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Open-File Report 2022–1022

U.S. Department of the Interior
U.S. Geological Survey

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)
yard (yd)	0.9144	meter (m)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	metric ton (t)
ton, long (2,240 lb)	1.016	metric ton (t)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
metric ton (t)	1.102	ton, short [2,000 lb]
metric ton (t)	0.9842	ton, long [2,240 lb]

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Abbreviations

CPUE	catch per unit effort
MS-222	tricaine methanesulfonate
PIT	passive integrated transponder
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

Distribution of Bull Trout (*Salvelinus confluentus*) in Conjunction with Habitat and Trout Assemblages in Creeks within the Klamath Basin, Oregon 2010–16

By Barbara A. Martin[1], Nolan Banish[2], David A. Hewitt[1], Brian S. Hayes[1], Amari Dolan-Caret[1], Alta C. Harris[1], and Caylen Kelsey[1]

Abstract

Bull trout (*Salvelinus confluentus*) in the Klamath Basin are on the southernmost border of the range of the species, where threats are most severe and where bull trout are most imperiled. In their recovery plan the U.S. Fish and Wildlife Service (2015, https://ecos.fws.gov/ecp/report/species-with-recovery-plans) suggested that Klamath Basin bull trout are at increased risk of extirpation due to habitat fragmentation, degradation of habitat complexity, and introduction of non-native trout species that often outcompete bull trout. The goals of this study were to determine if there was a lack of connectivity between habitat areas impeding migration, habitat differences, or interference by non-native species affecting bull trout distribution in the Klamath Basin. This study examined three populations of bull trout in conjunction with a concurrent native species (redband trout [*Oncorhynchus mykiss gairdnerii*]), and a concurrent non-native species (brown trout [*Salmo trutta*]) in tributaries of the upper Sprague River within the Klamath Basin. Culverts present at the beginning of the study may have impeded migration of bull trout, but culvert upgrades made during the study appeared to eliminate the impediments to migration. The presence of non-native brown trout appeared to cause bull trout to use a smaller portion of Leonard Creek, whereas the low numbers of brown trout in the studied portion of Brownsworth Creek did not appear to interfere with the local distribution of bull trout. Downstream migration of bull trout may have been impeded if there were increased numbers of brown trout or increased temperatures in the lower portions of the creeks outside of the study area. Although habitat complexity was not examined in detail during this study, there was an attempt to enhance the habitat for bull trout by introducing large woody debris into treatment sections of the creeks. We compared bull trout numbers between the treatment sections and nearby control sections prior to and after introduction of the large woody debris. The introduction of large woody debris did not appear to enhance the use of those areas by bull trout, but the large woody debris may not have been of suitable size to enhance the habitat for bull trout.

Introduction

Bull trout (*Salvelinus confluentus*) within the coterminous United States were listed as threatened in 1999, and since then there has been very little change in their general distribution (U.S. Fish and Wildlife Service [USFWS], 2015). Prior to listing, bull trout were extirpated from approximately 60 percent of their historical range primarily in the southern and western portions mainly due to habitat degradation and fragmentation, past land management practices, and the introduction of non-native species (Rieman and others, 1997; Thurow and others, 1997; USFWS, 2010; USFWS, 2015). Bull trout occur in Washington, Oregon, Montana, Idaho, and Nevada. Within these states are six recovery units: (1) Coastal Recovery Unit; (2) Klamath Recovery Unit; (3) Mid-Columbia Recovery Unit; (4) Upper Snake Recovery Unit; (5) Columbia Headwaters Recovery Unit; and (6) Saint Mary Recovery Unit (USFWS, 2015). At the time of listing, there were 187 populations identified within these recovery units. This project focused on a subset of the populations within the Klamath Recovery Unit, where threats are most severe and in which bull trout are most imperiled (USFWS, 2015).

Three core areas have been defined in the Klamath Recovery Unit: Sycan River, Upper Sprague River, and Upper Klamath Lake. When USFWS published their recovery plan in 2015, the Klamath Recovery Unit had eight extant populations (one in the Sycan River area, five in the Upper Sprague River area, and two in the Upper Klamath Lake area) and nine populations known to be extirpated. The loss of over half of its bull trout populations, loss of physical habitat, presence of dispersal barriers, and presence of non-native species led to the listing of this unit as the most imperiled (USFWS, 2015).

