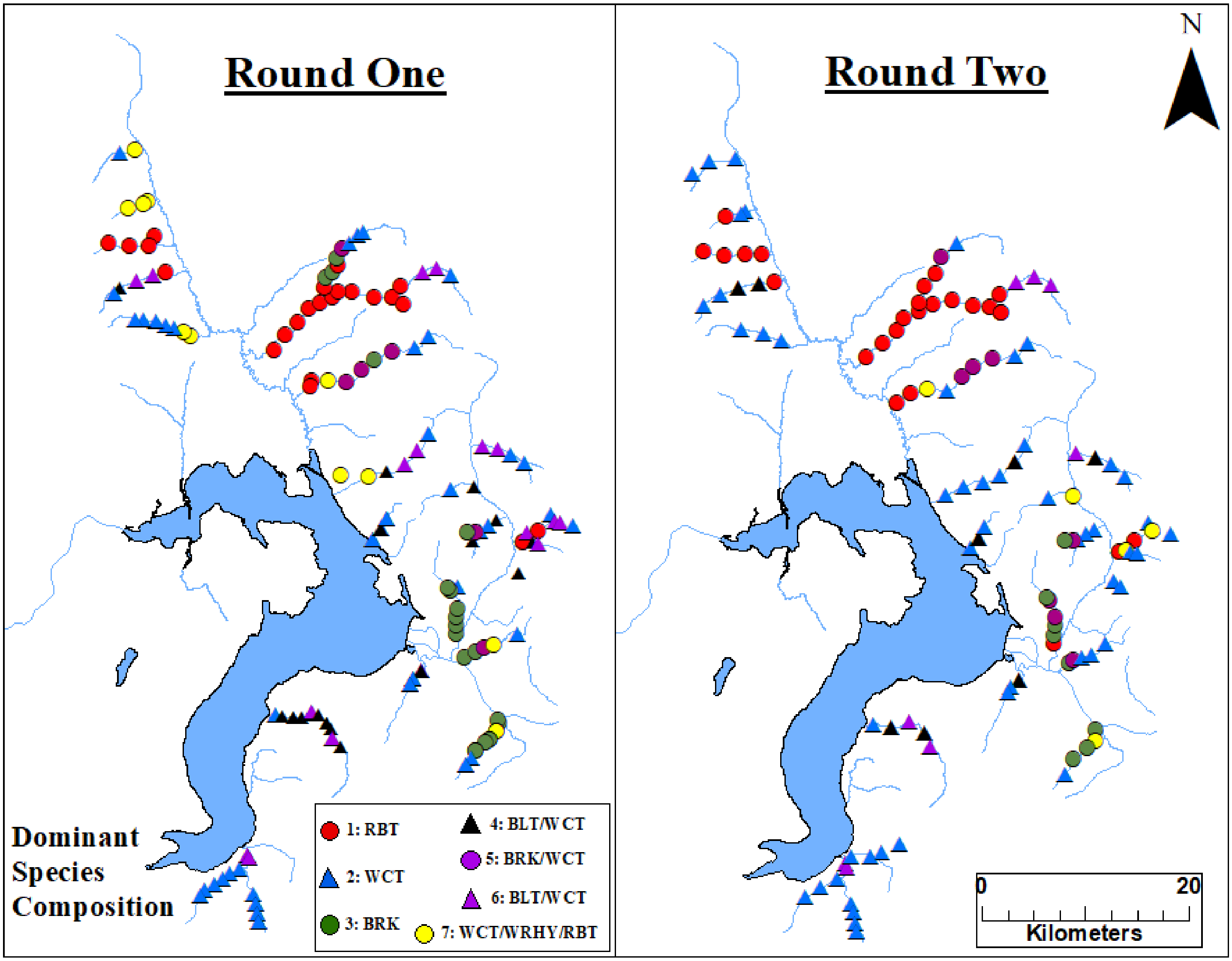


Figure 3. Cluster results from each sample round. Designations identify the dominant and/or abundant species, but others may be present in lower numbers.

Paired t-tests indicated that at the stream scale, total fish biomass (g/m^2) across all streams did not significantly change from the first to the second round (p = 0.780, n = 94 pairs; Figure 4), indicating they may be operating at carrying capacity for current conditions. Densities of WCT (p = 0.169, n = 85 pairs; Figure 5), RBT (p = 0.728, n = 48 pairs; Figure 6), and BLT (p = 0.199, n = 46 pairs; Figure 7) did not show a statistical change from the first to the second sample event. Westslope Cutthroat Trout exhibited the highest densities in all creeks. Additionally, W_r was highest for BLT, with an average of 102.5 during the study period. Westslope Cutthroat Trout and RBT exhibited lower relative weight values of 87.5 and 90.1, respectively (Figure 8).

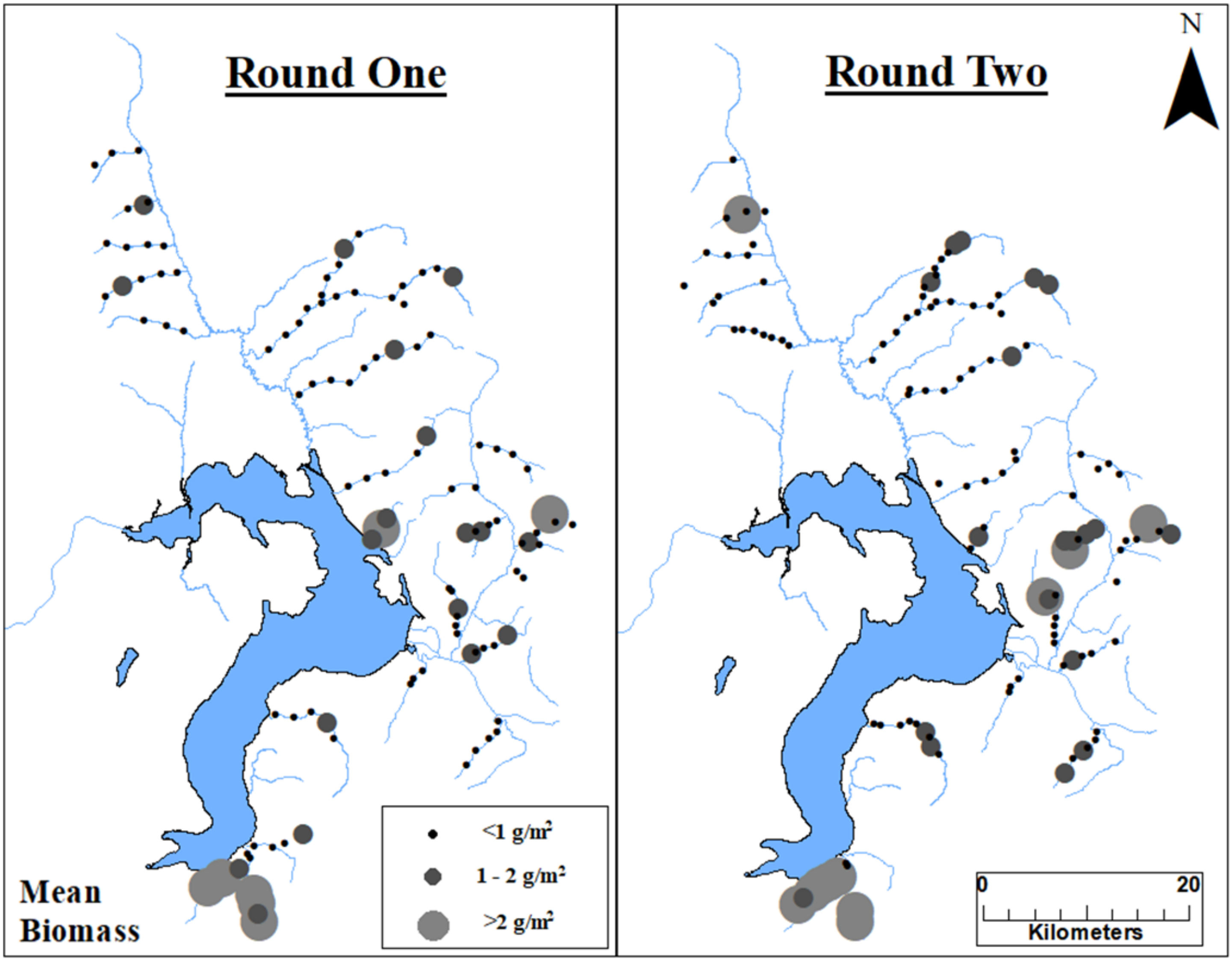


Figure 4. Total fish biomass (grams/m^2) in each section during sample rounds one and two. See legend for specific biomass ranges.

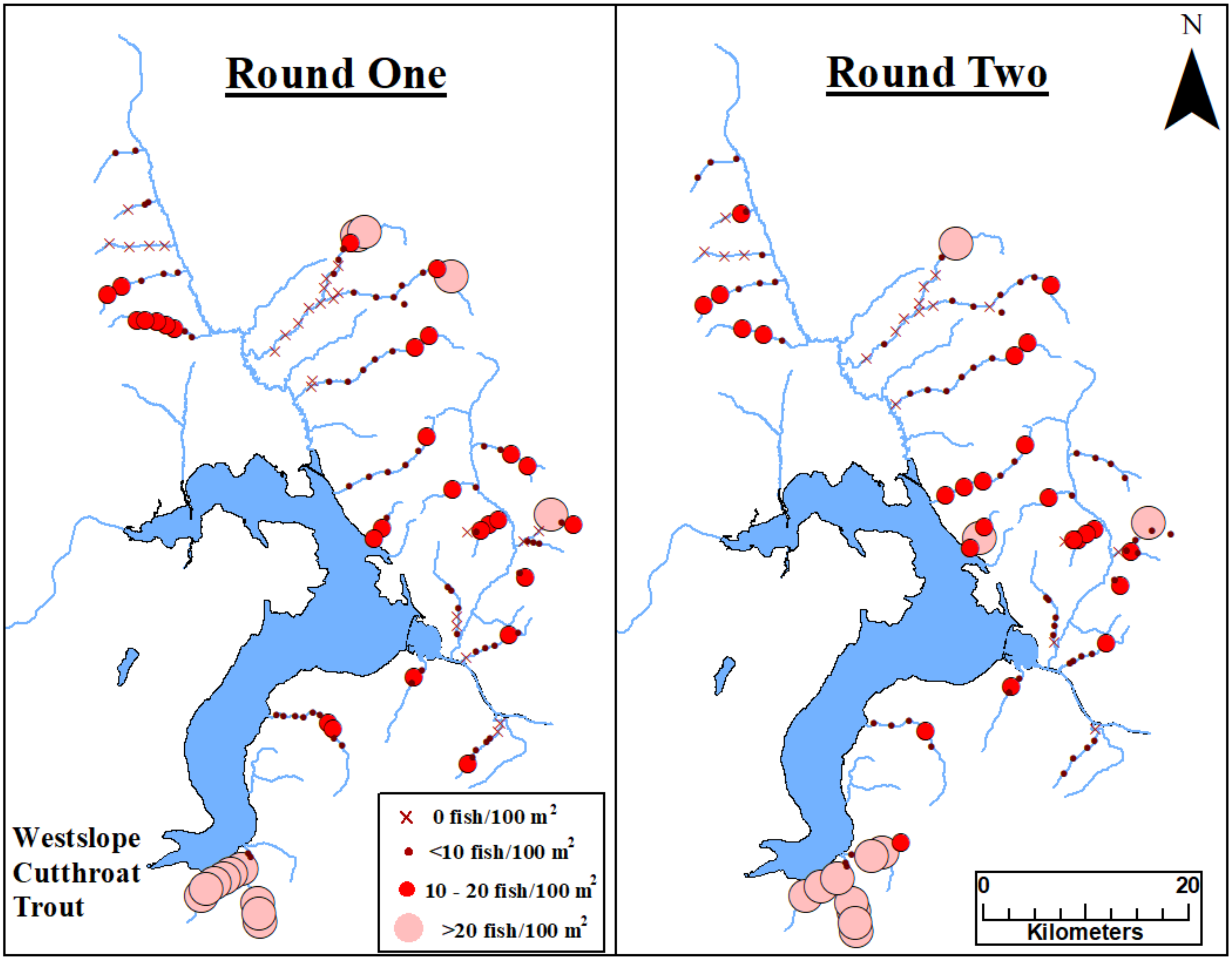


Figure 5. Density (fish/100 m^2) of Westslope Cutthroat Trout (WCT) during the first and second rounds of sampling. See legend for specific density ranges.

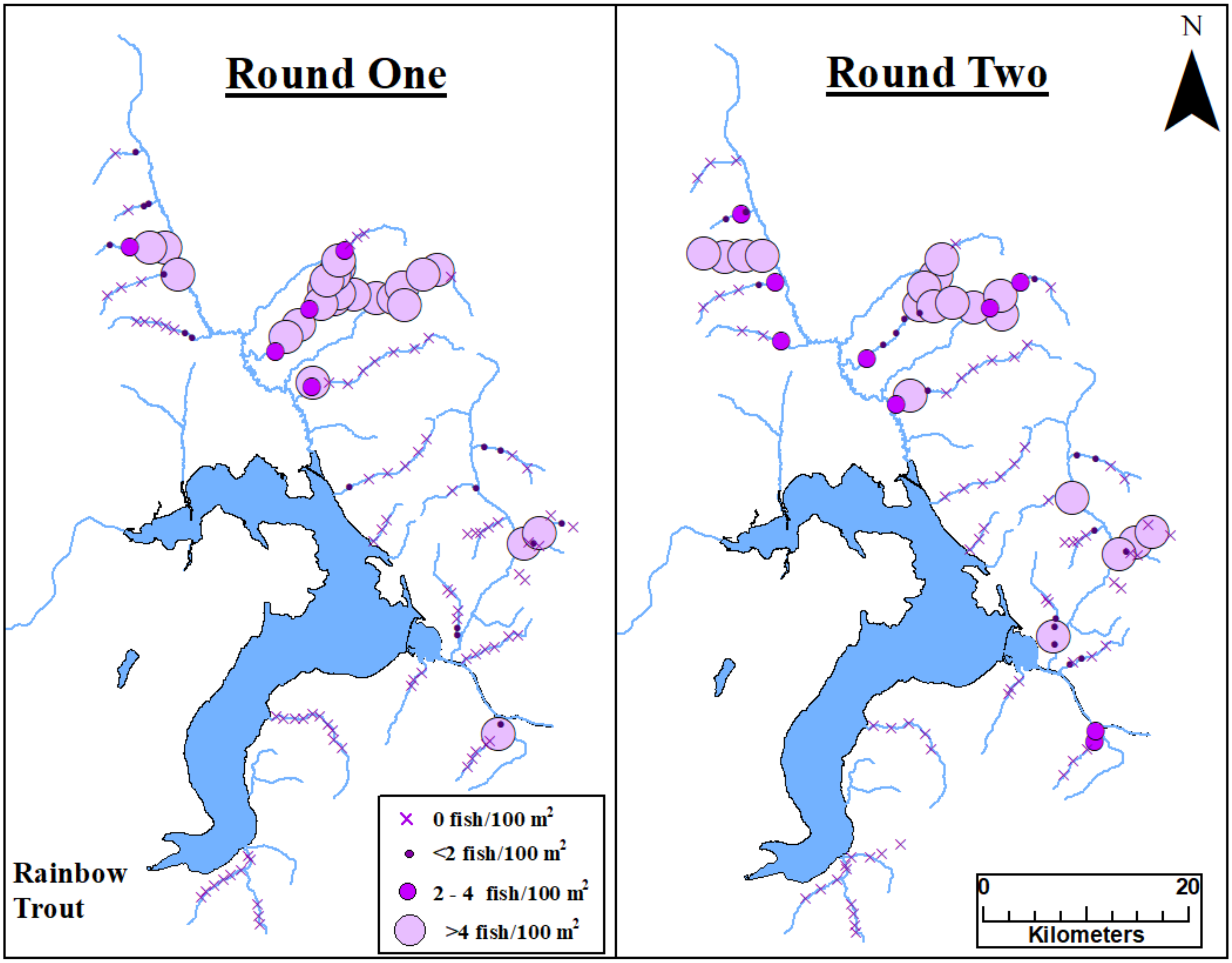


Figure 6. Density (fish/100 m^2) of Rainbow Trout (RBT) during the first and second rounds of sampling. See legend for specific density ranges.

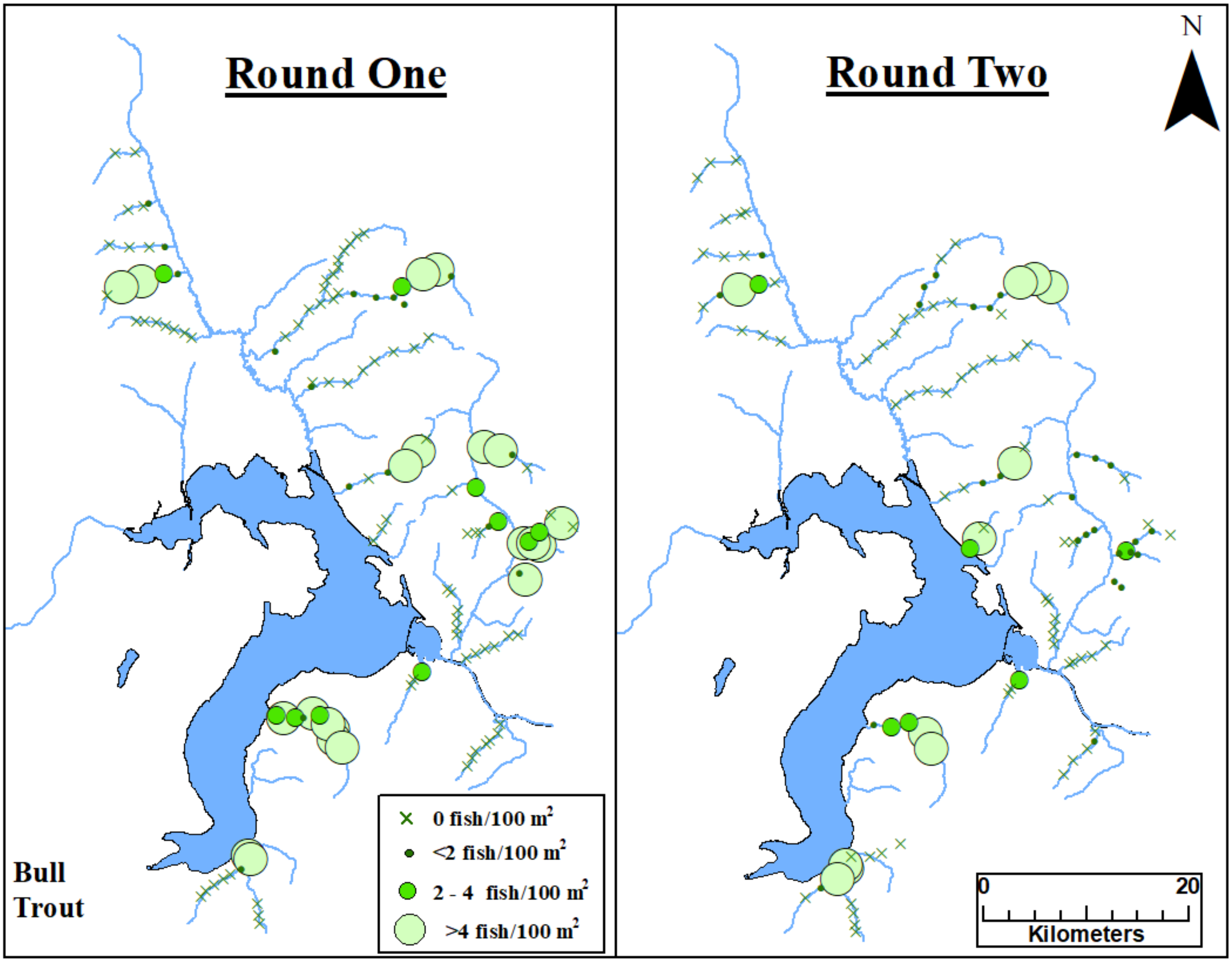


Figure 7. Density (fish/100 m^2) of Bull Trout (BLT) during the first and second rounds of sampling. See legend for specific density ranges.

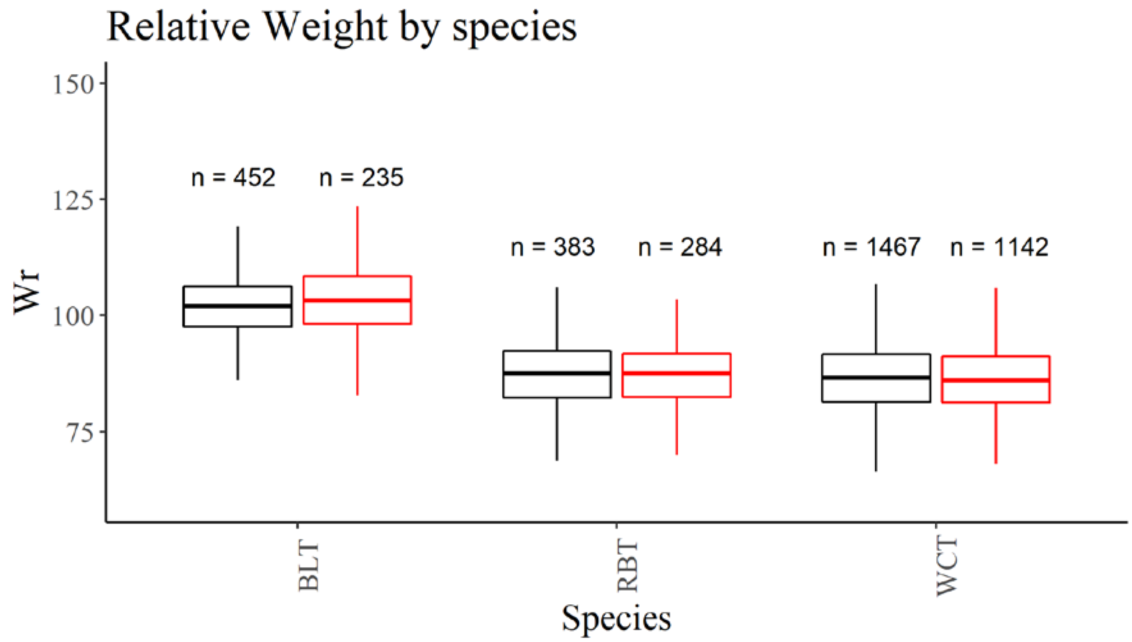


Figure 8. Mean relative weight (W_r) for Bull Trout, Rainbow Trout, and Westslope Cutthroat Trout during sampling from all streams combined. Round one of sampling identified in black and round two in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), and maximum (upper vertical bar) for each group.

Pearson's analysis show that the lagged redd density does have a significant and positive correlation on juvenile abundances (p = <0.01, r = 0.62). However, the moderate strength of the relationship suggests there is likely influence from environmental factors and not just spawner escapement (Figure 9).

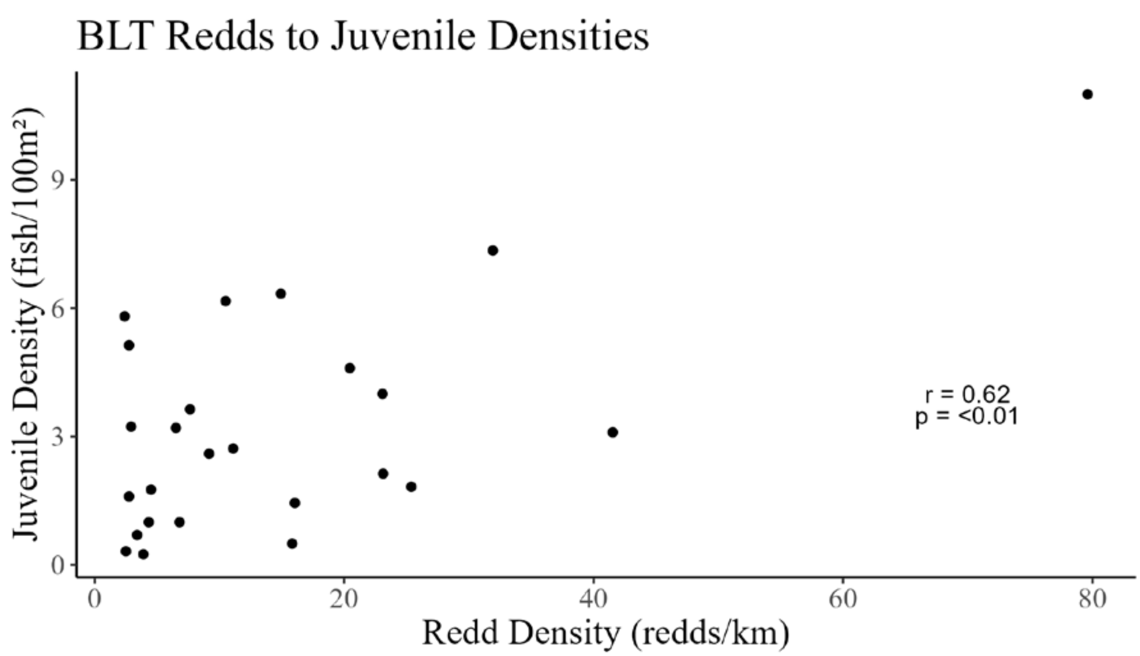


Figure 9. Scatterplot describing the correlation between Bull Trout redd density (redds/km) to resulting juvenile BLT density (fish/100m^2).

INDIVIDUAL STREAM TRENDS

Detailed fish density, size, and age data are included in the section below. Tributaries are grouped by drainage and then listed alphabetically.

Pack River Drainage

Berry Creek

Berry Creek is the first upstream sample tributary located along the western side of the mainstem Pack River. The species assemblage is dominated by WCT, and a fish passage barrier exists between reach three and four (Figure 10). Non-native fishes are present in reaches below this barrier. In addition, Section One was dry during both sample years and was not sampled. Fish densities overall remained similar through time. Sizes of WCT appear to be similar along the upstream gradient, however the subset of sampled fish exhibited older ages in higher reaches (Figure 11) and suggest they are non-migratory. Detailed capture data for WCT and RBT are displayed in Figures 11 and 12.

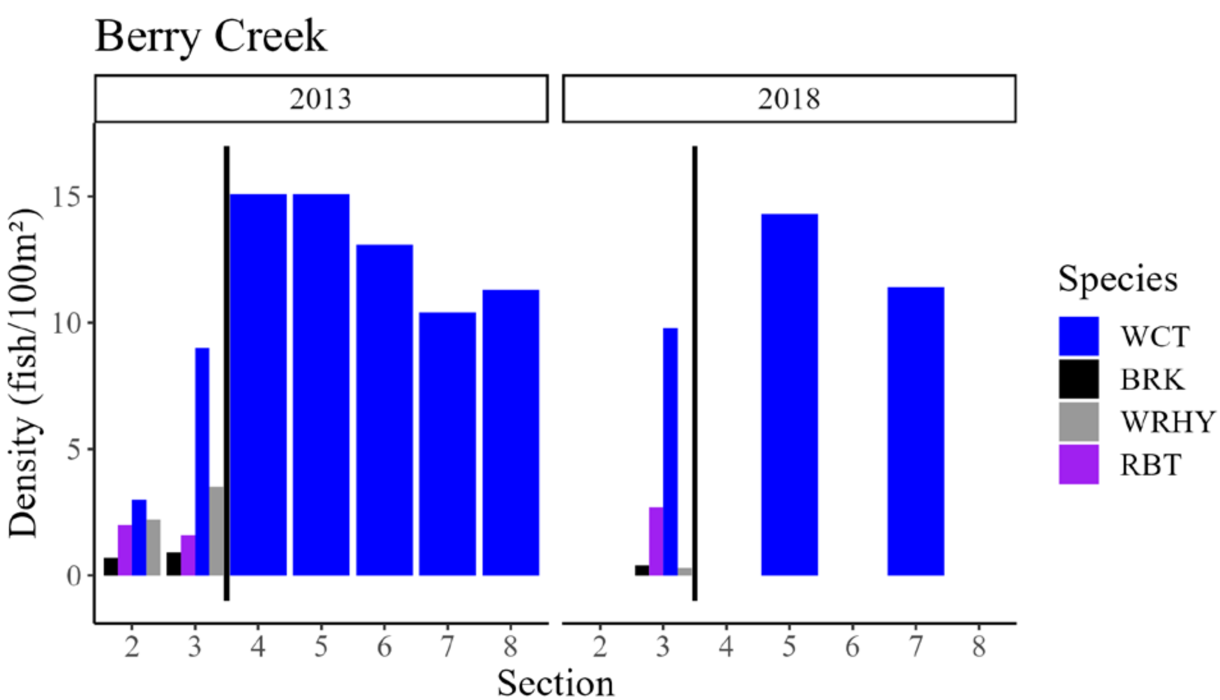


Figure 10. Fish densities for each shocking section in Berry Creek. Species specific densities are identified by color (see legend). The location of a barrier to upstream migration is identified with a tall black line.

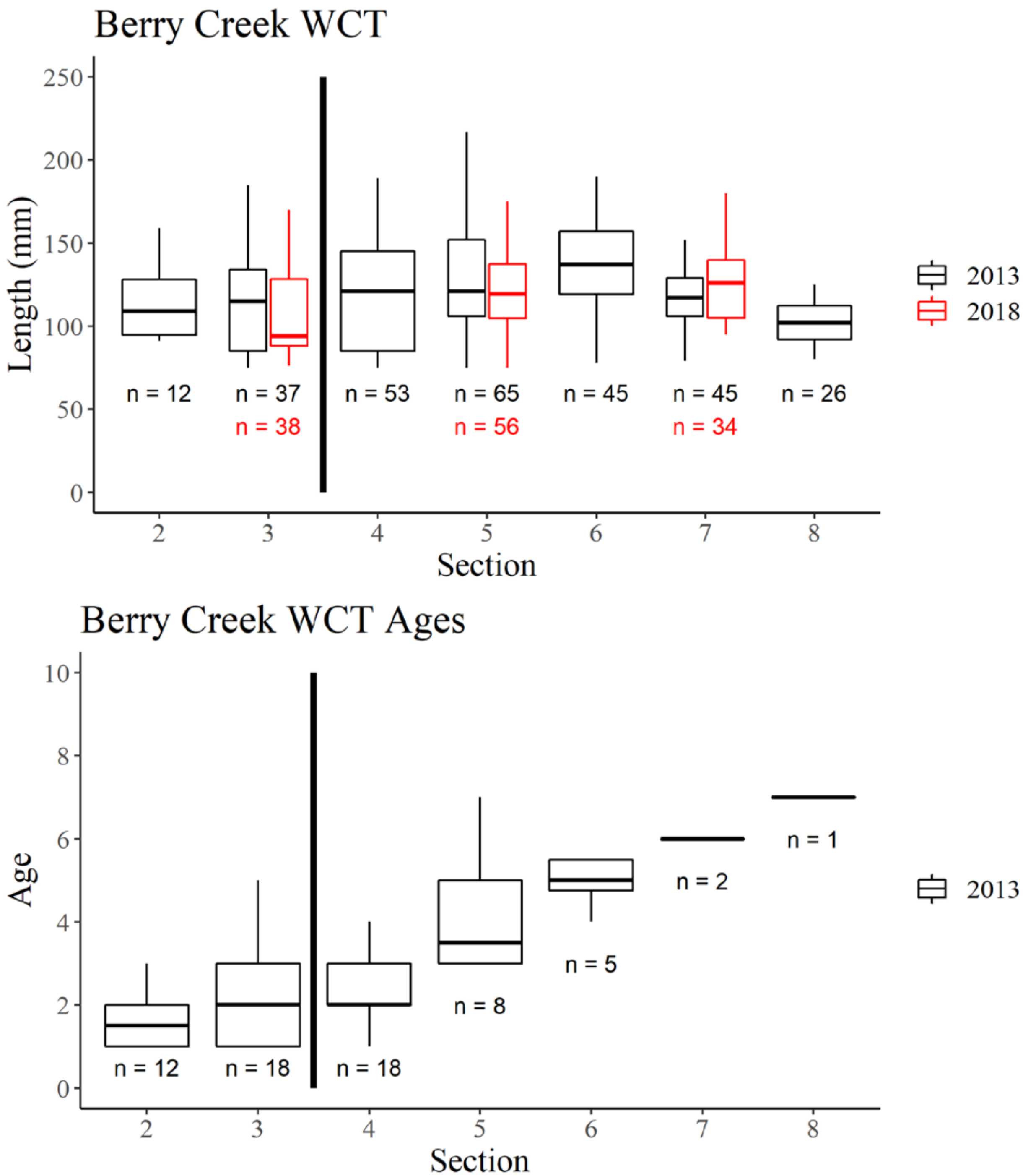


Figure 11. Length (mm; top panel) and age (years; lower panel) of Westslope Cutthroat Trout captured in each section of Berry Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

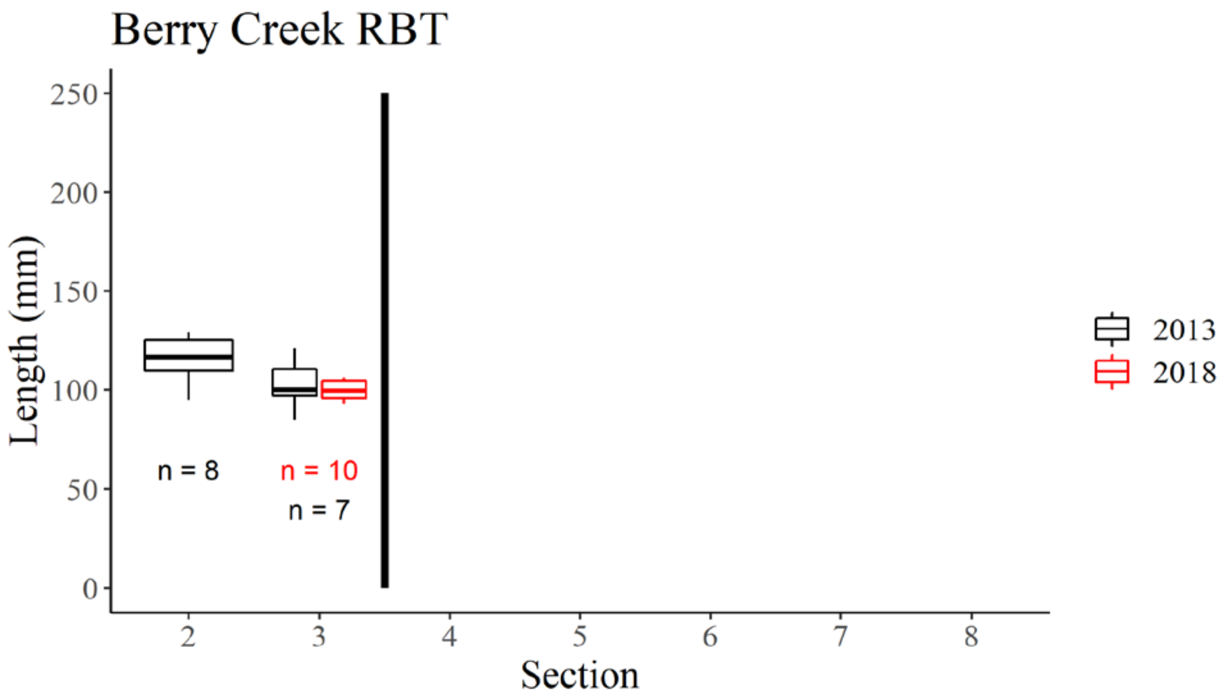


Figure 12. Length (mm) of Rainbow Trout captured in each section of Berry Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

Caribou Creek

Caribou Creek is the second upstream sample tributary located along the western side of the mainstem Pack River and is north of Berry Creek. Species assemblage is a mixture of WCT and BLT; however, low densities of RBT and WRHY are present (Figure 13). Overall fish densities remained similar through time. Sizes of WCT appear to be similar along the upstream gradient; however, sampled fish exhibited older ages in higher sections. Fish sizes appeared similar through time and across all reaches; however, a young age structure of WCT suggests migratory behavior may be present (Figure 14). Additionally, it is presumed that all RBT are progeny of migratory adults that mature in Lake Pend Oreille. Detailed capture data for WCT, RBT, and BLT are displayed in Figures 14, 15, and 16.

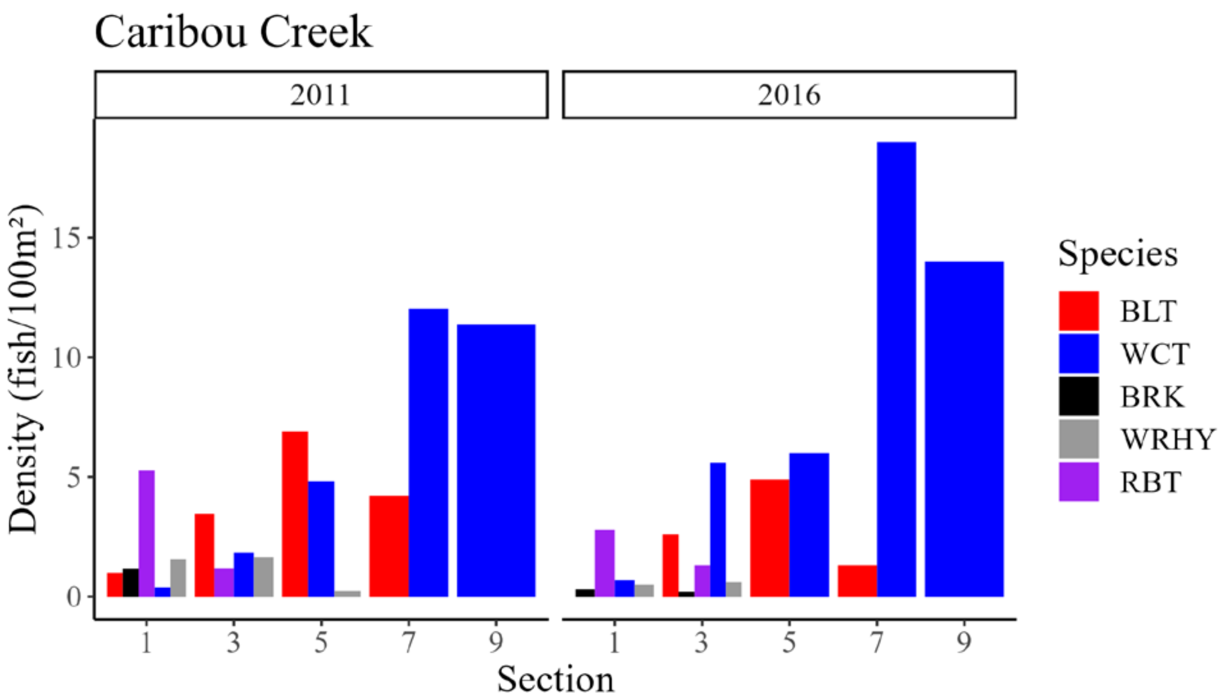


Figure 13. Fish densities for each shocking section in Caribou Creek. Species specific densities are identified by color (see legend).