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Bull trout exhibit two life history strategies: migratory and resident. Individuals that adopt a migratory life history are either adfluvial, fluvial, or anadromous. Adfluvial forms generally spend their first 4 years in their natal stream before migrating to lakes for their adult residence and returning to streams for spawning (Downs and others, 2006). Fluvial forms complete all their life stages within streams, but adults migrate up tributaries for spawning in their fourth or fifth year of life (Fraley and Shepard, 1989). Anadromous forms can be found in certain coastal regions (Brenkman and Corbett, 2005). These anadromous forms exhibit complex migratory patterns. Resident forms generally spawn at smaller sizes and presumably younger ages than migratory bull trout and do not attain as great a length as the migratory forms (Al-Chokhachy and Budy, 2008). Moyle (2002) suggested that most resident populations, which generally occur in small streams, are remnants of fluvial populations that no longer have access to previously available habitat and therefore complete their entire life cycle in their natal stream. Furthermore, other authors have found that the ability to migrate is essential to the persistence of the species, allowing individuals to utilize favorable habitat that is only available on an intermittent basis (Rieman and others, 1997; Dunham and Rieman, 1999; Muhlfeld and Marotz, 2005). Bull trout populations in the Klamath Recovery Unit are primarily resident forms that are believed to be limited by a variety of dispersal barriers including road culverts. The USFWS recovery plan (2015) identified the Leonard and Brownsworth Creek populations as resident forms.

The habitat of bull trout is typified by cold and clear water with complex habitat that is free of migration barriers (USFWS, 2015). Moyle (2002) suggested that the optimal temperature for survival and growth of juveniles and adults is 12–14 °C and for embryo incubation is 4–6° C. Likewise, Dunham and others (2003) found that the probability of finding a bull trout in an area was low (< 0.50) when maximum daily temperatures were above 14–16 °C, with bull trout usually located in waters 11–12 °C (probability > 0.75). Furthermore, Selong and others (2001) found that maximum growth with access to unlimited rations occurred at 13.2 °C. Bull trout use complex stream habitat cover such as deep pools, overhanging banks, large woody debris, root wads, or large boulders (Rieman and McIntyre, 1995; Watson and Hillman, 1997; Jakober and others, 1998; Rich and others, 2003). Consequently, bull trout are generally found in upper elevation streams where stream temperature is cold, and the habitat is still largely unaltered.

In streams where invasive species such as brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*) are present, these species have been implicated in the decline of bull trout and are considered to be an important reason for the listing of bull trout as threatened (Al-Chokhachy and others, 2016; Kovach and others, 2017). Brook trout have displaced bull trout due to their increased growth rates, which gives them a competitive advantage (Gunckel and others, 2002; McMahon and others, 2007). Hybridization is common between brook and bull trouts, leading to wastage of gametes due to mostly sterile interspecific hybrids (Leary and others, 1993). Brown trout have been shown to prey on juvenile and subadult bull trout (Al-Chokhachy and others, 2016). They also compete with bull trout for food, as both are top level predators (Al-Chokhachy and others, 2016). Furthermore, brown trout have been shown to interfere with bull trout reproductive success through redd superimposition (Al-Chokhachy and others, 2016).

Research suggests that bull trout may fare better in the face of competition with non-native trout if habitat complexity is high. For instance, Rich and others (2003) determined that bull trout may have an elevated biotic resistance to brook trout in streams with complex habitats, which include large woody debris. A reduction in natural, complex habitats is detrimental for native salmonids and may enable non-native species to colonize degraded habitat (Moyle and Light, 1996 a,b). Therefore, resource managers will need to understand if increasing habitat complexity in degraded reaches of streams will benefit the recovery of bull trout where they co-occur with non-native trout.

During this project we studied three of the Upper Sprague River core area bull trout populations in the Klamath Recovery Unit: Leonard, Brownsworth, and Boulder Creeks. Our study focused on tracking population changes through time in Leonard and Brownsworth Creeks. Our goal was to determine if bull trout distribution was affected by habitat differences, interference by non-native species, or a lack of connectivity resulting from migratory impediments. Specifically, we addressed (1) whether existing culverts presented a barrier to bull trout movements; (2) whether the addition of large woody debris in certain segments of each of the creeks increased detection of bull trout in those segments; and (3) whether habitat was partitioned among the different species within each of the creeks.

Study Area

The three creeks that were sampled during this study are all tributaries of the Sprague River and all originate in Southern/Central Oregon’s Lake and Klamath Counties (fig. 1). Each creek is a first or second order stream (based on a 1:24,000 U. S. Geological Survey topographic map) that originates in the Gearhart Mountain Wilderness (Banish and others, 2016). Leonard Creek is a tributary to Brownsworth Creek, which flows into the South Fork Sprague River, and Boulder Creek is a tributary to the North Fork Sprague River. Boulder Creek is located west of Gearhart Mountain, whereas Leonard and Brownsworth Creeks are located south of the mountain. Within each of the three creeks, we aimed to establish study reaches that were 250-meters (m) long. Actual distances of study reaches varied based on suitability of block net placement for initial capture of trout and ranged from 164 to 445 meters. Culverts were located at road crossings of Leonard and Brownsworth Creeks (figs. 2 and 3).

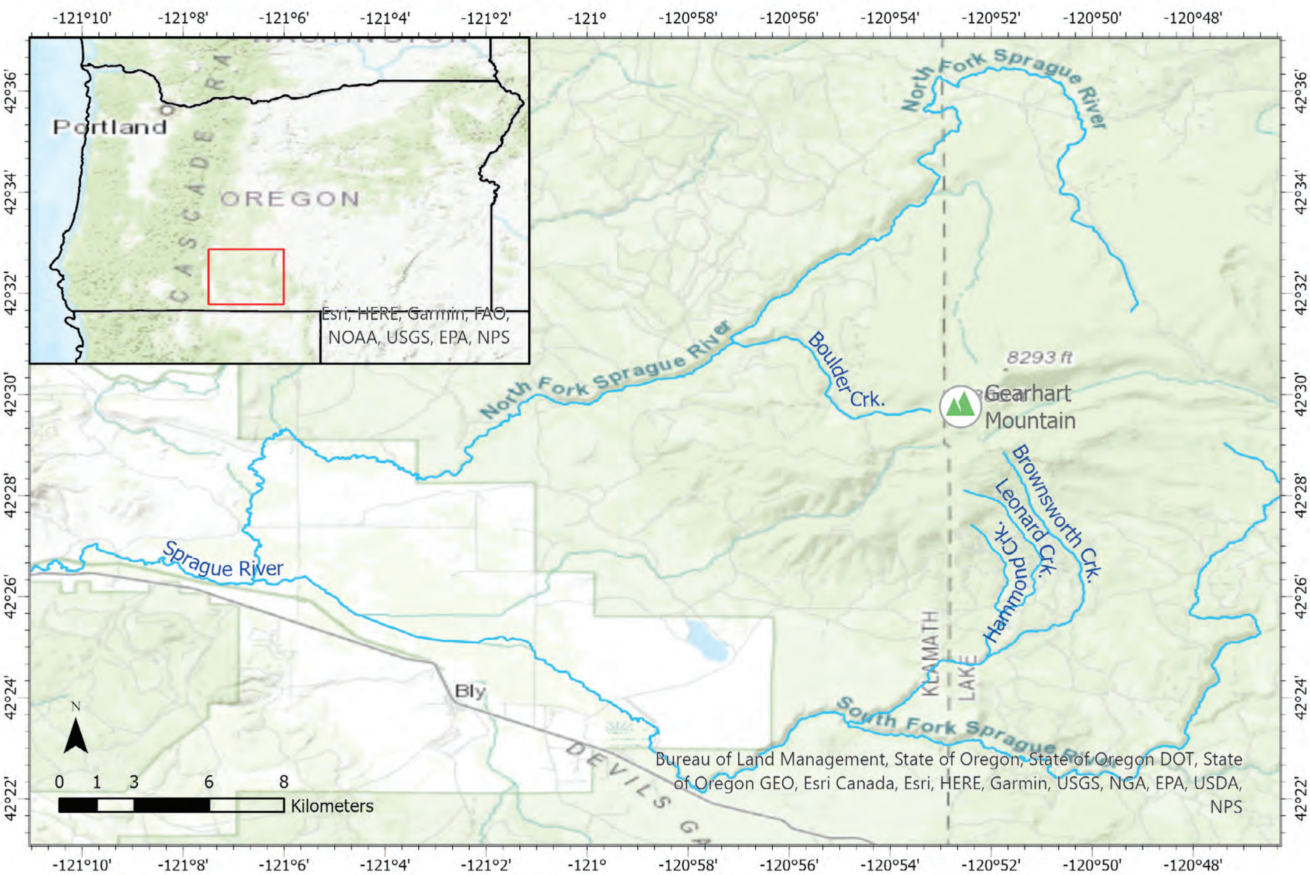

Figure 1. Locations of creeks surveyed during this study, Klamath Basin, southern Oregon. Map uses NAD 1983 datum.