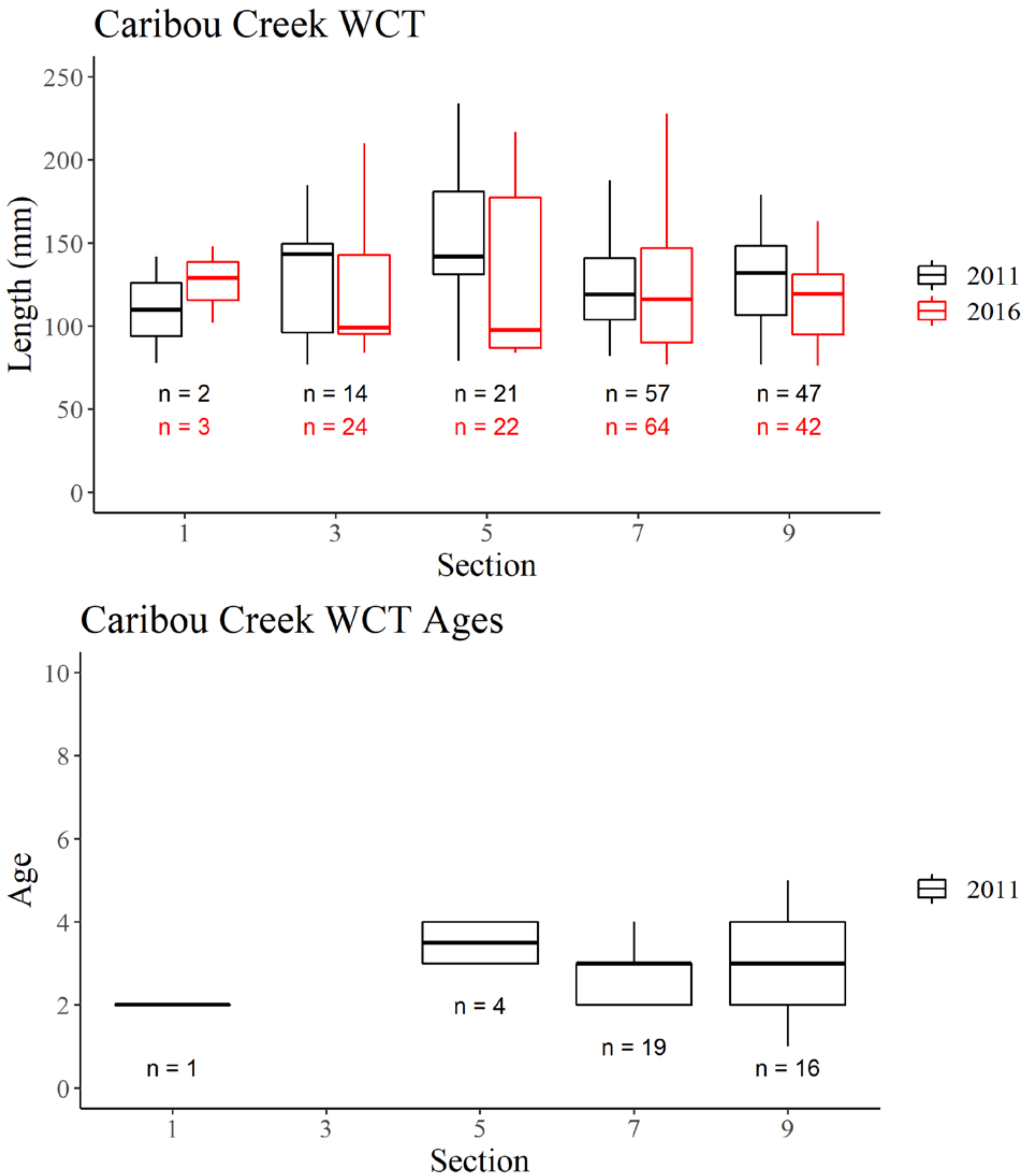


Figure 14. Length (mm; top panel) and age (years; lower panel) of Westslope Cutthroat Trout in each section of Caribou Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

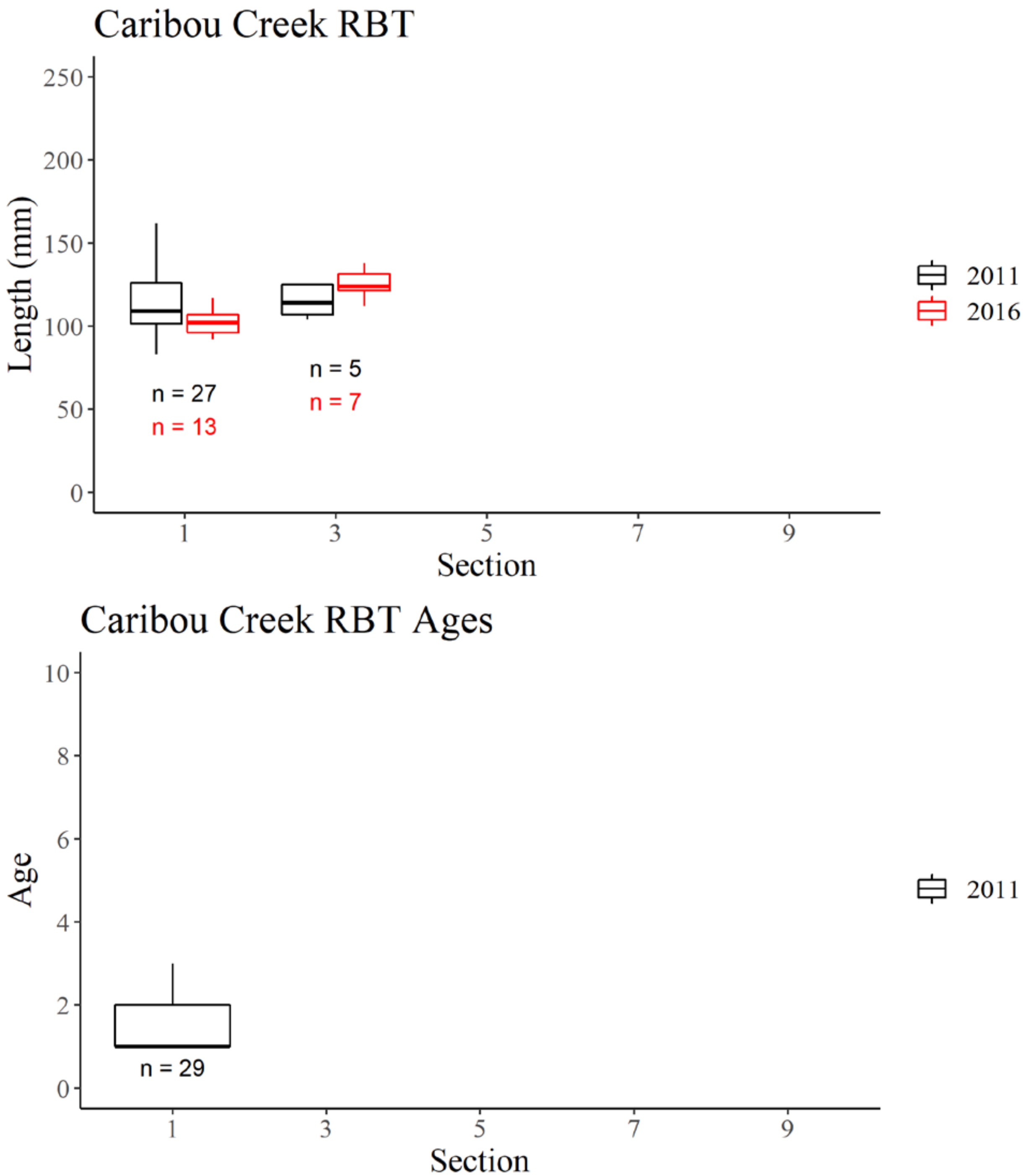


Figure 15. Length (mm; top panel) and age (years; lower panel) of Rainbow Trout captured in each section of Caribou Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

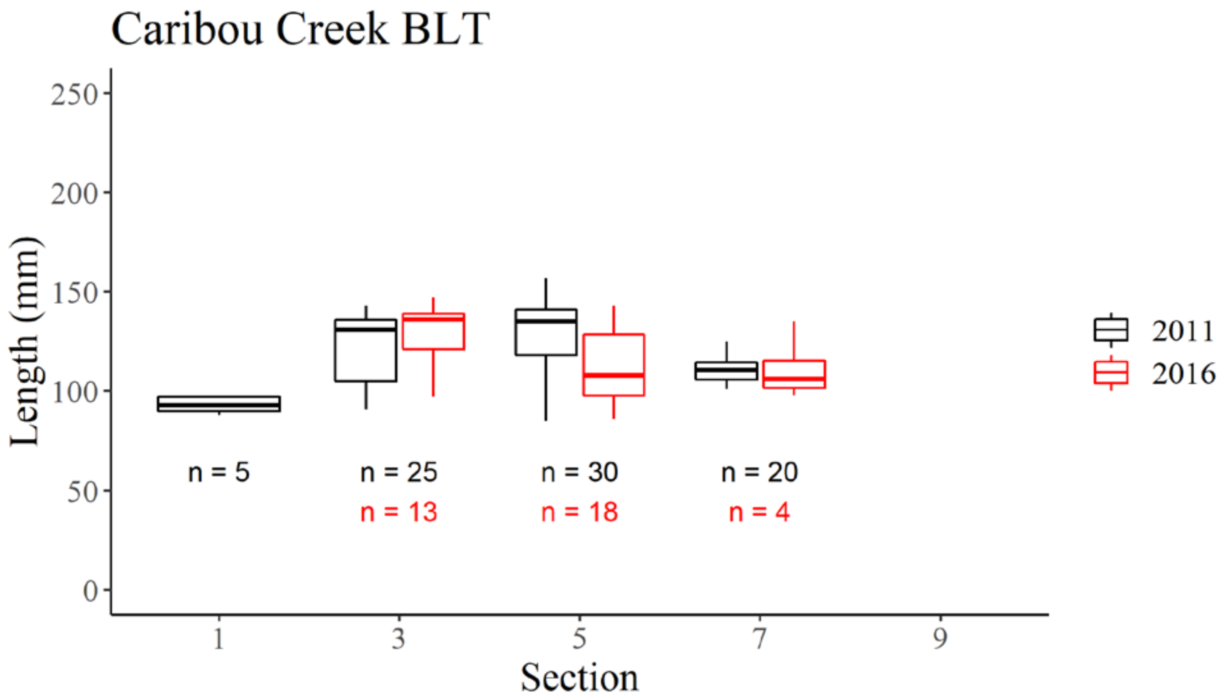


Figure 16. Length (mm) of Bull Trout captured in each section of Caribou Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

Grouse Creek

Grouse Creek is the largest tributary to the Pack River and enters from the eastern side downstream of Berry Creek. Downstream reaches of Grouse Creek are dominated by RBT, but this transitions to a WCT and BLT assemblage moving upstream (Figure 17). Brook Trout and BBHY are present to a lesser extent throughout the stream. Rainbow Trout, WRHY, and WCT densities declined from 2010 to 2015; however, BLT remained stable in the upstream reaches. Size and age structure of all species were relatively consistent through time and section, with BRK generally being the largest in size. Similar to Caribou Creek, WCT size and age structure may indicate migratory life histories are present (Figure 18). The only age-4 RBT observed in any tributary during this study were present in 2010, however they were not present again in 2015 (Figure 19). While no age data exists at this time, the small size structure of BLT suggests that older aged or resident fish do not inhabit Grouse Creek (Figure 20). Detailed capture data for WCT, RBT, BLT, and BRK are displayed in Figures 18, 19, 20, and 21.

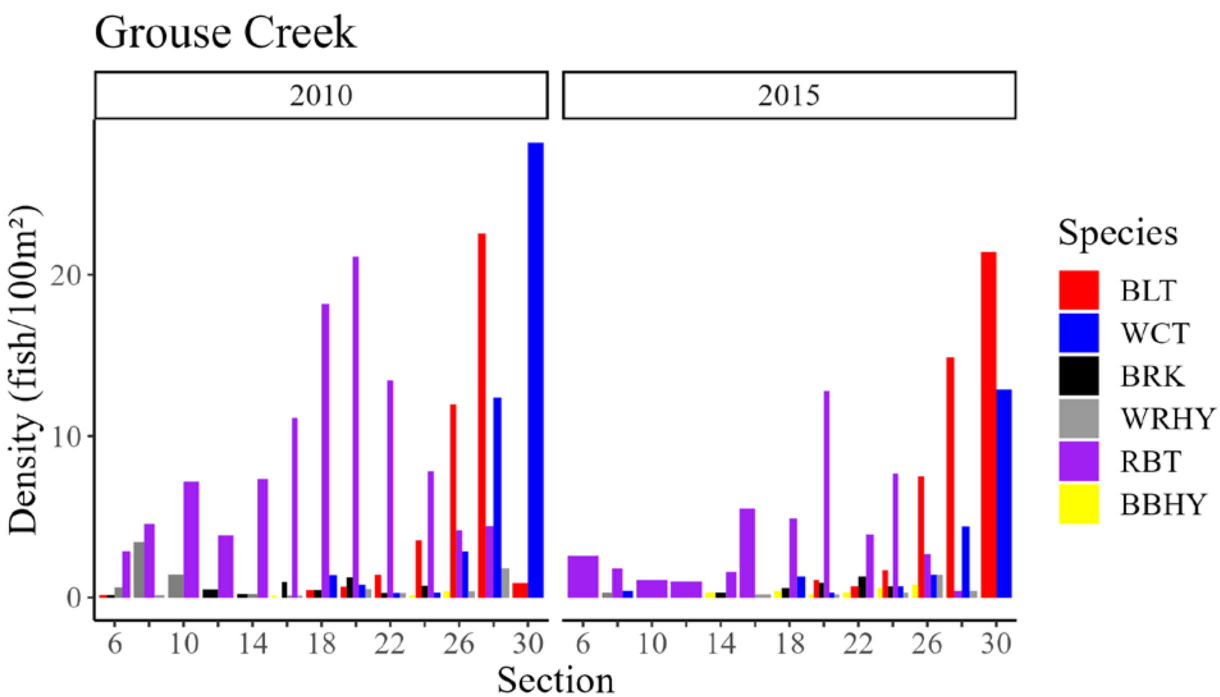
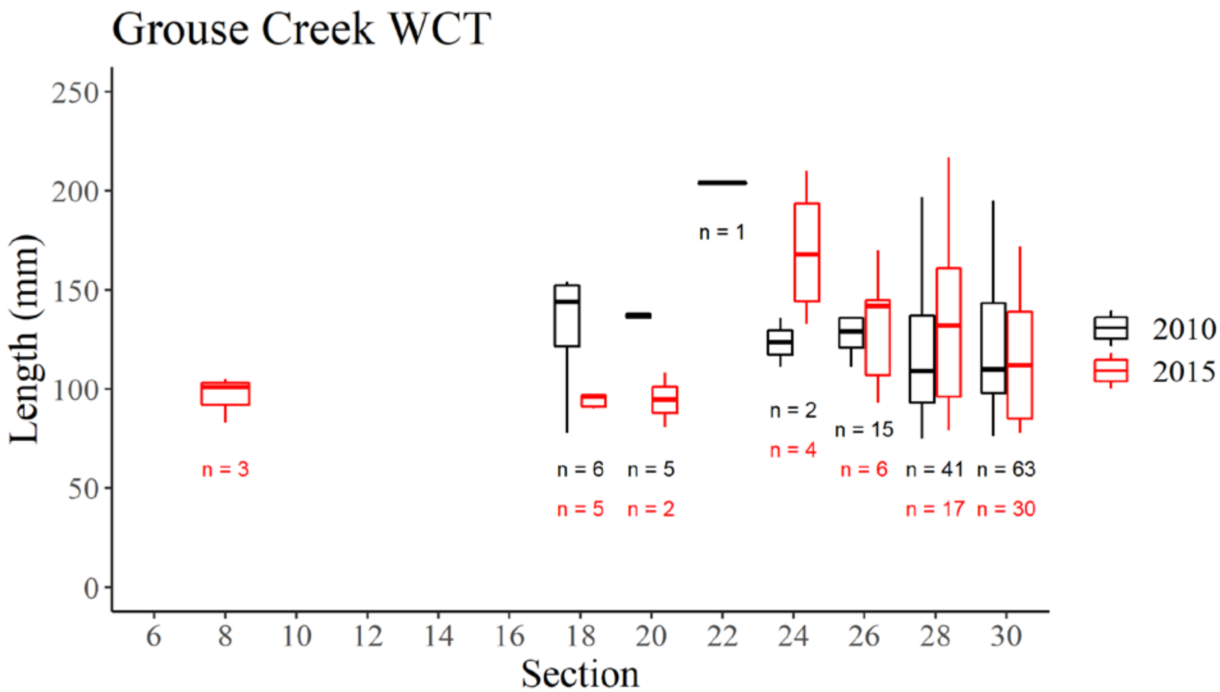


Figure 17. Fish densities for each shocking section in Grouse Creek. Species specific densities are identified by color (see legend).



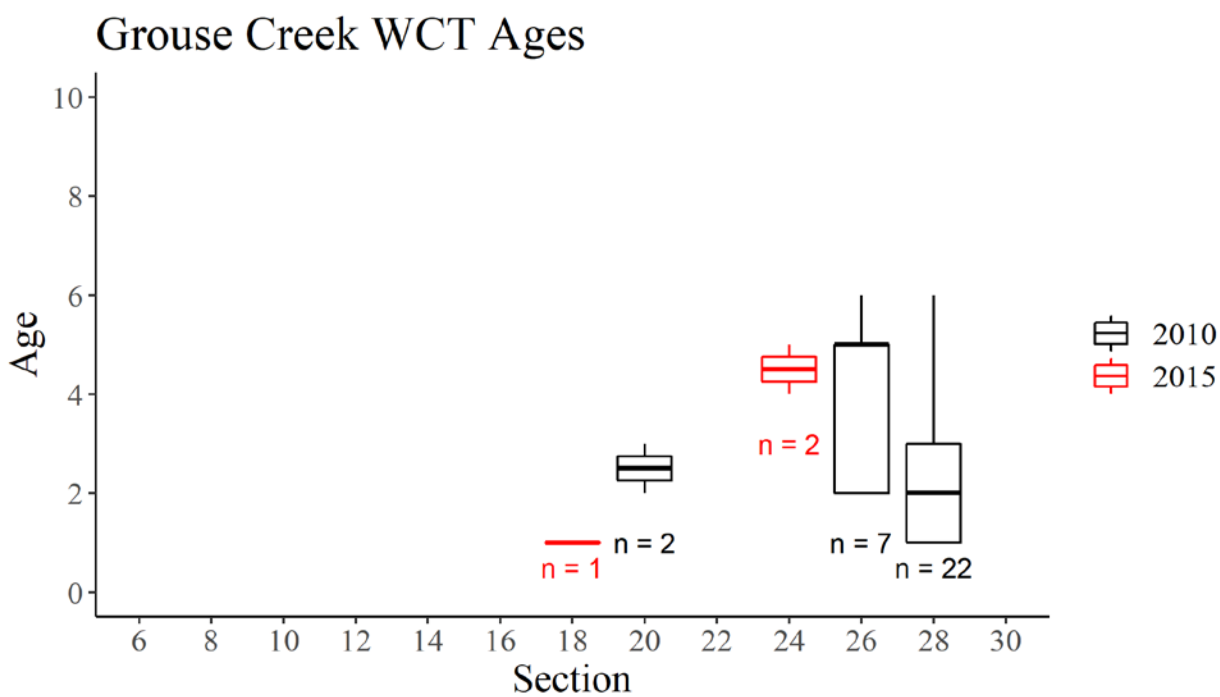


Figure 18. Length (mm; top panel) and age (years; lower panel) of Westslope Cutthroat Trout captured in each section of Grouse Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

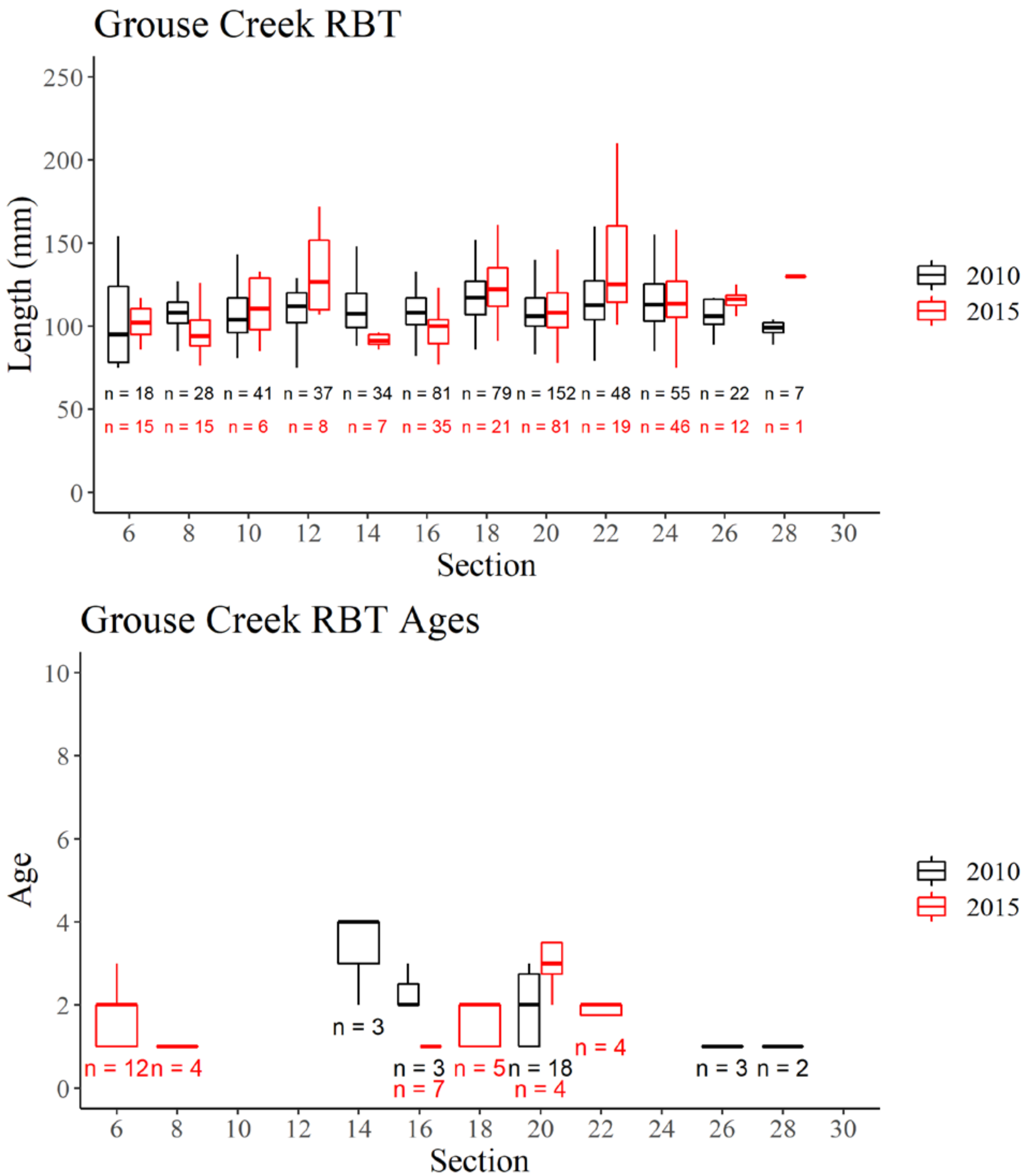


Figure 19. Length (mm; top panel) and age (years; lower panel) of Rainbow Trout captured in each section of Grouse Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

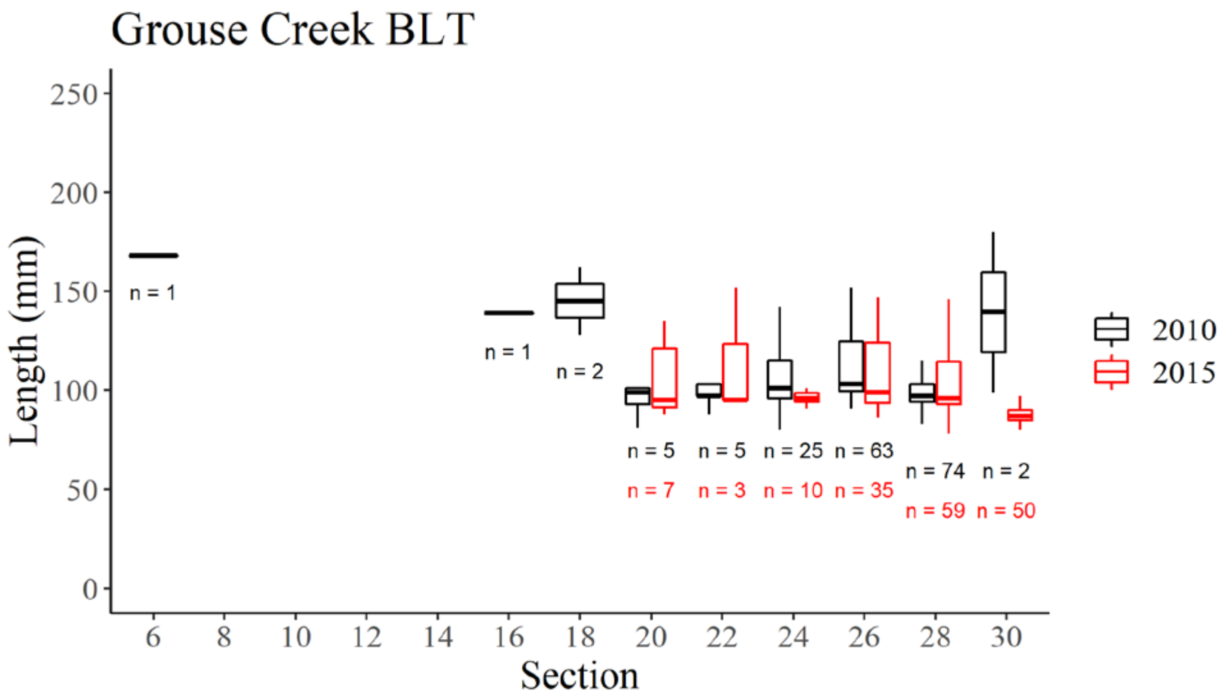


Figure 20. Length (mm) of Bull Trout captured in each section of Grouse Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

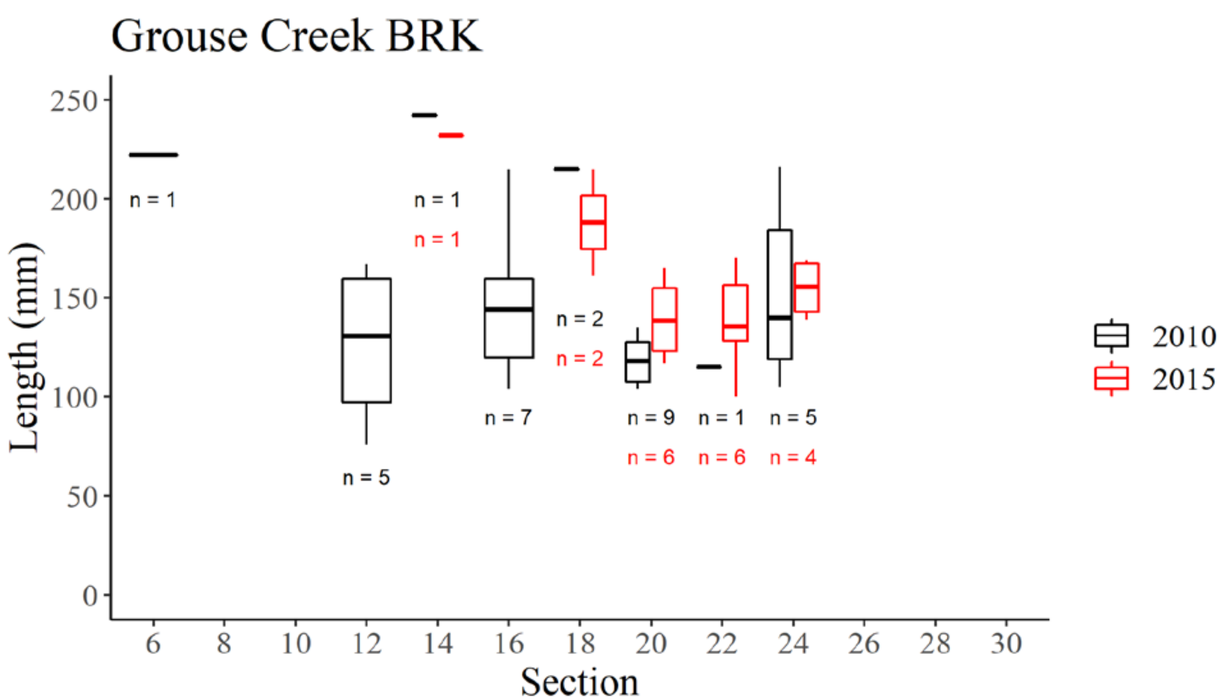


Figure 21. Length (mm) of Brook Trout captured in each section of Grouse Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

North Fork Grouse Creek

North Fork Grouse Creek is a tributary to Grouse Creek that enters from the northern side of the drainage. This stream exhibits a RBT and BRK dominated species assemblage, however WCT do persist above a barrier upstream of section seven (Figure 22). Low densities of BLT were observed during the second round of sampling, and BRK declined in number. RBT and WCT densities remained similar (Figure 22). No BLT spawning has been observed in North Fork Grouse, and the few individuals present likely moved into the stream as juveniles. All species exhibited similar sizes. Older individuals present in reaches upstream of the barrier indicate that resident WCT inhabit the headwaters of North Fork Grouse Creek where migrants are not able to reach (Figure 23). Detailed capture data for WCT, RBT, BLT, and BRK are displayed in Figures 23, 24, 25, and 26.

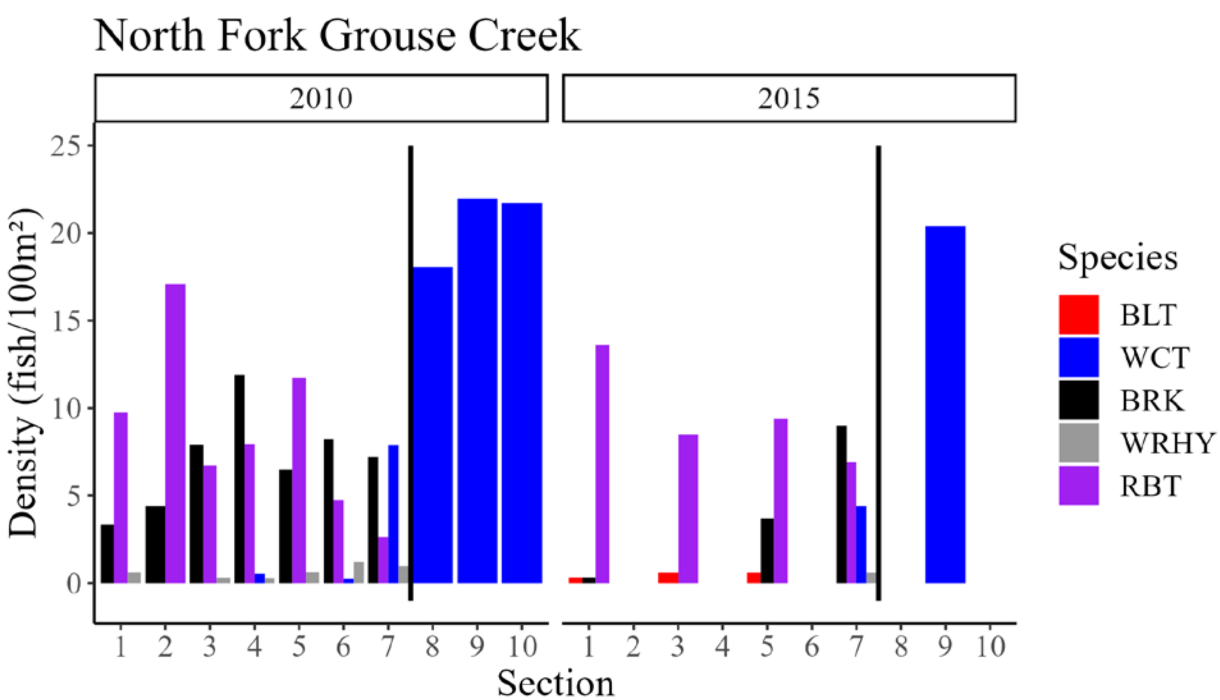
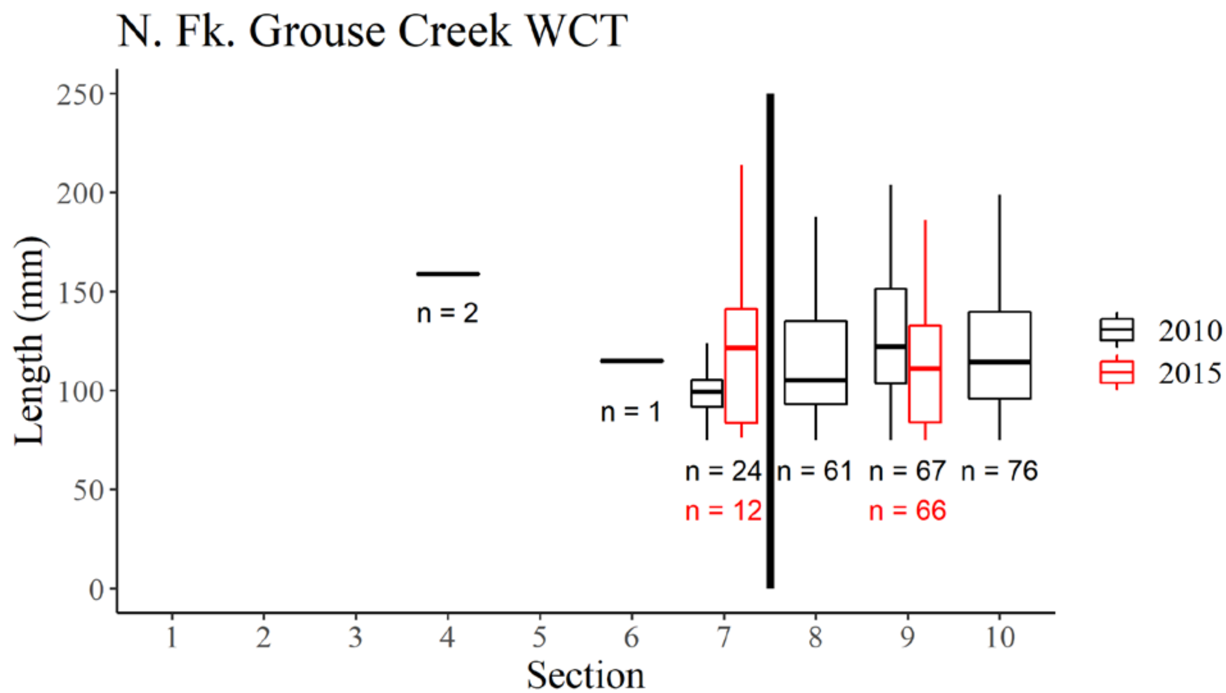


Figure 22. Fish densities for each shocking section in North Fork Grouse Creek. Species specific densities are identified by color (see legend). The location of a barrier to upstream migration is identified with a tall black line.



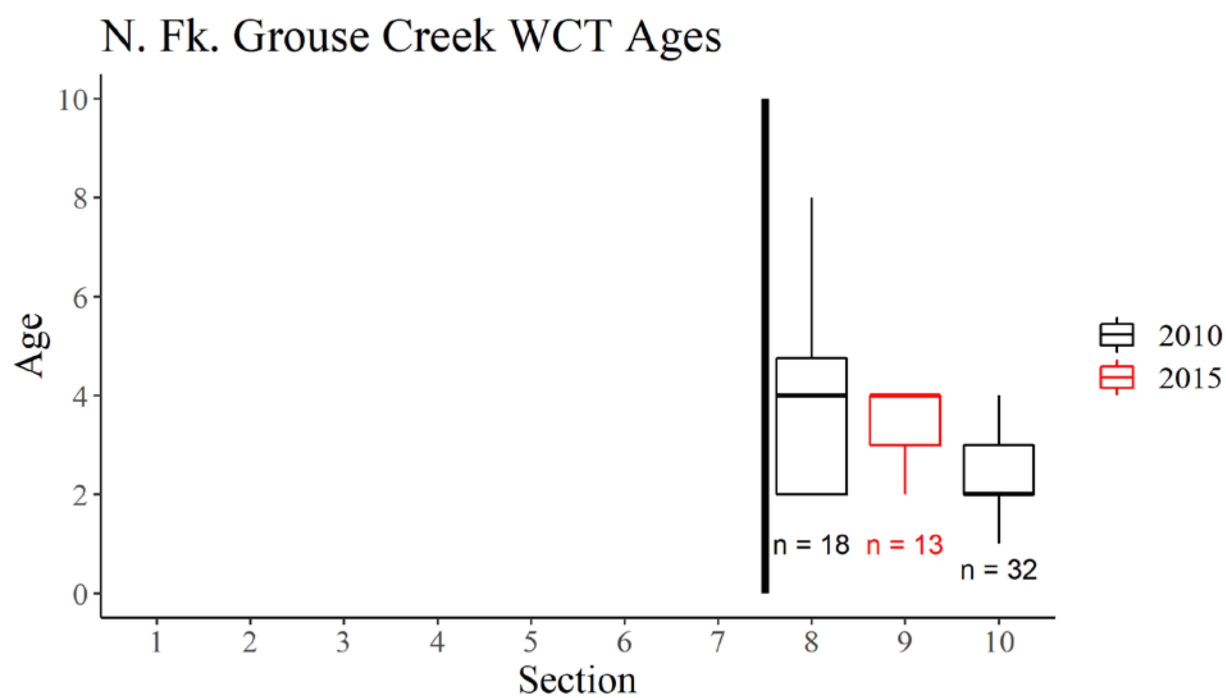


Figure 23. Length (mm; top panel) and age (years; lower panel) of Westslope Cutthroat Trout captured in each section of North Fork Grouse Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

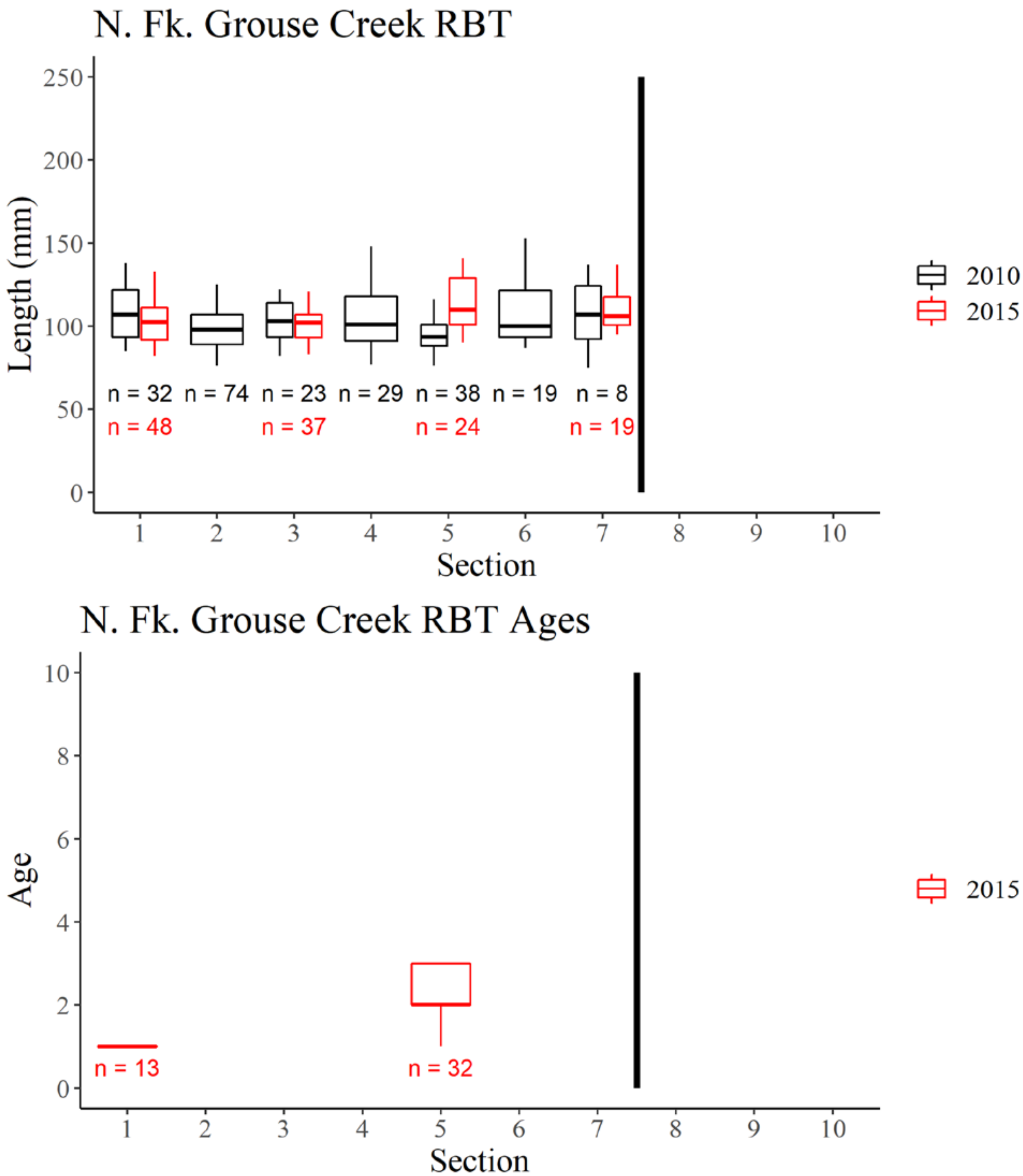


Figure 24. Length (mm; top panel) and age (years; lower panel) of Rainbow Trout captured in each section of North Fork Grouse Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

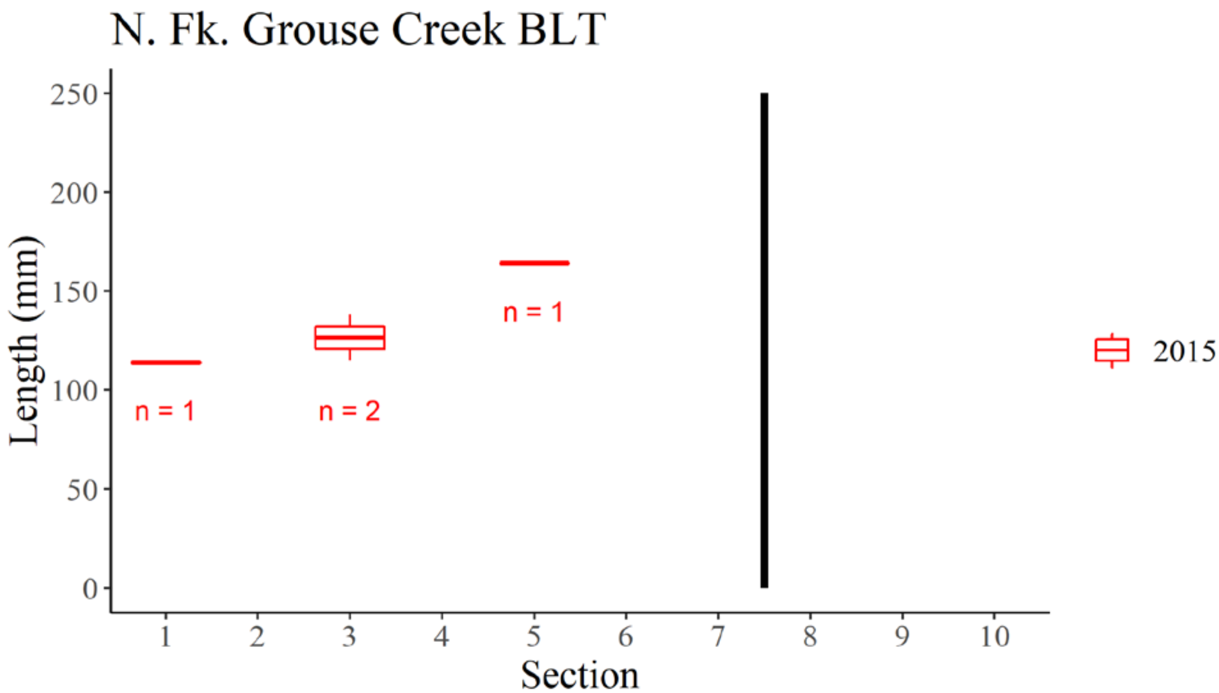


Figure 25. Length (mm) of Bull Trout captured in each section of North Fork Grouse Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

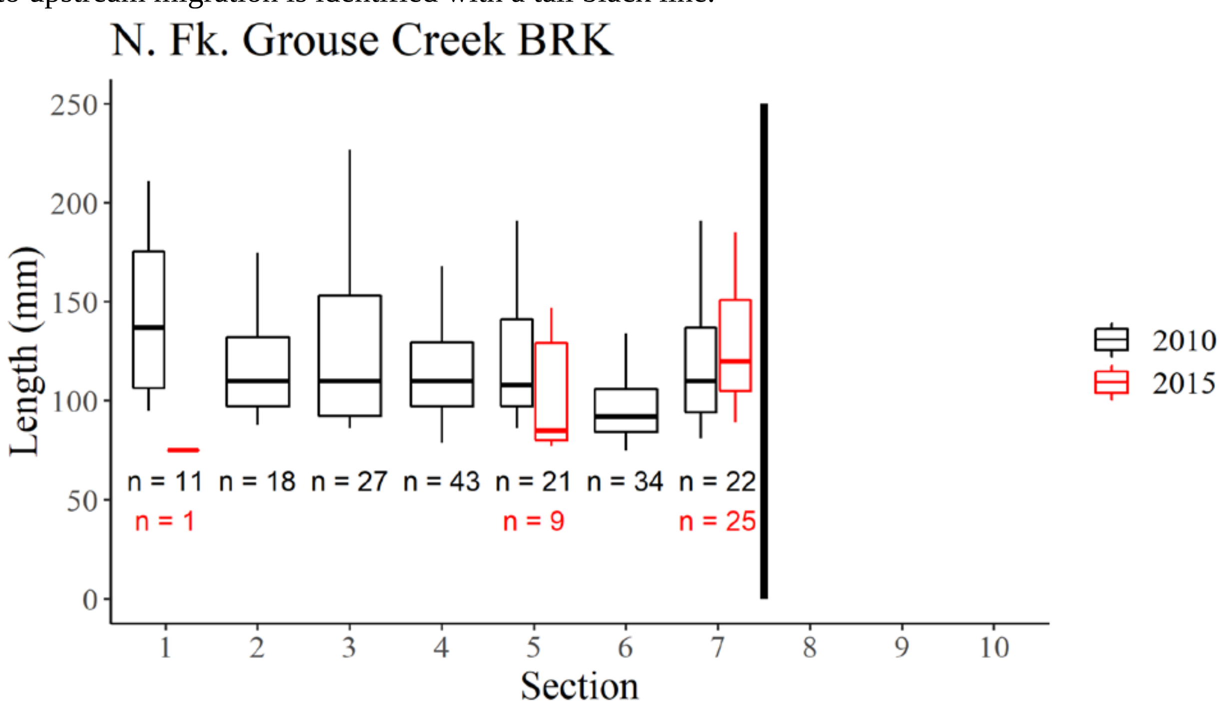


Figure 26. Length (mm) of Brook Trout captured in each section of North Fork Grouse Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

South Fork Grouse Creek

South Fork Grouse Creek is a tributary to Grouse Creek that enters from the south. It is predominantly a RBT stream, with some BRK, WCT, and BLT present in some locations (Figure 27). No BLT spawning has been observed in South Fork Grouse, and individuals present likely moved into the stream as juveniles. Detailed capture data for WCT, RBT, BLT, and BRK are displayed in Figures 28, 29, 30, and 31.