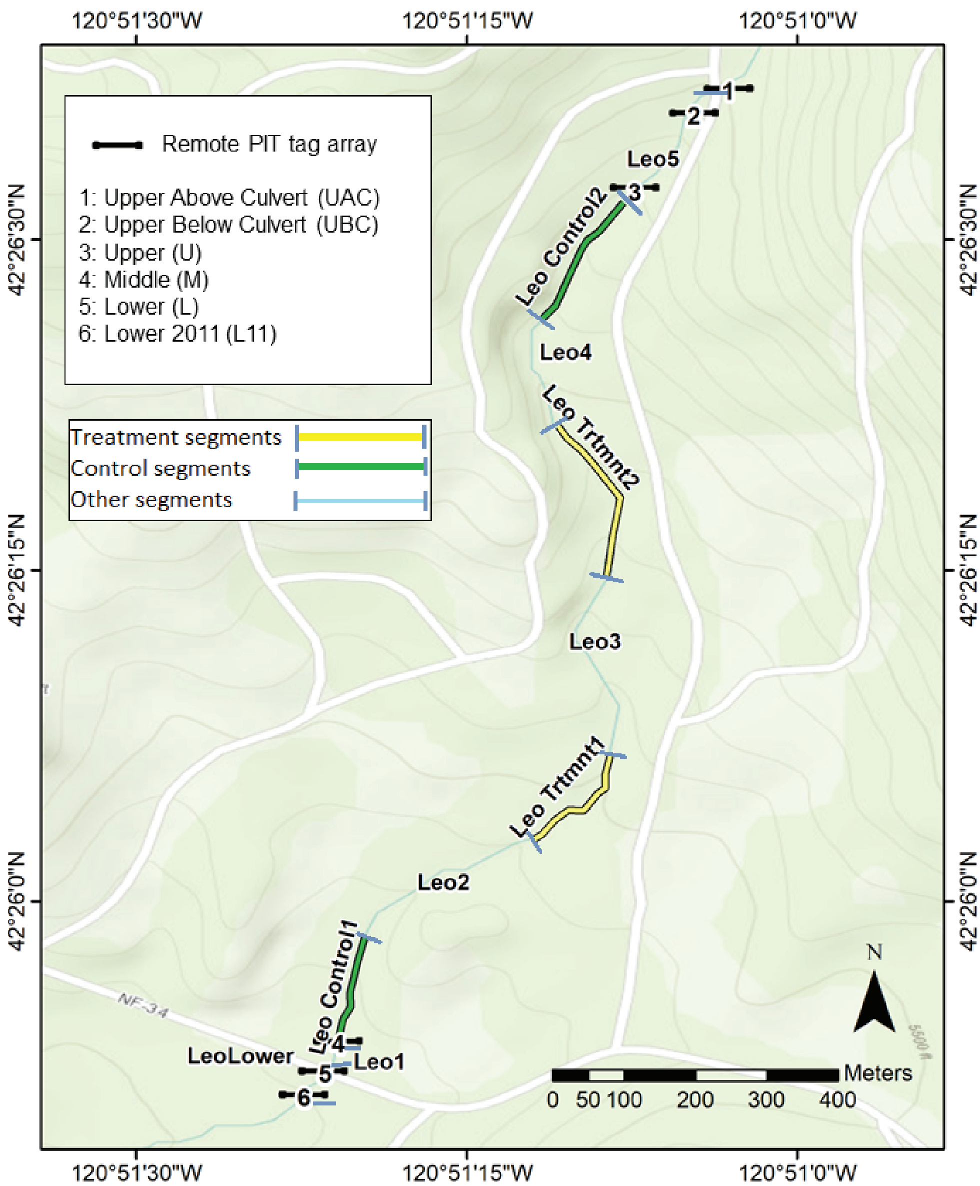

Figure 2. Preset study reaches and passive integrated transponder (PIT) tag antenna placement in Leonard Creek, Klamath Basin, Oregon. Culverts are located at road crossings.