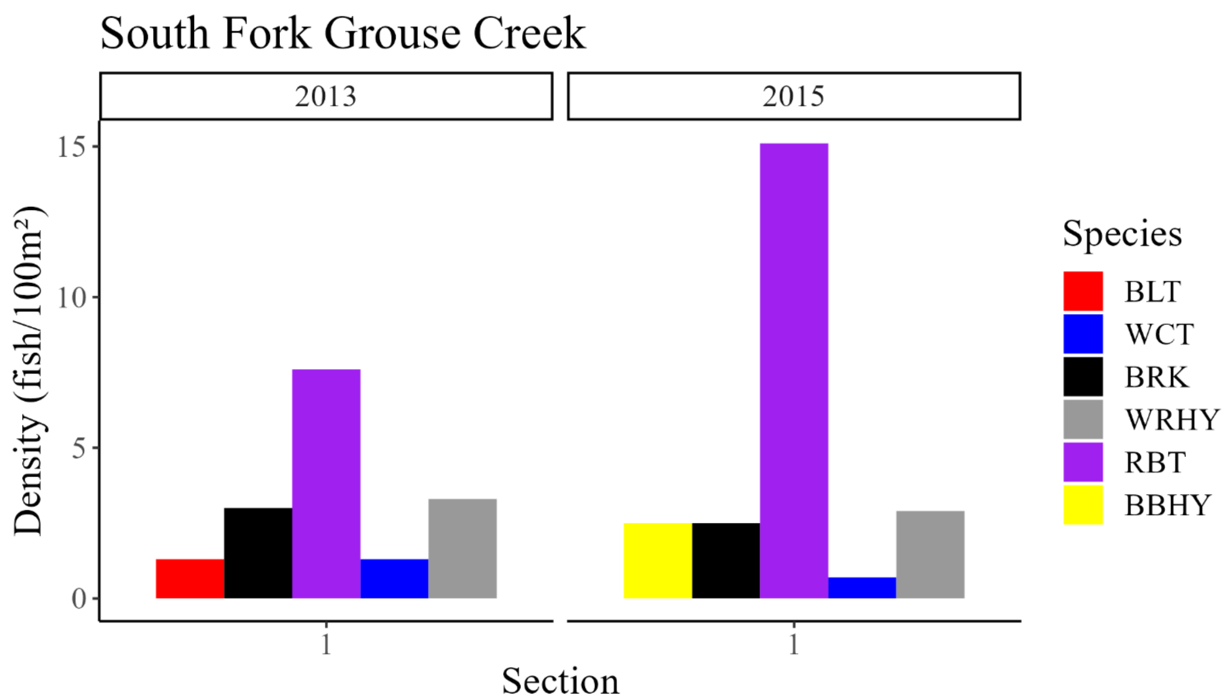


Figure 27. Fish densities for each shocking section in South Fork Grouse Creek. Species specific densities are identified by color (see legend).

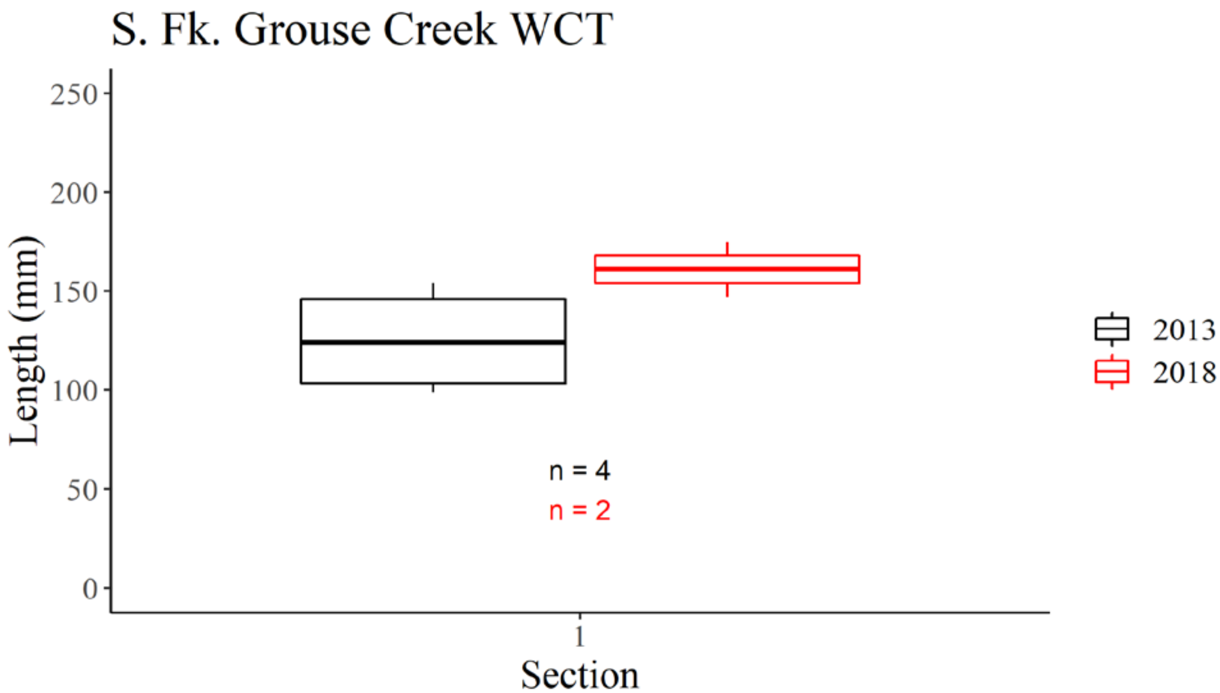


Figure 28. Length (mm) of Westslope Cutthroat Trout captured in each section of South Fork Grouse Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

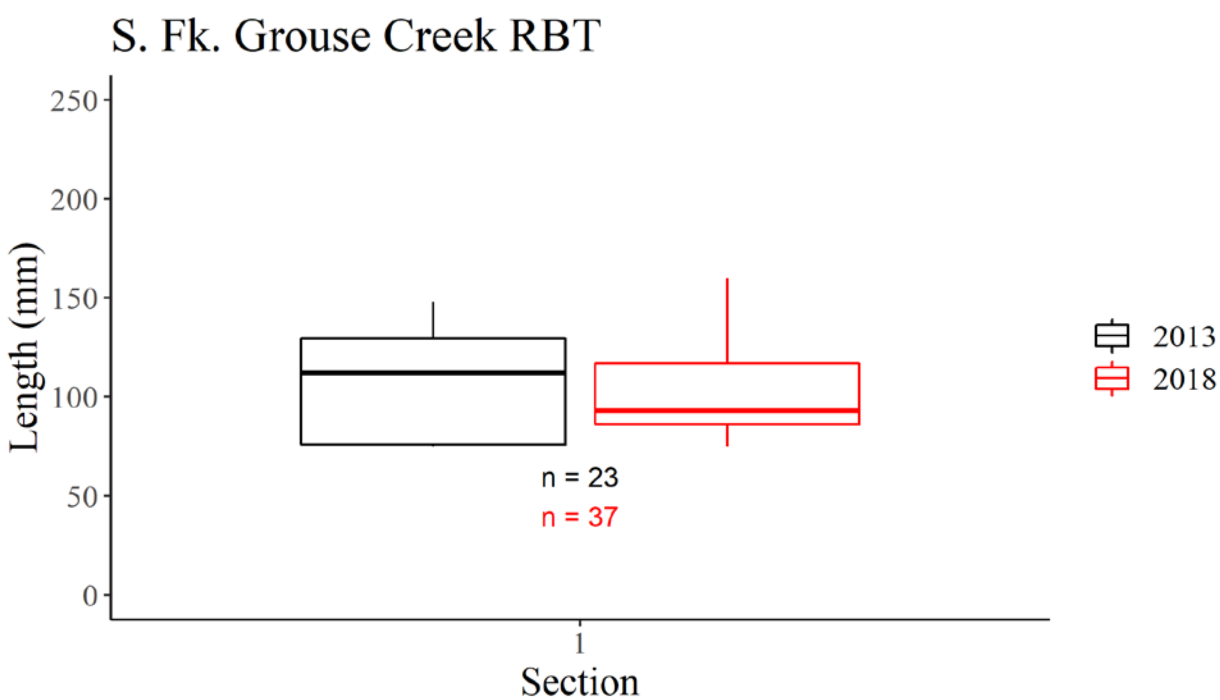


Figure 29. Length (mm) of Rainbow Trout captured in each section of South Fork Grouse Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

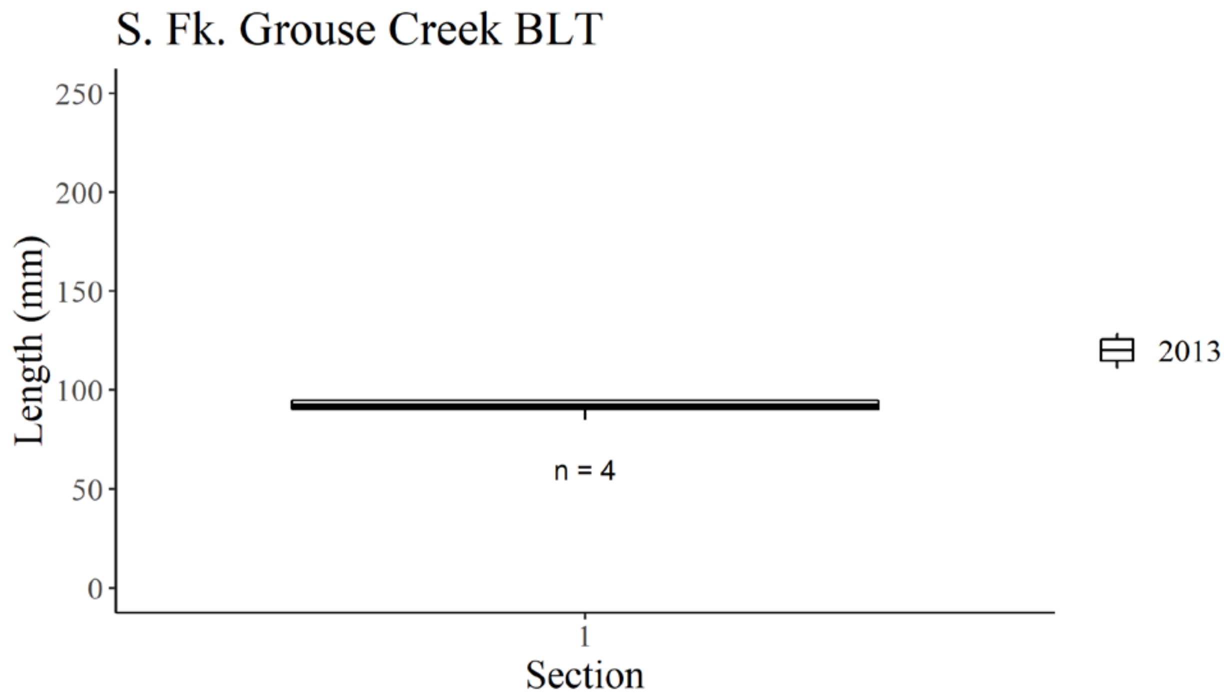


Figure 30. Length (mm) of Bull Trout captured in each section of South Fork Grouse Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

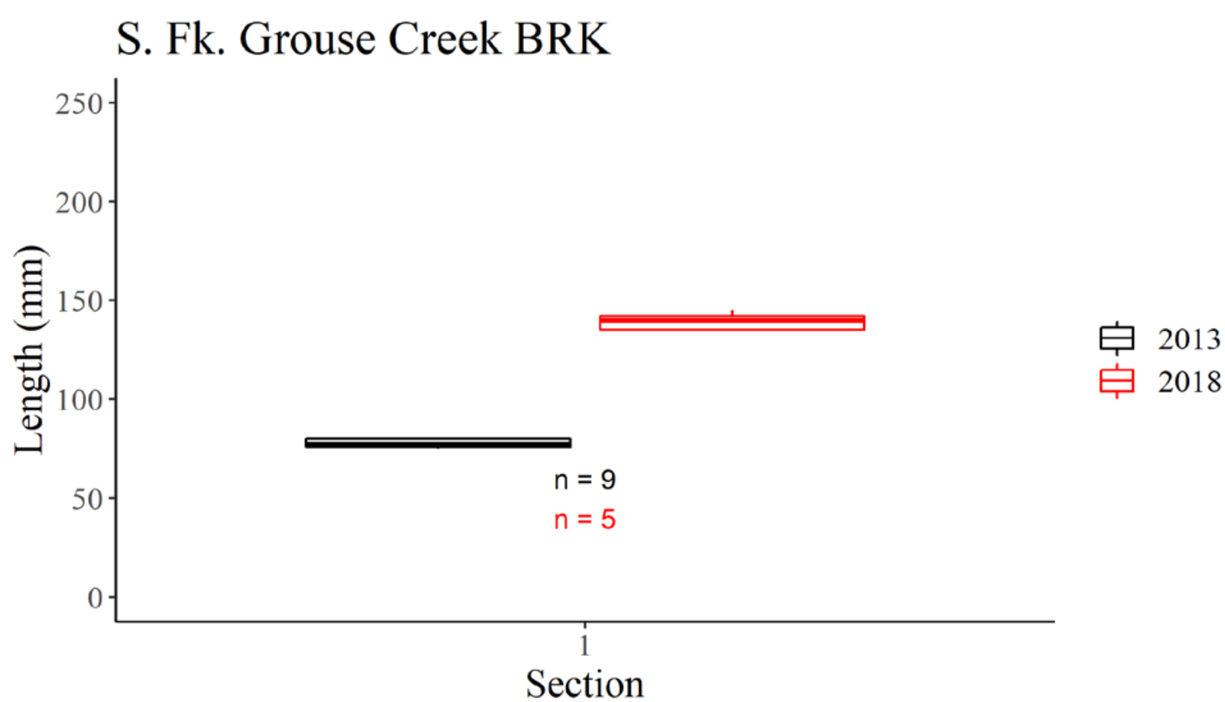


Figure 31. Length (mm) of Brook Trout captured in each section of South Fork Grouse Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

Hellroaring Creek

Hellroaring Creek is located in the upper Pack River and is directly north of Caribou Creek. Rainbow Trout are the dominant species present, however the migratory Gerrard strain is only present in Section One. Above the waterfall barrier that exists between sections One and Two, a coastal strain of RBT (Campbell et al. 2013) is present and is the only species observed (Figure 32). Adfluvial BLT do persist in low levels below the waterfall barrier where they have access for spawning (Figure 32). Sizes of RBT throughout the stream declined during the second sample event while densities increased. Detailed capture data for WCT, RBT, and BLT are displayed in Figures 33, 34, and 35.

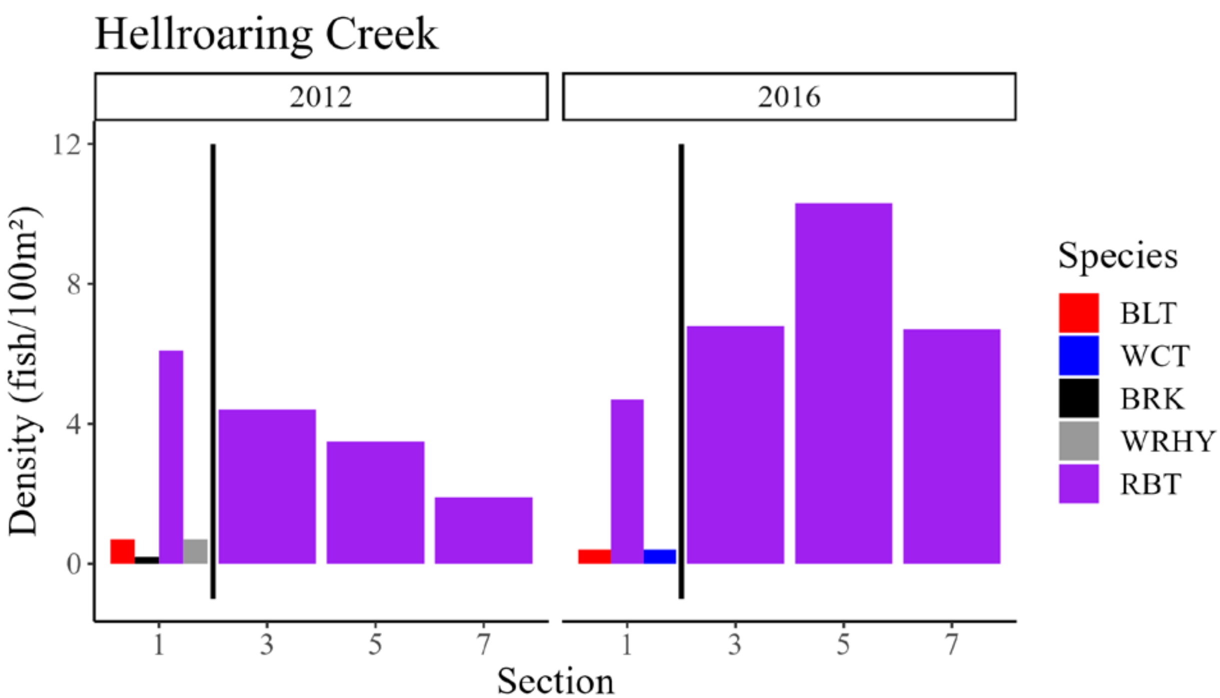


Figure 32. Fish densities for each shocking section in Hellroaring Creek. Species specific densities are identified by color (see legend). The location of a barrier to upstream migration is identified with a tall black line.

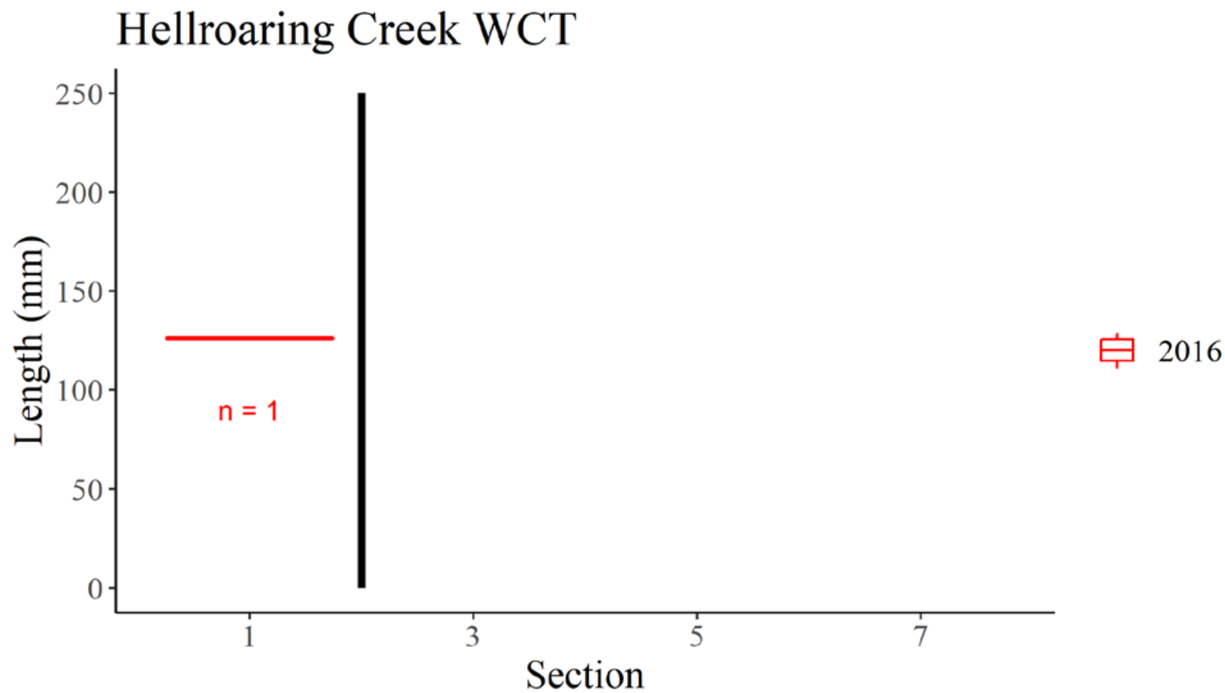


Figure 33. Length (mm) of Westslope Cutthroat Trout captured in each section of Hellroaring Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

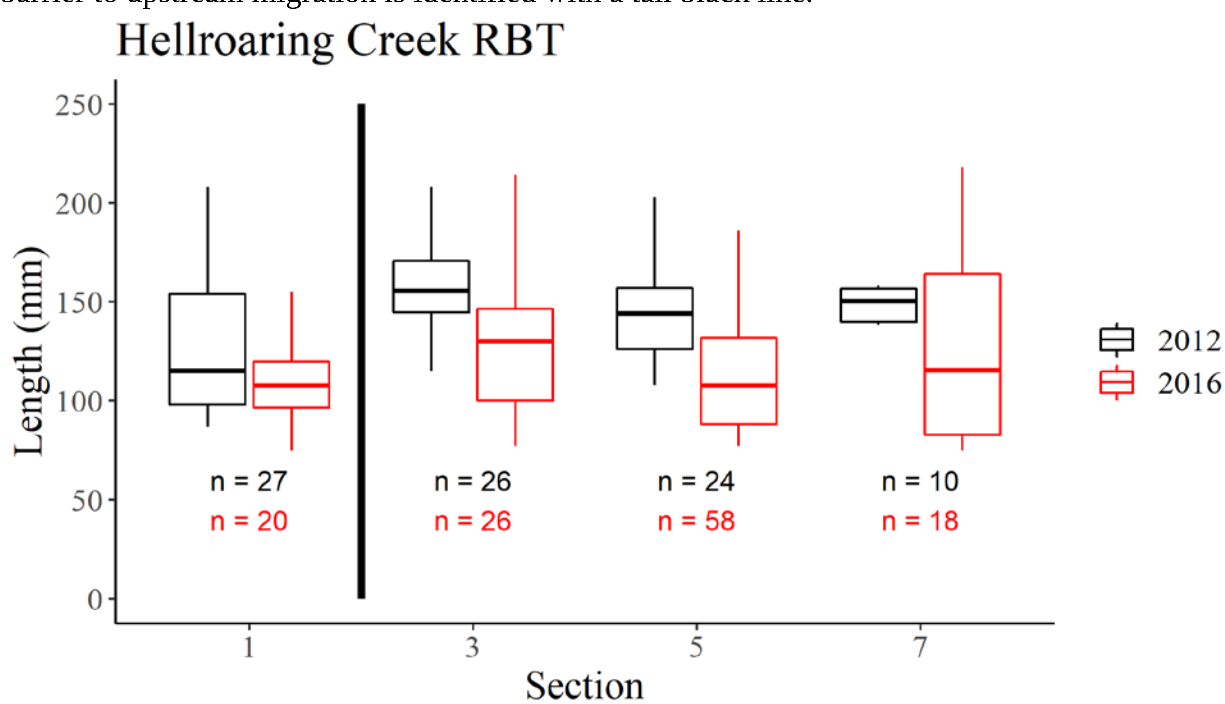


Figure 34. Length (mm) of Rainbow Trout captured in each section of Hellroaring Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

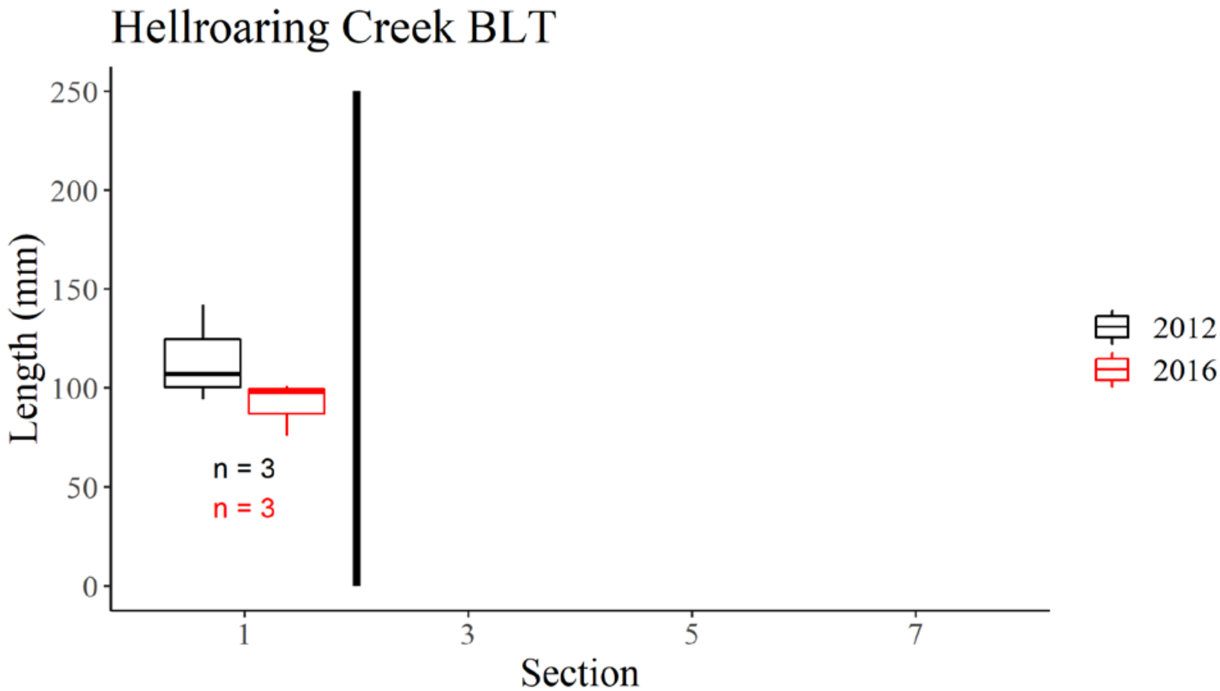


Figure 35. Length (mm) of Bull Trout captured in each section of Hellroaring Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

Jeru Creek

Jeru Creek is located on the western side of the upper Pack River and is north of Hellroaring Creek. Predominantly a WCT stream, RBT and WRHY are present to a lesser extent (Figure 36). Interestingly, RBT are present higher in the stream than WCT. Westslope Cutthroat that are present were observed to be young in age structure, which may suggest migratory behavior is present (Figure 37). No BLT have been observed in Jeru Creek. Detailed capture data for WCT and RBT are displayed in Figures 37 and 38.

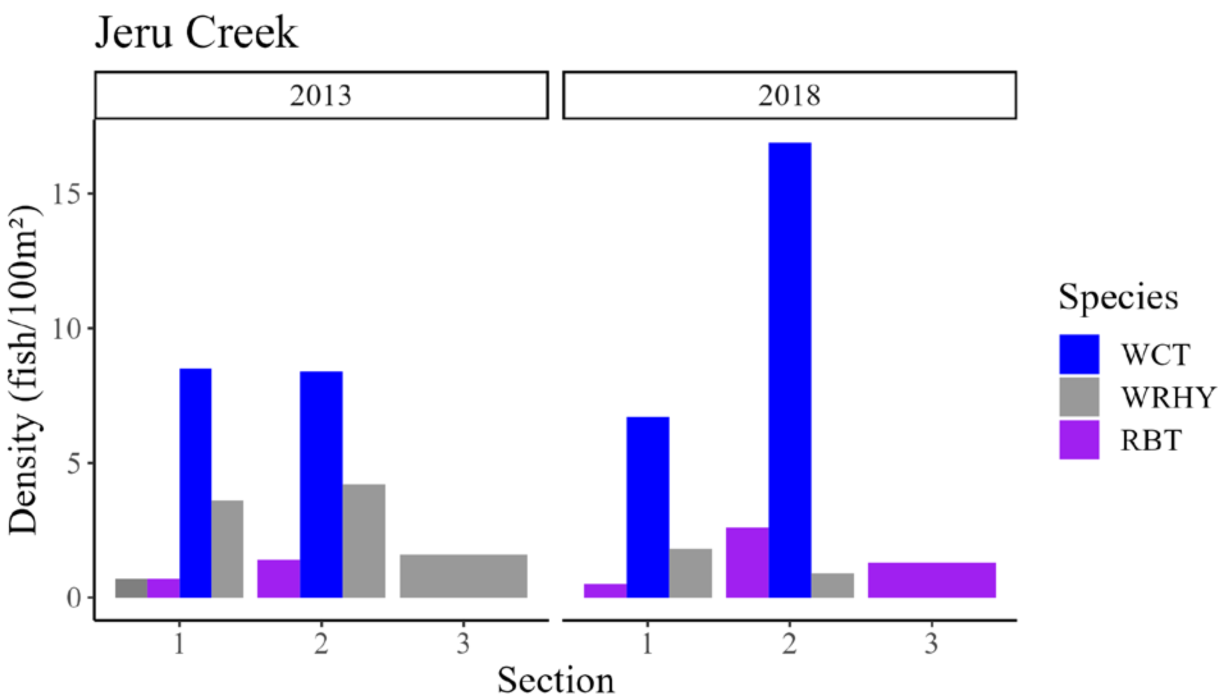
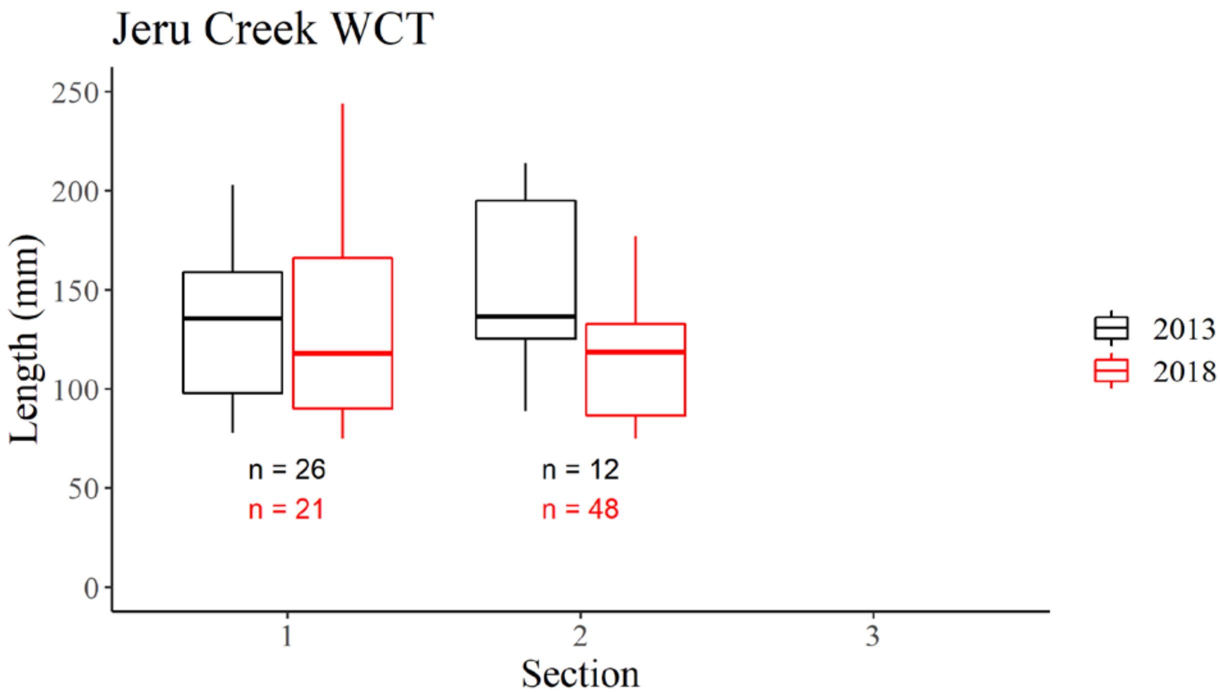


Figure 36. Fish densities for each shocking section in Jeru Creek. Species specific densities are identified by color (see legend).



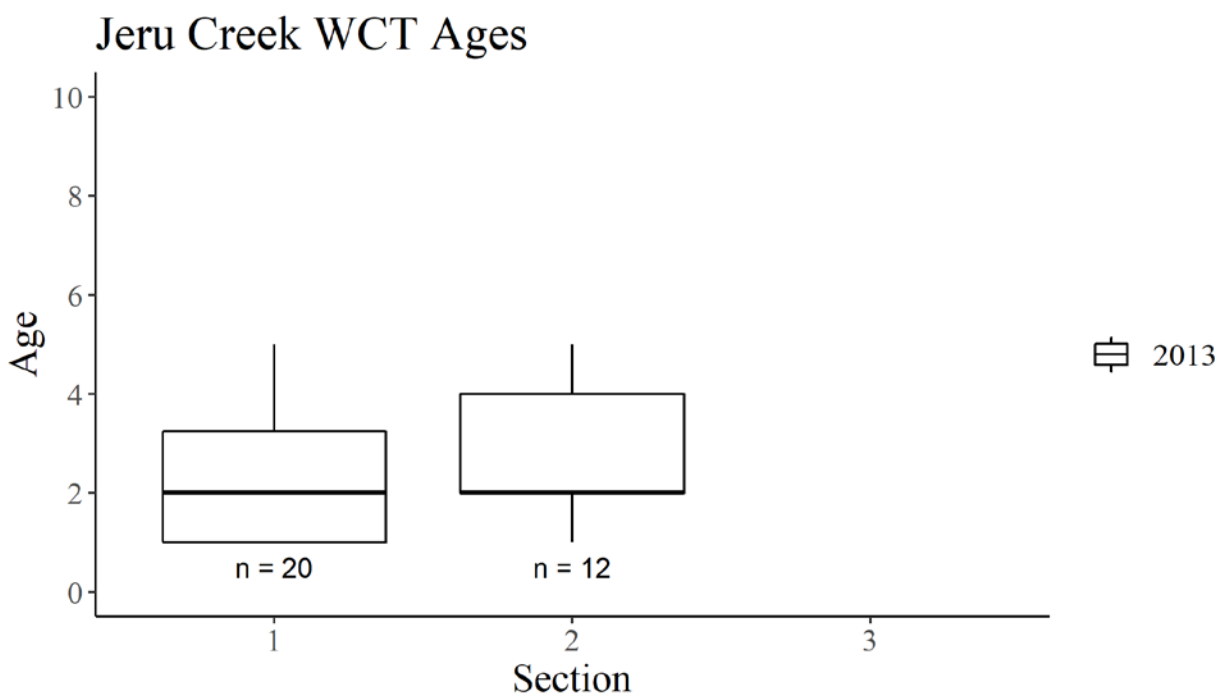


Figure 37. Length (mm; top panel) and age (years; lower panel) of Westslope Cutthroat Trout captured in each section of Jeru Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

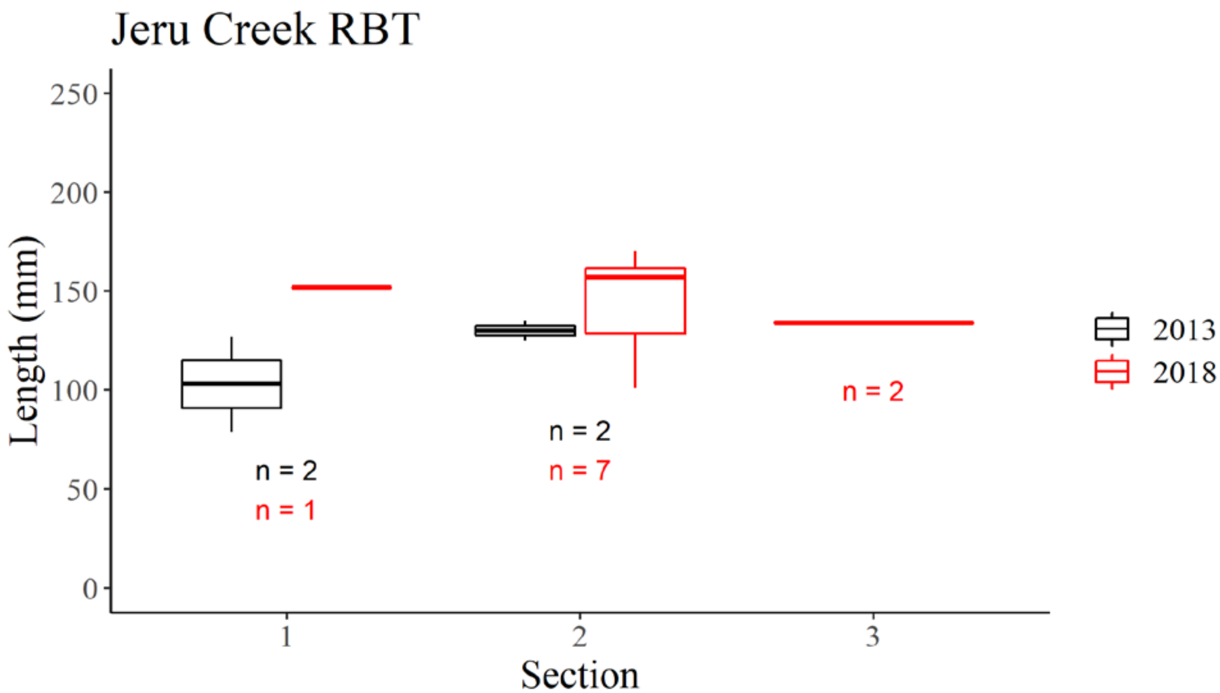


Figure 38. Length (mm) of Rainbow Trout captured in each section of Jeru Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

McCormick Creek

McCormick Creek is the uppermost sample tributary in the Pack River on the western side of the drainage. Primarily a WCT dominated stream, low densities of RBT were observed in the first section in 2012 (Figure 39). Though no fish were captured in section five during the 2012 sampling effort, a single smaller fish believed to be a WCT was observed but not captured. During the 2016 sampling, a single 230 mm WCT was captured from the same pool where a smaller fish was seen but not captured in 2012. It is possible this fish may have originated from WCT stocked upstream in McCormick Lake and flushed downstream. To date, no BLT have been observed in McCormick Creek. Detailed capture data for WCT and RBT are displayed in Figures 40 and 41.

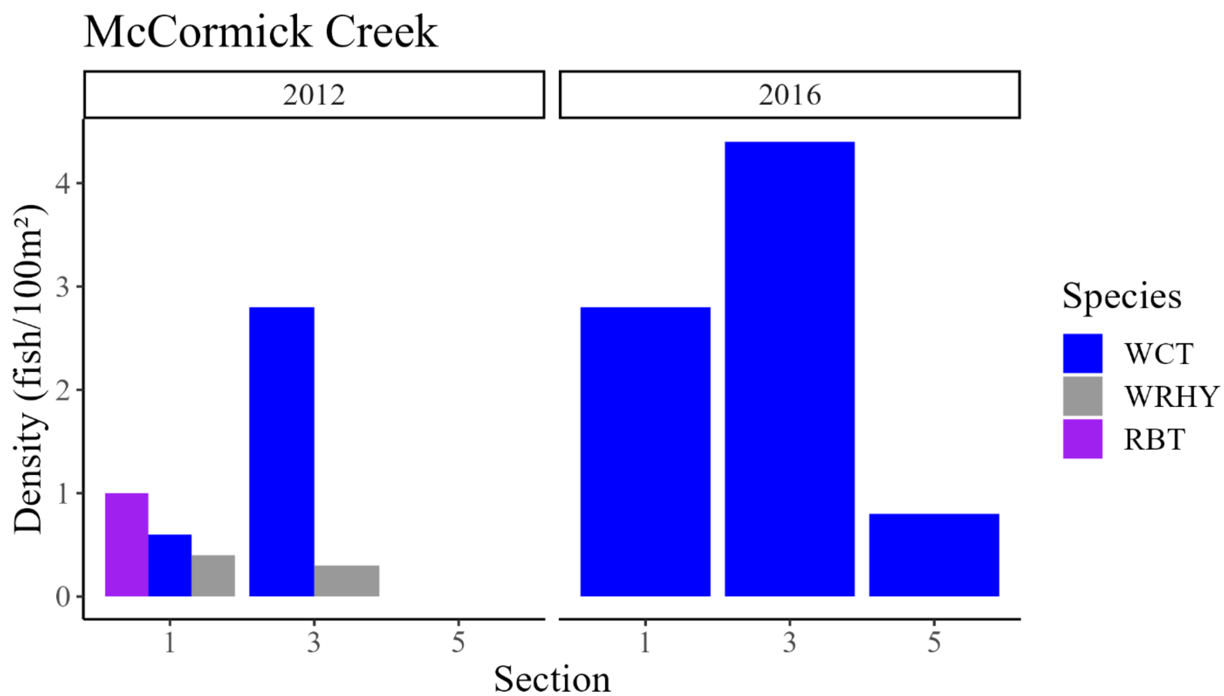


Figure 39. Fish densities for each shocking section in McCormick Creek. Species specific densities are identified by color (see legend).