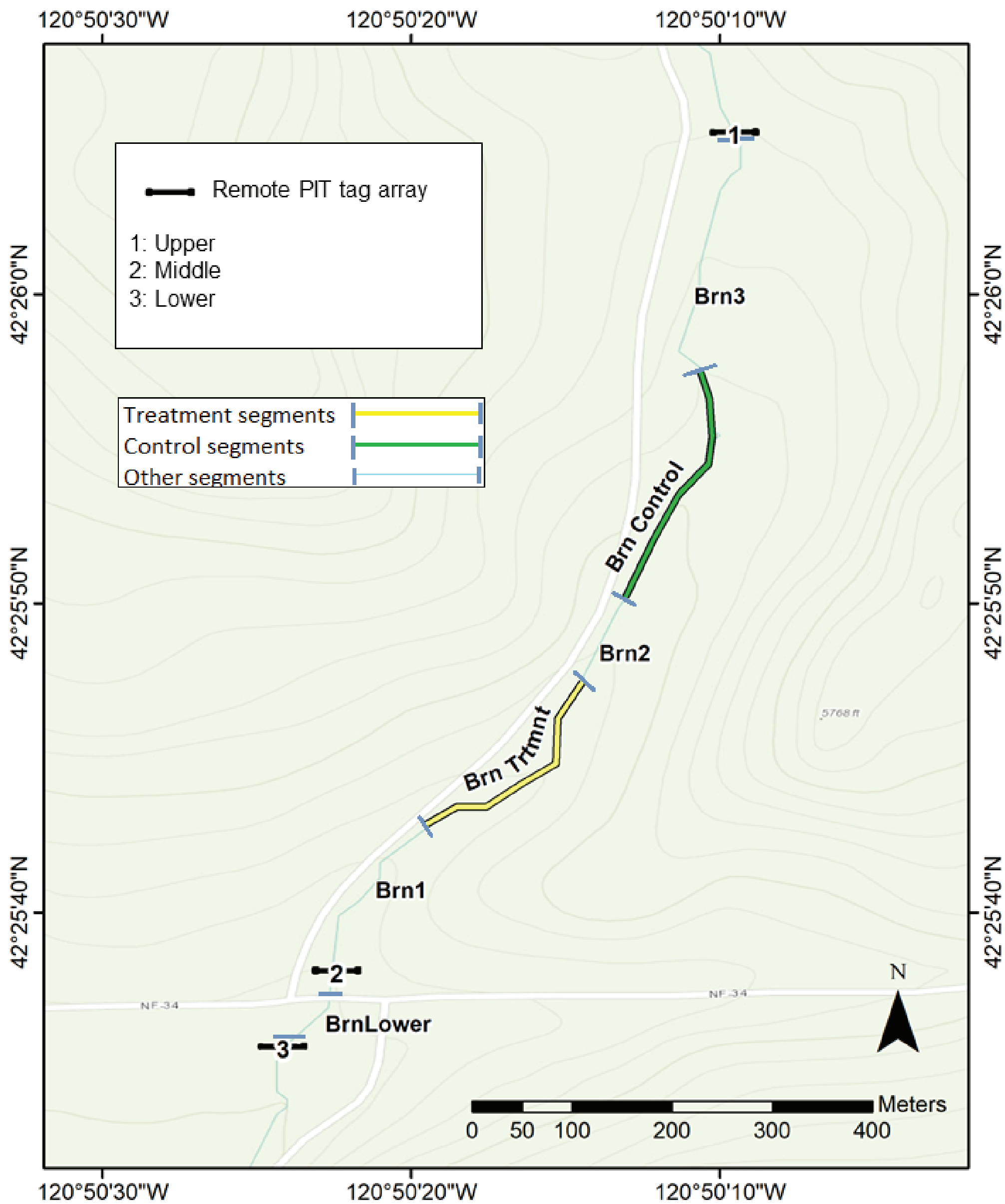

Figure 3. Preset study reaches and passive integrated transponder (PIT) tag antenna placement in Brownsworth Creek, Klamath Basin, Oregon. Culverts are located at road crossings.