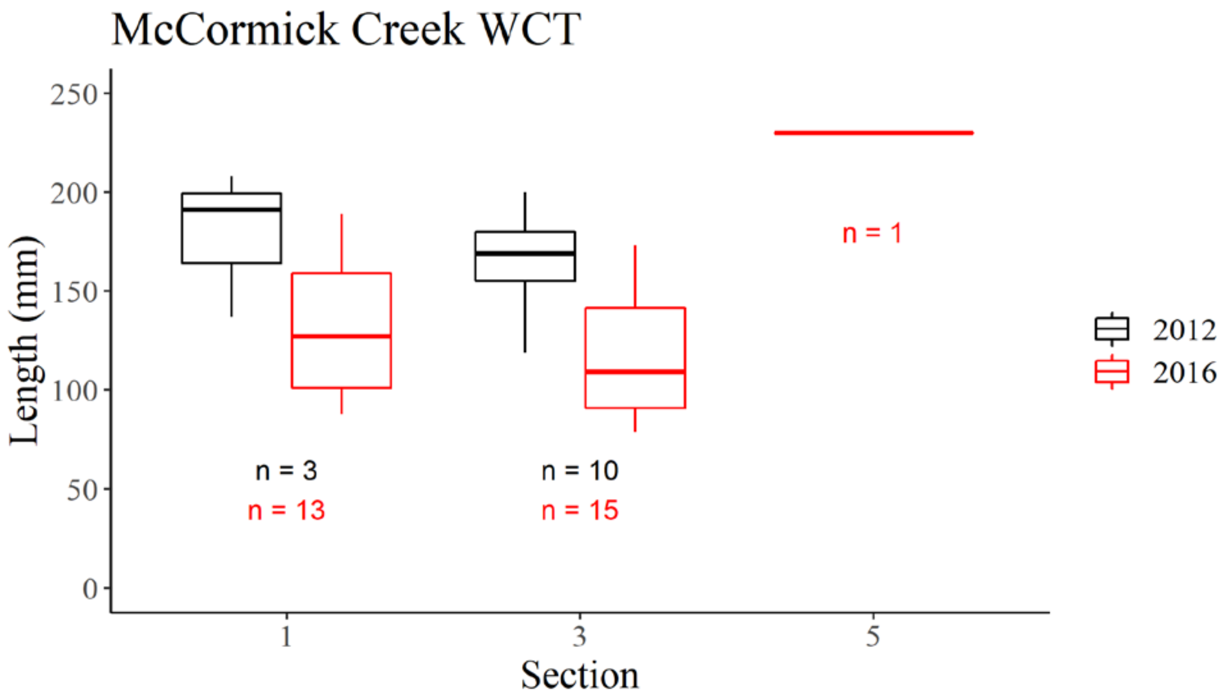


Figure 40. Length (mm) of Westslope Cutthroat Trout captured in each section of McCormick Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

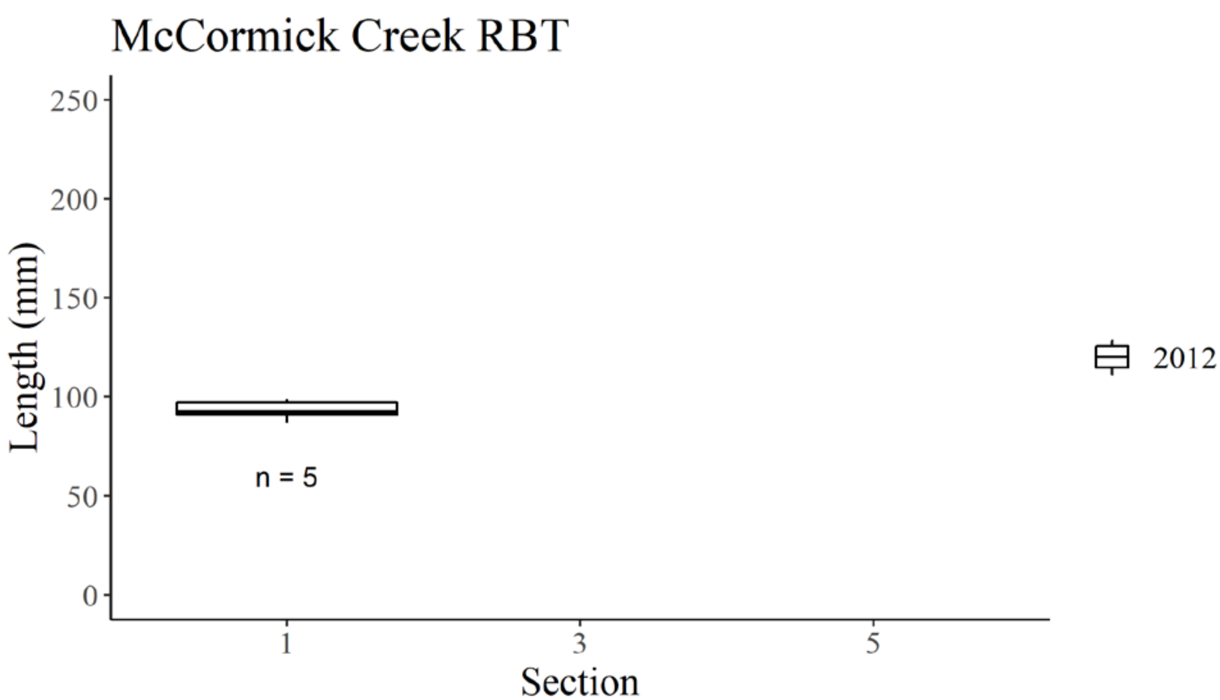


Figure 41. Length (mm) of Rainbow Trout captured in each section of McCormick Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), sample size (labeled) for each group.

Rapid Lightning Creek

Rapid Lightning Creek is a low gradient stream that joins the Pack River south of the confluence with Grouse Creek. Largely populated by WCT and BRK, lower reaches of the creek are dominated by RBT (Figure 42). Additionally, RBT are found in sections one through seven but not above, suggesting a barrier likely exists. Sizes of all species remained similar through time; however, age structure of WCT was reduced during the second sample event (Figure 43). Based on WCT size and age structure, both migratory and resident life history forms may be present. Two BLT were observed in Section Three in 2010; however, no spawning has been documented and these fish likely migrated into Rapid Lightning Creek as juveniles. Detailed capture data for WCT, RBT, BLT, and BRK are displayed in Figures 43, 44, 45, and 46.

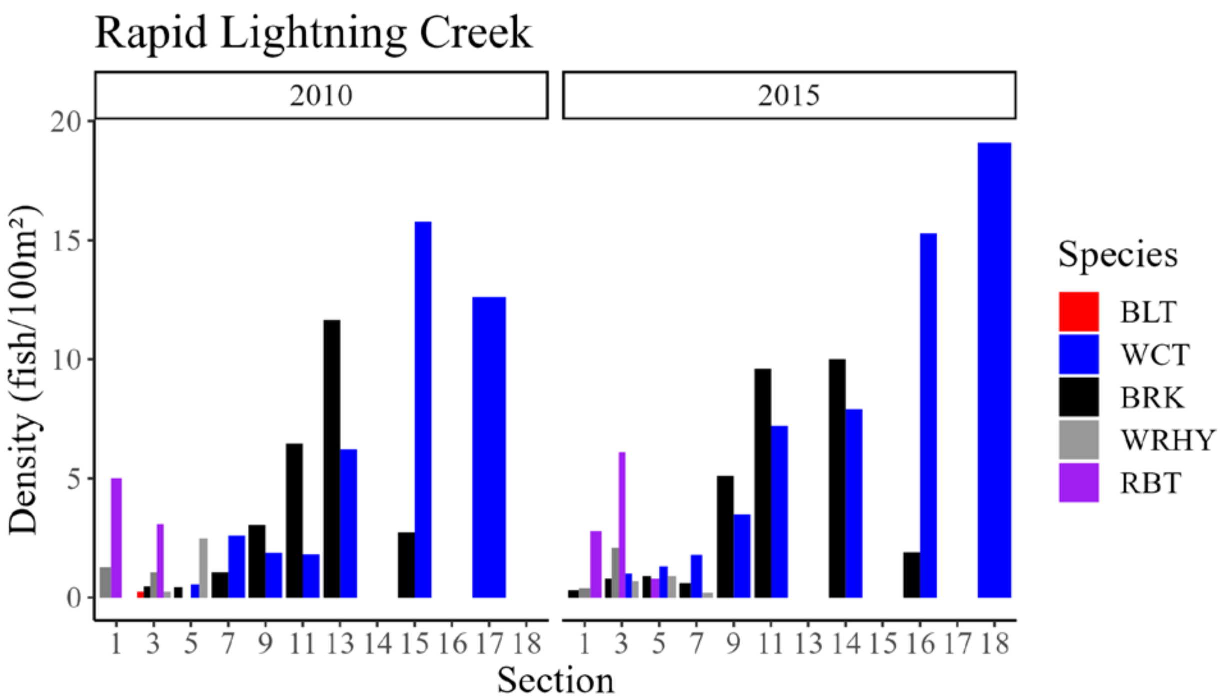


Figure 42. Fish densities for each shocking section in Rapid Lightning Creek. Species specific densities are identified by color (see legend).

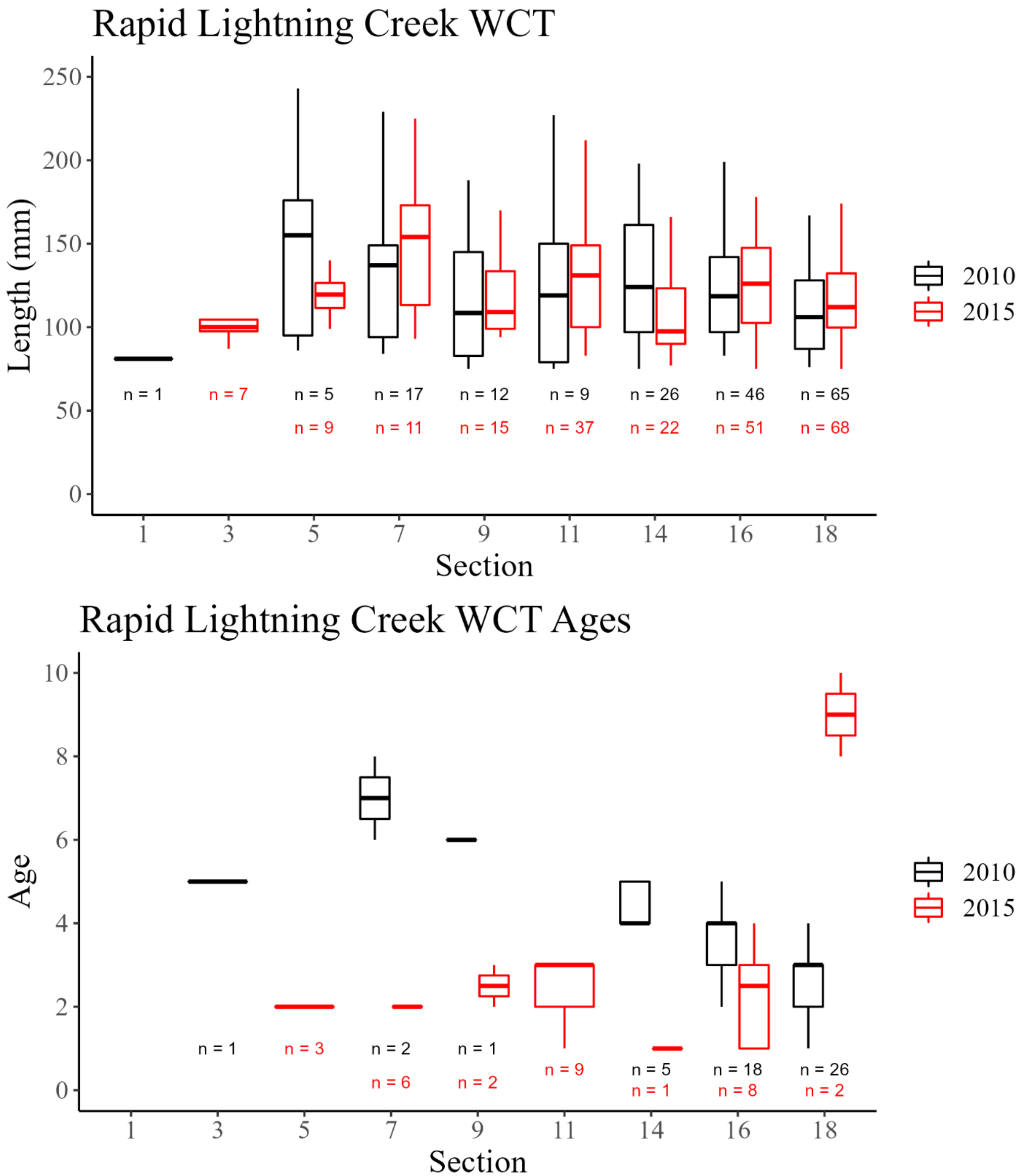


Figure 43. Length (mm; top panel) and age (years; lower panel) of Westslope Cutthroat Trout captured in each section of Rapid Lightning Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

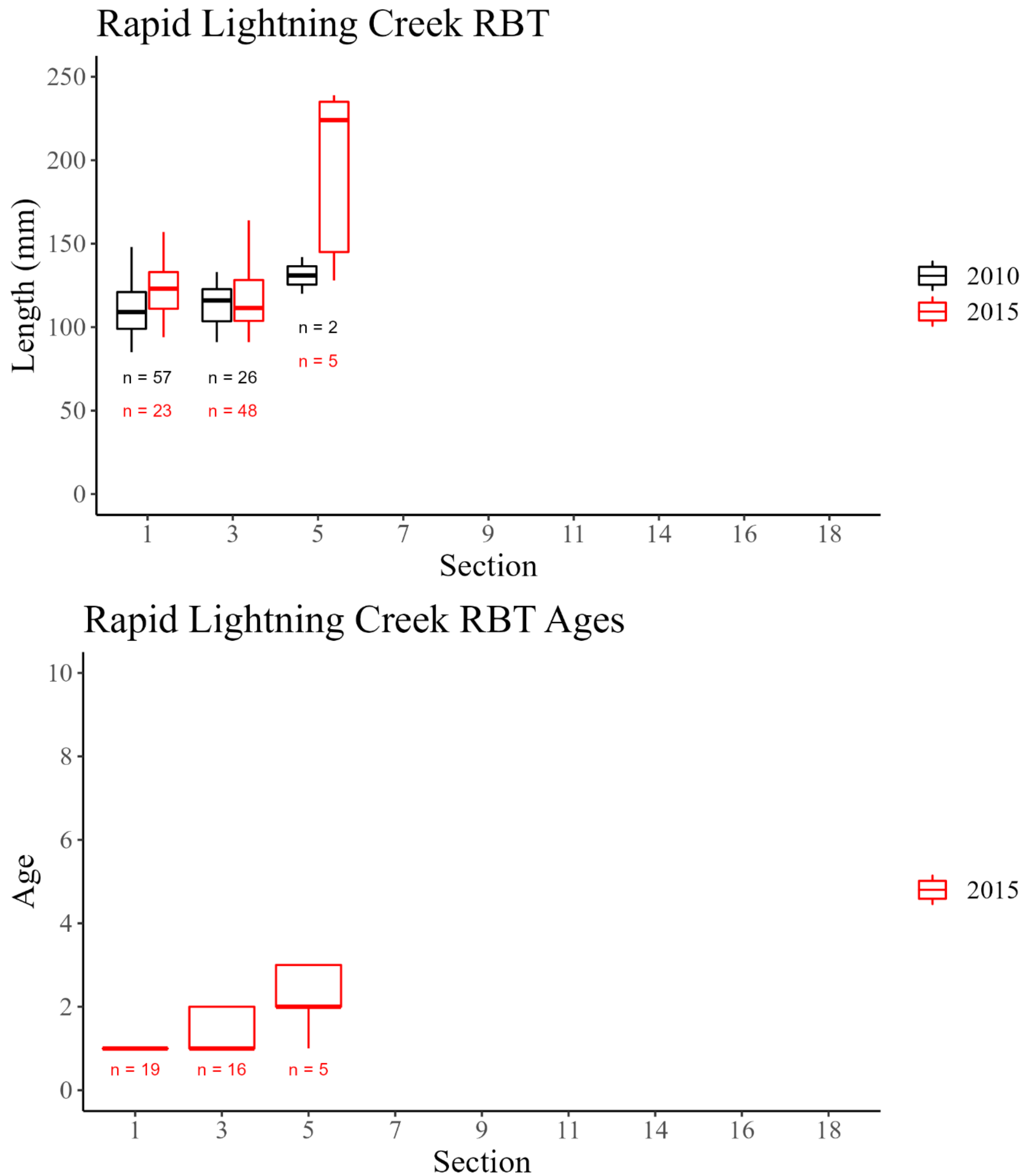


Figure 44. Length (mm; top panel) and age (years; lower panel) of Rainbow Trout captured in each section of Rapid Lightning Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

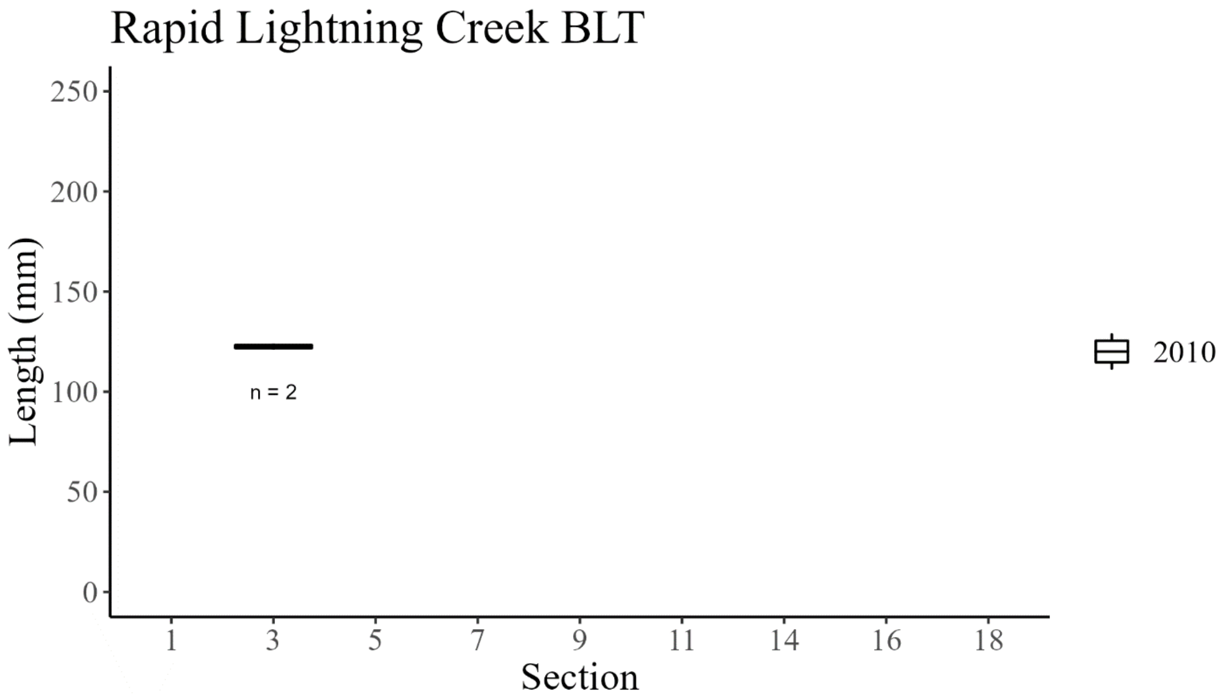


Figure 45. Length (mm) of Bull Trout captured in each section of Rapid Lightning Creek. The year of the first sample event is identified in black, and the second sample in red. Each boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

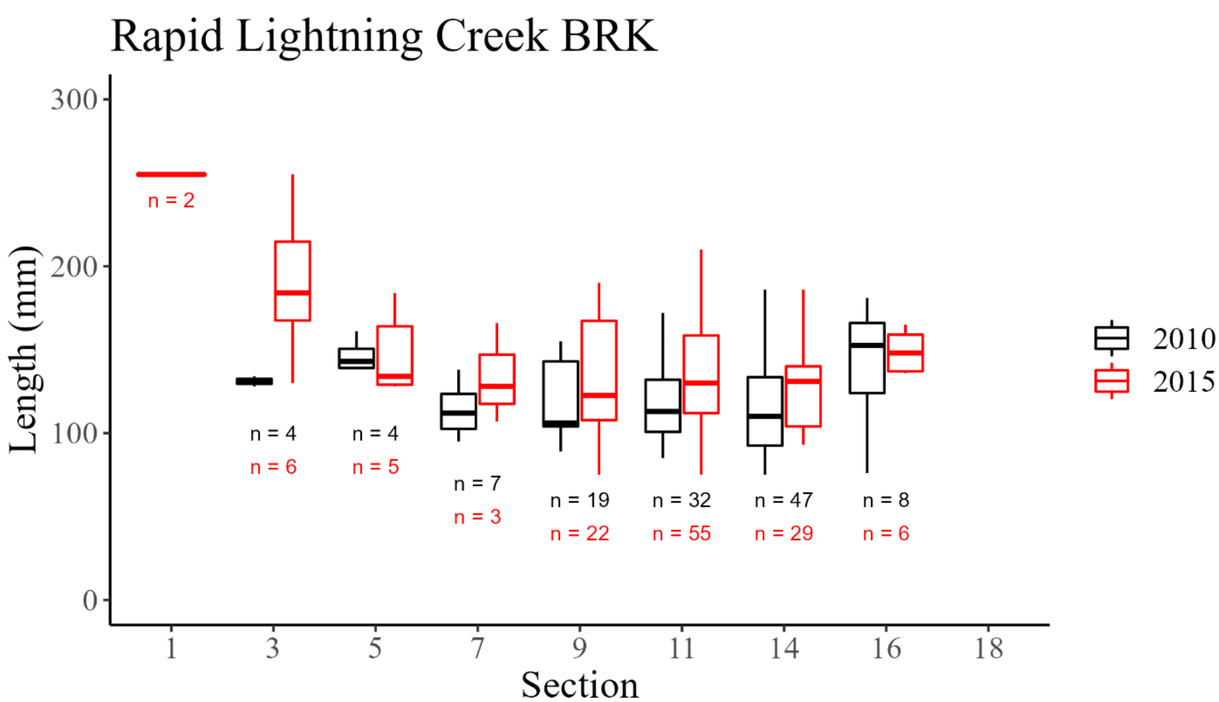


Figure 46. Length (mm) of Brook Trout captured in each section of Rapid Lightning Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

Lightning Creek Drainage

Char Creek

Char Creek is a tributary to the East Fork Lightning Creek and enters upstream of Savage Creek from the north. An extraordinary amount of WCT were documented in 2013, and densities in 2018 may be more representative of usual trends (Figure 47). While a decline in density was observed, average size of the remaining fish increased by approximately 50 mm. Otolith analysis in 2013 suggested resident fish are present (Figure 48). No other species have been documented in Char Creek, however a logjam barrier upstream of Section One has been present since 2008. Historically, there were more numerous observations of BLT spawners in Char Creek (15–20 redds counted annually; Jakubowski and Bouwens 2019), but they have declined in subsequent years.

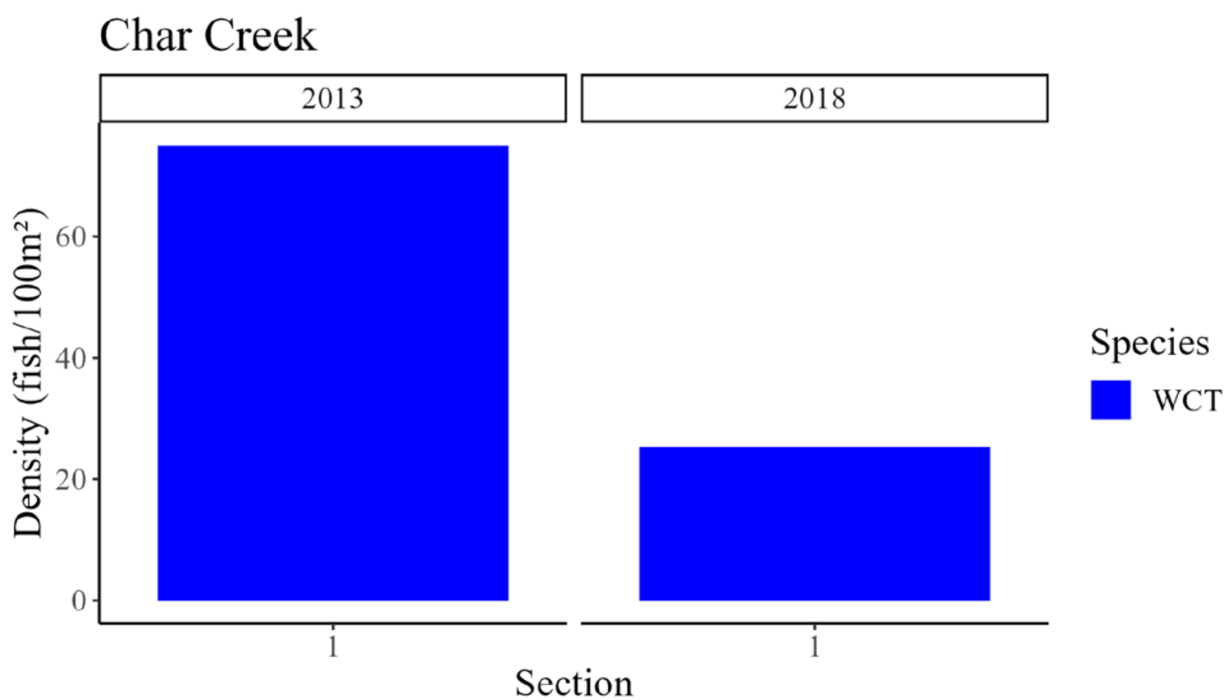


Figure 47. Fish densities for each shocking section in Char Creek. Species specific densities are identified by color (see legend).

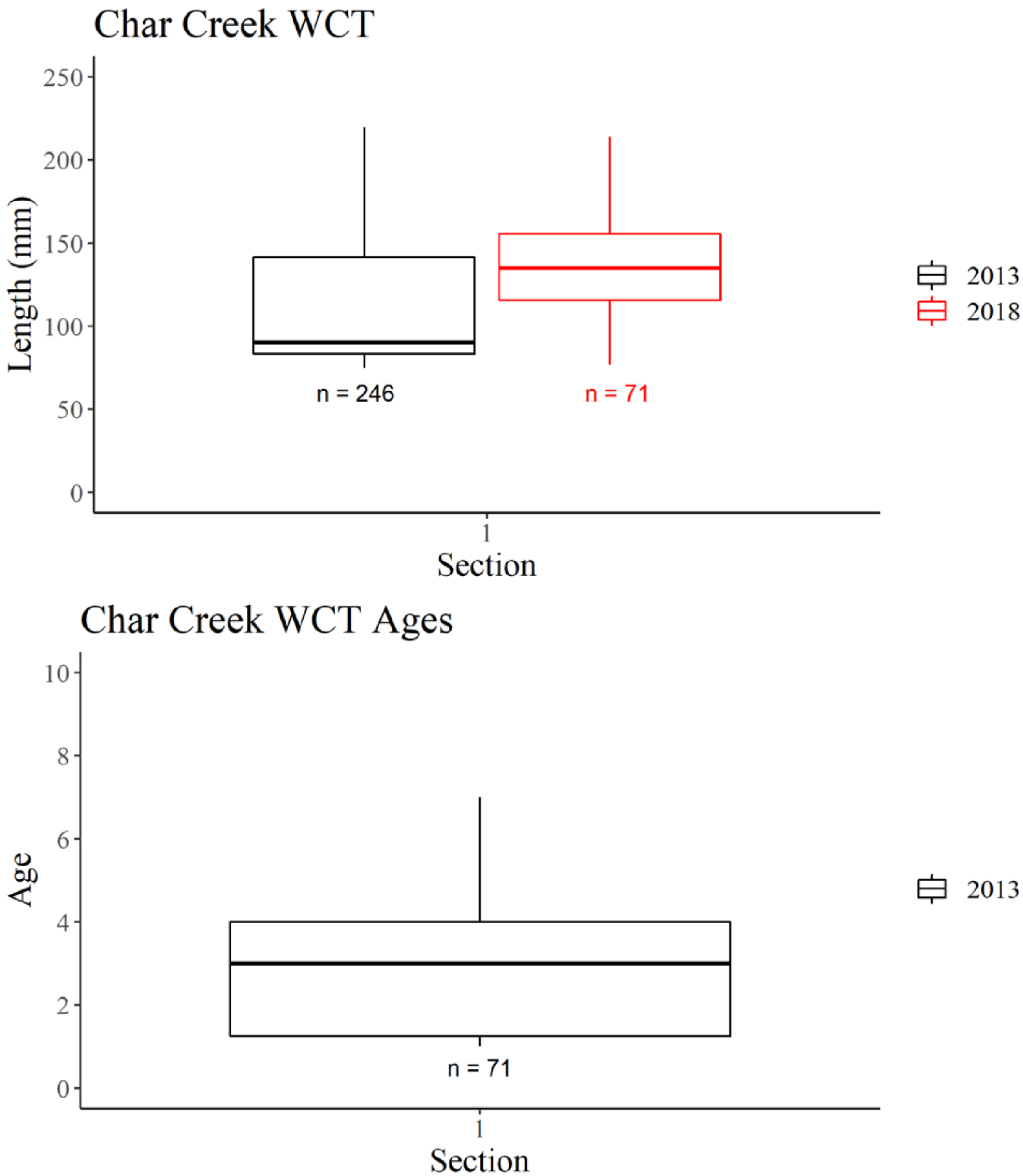


Figure 48. Length (mm; top panel) and age (years; lower panel) of Westslope Cutthroat Trout captured in each section of Char Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

East Fork Lightning Creek

The East Fork of Lightning Creek is the largest tributary to Lightning Creek, and it has a confluence upstream of Morris Creek on the eastern side of the mainstem. The East Fork has a broad species assemblage, with RBT becoming the most dominant during the second sample event (Figure 49). Bull Trout densities declined throughout the stream, however sizes of individuals greatly increased. The increase in density and decrease in size exhibited by RBT and decrease in density and increase in size of BLT may indicate the stream is operating near a biological carrying capacity. The reduction in BLT densities may be the result of a major rain-on-snow flood event in December of 2015 that likely caused high mortality of incubating BLT eggs. Westslope Cutthroat Trout are still the only species present in the uppermost section. Detailed capture data for WCT, RBT, and BLT are displayed in Figures 50, 51, and 52.

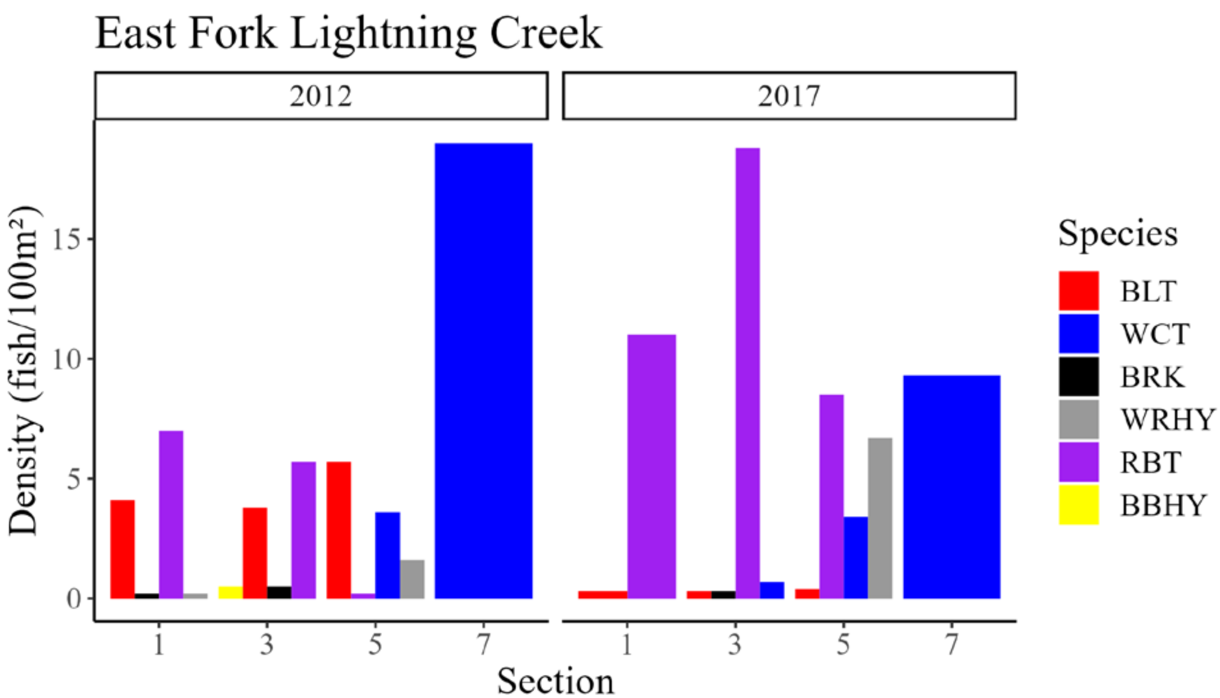


Figure 49. Fish densities for each shocking section in East Fork Lightning Creek. Species specific densities are identified by color (see legend).

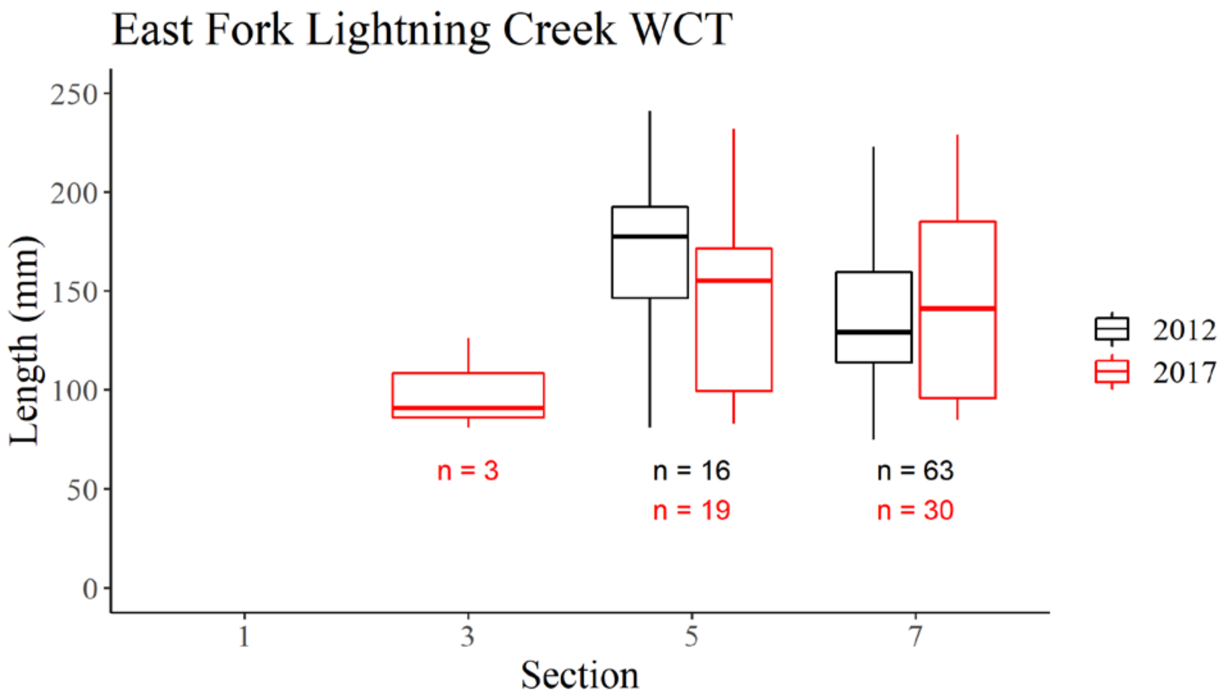


Figure 50. Length (mm) of Westslope Cutthroat Trout captured in each section of East Fork Lightning Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

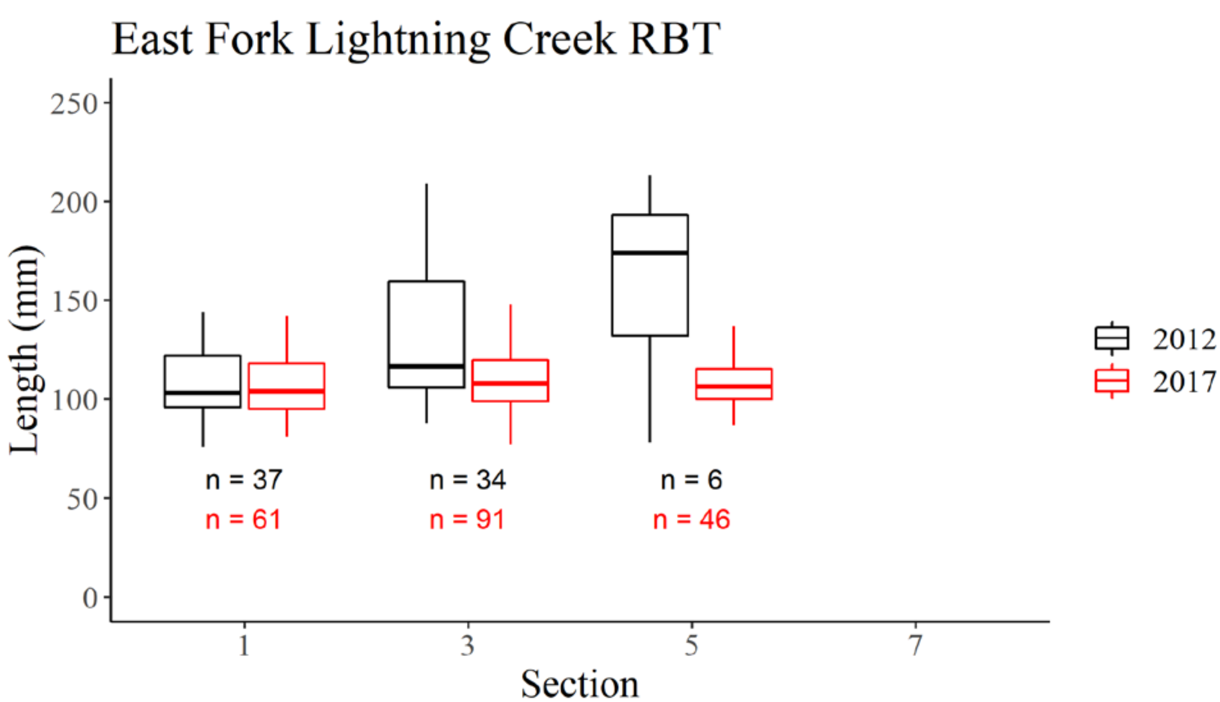


Figure 51. Length (mm) of Rainbow Trout captured in each section of East Fork Lightning Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

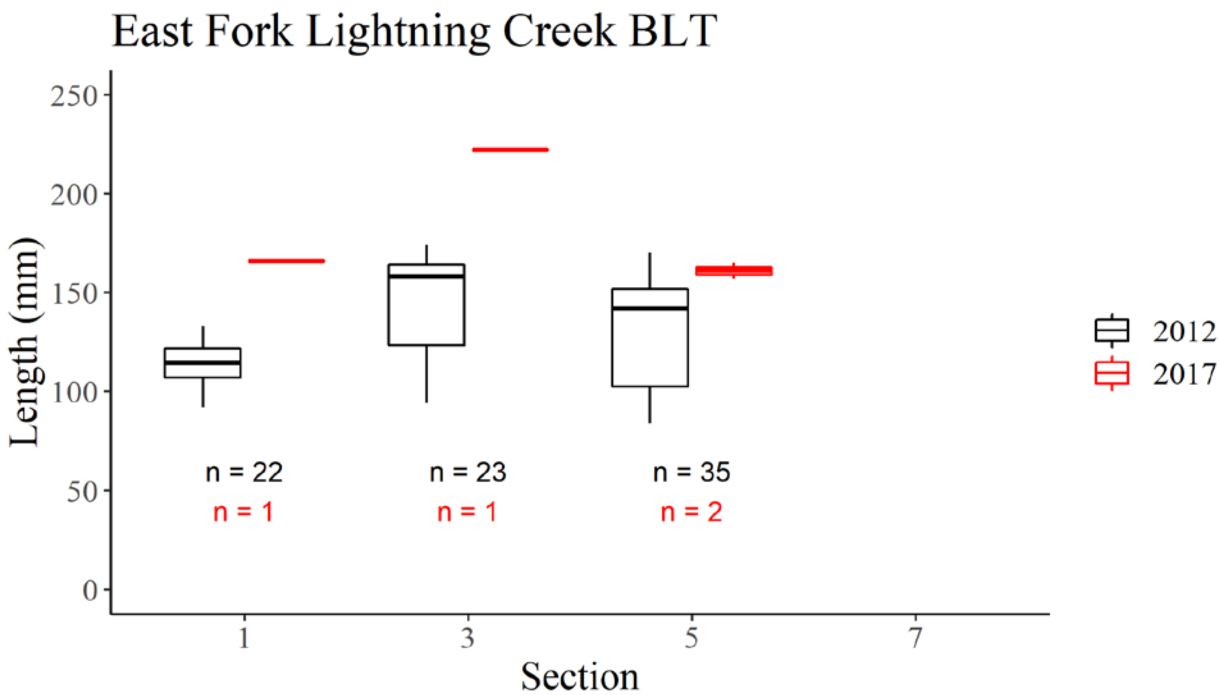


Figure 52. Length (mm) of Bull Trout captured in each section of East Fork Lightning Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

Morris Creek

Morris Creek is the first upstream tributary sampled in the Lightning Creek drainage, and it is located on the eastern side of the mainstem. This creek is the most downstream spawning tributary for BLT in the drainage. Both WCT and BLT dominate the species assemblage, however a reduction in BLT and increase in WCT was observed from 2011 to 2016 (Figure 53). Interestingly, no RBT have been observed but WRHY are present. This may indicate juvenile movement between tributaries, or a single RBT or WRHY migrated into Morris Creek and successfully spawned with a WCT. For the purposes of this study, the level of introgression is not reported (e.g., F1 or F2). A dry section at the mouth of Morris creek below Section One has been increasing in severity since sampling began and may explain the reduction in BLT densities if it now acts as a migration barrier to BLT. Redd counts in Morris Creek have also been declining in a similar pattern (Jakubowski and Bouwens 2019). Detailed capture data for WCT, and BLT are displayed in Figures 54 and 55.

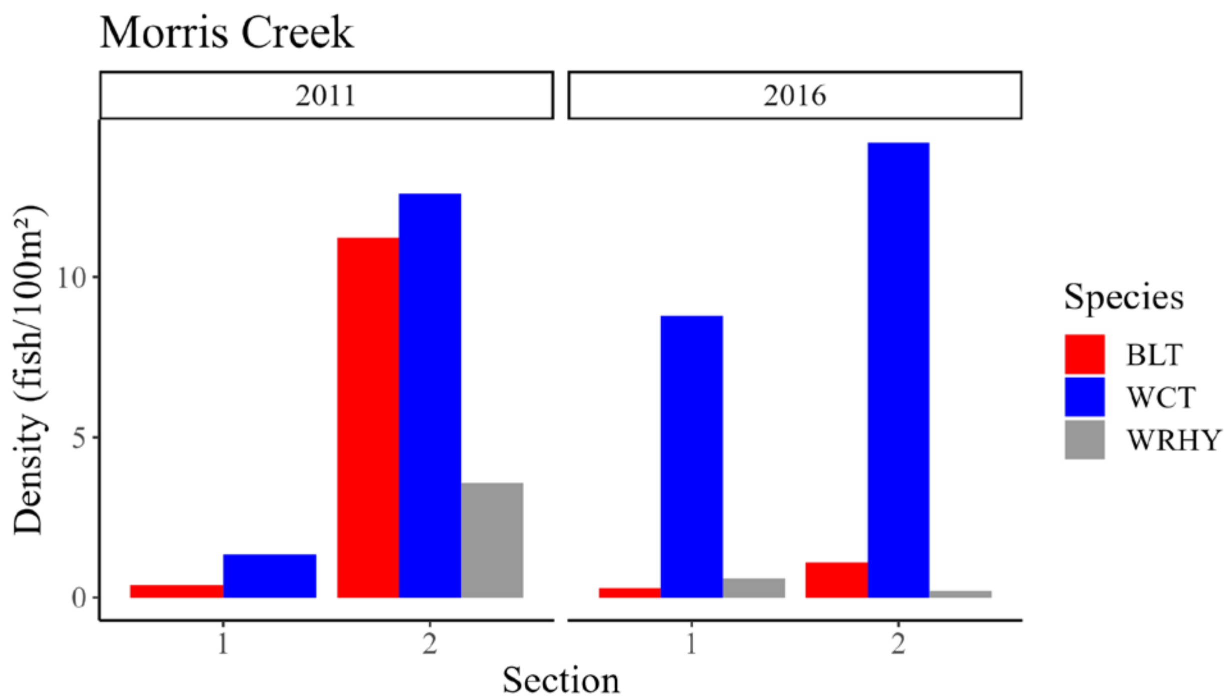
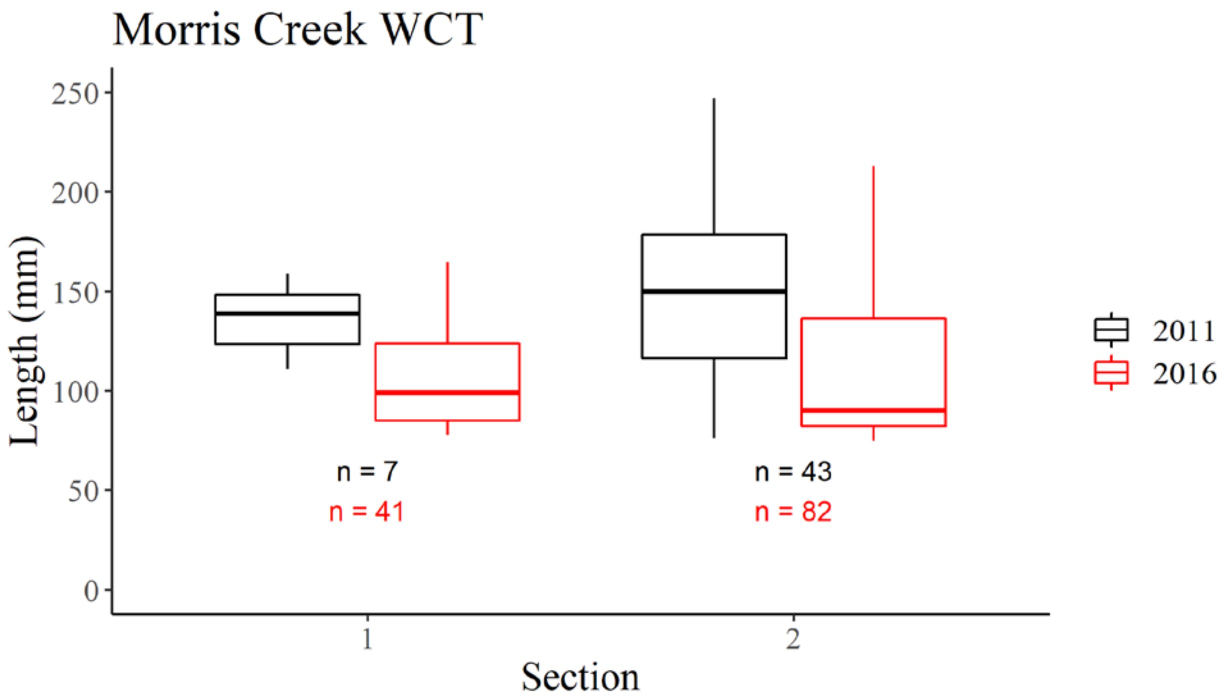


Figure 53. Fish densities for each shocking section in Morris Creek. Species specific densities are identified by color (see legend).



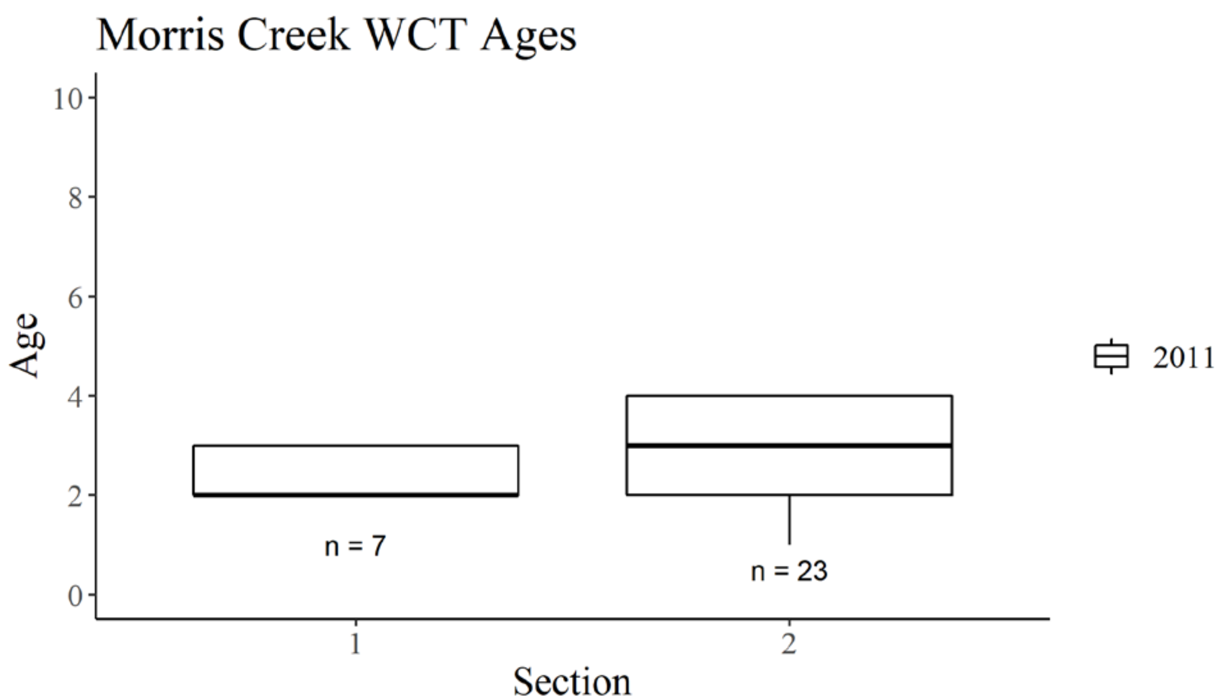


Figure 54. Length (mm; top panel) and age (years; lower panel) of Westslope Cutthroat Trout captured in each section of Morris Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

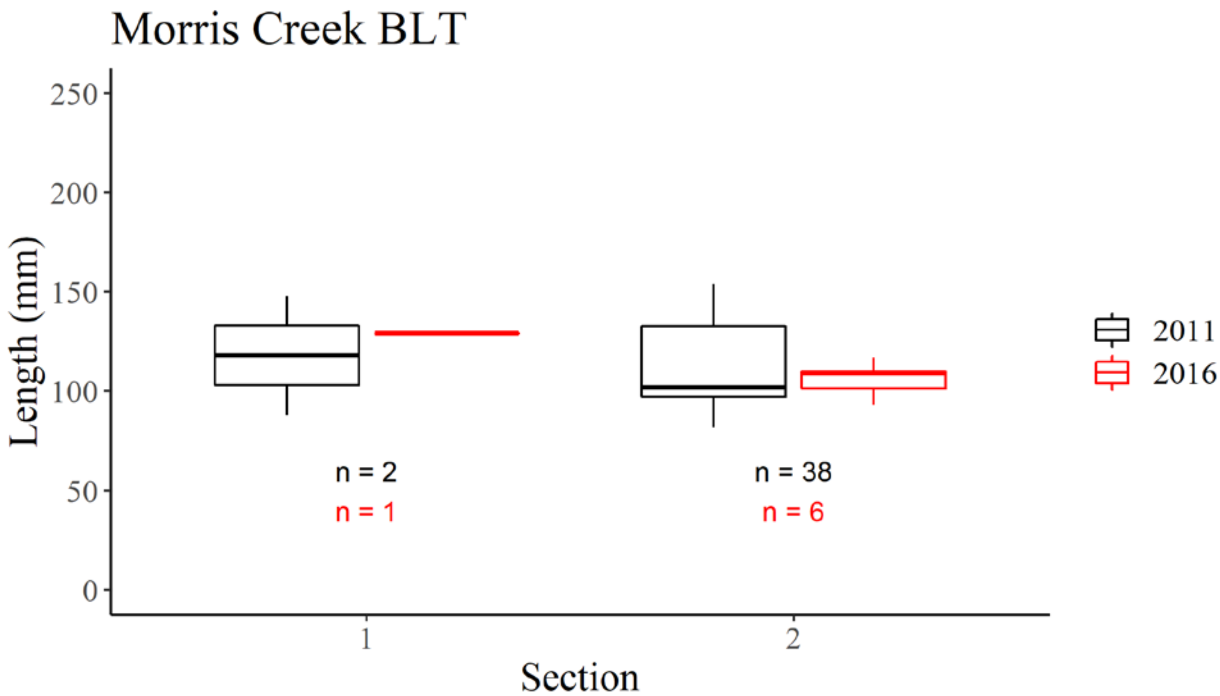


Figure 55. Length (mm) of Bull Trout captured in each section of Morris Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

Porcupine Creek

Porcupine Creek is the first sample tributary on the western side of Lightning Creek and is located above the confluence with East Fork Lightning Creek. A series of bedrock falls act as a barrier to upstream migration between sections four and five, and only BRK are present above it (Figure 56). Porcupine Lake is located at the top of the stream, and it was historically the source population for BRK in the system. The lake was treated with rotenone in 2010 to eliminate BRK; however, BRK in Porcupine Creek do not appear to have been affected by this action. WCT and BLT are present in downstream reaches, and RBT were first documented in the 2017 sample event. Detailed capture data for WCT, RBT, BLT, and BRK are displayed in Figures 57, 58, 59, and 60.

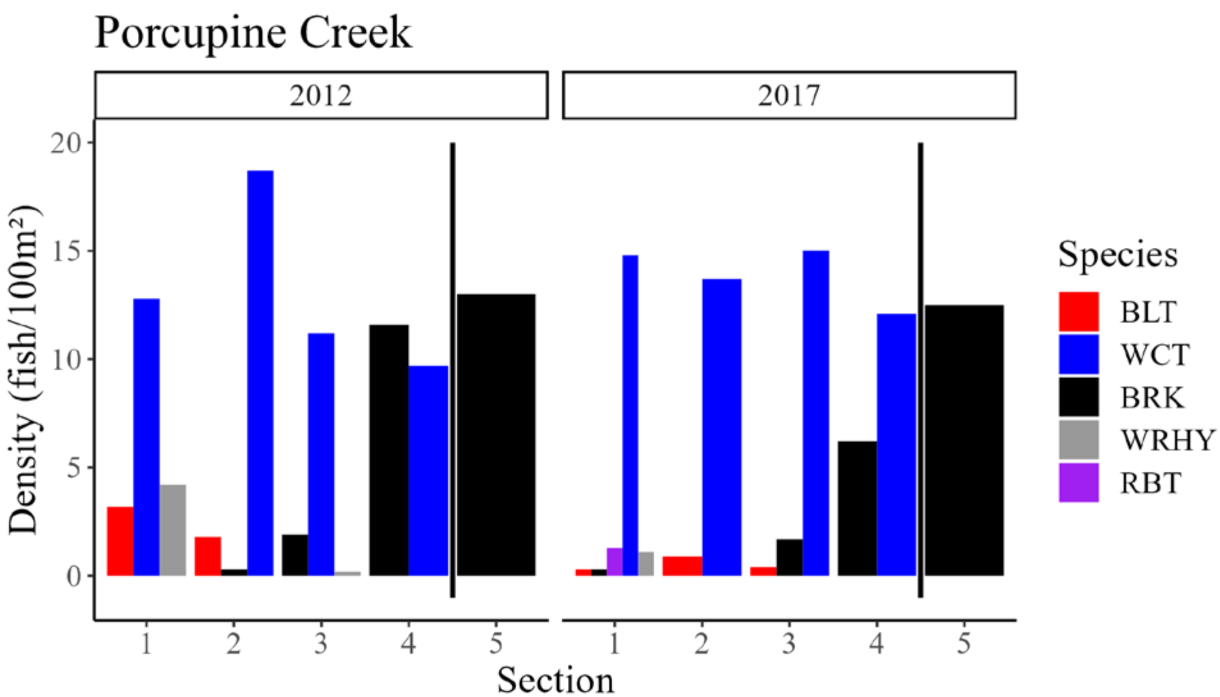


Figure 56. Fish densities for each shocking section in Porcupine Creek. Species specific densities are identified by color (see legend). The location of a barrier to upstream migration is identified with a tall black line.

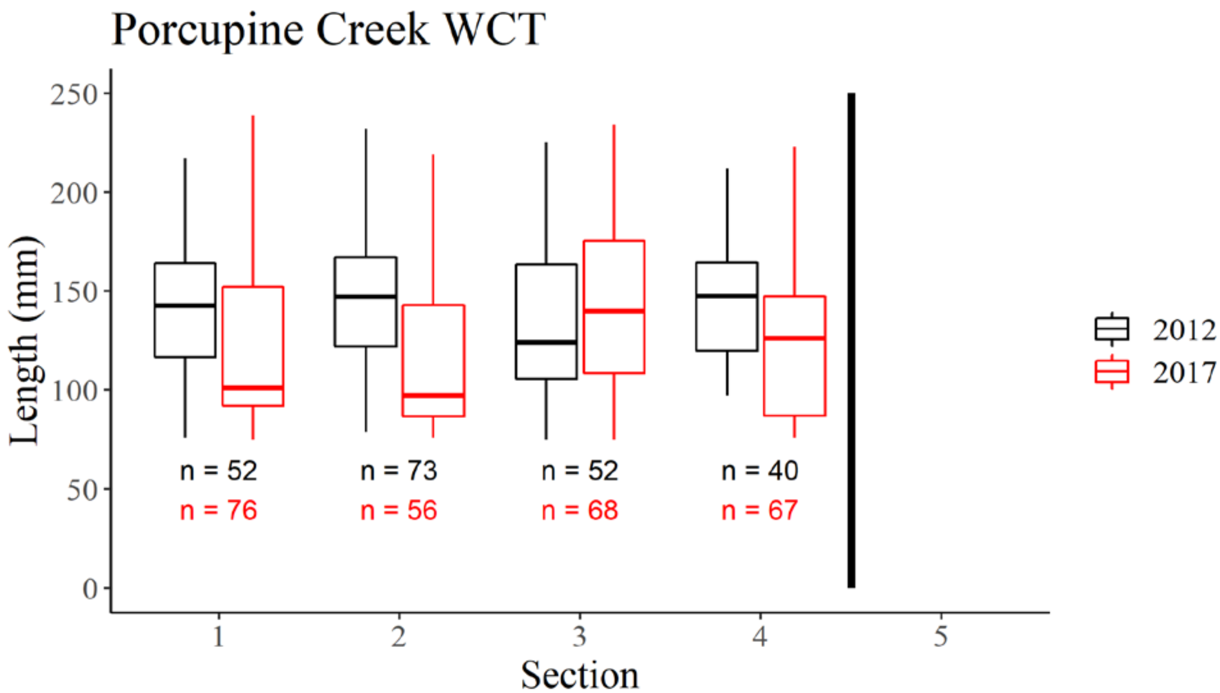


Figure 57. Length (mm) of Westslope Cutthroat Trout captured in each section of North Fork Grouse Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

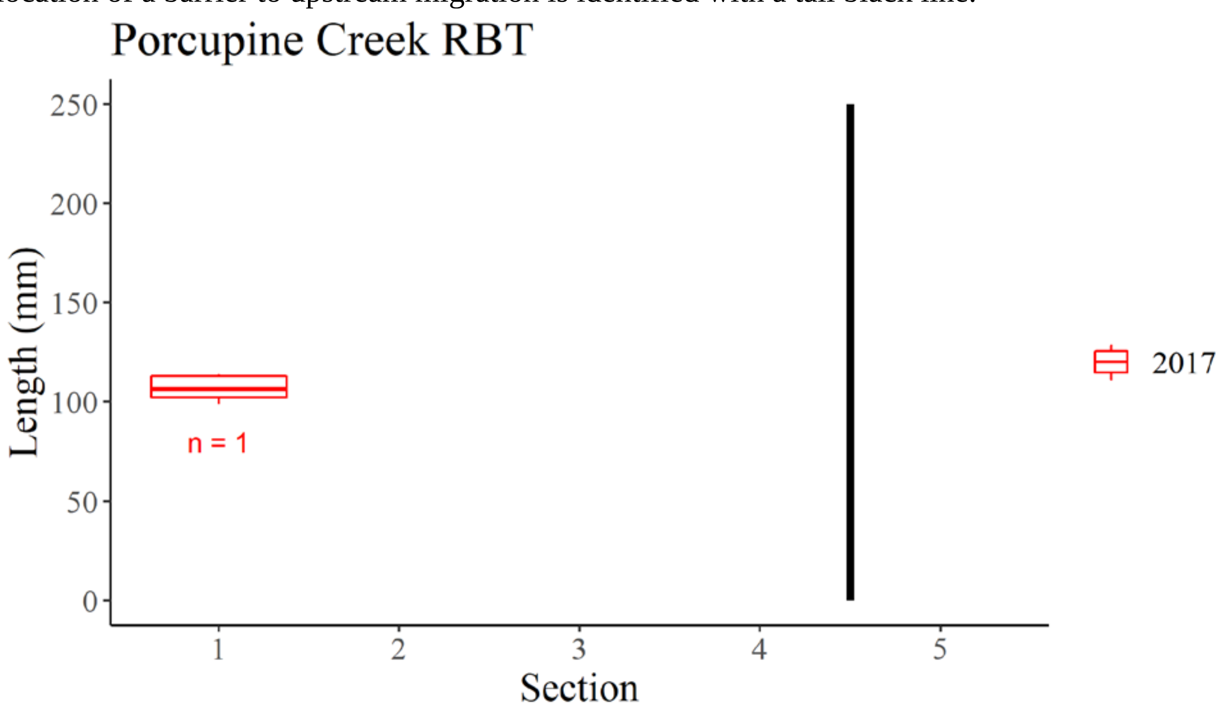


Figure 58. Length (mm) of Rainbow Trout captured in each section of Porcupine Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

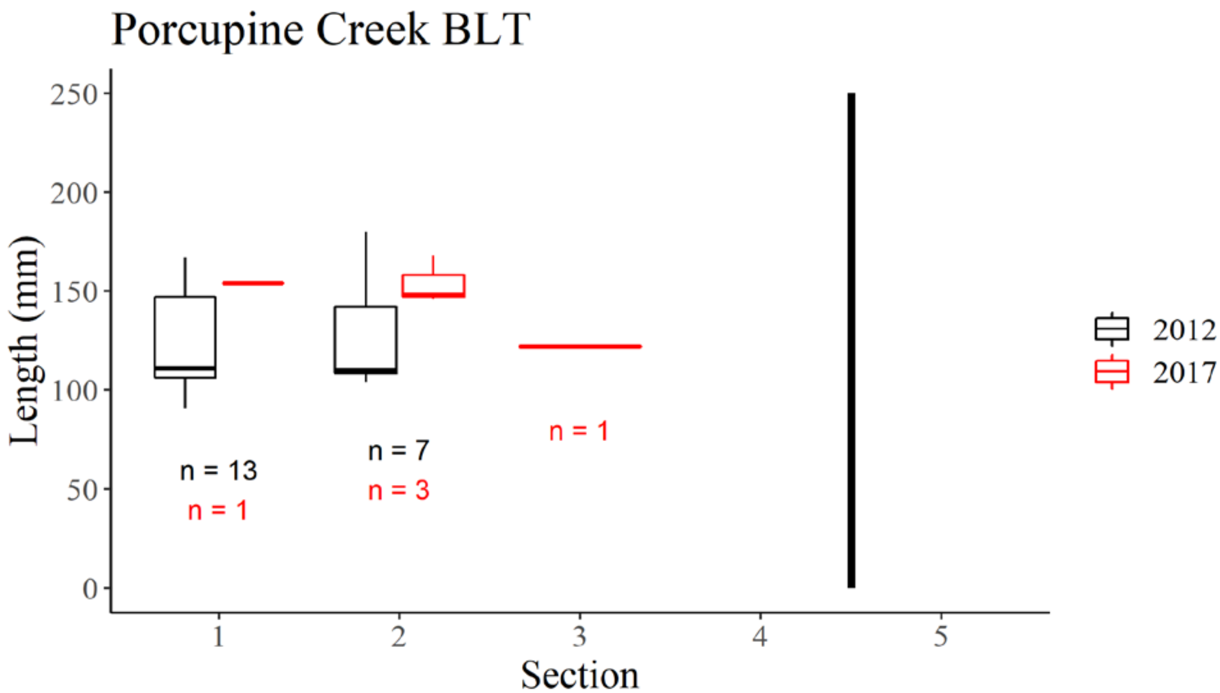


Figure 59. Length (mm) of Bull Trout captured in each section of Porcupine Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

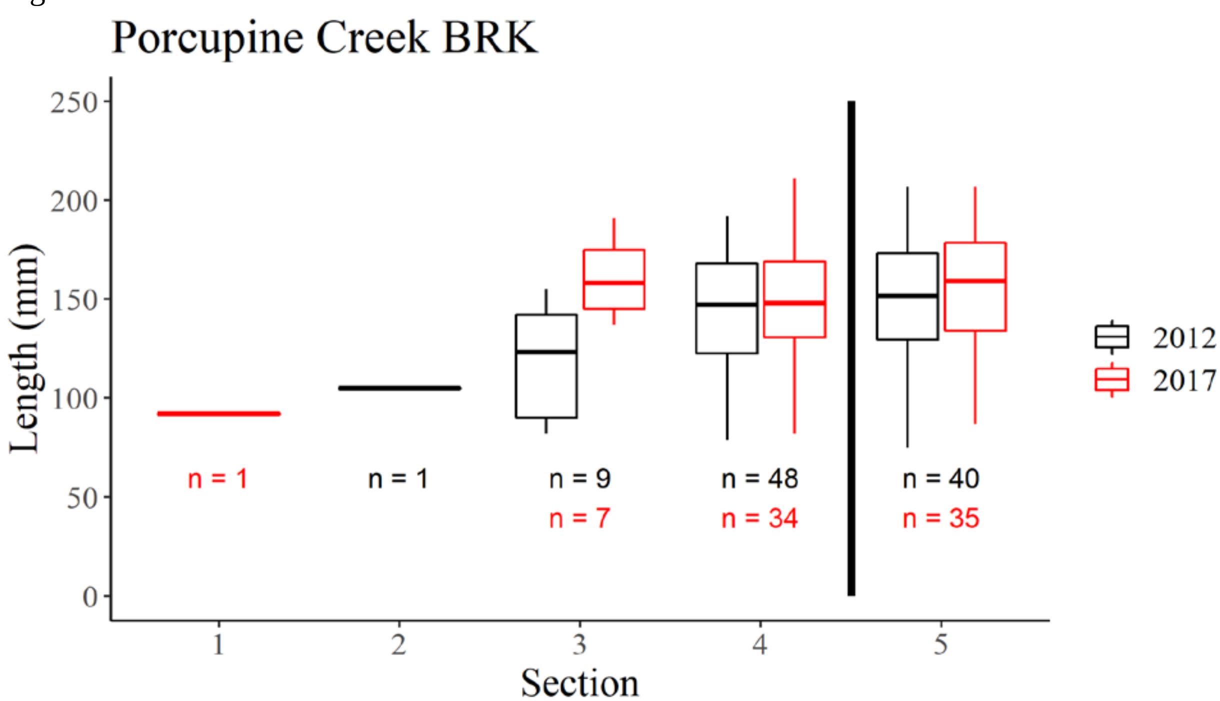


Figure 60. Length (mm) of Brook Trout captured in each section of Porcupine Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

Rattle Creek

Rattle Creek is the furthest upstream sample tributary on the eastern side of Lightning Creek. While still dominated by WCT and BLT, there was a decline in BLT densities during the second sample event (Figure 61). However, lengths of individual BLT increased, suggesting they may be subject to density-dependent factors (Figure 64). Rainbow Trout were consistently present in downstream reaches in low densities. A waterfall barrier exists between sections five and seven, and it is likely that section seven will remain a stronghold for genetically pure WCT. Additionally, increasingly long sections of the creek flow sub-surface after runoff occurs and may present a barrier to migration for adfluvial BLT. Large rain-on-snow flood events have also removed much of the woody debris in the stream. As a result, small to medium substrate ideal for salmonid reproduction is removed from the system during periods of high flow. We hypothesize that these habitat conditions are negatively impacting juvenile BLT densities and redd counts (Jakubowski and Bouwens 2019). Detailed capture data for WCT, RBT, and BLT are displayed in Figures 62, 63, and 64.

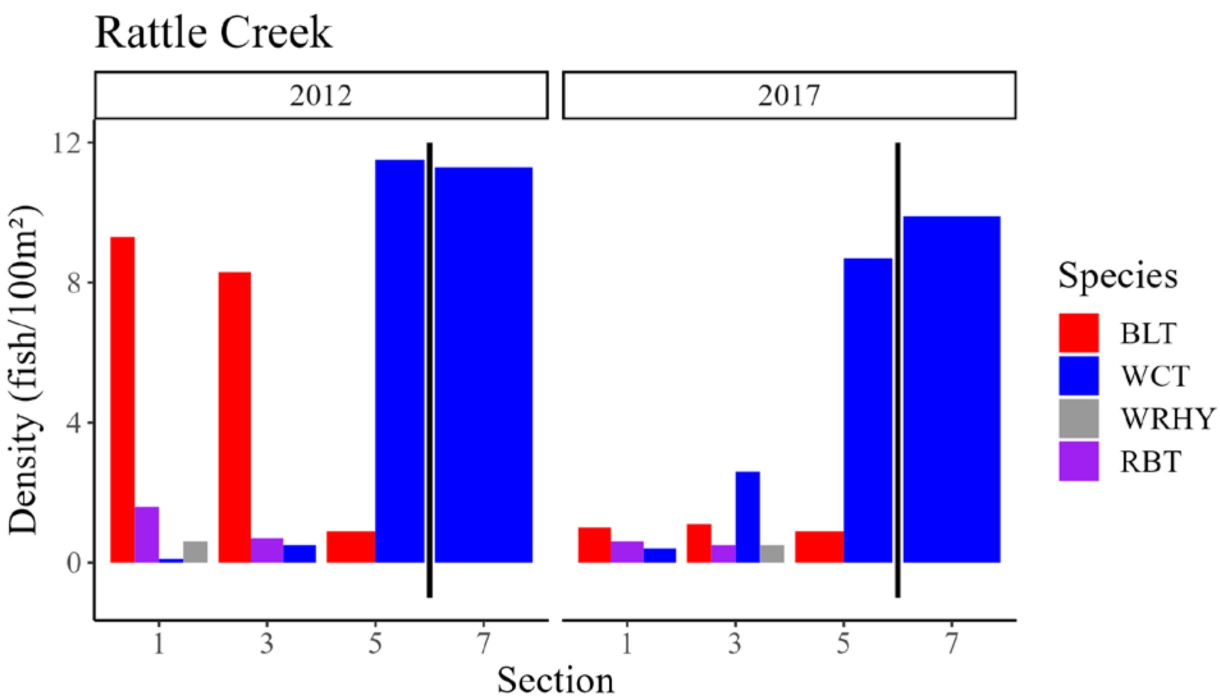


Figure 61. Fish densities for each shocking section in Rattle Creek. Species specific densities are identified by color (see legend). The location of a barrier to upstream migration is identified with a tall black line.

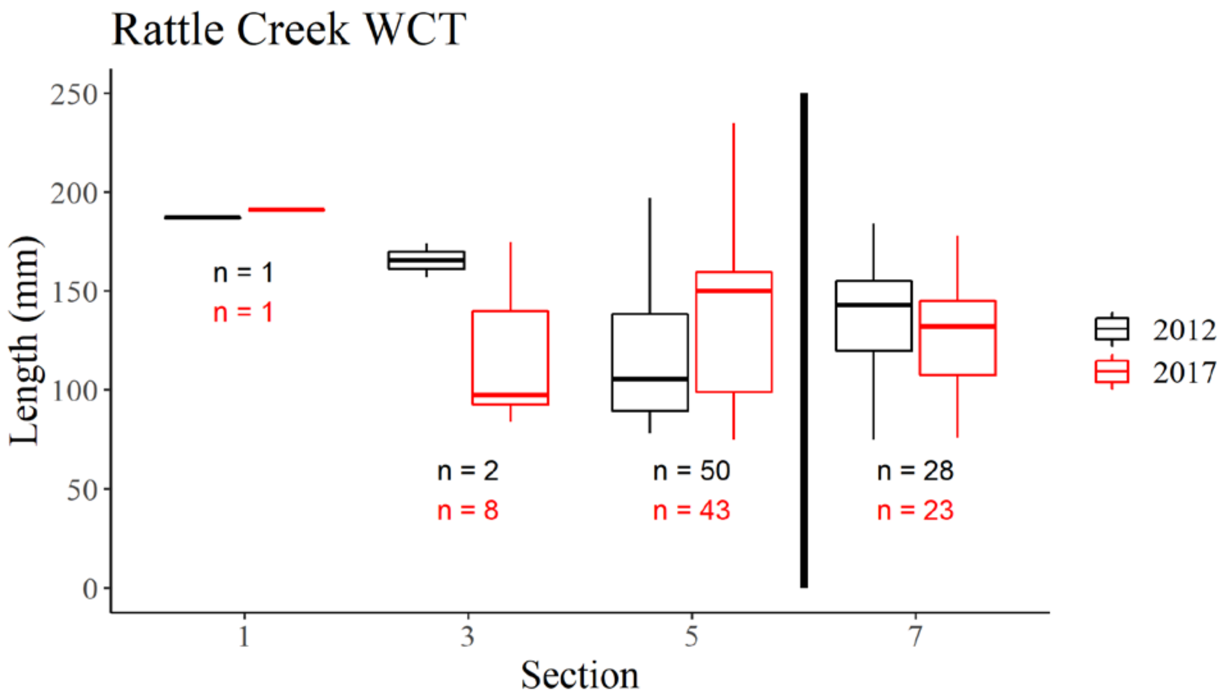


Figure 62. Length (mm) of Westslope Cutthroat Trout captured in each section of Rattle Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

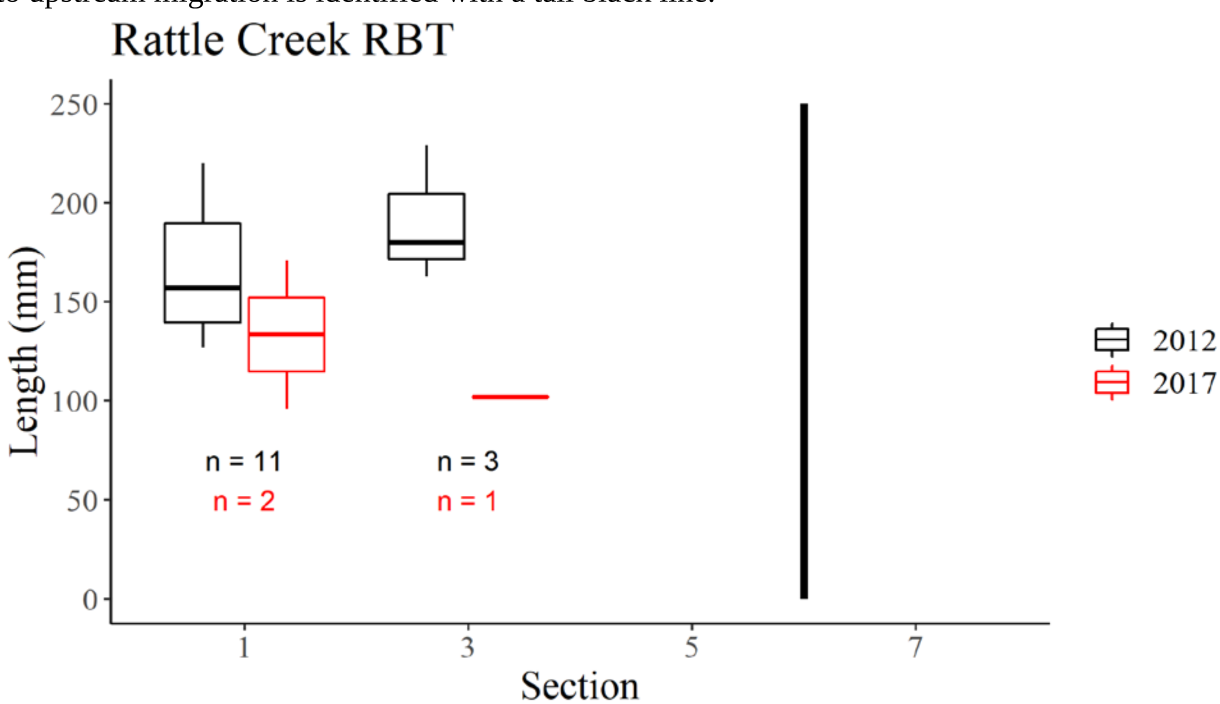


Figure 63. Length (mm) of Rainbow Trout captured in each section of Rattle Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

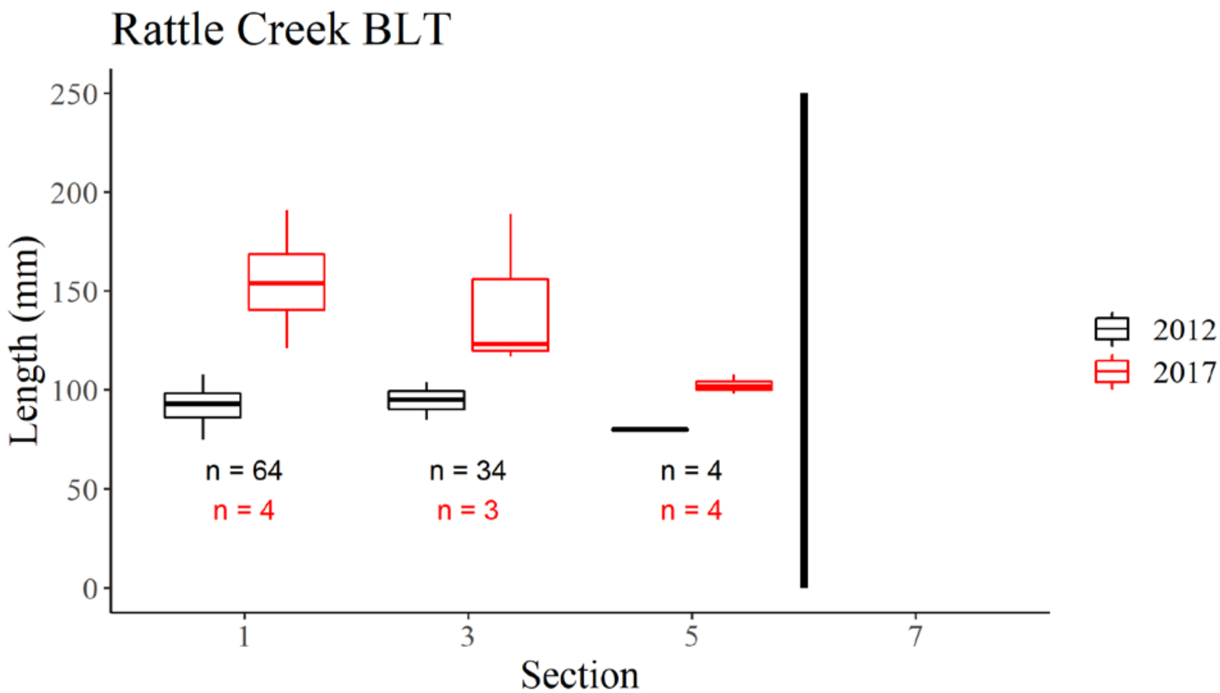


Figure 64. Length (mm) of Bull Trout captured in each section of Rattle Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

Savage Creek

Savage Creek is a tributary to East Fork Lightning Creek and enters downstream of Char Creek on the southern side. Savage Creek exhibits similar trends to others in the Lightning Creek drainage (Figure 65). Westslope Cutthroat Trout are now the dominant species and increased in abundance during the second sample event. Interestingly, higher densities of WRHY are present compared to RBT. Detailed capture data for WCT, RBT, and BLT are displayed in Figures 66, 67, and 68.

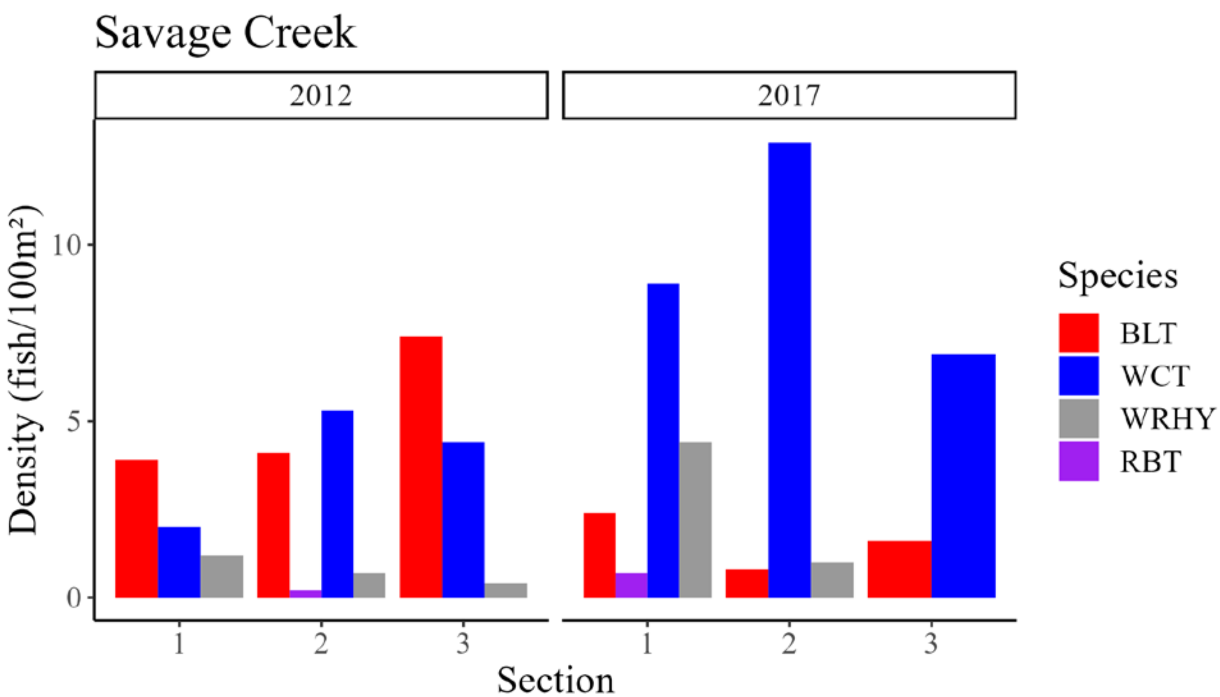


Figure 65. Fish densities (fish per 100m^2) for each shocking section in Savage Creek. Species specific densities are identified by color (see legend).

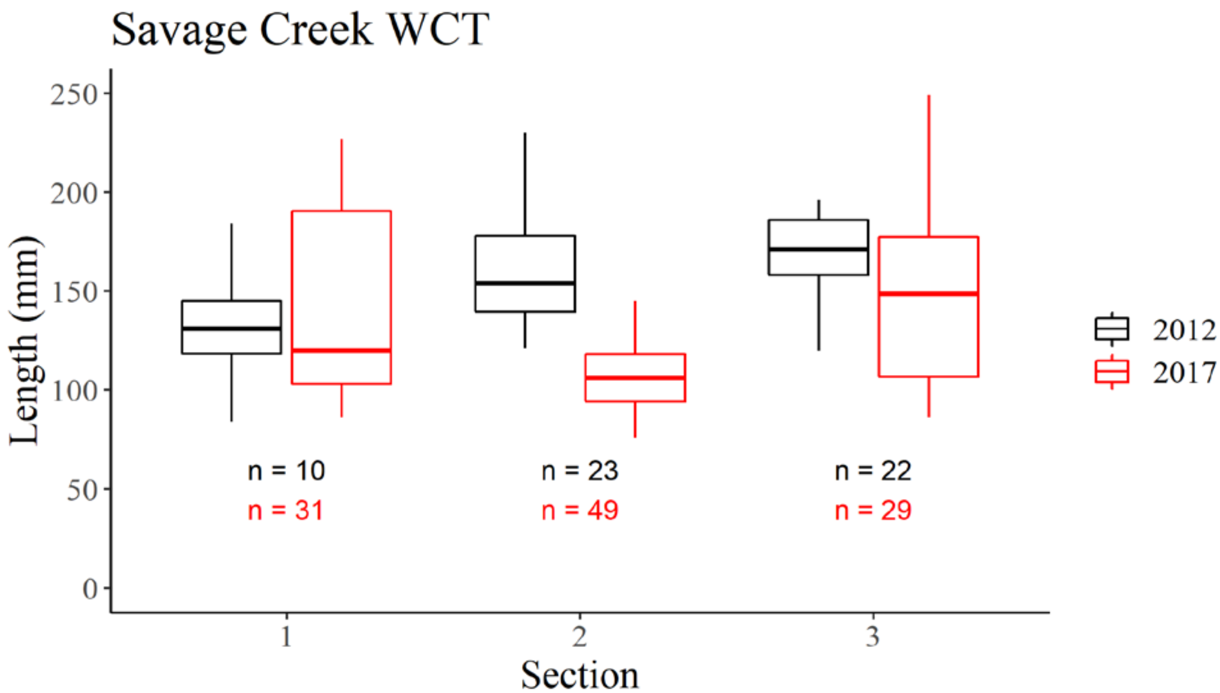


Figure 66. Length (mm) of Westslope Cutthroat Trout captured in each section of Savage Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

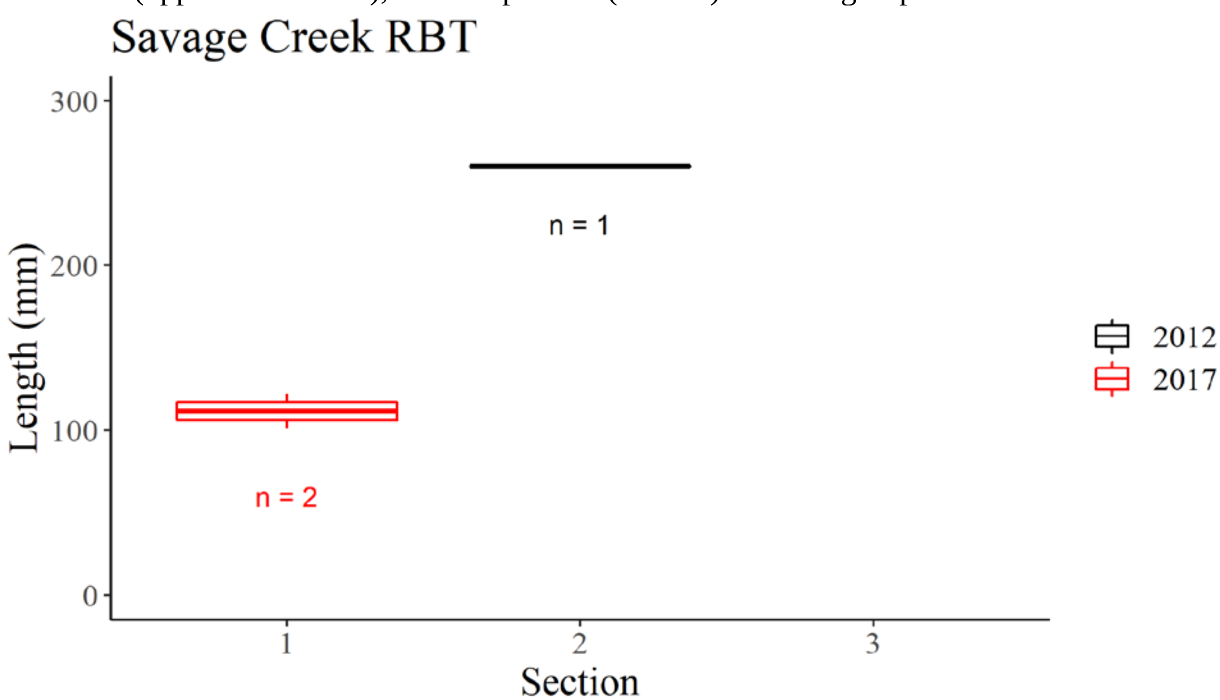


Figure 67. Length (mm) of Rainbow Trout captured in each section of Savage Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

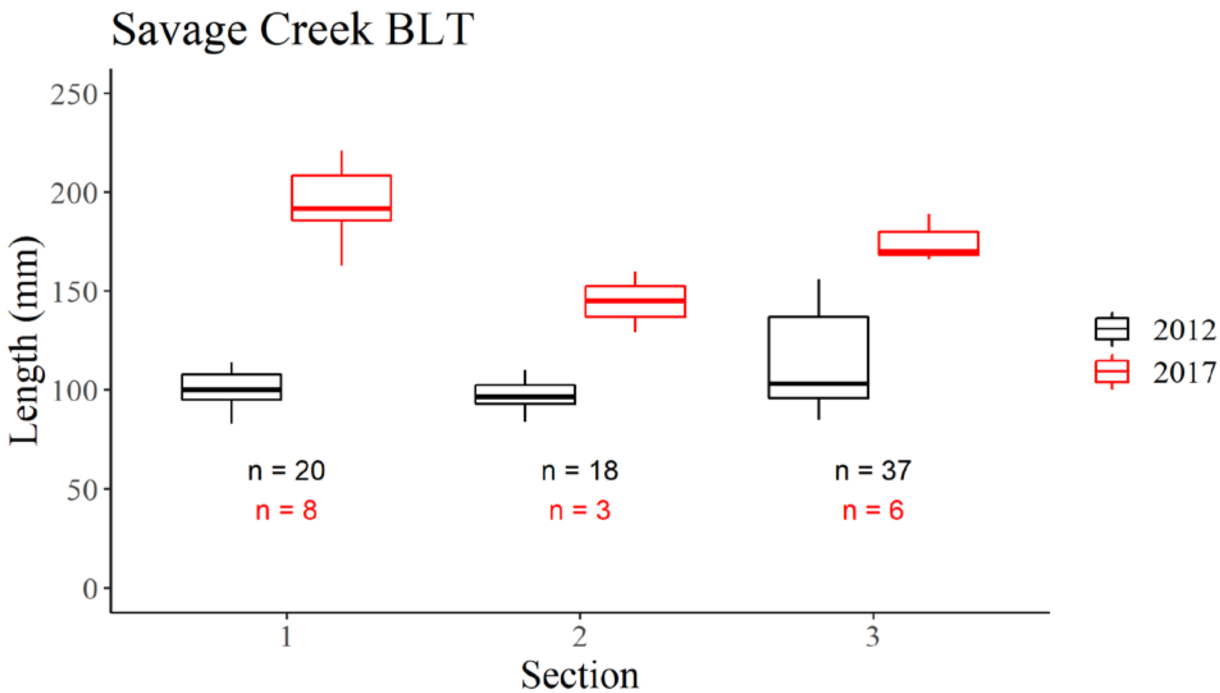


Figure 68. Length (mm) of Bull Trout captured in each section of Savage Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

Spring Creek

Spring Creek is a low elevation tributary to Lightning Creek and enters the mainstem roughly a kilometer upstream of the Clark Fork River. The Clark Fork Hatchery was operational on Spring Creek until the mid-1990s, and infectious pancreatic necrosis virus (IPN) was documented in the hatchery as early as 1979. This virus can cause mortality in young salmonids in aquaculture settings, but may have less of an impact on wild populations. Fish were recently sampled for prevalence of IPN and it was predominantly found in BRK, which is the dominant species present in the stream (Bouwens et al. 2019b). However, removal efforts between 2013 and 2018 (Bouwens et al. 2019b) drastically lowered densities (Figure 69). Brown Trout and RBT are also present in low densities, and redds from both species have been documented (Jakubowski, unpublished data). Detailed capture data for WCT, RBT, and BRK are displayed in Figures 70, 71, and 72.

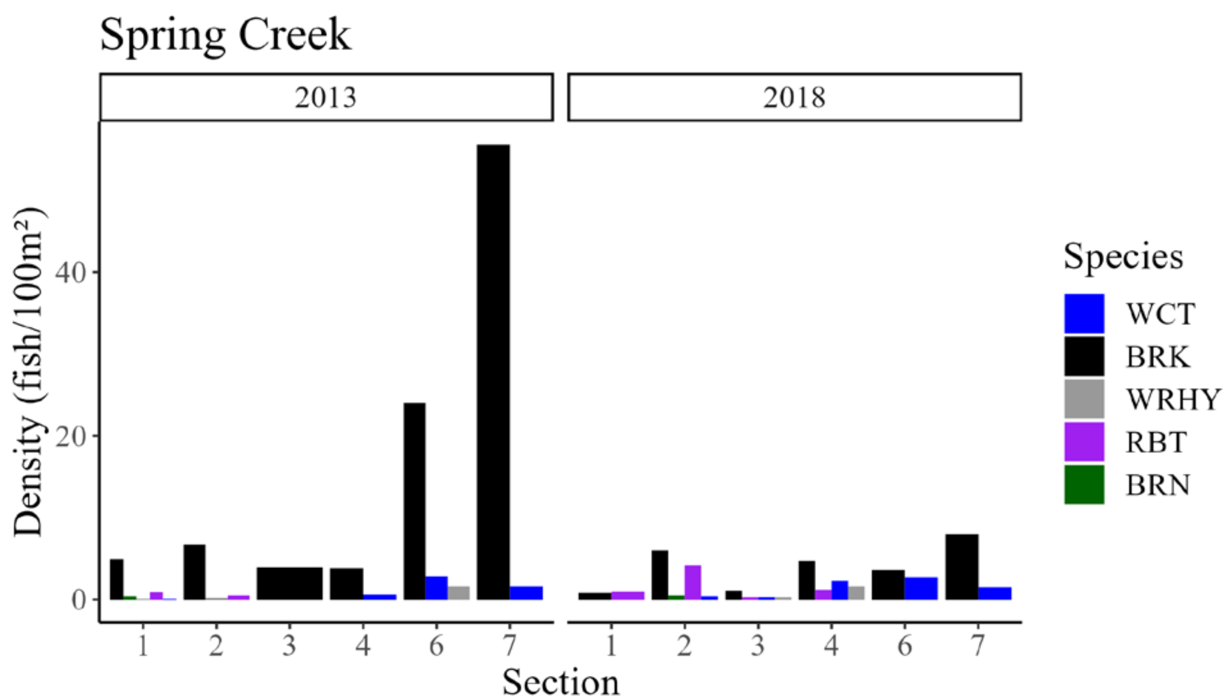


Figure 69. Fish densities (fish per $100m^2$) for each shocking section in Spring Creek. Species specific densities are identified by color (see legend).

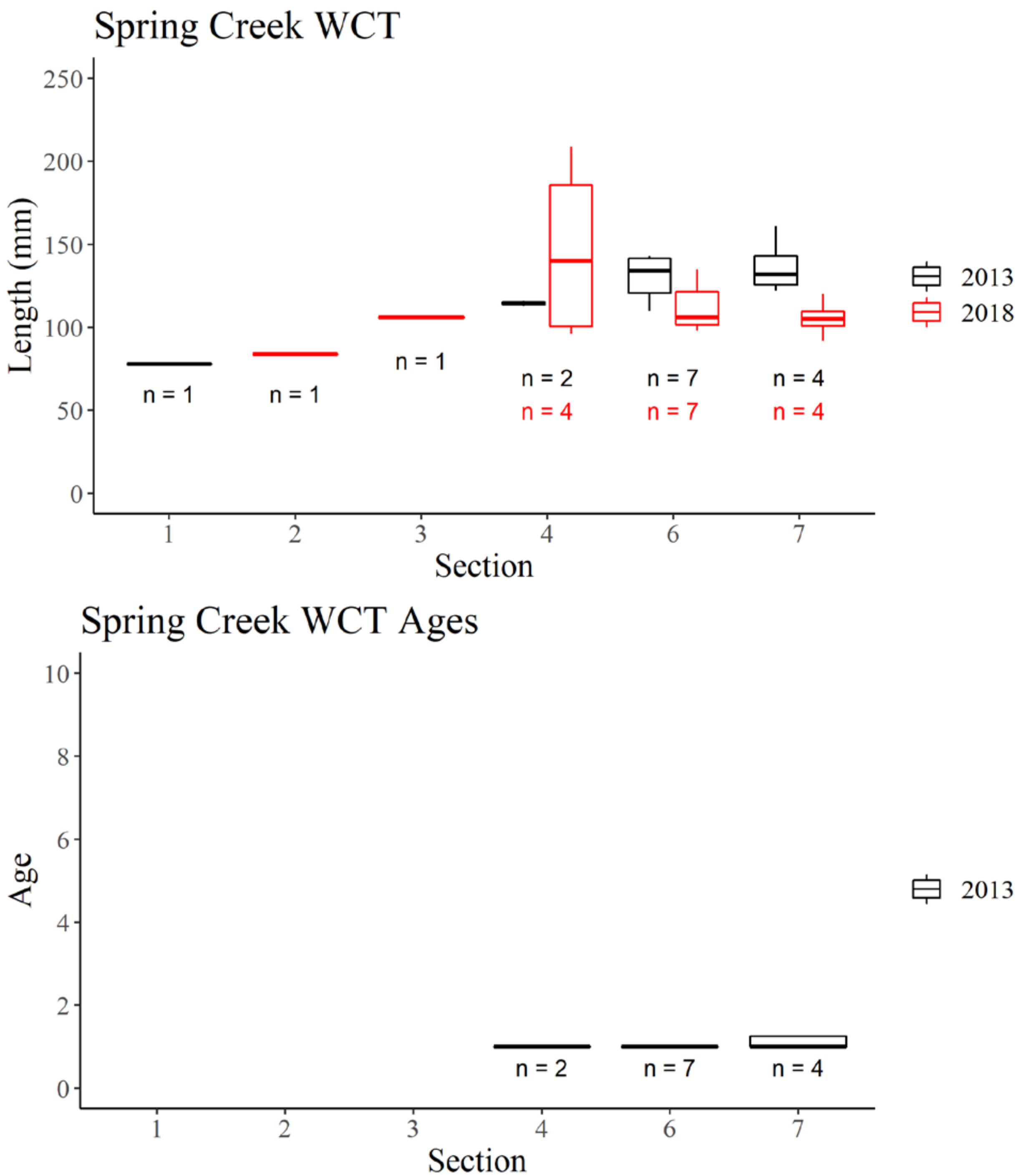


Figure 70. Length (mm; top panel) and age (years; lower panel) of Westslope Cutthroat Trout captured in each section of Spring Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

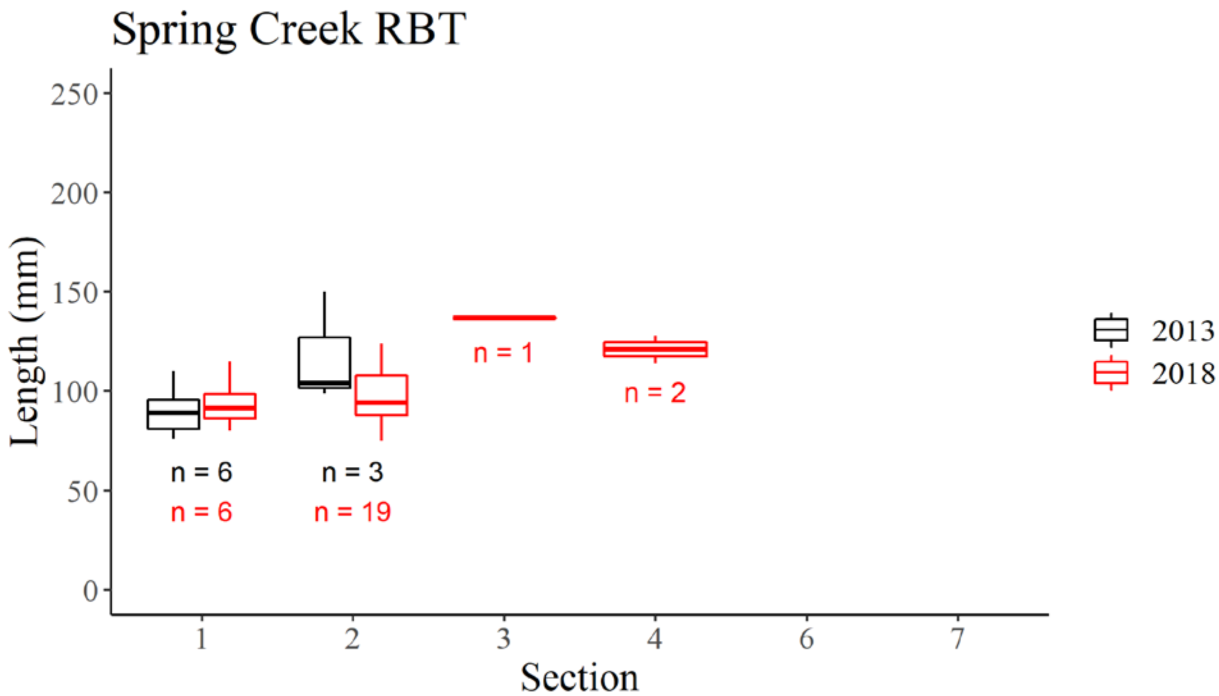


Figure 71. Length (mm) of Rainbow Trout captured in each section of Spring Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

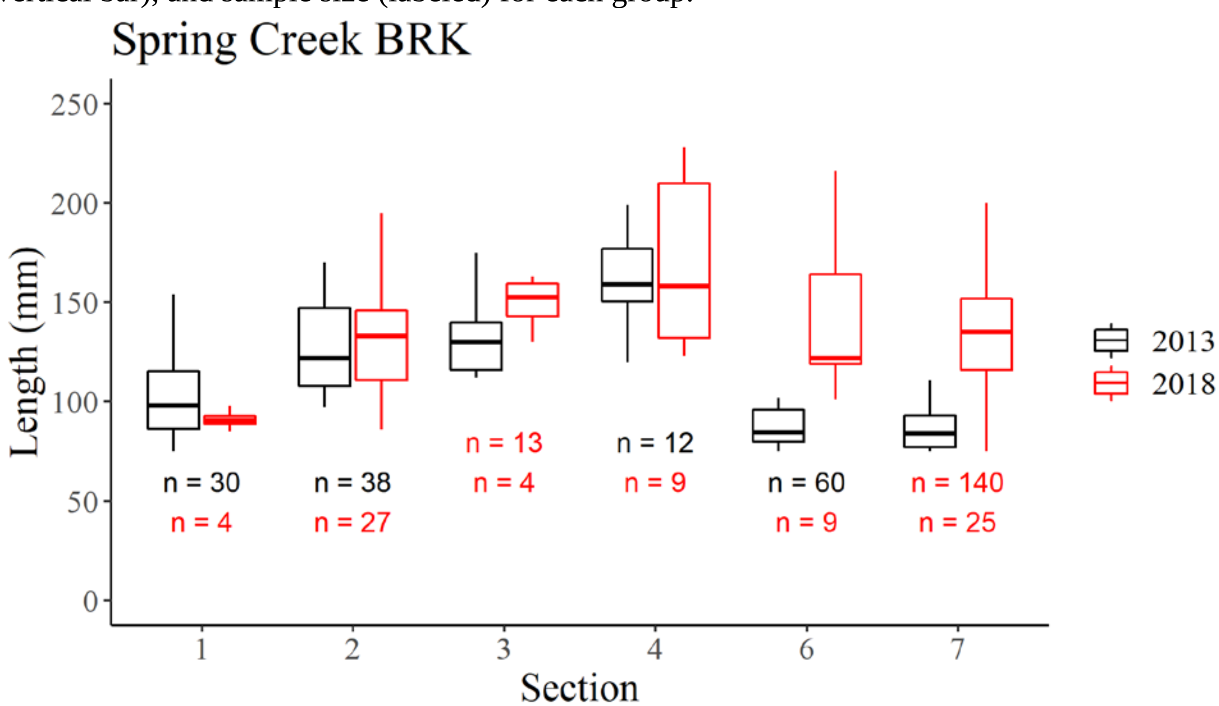


Figure 72. Length (mm) of Brook Trout captured in each section of Spring Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

Wellington Creek

Wellington Creek is a tributary to Lightning Creek and is located north of Porcupine Creek on the western side of the mainstem. A large waterfall barrier exists between sections one and three, with WCT being the only species present above. Migratory BLT, WCT, and RBT are present below the waterfall; however, a log jam at the mouth of the stream may be impacting access by fall spawning fish (Figure 73). A decrease in BLT abundance and redds was observed from 2012 to 2017 (Jakubowski and Bouwens 2019), but spring spawning WCT and RBT exhibited an increase (Figure 73). Brook Trout were not observed during the second sample event. Detailed capture data for WCT, RBT, and BLT are displayed in Figures 74, 75, and 76.

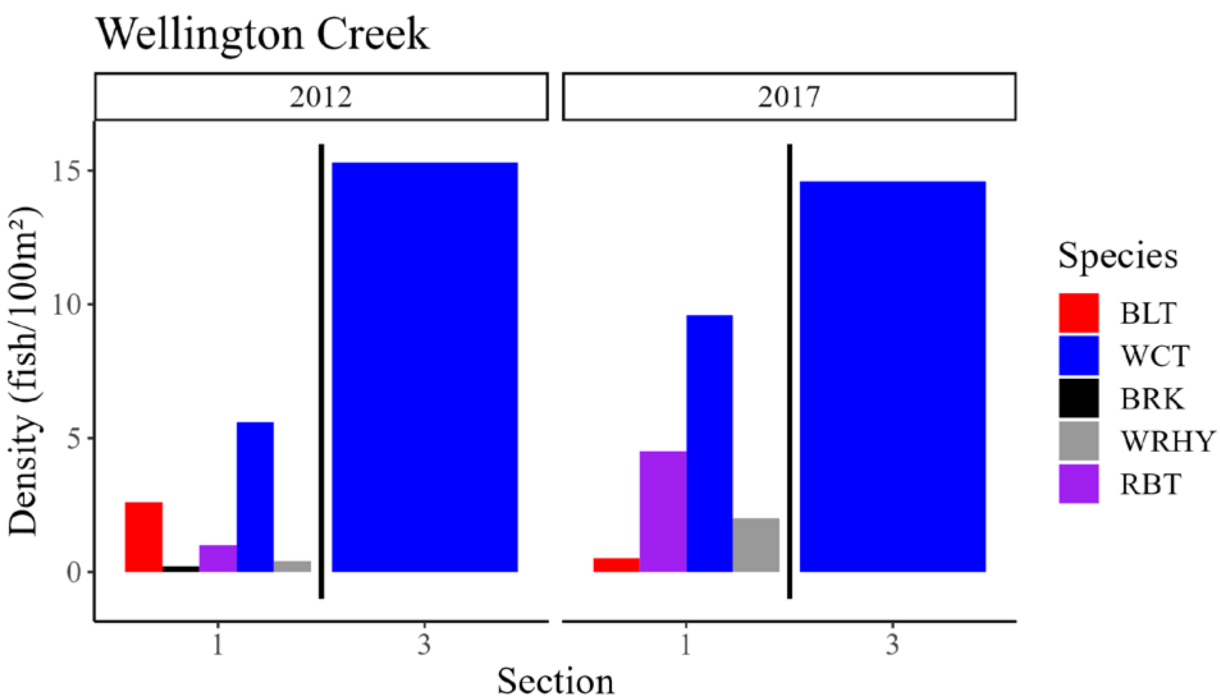


Figure 73. Fish densities (fish per $100m^2$) for each shocking section in Wellington Creek. Species specific densities are identified by color (see legend). The location of a barrier to upstream migration is identified with a tall black line.

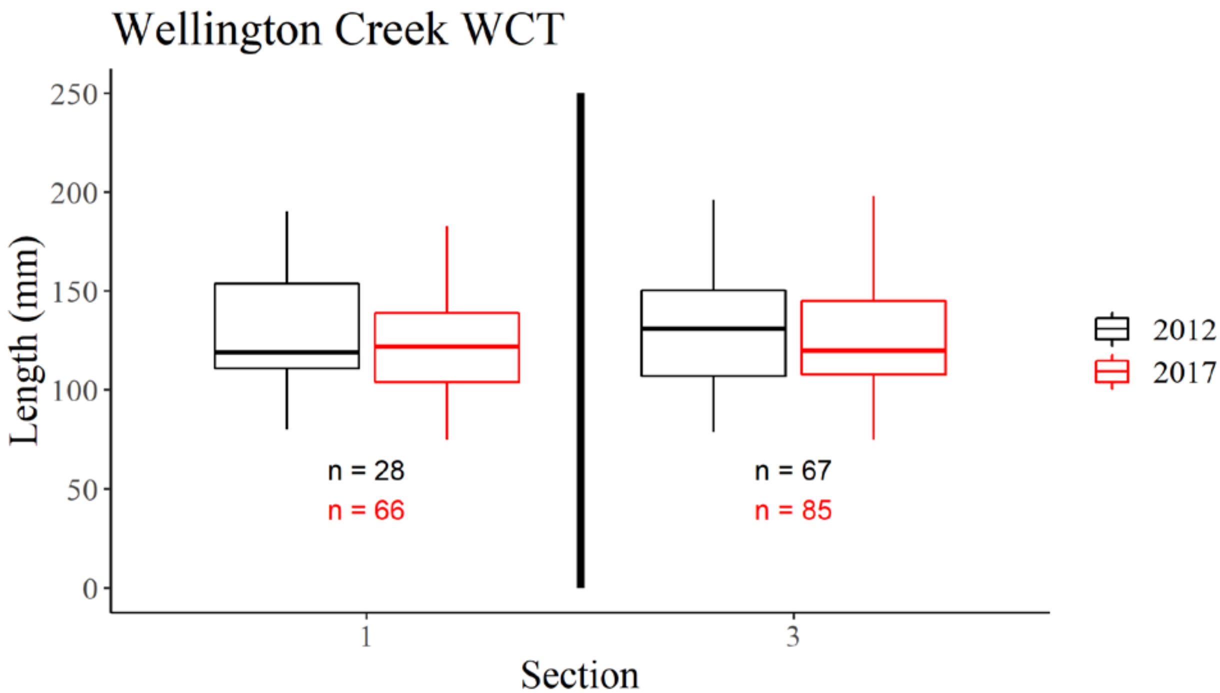


Figure 74. Length (mm) of Westslope Cutthroat Trout captured in each section of Wellington Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

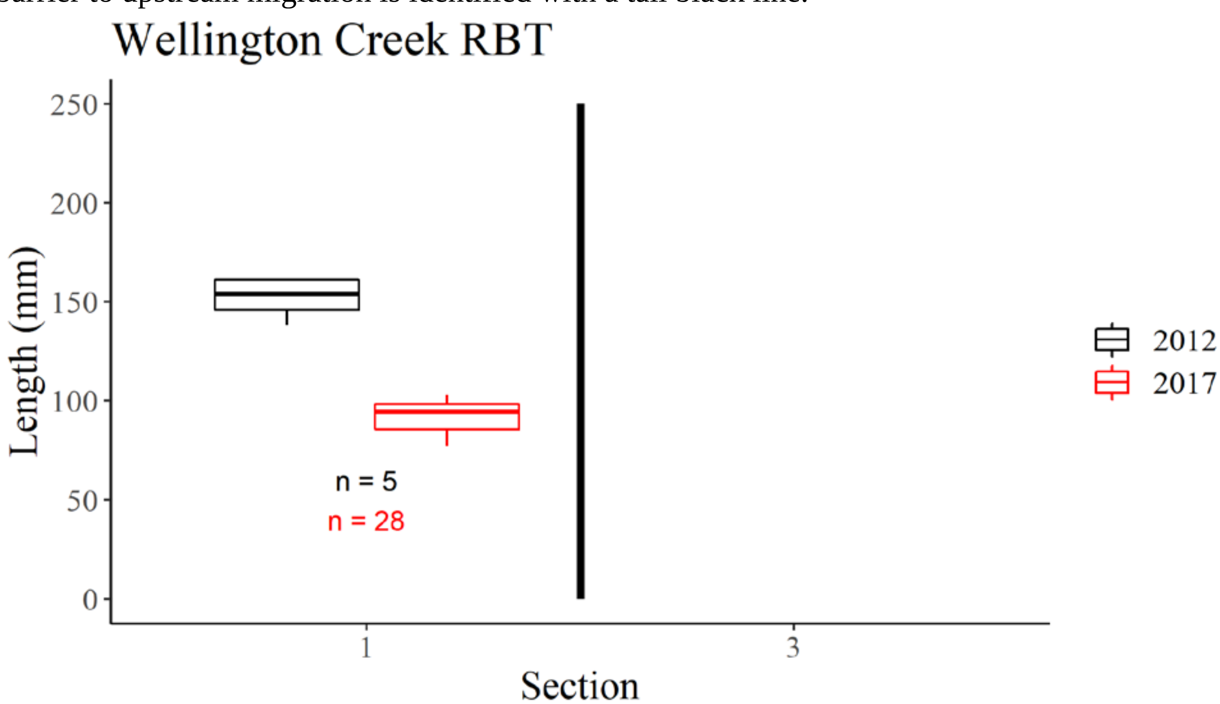


Figure 75. Length (mm) of Rainbow Trout captured in each section of Wellington Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

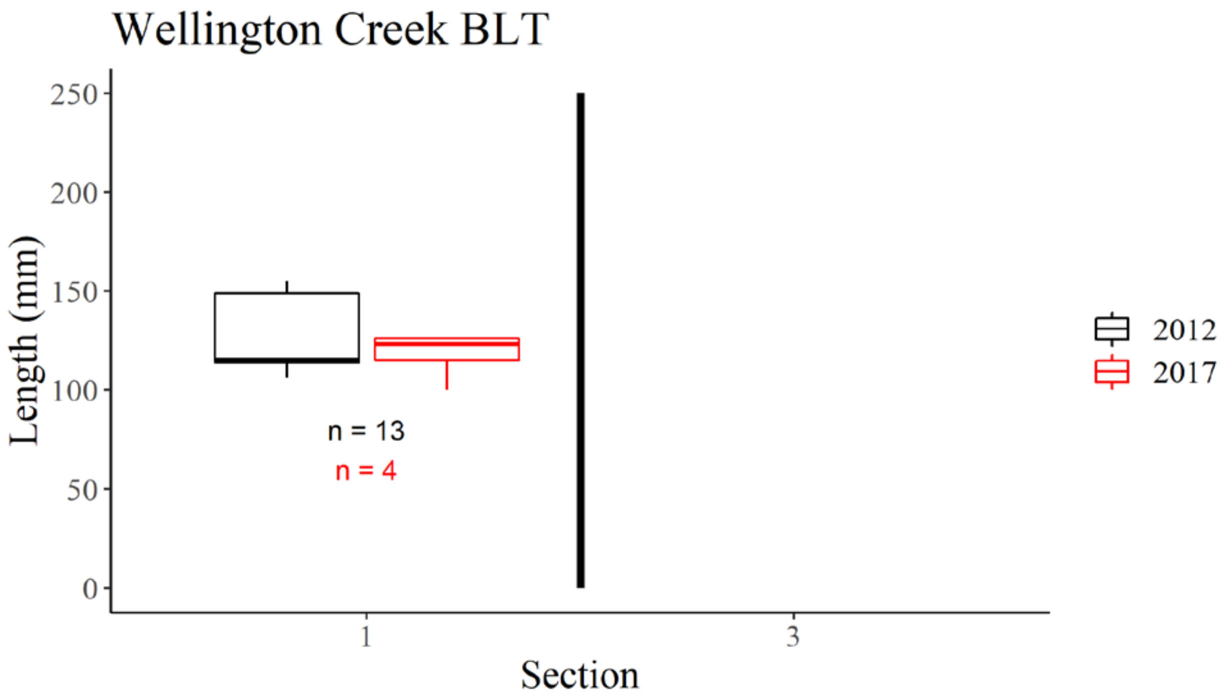


Figure 76. Length (mm) of Bull Trout captured in each section of Wellington Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

Direct Tributaries to the Clark Fork River

Johnson Creek

Johnson Creek is a tributary on the northeastern end of Lake Pend Oreille that flows into the Clark Fork River Delta. A waterfall barrier exists just upstream of reach one, however BLT are present below it. Above the barrier, only WCT are present (Figure 77). Densities were similar between sample events, however size and age structure trended towards smaller and younger individuals for both BLT and WCT in 2014 (Figure 77). Interestingly, no RBT or BRK have been observed in Johnson Creek despite its close proximity to the lake and the short migration distance required by spawning adults. A seasonal dry section at the mouth of the river has been forming in recent years, and may reduce access by fish attempting to migrate upstream during winter months when the lake level is intentionally lowered. Detailed capture data for WCT and BLT are displayed in Figures 78 and 79.

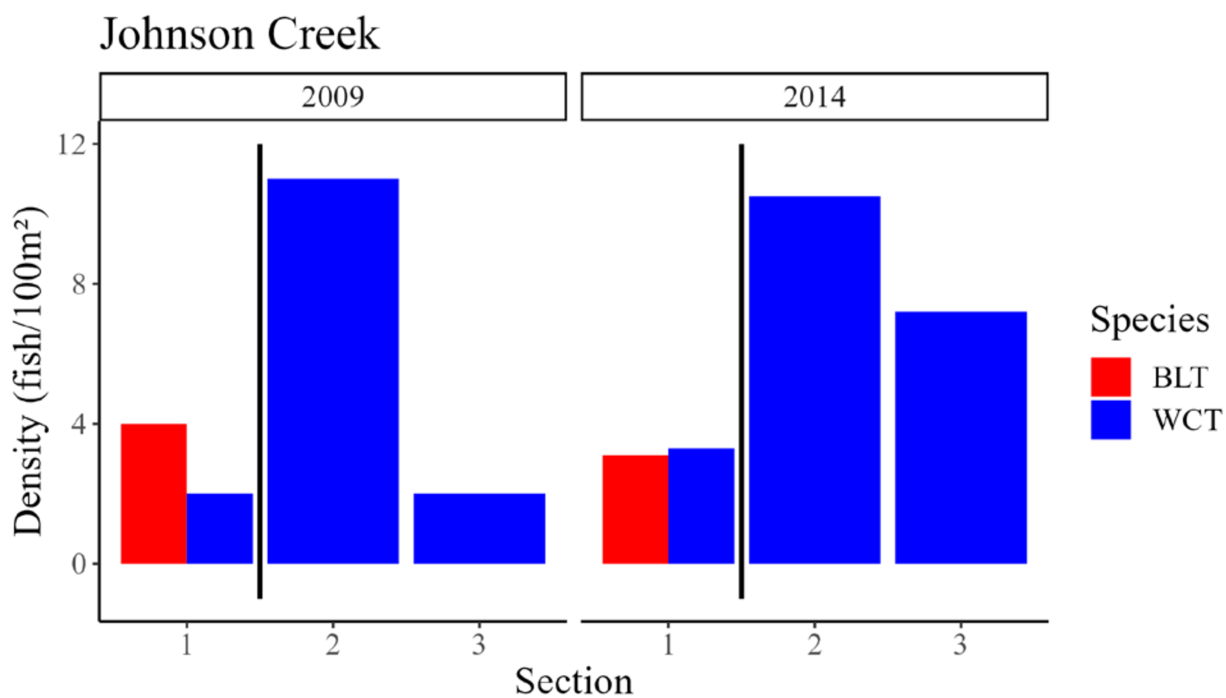


Figure 77. Fish densities (fish per $100m^2$) for each shocking section in Johnson Creek. Species specific densities are identified by color (see legend). The location of a barrier to upstream migration is identified with a tall black line.

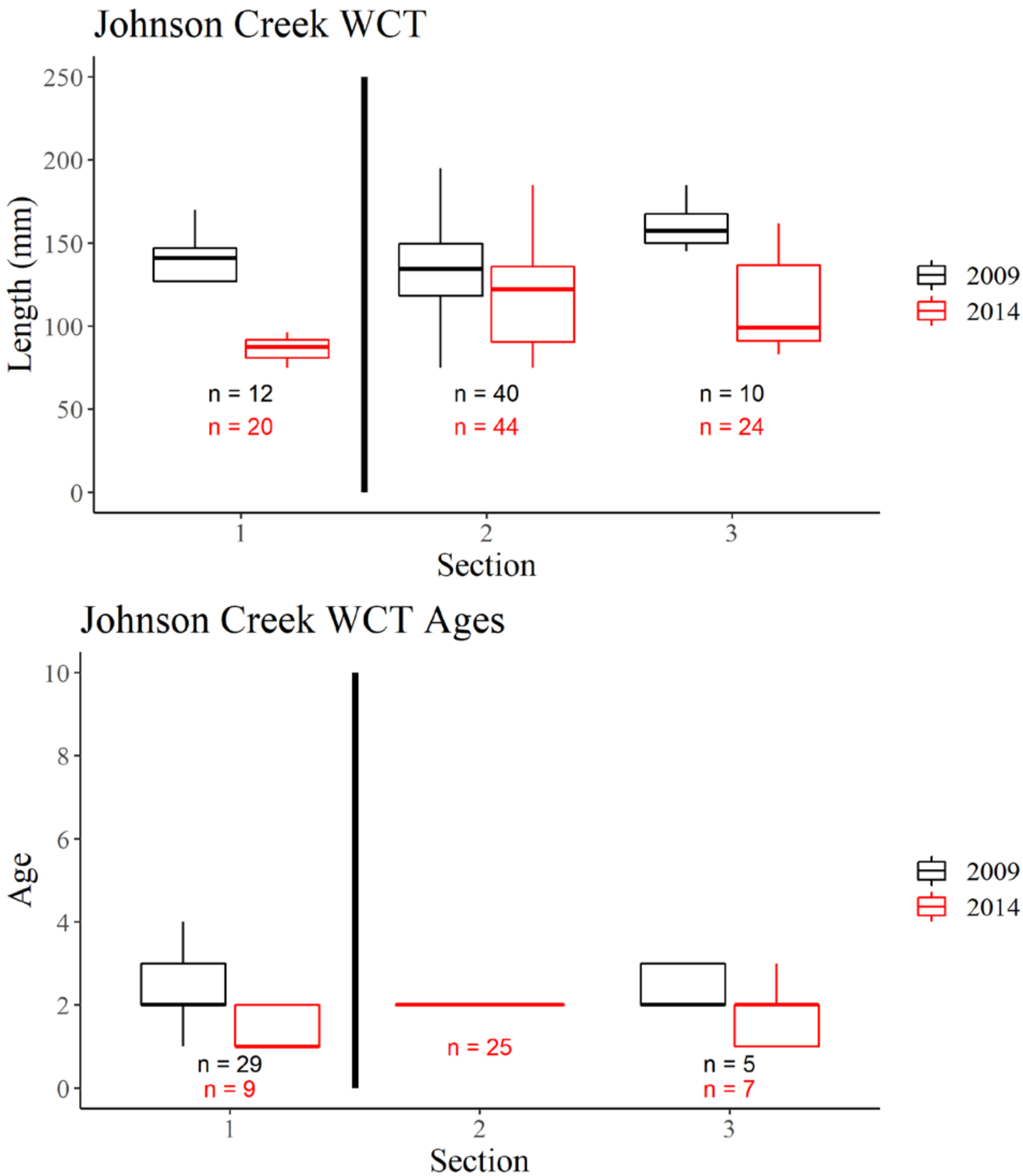


Figure 78. Length (mm; top panel) and age (years; lower panel) of Westslope Cutthroat Trout captured in each section of Johnson Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

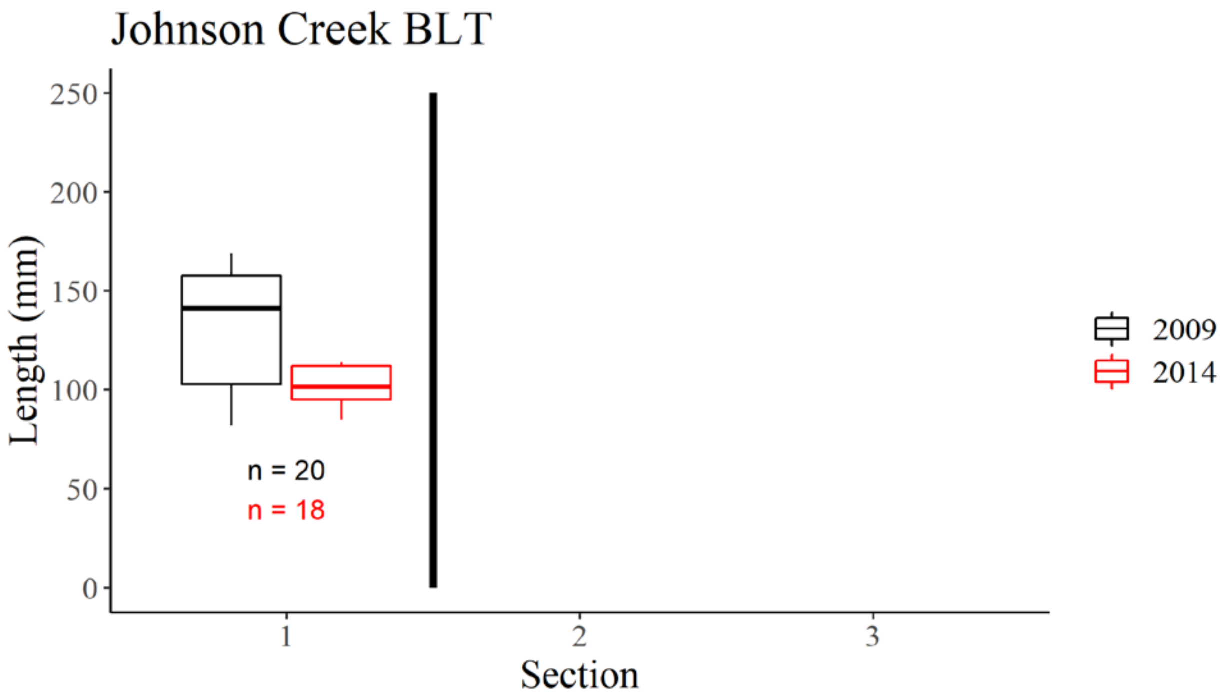


Figure 79. Length (mm) of Bull Trout captured in each section of Johnson Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

Mosquito Creek

Mosquito Creek flows into the north side of the Clark Fork River just upstream of the mouth of Lightning Creek. Lowland sections of the tributary are dominated by BRK; however, after gradient increases the species composition primarily becomes WCT (Figure 80). Beavers are prevalent in the low gradient downstream reaches, and the presence of a dam complex caused a braided and slow-moving channel in reach one in 2018. To compensate for this, reach one was moved approximately 800m upstream. Mosquito Creek is another example of a tributary that exhibits more WRHY than RBT; however, RBT were present in the 2018 sample (Figure 80). Brown Trout are also present in lower reaches of the stream, but are not widespread (Bouwens et al. 2019b, Frawley et al. 2019). Detailed capture data for WCT, RBT, and BRK are displayed in Figures 81, 82, and 83.

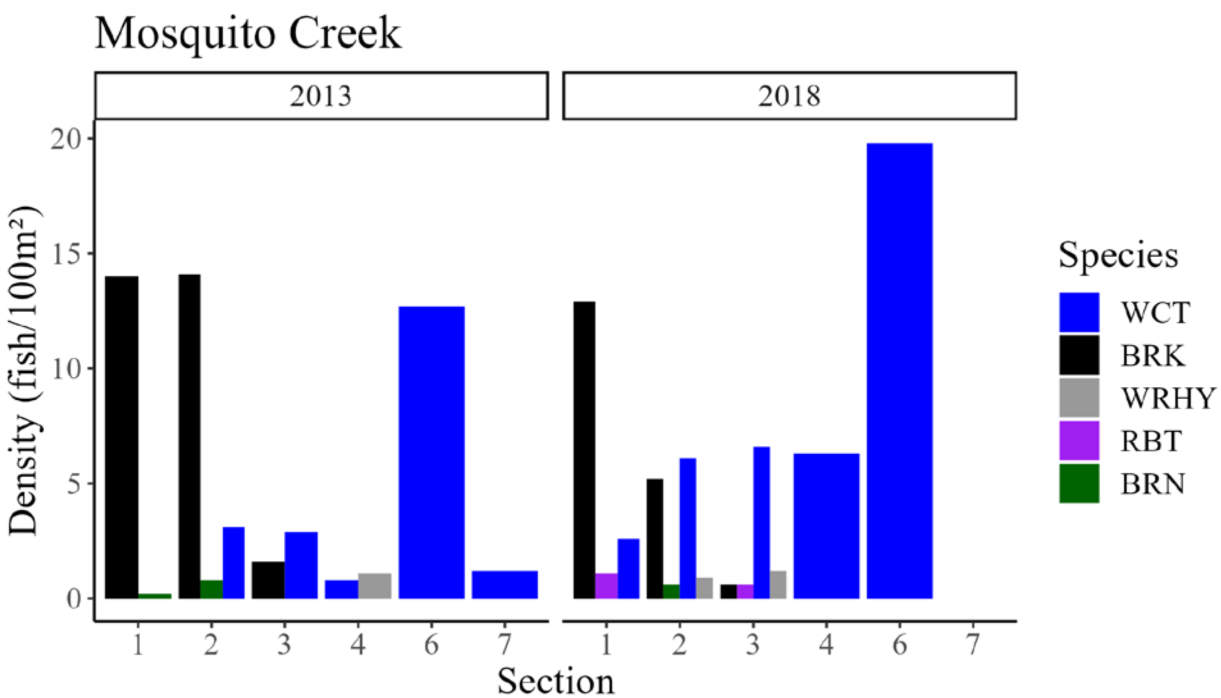


Figure 80. Fish densities (fish per 100m^2) for each shocking section in Mosquito Creek. Species specific densities are identified by color (see legend).

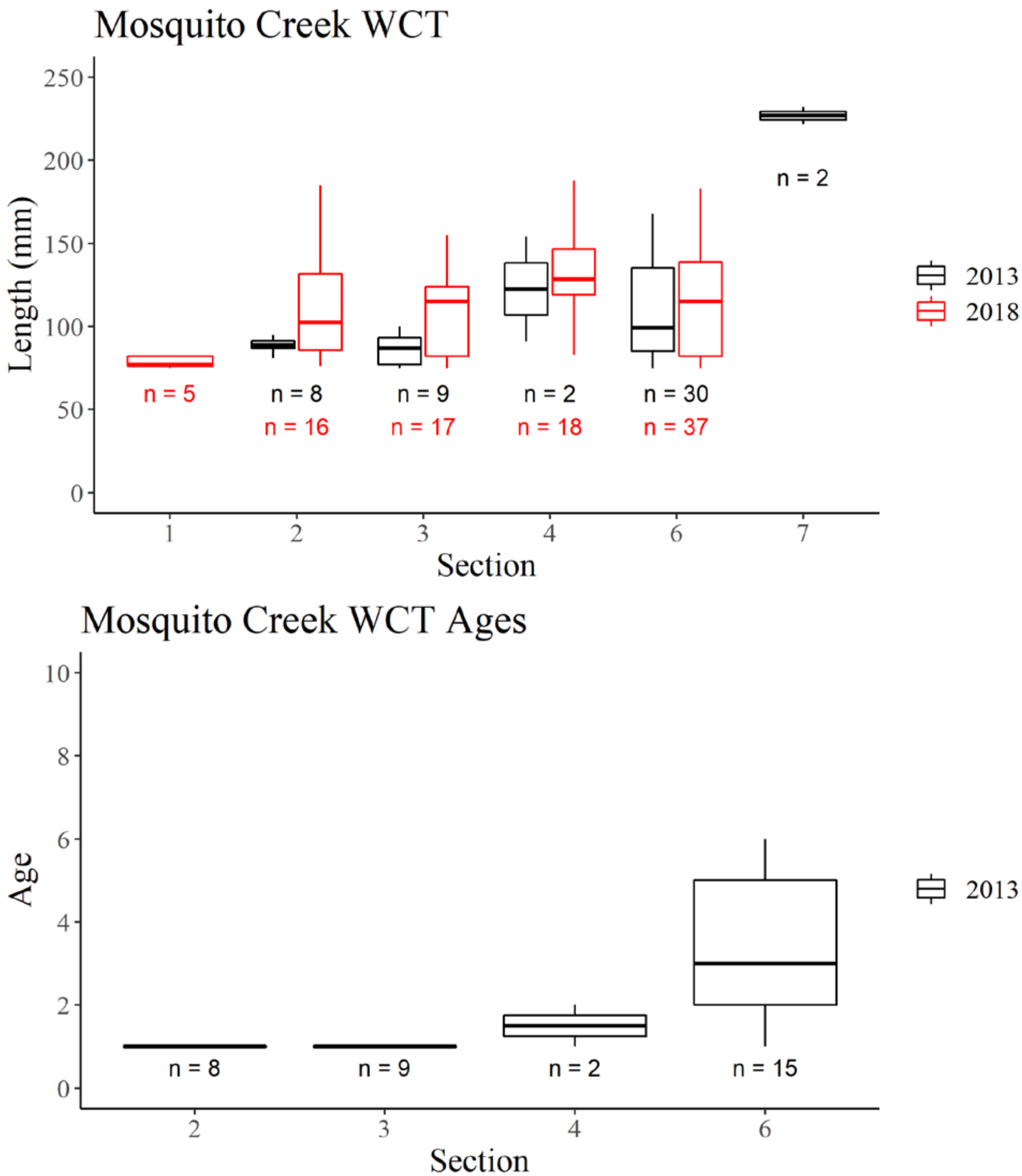


Figure 81. Length (mm; top panel) and age (years; lower panel) of Westslope Cutthroat Trout captured in each section of Mosquito Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

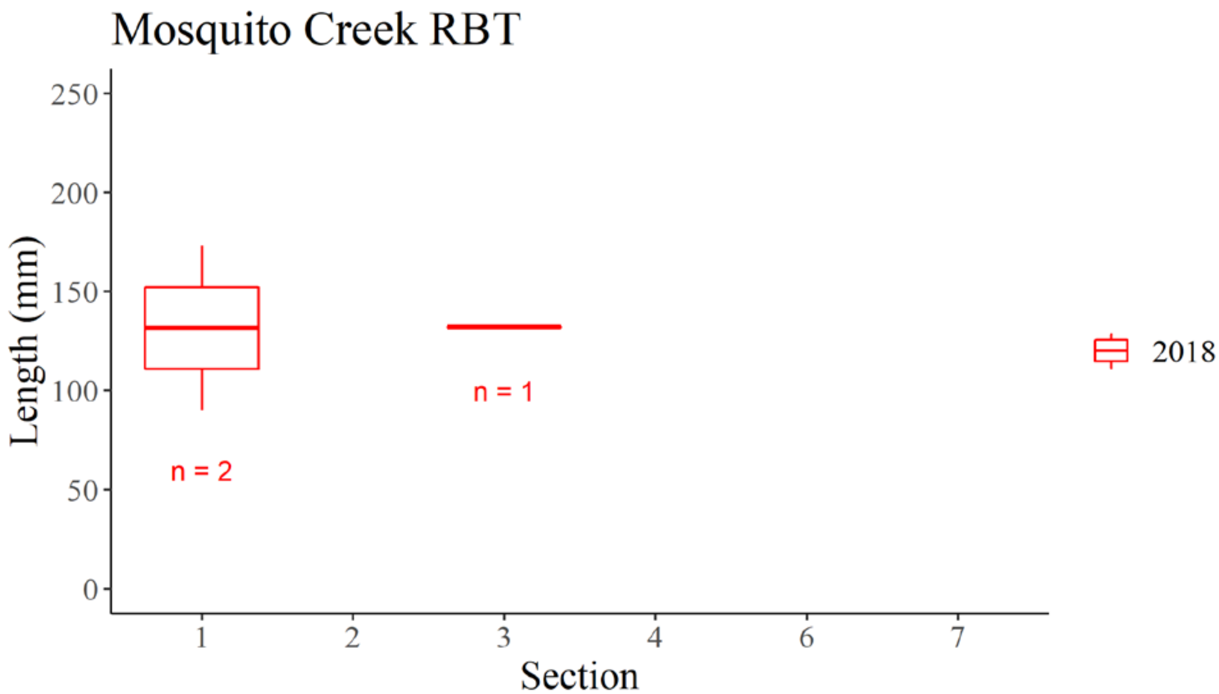


Figure 82. Length (mm) of Rainbow Trout captured in each section of Mosquito Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

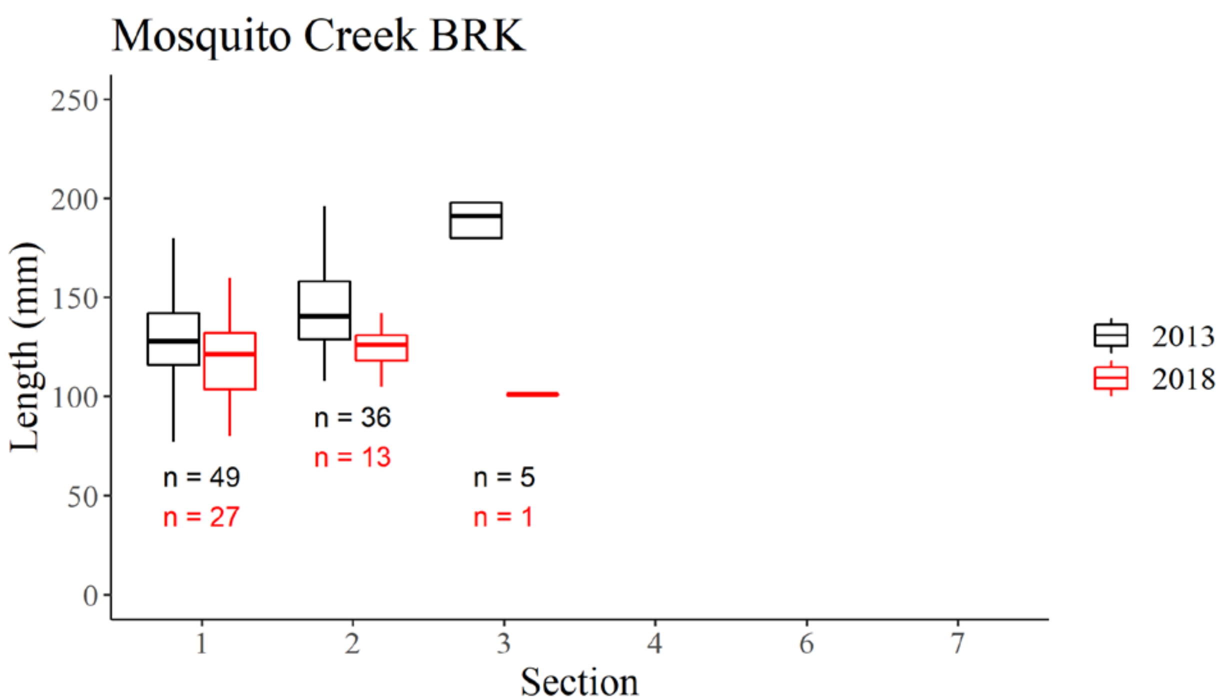


Figure 83. Length (mm) of Brook Trout captured in each section of Mosquito Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

Twin Creek

Twin Creek is located upstream of Mosquito Creek on the Clark Fork River and flows into the mainstem from the south. A barrier to migratory fish exists between Sections Two and Three, and the BRK present above this were likely stocked in the mid-1900s. Rainbow Trout are present below the barrier, but declined in abundance from 2009 to 2014 (Figure 84). Brown Trout have also been documented in the stream, but are not widespread (Figure 84). Prior to 2009, a weir was operated to assess up and downstream migrating fish, and large numbers of juvenile BRN were observed migrating downstream (Ryan et al. 2009). Our electrofishing surveys may indicate a decline in abundance, or individuals do not reside in the creek during summer periods when sampling occurs. A habitat improvement project was conducted in 2016 to remove a dry stretch of stream between reach one and two and appears to be maintaining consistent flow. However, a beaver dam complex has been constructed downstream of this area in recent years and may pose as a barrier to migration. Detailed capture data for WCT, RBT, BLT, and BRK are displayed in Figures 85, 86, 87, and 88.

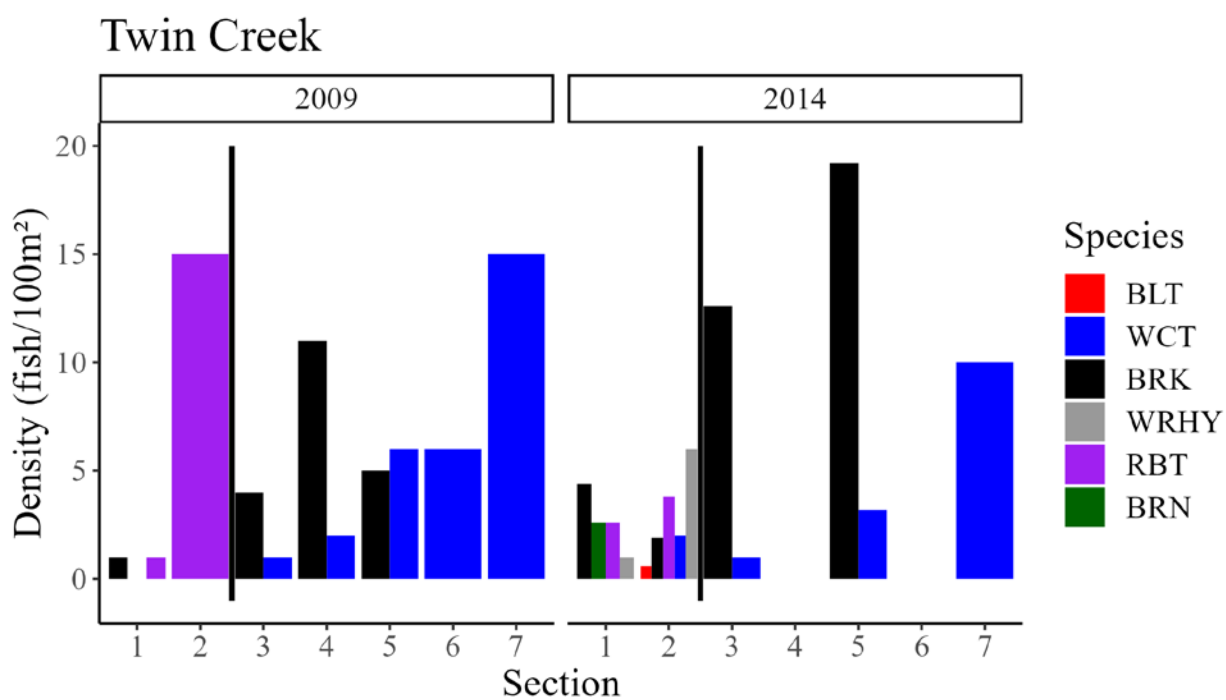


Figure 84. Fish densities (fish per $100m^2$) for each shocking section in Twin Creek. Species specific densities are identified by color (see legend). The location of a barrier to upstream migration is identified with a tall black line.

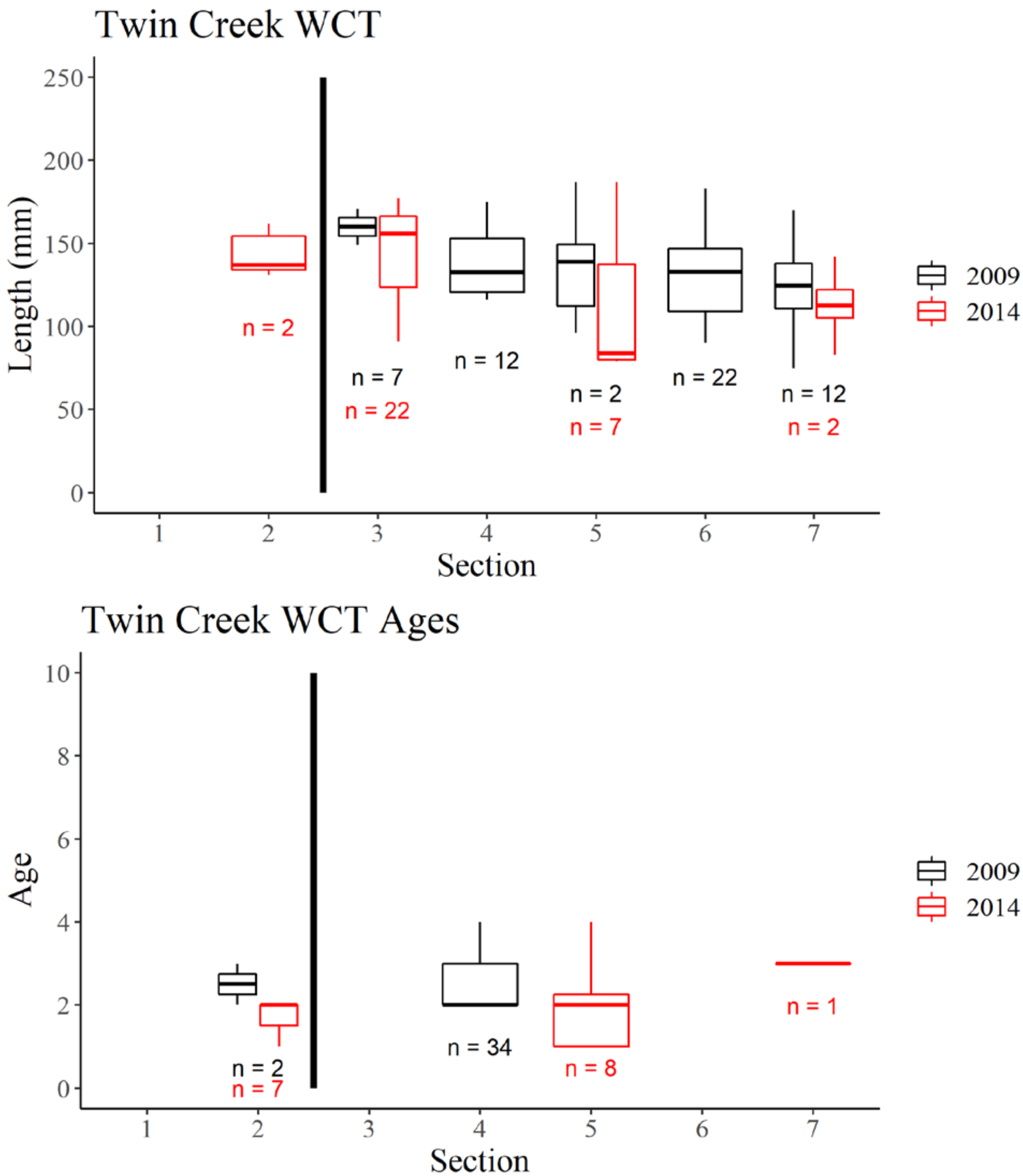


Figure 85. Length (mm; top panel) and age (years; lower panel) of Westslope Cutthroat Trout captured in each section of Twin Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

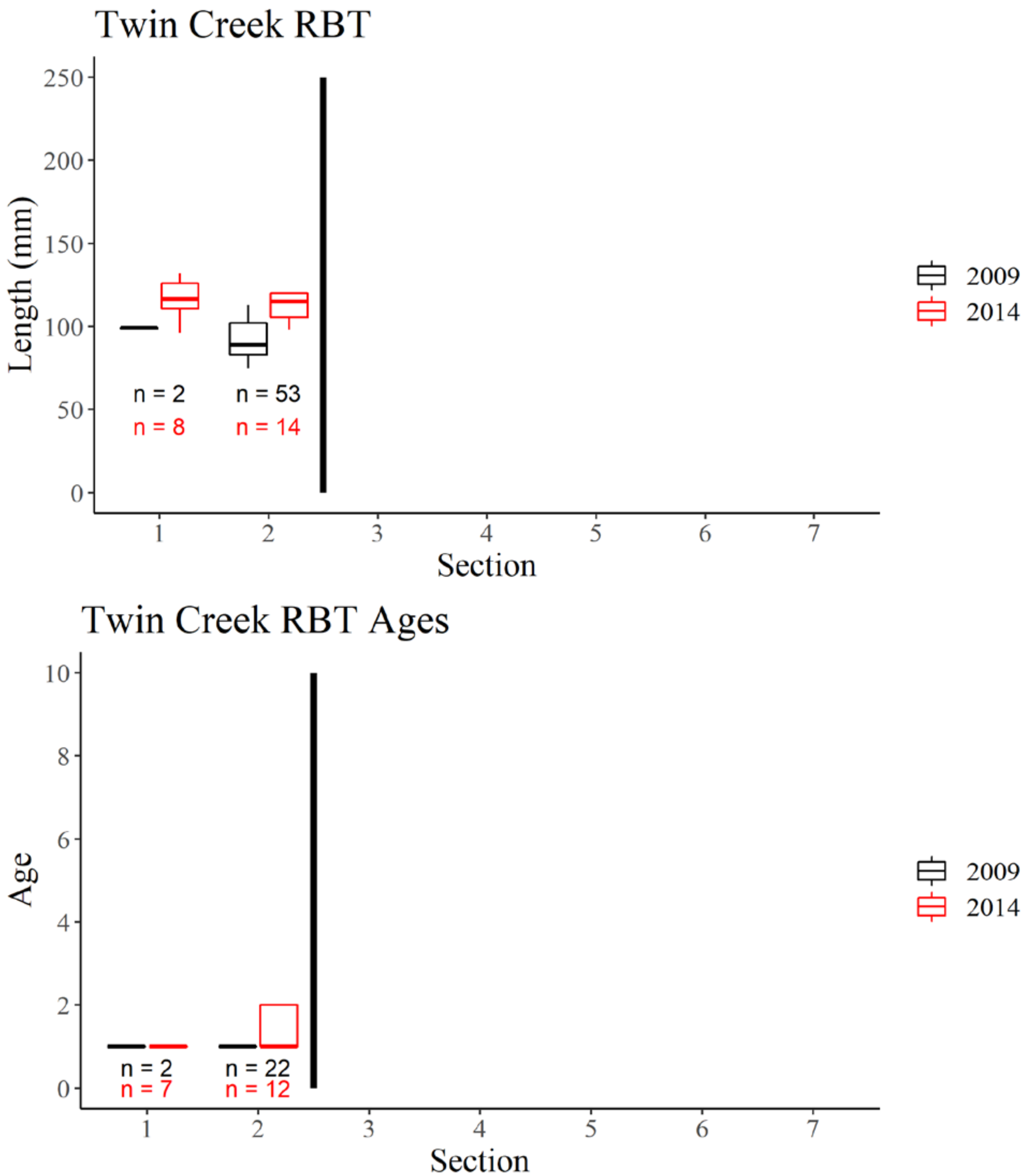


Figure 86. Length (mm; top panel) and age (years; lower panel) of Rainbow Trout captured in each section of Twin Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

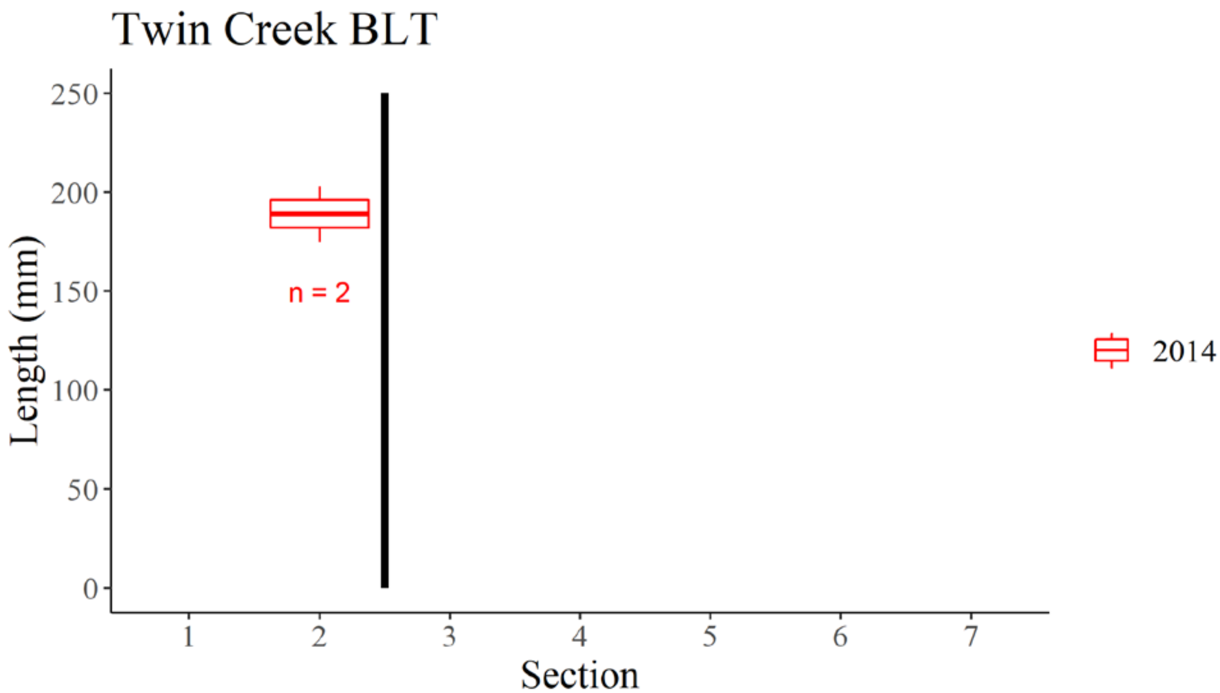


Figure 87. Length (mm) of Bull Trout captured in each section of Twin Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

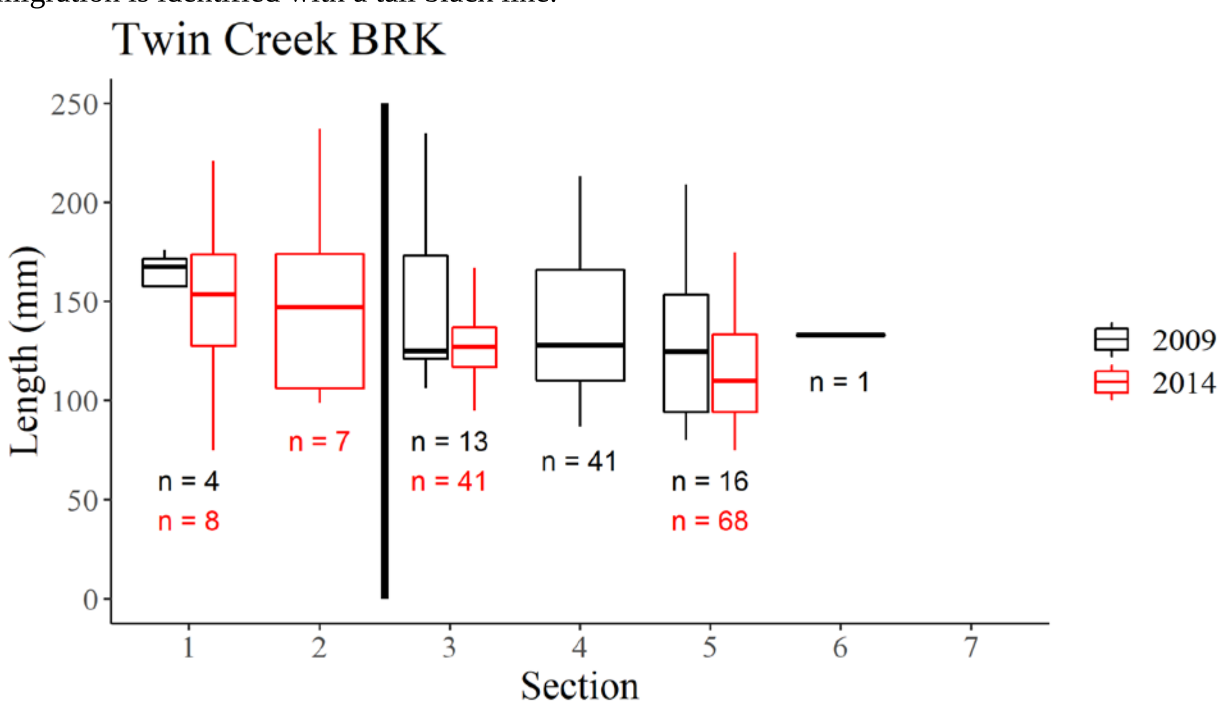


Figure 88. Length (mm) of Brook Trout captured in each section of Twin Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

Gold Creek

Gold Creek flows directly into the southern end of Lake Pend Oreille. A migration barrier exists in the form of a dry reach upstream of Section Two, which extended to reach six in 2009 and reach five in 2014. An additional barrier in the form of a log jam may also be forming at the mouth in recent years. Bull Trout and WCT appear to be unaffected, but kokanee have been relegated to spawning downstream and on the lake shore (Bill Harryman, personal communication). Regardless, Gold Creek supports high densities of BLT and WCT (Figure 89). Densities of WCT remained similar throughout the two sample events, however BLT have declined in the two reaches where they are present (Figure 89). Detailed capture data for WCT, and BLT are displayed in Figures 90 and 91.

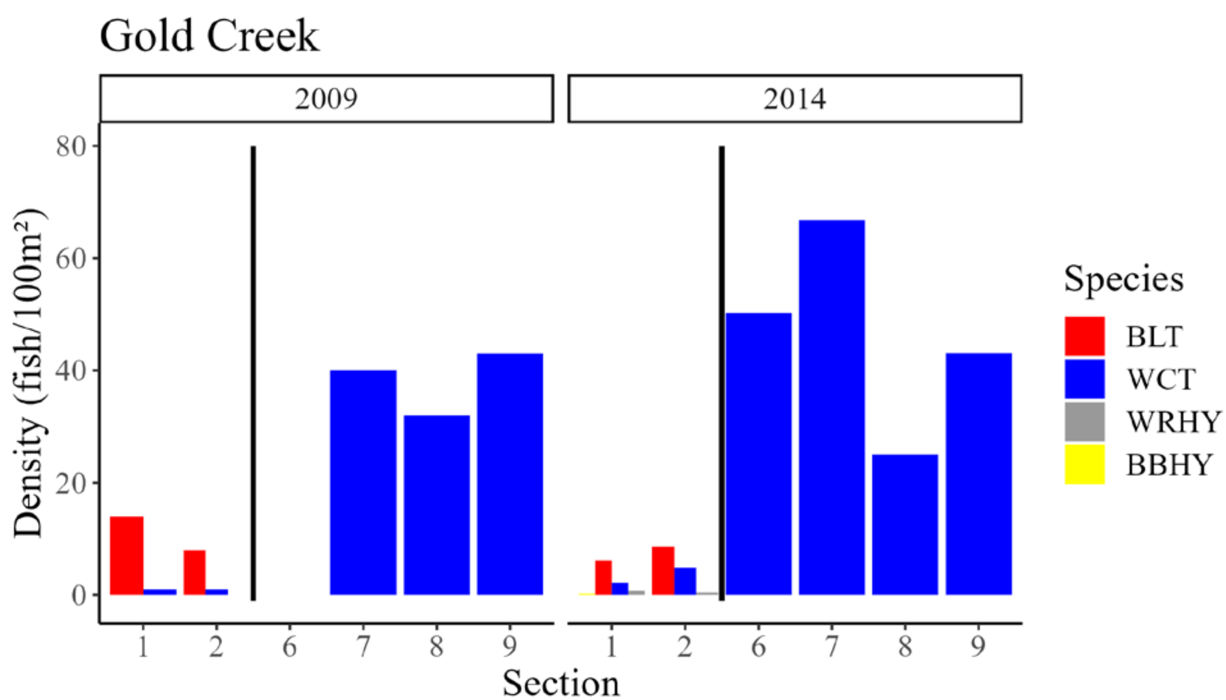


Figure 89. Fish densities (fish per 100m^2) for each shocking section in Gold Creek. Species specific densities are identified by color (see legend). The location of a barrier to upstream migration is identified with a tall black line.

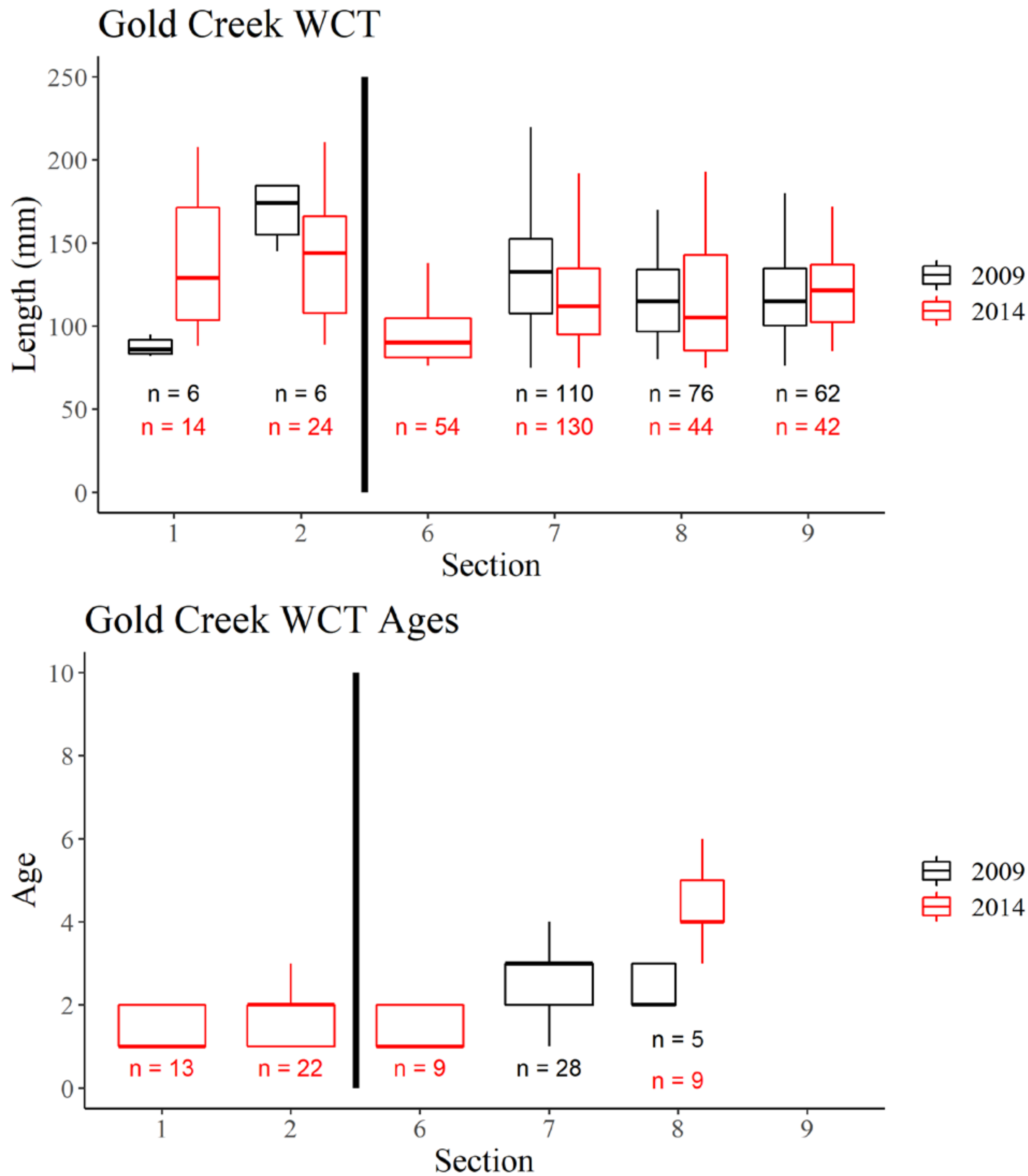


Figure 90. Length (mm; top panel) and age (years; lower panel) of Westslope Cutthroat Trout captured in each section of Gold Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

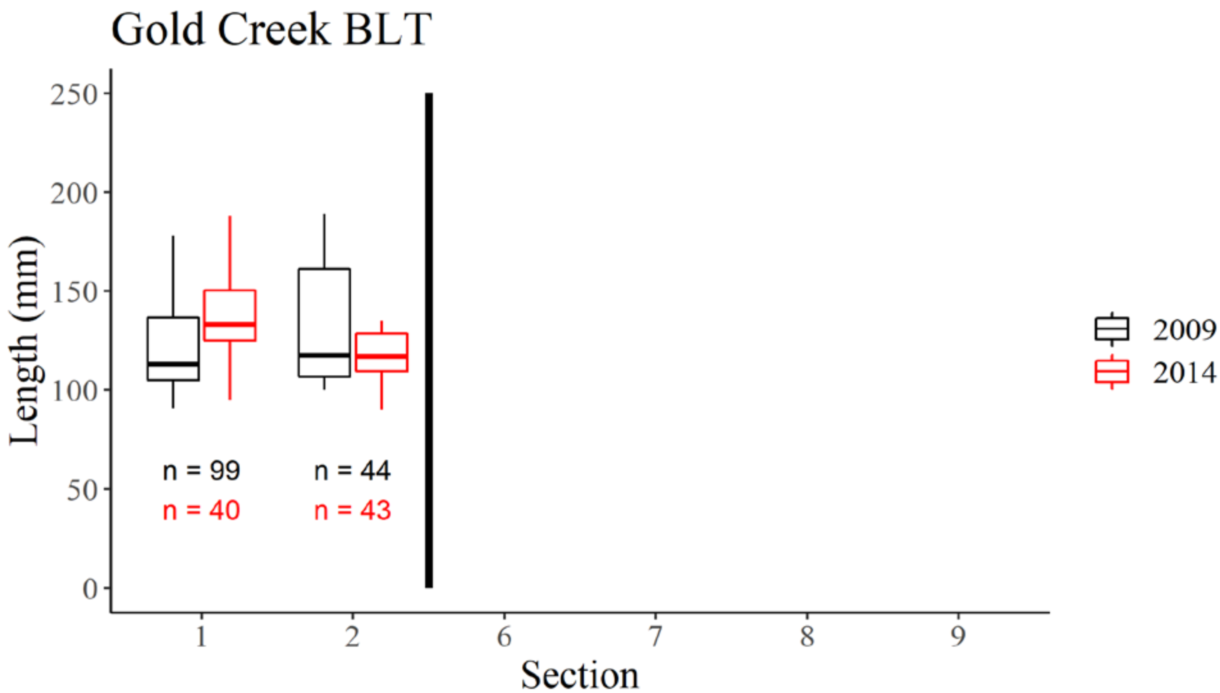


Figure 91. Length (mm) of Bull Trout captured in each section of Gold Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

West Gold Creek

West Gold Creek is a tributary to Gold Creek that enters the west side of the mainstem below the dry section. Only BLT and WCT were present during both sample events, and both species appear to be increasing in abundance (Figure 92). Distribution of BLT also increased upstream into Section Three. Detailed capture data for WCT and BLT are displayed in Figures 92 and 93.

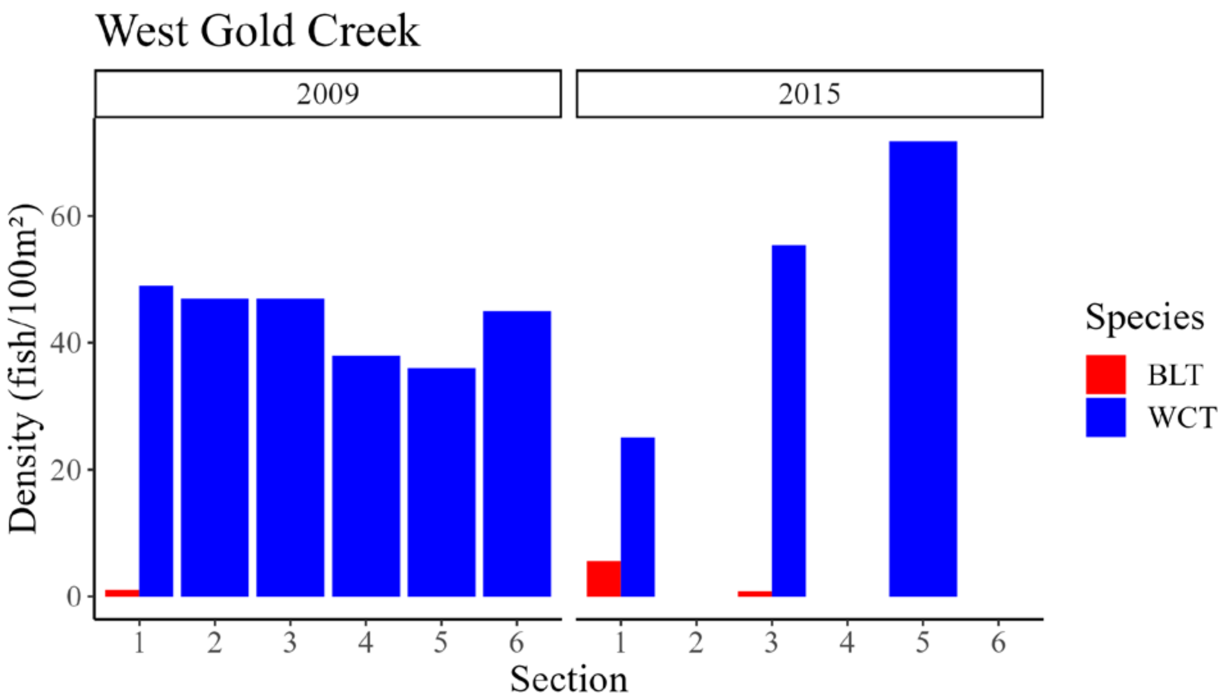


Figure 92. Fish densities (fish per $100m^2$) for each shocking section in West Gold Creek. Species specific densities are identified by color (see legend).

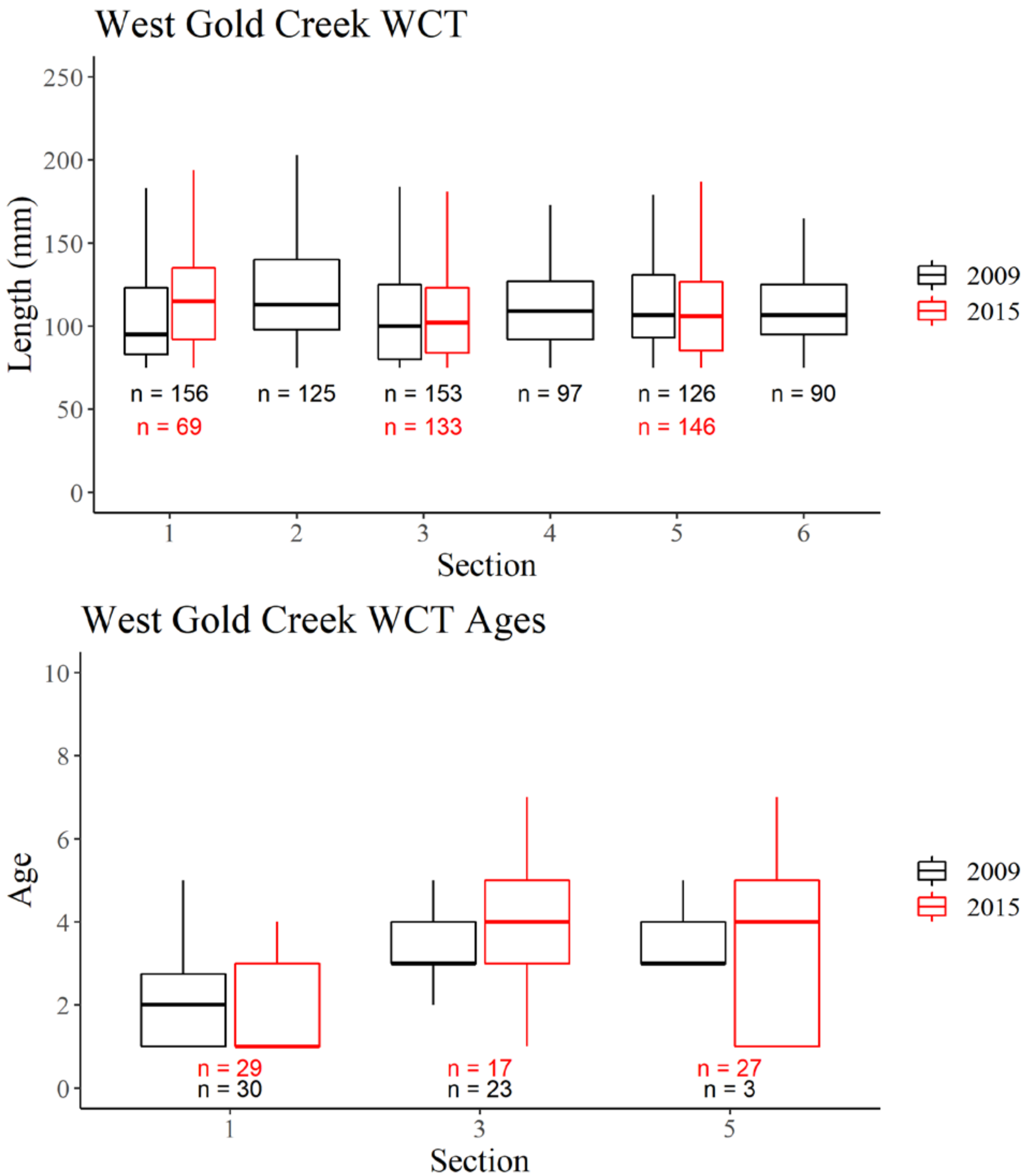


Figure 93. Length (mm; top panel) and age (years; lower panel) of Westslope Cutthroat Trout captured in each section of West Gold Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

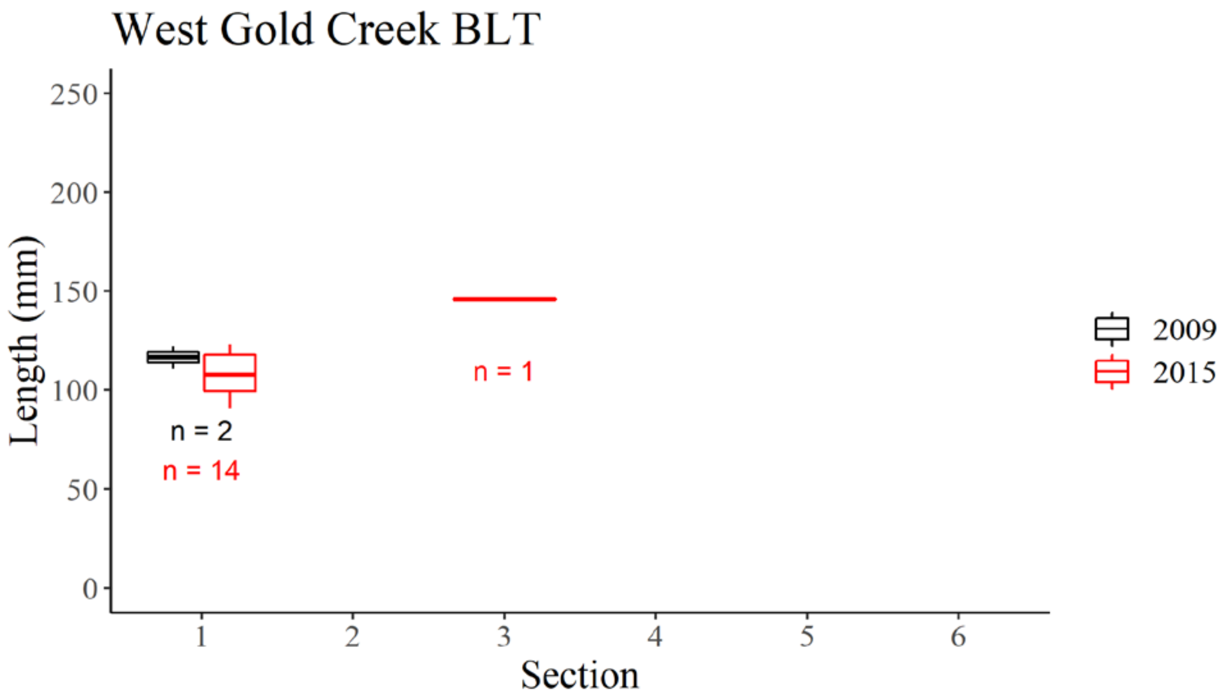


Figure 94. Length (mm) of Bull Trout captured in each section of West Gold Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

Granite Creek

Granite Creek flows directly into Lake Pend Oreille along its eastern shoreline. Both BLT and WCT are abundant throughout all sample reaches, and size of individuals remained consistent between 2009 and 2014. Bull Trout appear to remain consistent throughout the longitudinal profile of the creek (Figure 95); however, WCT exhibit increasing size and age moving upstream (Figure 96). Additionally, BLT densities increased in upstream reaches during the second sample event, but WCT exhibited a decline (Figure 96 and 97). Interestingly, WRHY were observed without the presence of RBT, and may be the result of an individual hybridization event.

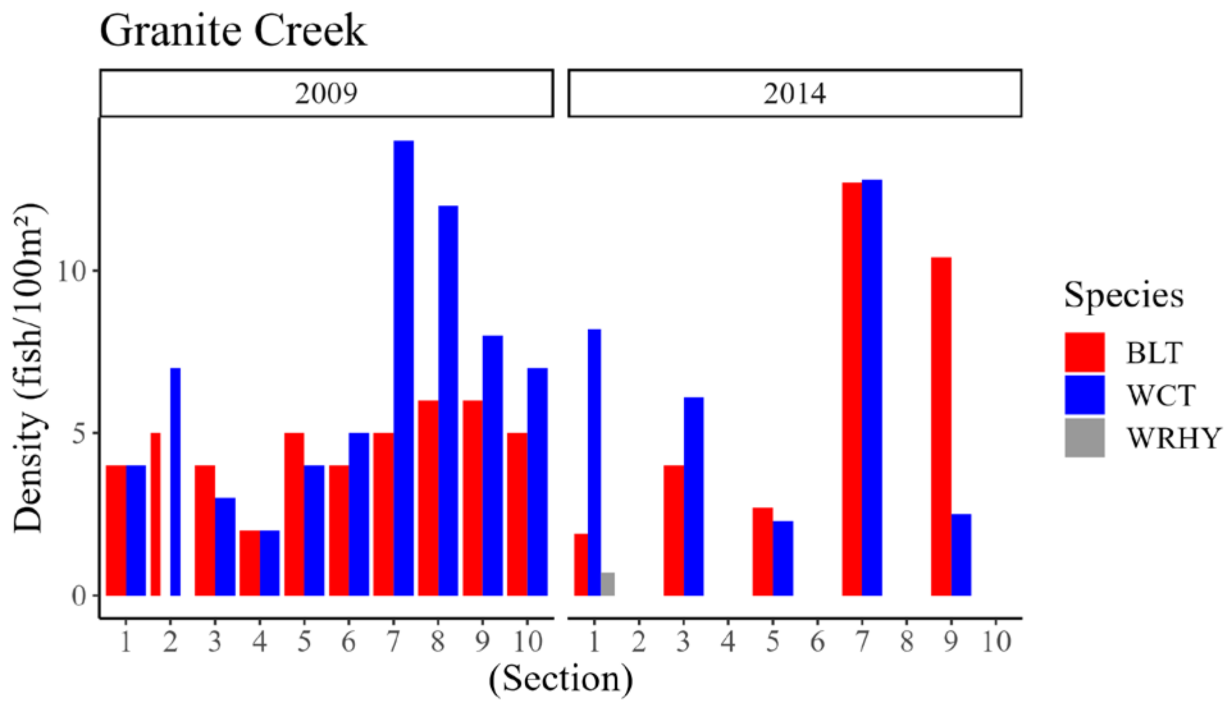


Figure 95. Fish densities (fish per 100m^2) for each shocking section in Granite Creek. Species specific densities are identified by color (see legend).

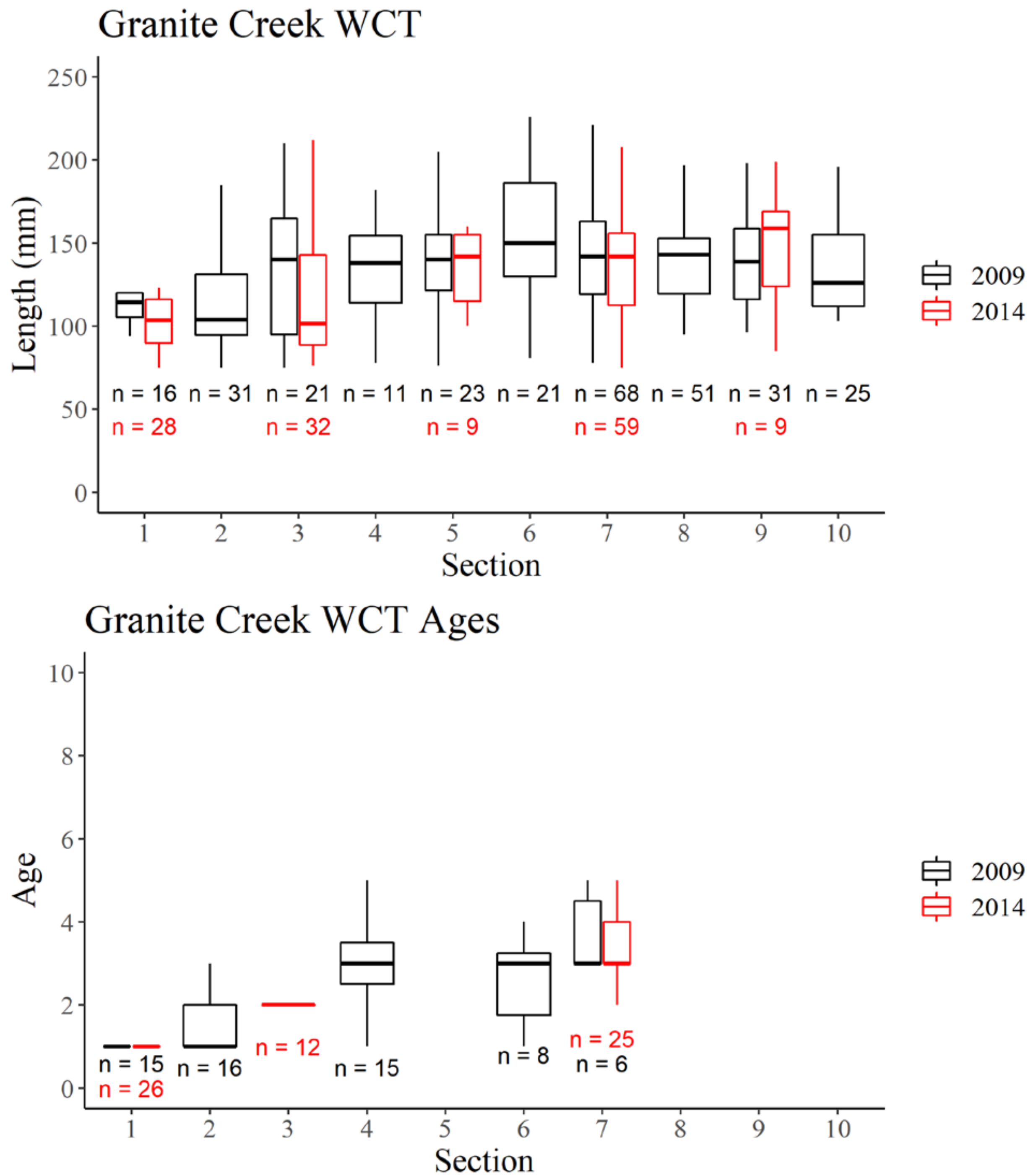


Figure 96. Length (mm; top panel) and age (years; lower panel) of Westslope Cutthroat Trout captured in each section of Granite Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

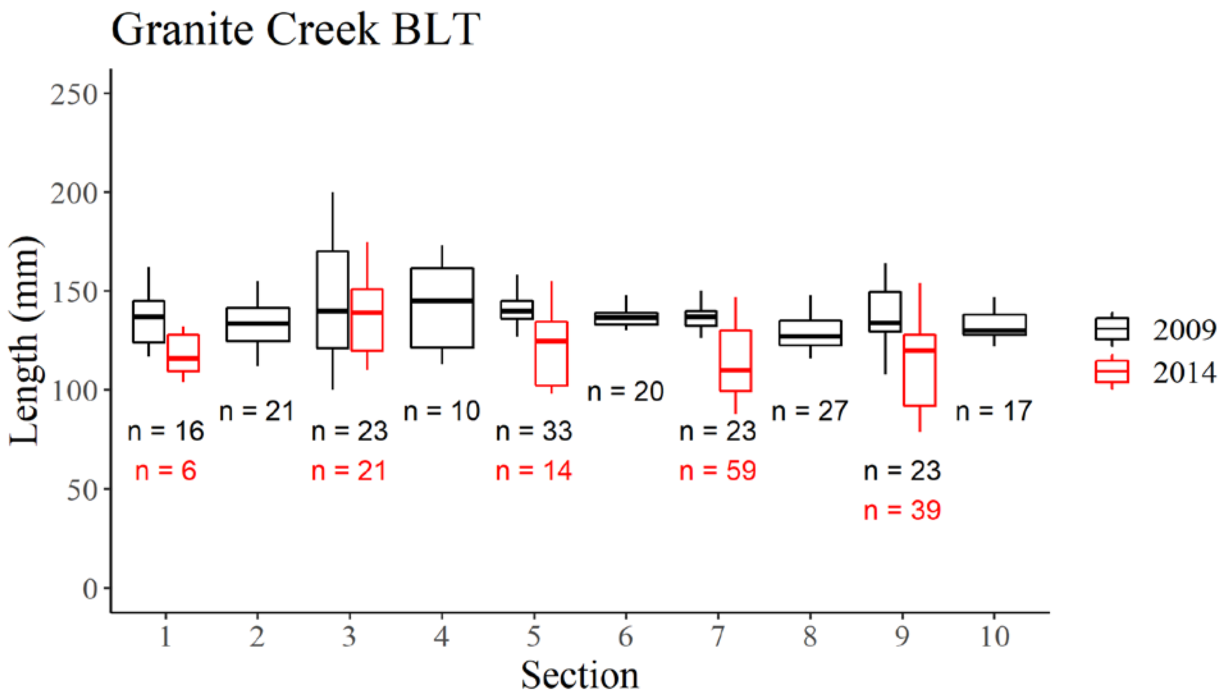


Figure 97. Length (mm) of Bull Trout captured in each section of Granite Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

Strong Creek

Strong Creek flows directly into Lake Pend Oreille on the northern end of the lake. Predominantly a WCT stronghold, BLT were present during the second year of sampling (Figure 98). An ephemeral section located near the mouth of the stream may prohibit migrating adult BLT during the time of spawning in some years, and juvenile densities may be sporadic as a result. Only one RBT was sampled in 2009, and densities were too low to properly visualize in Figure 97. Detailed capture data for WCT, RBT, and BLT are displayed in Figures 99, 100, and 101.

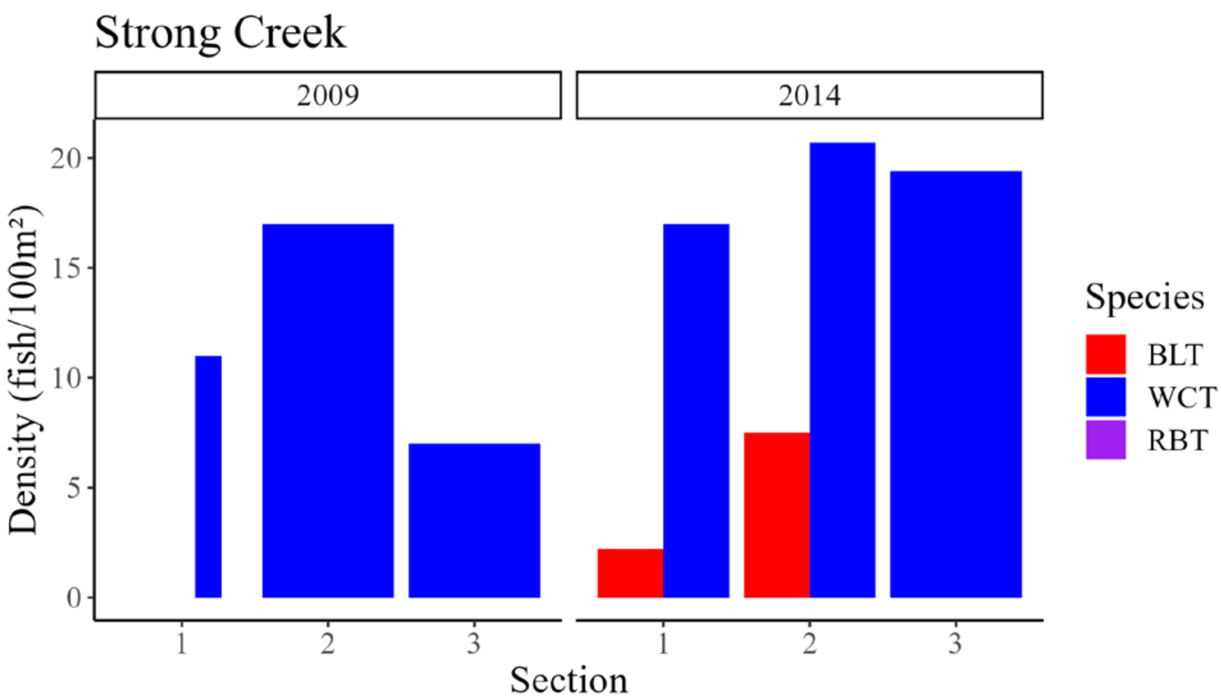


Figure 98. Fish densities (fish per $100m^2$) for each shocking section in Strong Creek. Species specific densities are identified by color (see legend).

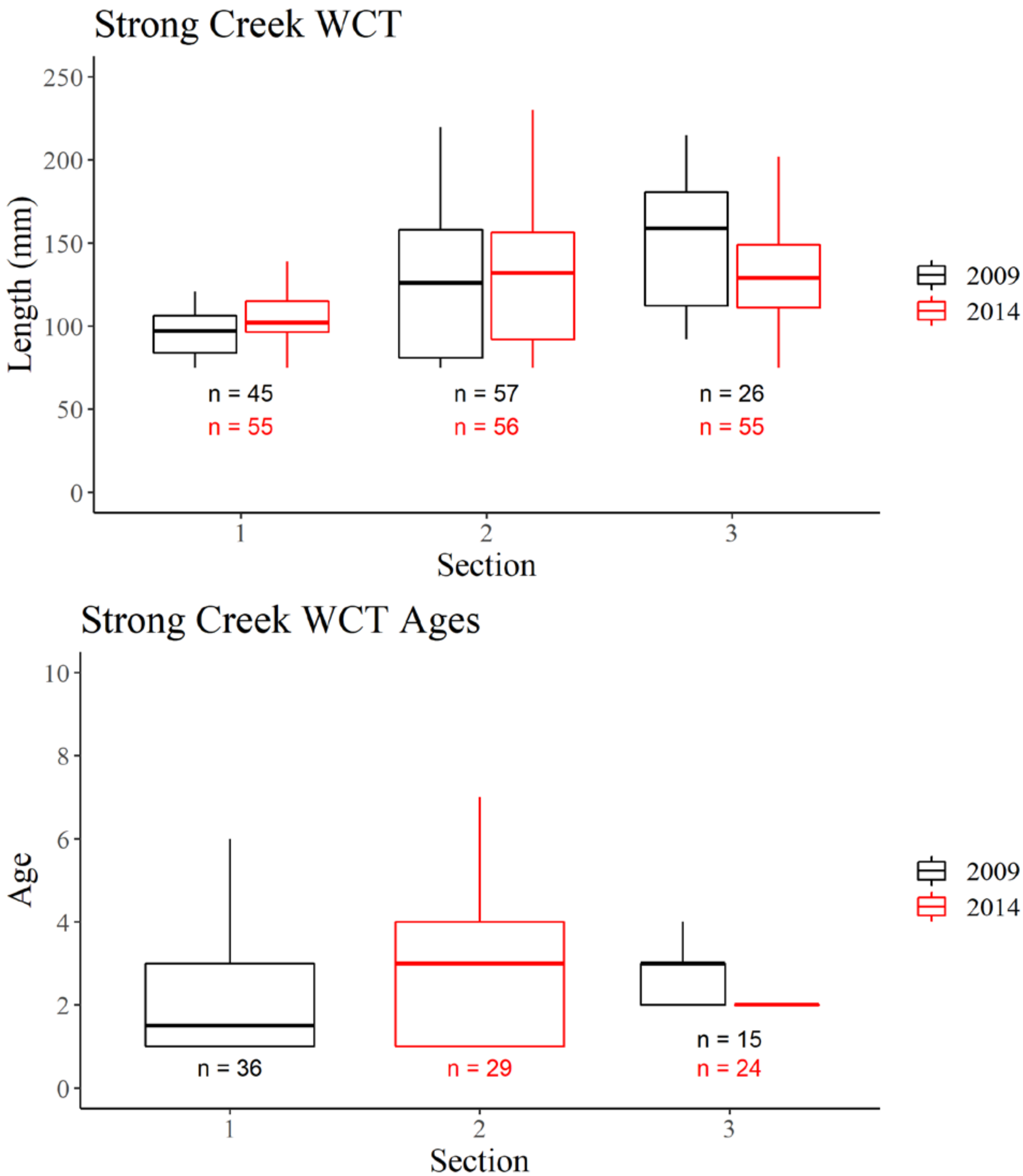


Figure 99. Length (mm; top panel) and age (years; lower panel) of Westslope Cutthroat Trout captured in each section of Strong Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

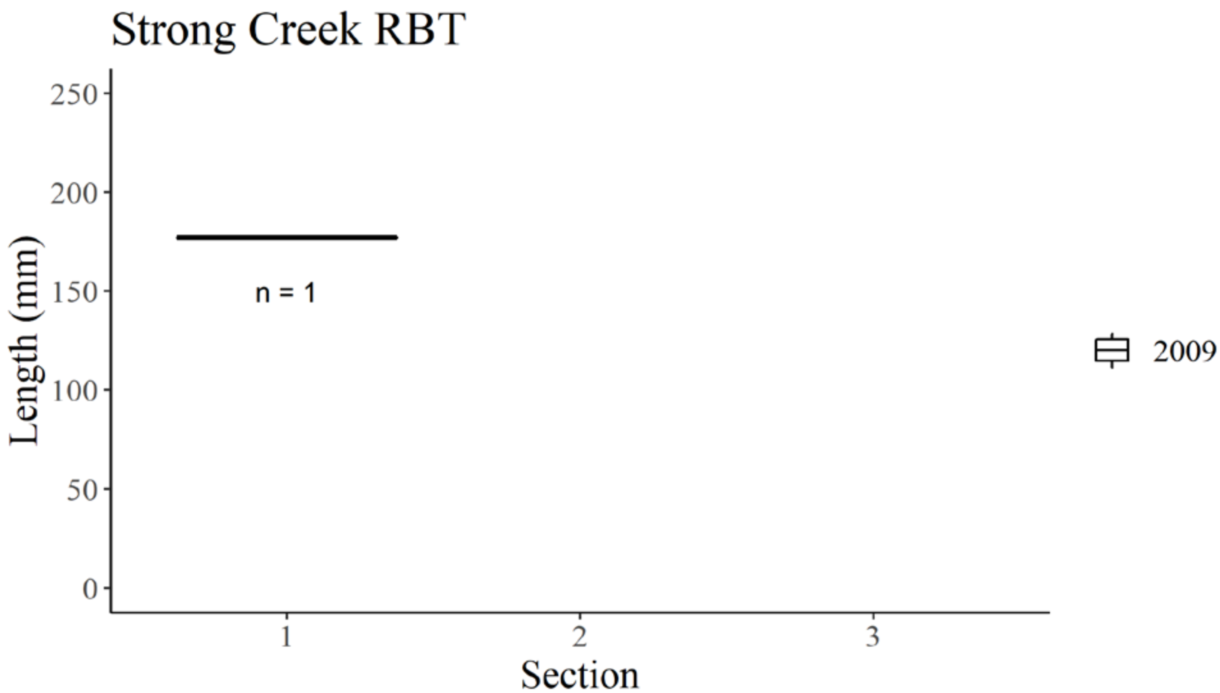


Figure 100. Length (mm) of Rainbow Trout captured in each section of Strong Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

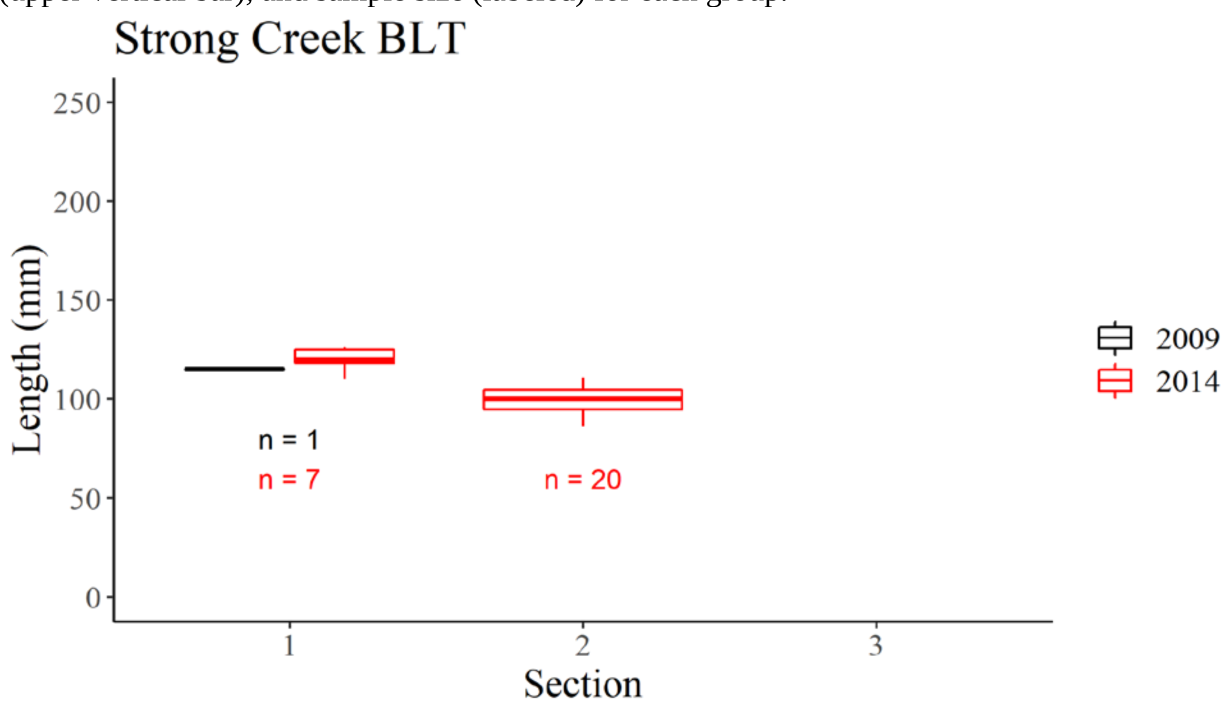


Figure 101. Length (mm) of Bull Trout captured in each section of Strong Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

Trestle Creek

Trestle Creek is located on the north end of Lake Pend Oreille and flows directly into the lake to the east of the mouth of the Pack River. Redd count numbers are consistently high in Trestle Creek; however, the juvenile densities observed are lower than expected when compared to other creeks. This may indicate the stream is operating at a biological carrying capacity for BLT, or a recruitment bottleneck is present during the first year of life. Size of juvenile BLT sampled also indicated a small size structure compared to other streams; however, this is difficult to interpret without age data. Westslope Cutthroat Trout densities increased, sometimes substantially, in all reaches during the second sample event (Figure 102). Interestingly, no RBT or WRHY were observed in 2016, and may suggest hybridization is sporadic in this stream. Detailed capture data for WCT and BLT are displayed in Figures 103 and 104.

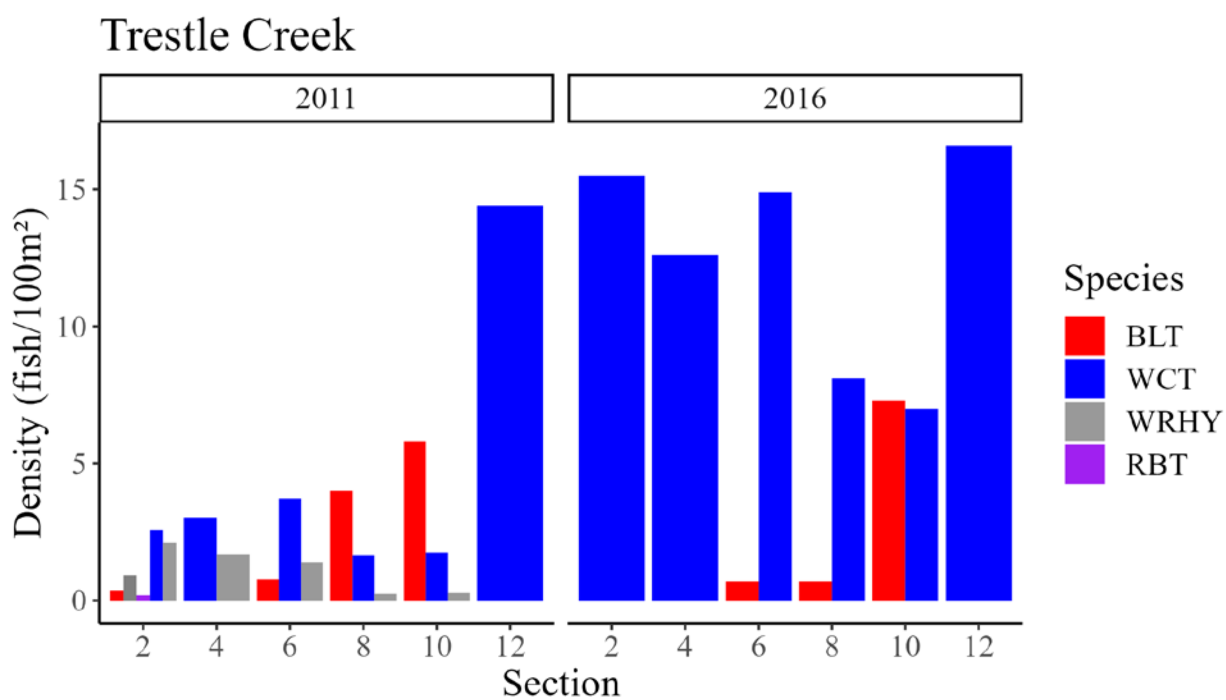


Figure 102. Fish densities (fish per 100m^2) for each shocking section in Trestle Creek. Species specific densities are identified by color (see legend).

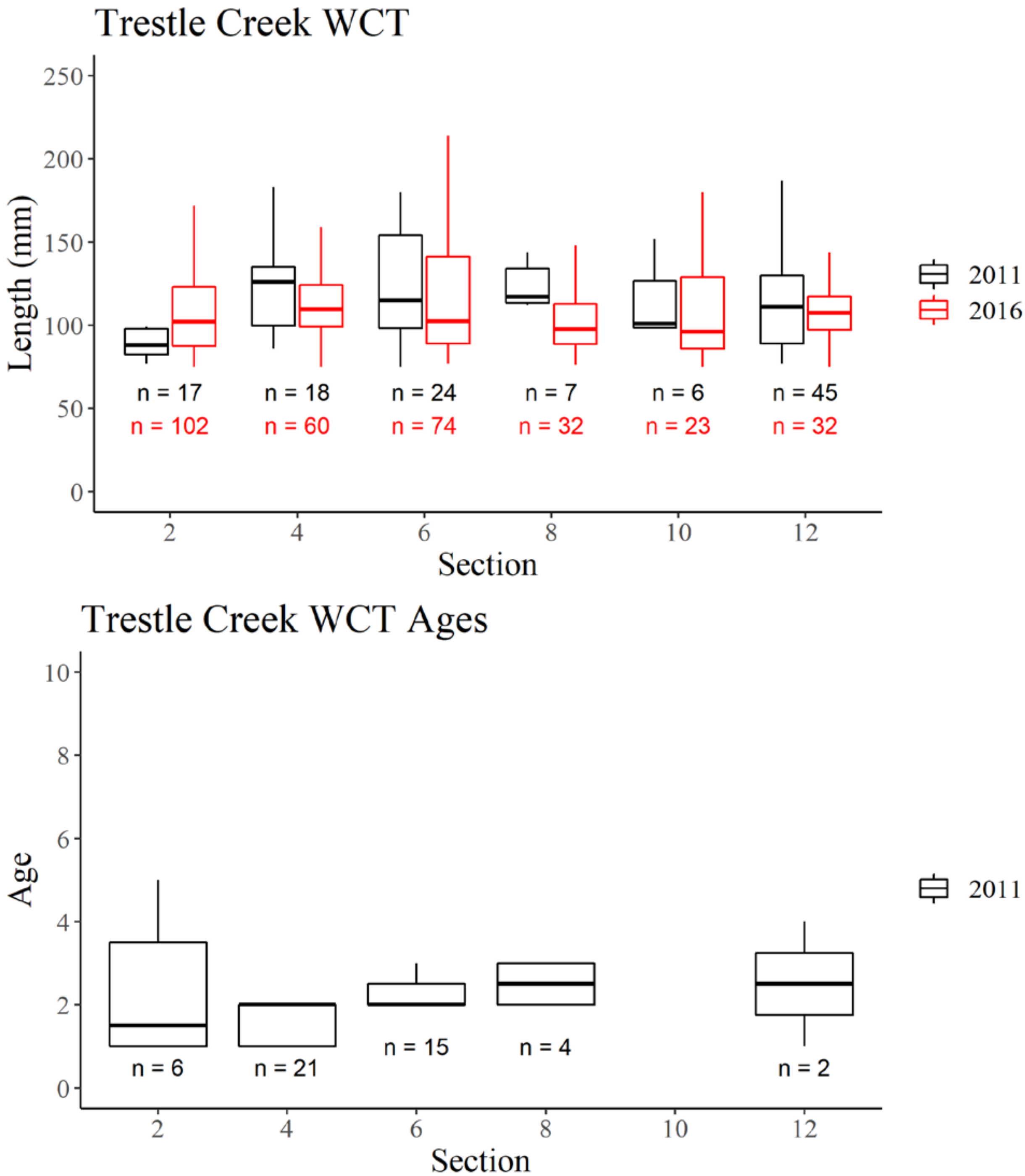


Figure 103. Length (mm; top panel) and age (years; lower panel) of Westslope Cutthroat Trout captured in each section of Trestle Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group. The location of a barrier to upstream migration is identified with a tall black line.

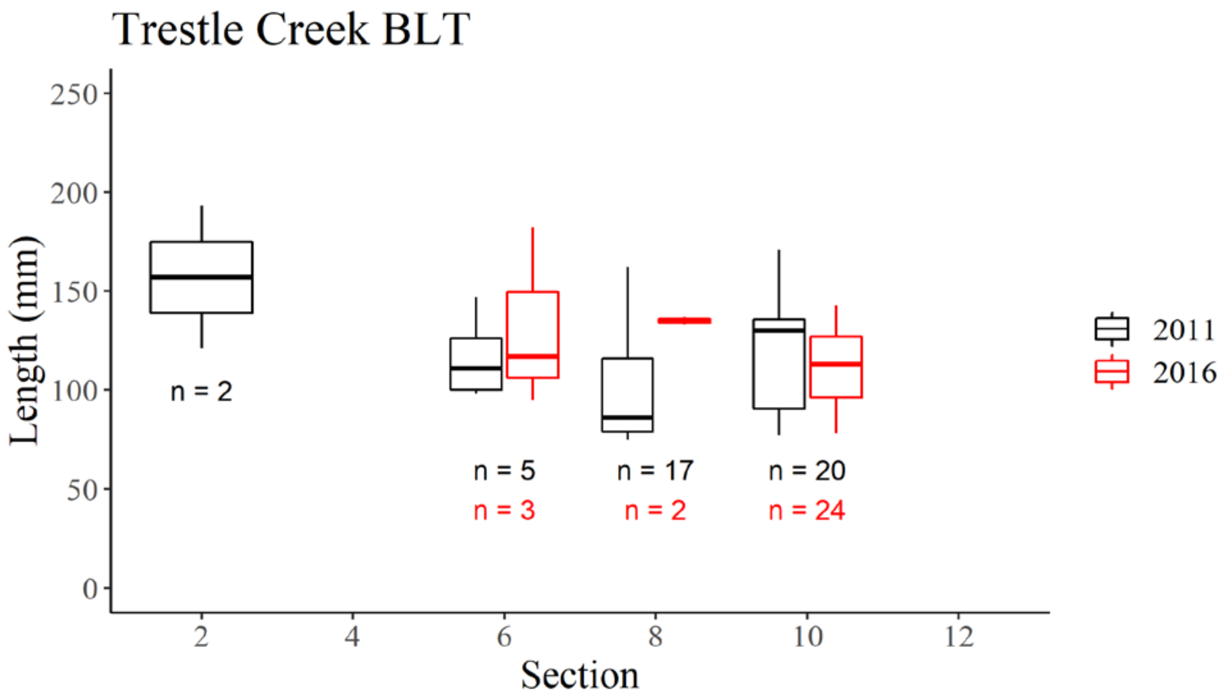


Figure 104. Length (mm) of Bull Trout captured in each section of Trestle Creek. The year of the first sample event is identified in black, and the second sample in red. Boxplots identify the median (center line), interquartile range (box), minimum (lower vertical bar), maximum (upper vertical bar), and sample size (labeled) for each group.

DISCUSSION

Data collected during our monitoring surveys provide detailed longitudinal information on distribution and abundances of salmonids in tributaries to LPO. A third round of monitoring is currently underway and is scheduled for completion in 2023. Thus far, there does appear to be relative stability in a subset of streams; however, roughly half exhibited variable species composition after a five-year period. This sampling strategy is effective for monitoring fish densities at a fine spatial scale within each stream. However, depending on future data needs and ongoing projects within the LPO basin, a reassessment of the frequency and extent of sampling may be warranted to best meet objectives. For example, considerable effort is currently being directed towards investigating the adfluvial life history forms of BLT and WCT, and prioritizing streams where both of these species and life forms reside may benefit the overall goals of the program.

The analysis investigating trends in species composition and distribution was inconclusive after two rounds of sampling. Several streams exhibited changes in overall species composition driven by a loss of BLT and an increase in RBT or WCT. A decrease in BLT or RBT appeared to promote an increase in WCT and may suggest that WCT are less dominant when other species are more prevalent. However, actual abundances of BLT, RBT, WCT, and total fish biomass (>75mm) did not change at the basin-wide scale between sampling events. The juxtaposition of these results highlights the inherent variability in survival and recruitment in tributaries to LPO.

The variability in species composition may be partly influenced by changes to in-lake survival and growth rates of adults. During the ten-year period where tributary sampling was conducted the kokanee population in LPO was recovered to pre-collapse (1999 to 2001; Dux et al. 2019) levels. This resurgence of kokanee also resulted in a recovery of the trophy RBT fishery and body size of adults increased (Andy Dux, personal communication). The observed increase in juvenile RBT in specific tributaries may be the result of an increased number of spawning adults or an increase in fecundity by the individuals present. This same trend may also be occurring with BLT, and likely contributes to the inconsistent relationship between redd counts and juvenile densities. Data investigating total spawner abundance, female fecundity, and egg to age-0 survival have the potential to help understand these population dynamics.

Relative weight (W_r) was below average for RBT and WCT across all sampled tributaries. Fish condition is often considered to be driven by local habitats and environmental conditions (Blackwell et al. 2000). Lake Pend Oreille tributaries are subject to large, but infrequent, rain-on-snow events that restructure the stream channel, redistribute sediments, and remove woody debris. These events may have resulting effects on stream fish populations and the biomass capacity the stream can support. Historical surveys have been conducted to document the distribution of in-stream habitats (Pratt 1985; Cascades Environmental Services, Inc 1998); however, several of these rain-on-snow events have occurred since the last survey and distribution has changed. Additionally, to the authors' knowledge, no study has investigated the current status of aquatic macroinvertebrates within tributaries to LPO that act as a primary food source for fish. The bedload movement dynamics exhibited by these streams may hamper macroinvertebrate populations and reduce the overall prey biomass and diversity (Tonkin et al. 2013, Woodward et al. 2015). Future studies should aim to survey current habitat conditions and investigate seasonal and longitudinal macroinvertebrate distributions, species composition, and densities.

The collection of more age and growth structures would provide valuable information regarding emigration timing by adfluvial fish, the potential for interspecific competition, and annual recruitment (Quist and Isermann 2017). Otoliths are ideal for ageing of salmonid species (Downs et al. 1997, Schill et al. 2010), but non-lethal ageing techniques such as scales or fin rays can also be effective at ageing juveniles (Zymonas et al. 2009). Current knowledge of BLT emigration is that juveniles reside in Trestle Creek until age-3 before emigration to LPO (Downs et al. 2006). While age at emigration is likely similar throughout the basin, this has never been evaluated in streams with longer migration distances, such as Rattle or Caribou creeks. Moreover, little to no information currently exists with respect to emigration dynamics of RBT or WCT within the LPO basin. The lakewide adult WCT surveys conducted with nearshore surface gillnets indicate that WCT are present at age-2; however, they are not fully recruited to the gear until age-4. This may coincide with the age at which all WCT have emigrated out of rearing tributaries before returning as adult spawners. Increasing understanding of these life history strategies can help guide future habitat projects that optimize specific habitats and conditions for these fish before moving to LPO.

Adfluvial WCT exist within LPO, but with the exception of Trestle Creek, Granite Creek, and the Lightning Creek drainage, the extent of tributaries where these fish originate is unknown (Downs and Jakubowski 2007; Ransom et al. 2021a; Ransom et al. 2021b). Results from tributary electroshocking and size at age estimates suggest migratory life histories may be widespread, but this has not been confirmed. Technologies assessing the microchemical composition of sagittal otoliths have the ability to discern natal origin of migratory freshwater fish, and should be considered in the future for this purpose (Pangle et al. 2010). Further, the prevalence of WRHY continues to be sporadic within the LPO basin (Cascades Environmental Services, Inc 1998). Progeny resulting from hybridization events exhibit physical and behavioral differences compared to non-hybrids (Corsi et al. 2013, Strait et al. 2021) and may be more prone to migratory behavior depending on the level of introgression. Future studies should consider implementing a detailed investigation into hybridization prevalence and migratory behavior using both genetic and microchemical analyses.

While small spatial scale changes in species composition occur within tributaries to LPO, abundances across the basin appeared to be stable over a ten-year period. This long-term sampling effort is valuable for identifying large population-scale changes; however, it should be supplemented with other techniques to best inform management decisions, especially at smaller scales (e.g., tributary). These data can be further utilized to identify areas where habitat improvement projects are best suited and should be considered in the future. The third round of tributary sampling is scheduled to be completed in 2023 and should be compared with this study to reassess temporal trends in abundance and distribution for species of interest.

RECOMMENDATIONS

1) Complete third round of standardized 5-year rotational tributary sampling.
2) Increase the collection of scales for investigating age and growth in BLT, RBT, and WCT.
3) PIT-tag WCT above and below barriers for age validation and migratory behavior.
4) Re-evaluate timing and scope of sampling protocol after the completion of the third round of rotational sampling.
5) Investigate the feasibility of assessing stream habitat, primary productivity, and macroinvertebrate populations across the LPO basin.

ACKNOWLEDGEMENTS

The author would like to thank all of the employees and volunteers from Avista, IDFG, MFWP, and others for help in the field. We would like to thank Andy Dux (IDFG), Travis Rehm (MFWP), Kevin Aceituno (USFWS), Paul Kusnierz (Avista) and Sean Moran (Avista) for reviewing previous versions of this report. We would also like to thank Avista employees Nate Hall, Paul Kusnierz, Davina Brown, and Heide Evans for their oversight and administrative support.

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