Methods

Collection and Tagging of Trout

Sampling events occurred during summer (June–August) 2010–14 and 2016 (table 1). To capture fish, we used a Smith-Root (Vancouver, Washington) LR-24 backpack electrofisher set at 650–750 volts (V), 50–60 hertz (Hz), and pulsed direct current, with an 11-inch stainless-steel anode ring electrode and a rat tail cathode. Sampling time was not recorded in 2010 and 2011 but was recorded during the remainder of the study. Spot readings of water temperature were taken at the beginning and end of each sampling day. All trout species (bull, brown, and redband [*Oncorhynchus mykiss gairdnerii*]) captured during sampling were measured for fork length to the nearest millimeter (mm) and checked for a passive integrated transponder (PIT) tag. If a PIT tag was not detected, the fish was sedated with 15–30 milligrams per liter (mg/L) tricaine methanesulfonate (MS-222) and tagged with a 9- or 12-millimeter (mm) full-duplex PIT tag using a 12-gauge needle inserted into the dorsal musculature of the fish posterior to the dorsal fin. The 9 mm tags were used on smaller fish in the range of 70–99 mm fork length, whereas the 12 mm tags were used on fish greater than 99 mm fork length. After handling and tagging, trout were placed in a bucket of fresh creek water until they regained equilibrium. Trout were subsequently released evenly throughout the enclosed reach from which they were captured. In 2010, capture location within the creek was broadly recorded as above or below Forest Service Road 34 (NF-34). In 2010, all sampling in Leonard Creek was above the culvert located at Forest Service Road 34, whereas in Brownsworth Creek sampling on July 19 and 20 was above the culvert at Forest Service Road 34 and on July 21 was below the culvert. In 2011 and 2012, sampling occurred in 100 meter stream segments that were converted to the study reaches used in later years (table 2). However, because study reaches did not start and end within 100 m stream segments, there may have been errors associated with assigned study reaches. During 2013, 2014, and 2016, sampling was conducted in preset study reaches of Leonard and Brownsworth Creeks (figs. 2 and 3; table 2).

Active Detections Using Portable Passive Integrated Transponder (PIT) Tag Antennas

Surveys were conducted during the summers of 2010–13 in Leonard and Brownsworth Creeks and on July 20, 2012 in Boulder Creek using Biomark BP portable antenna detection wands (table 1). The portable antenna was connected to a chest pack containing a Biomark portable transceiver (model FS2001FS-ISO) that recorded all detected PIT tags, a tuning box that controlled antenna current, and a 12-V sealed lead acid battery that provided power (Banish and others, 2016). In 2011–12, surveys in Leonard and Brownsworth Creeks often occurred just prior to or just after electrofishing. A wand survey only occurred once in Boulder Creek, and it took place 2 days after tagging. During 2012–13, locations of detections in Leonard and Brownsworth Creeks were recorded for preset study locations; otherwise, detection locations were recorded as within a 100 m reach (figs. 2 and 3; table 2). Detection locations that were recorded in 100 m stream segments sometimes overlapped two study reaches. Therefore, assignment of a 100 m stream segment did not necessarily correspond to the proper study reach, with a possibility of having assigned a trout detection location to an adjacent study reach. Sampling in each creek was completed from downstream to upstream in a single pass that often spanned multiple days, with one complete pass occurring each month from June or July through September.

Table 1. Sampling events of electrofishing or portable antenna surveys by creek and year, Klamath Basin, Oregon.

[Date format is month/day. Biomark BP portable antenna detection wands and Biomark receiver (model FS2001FS-ISO) were used. –, not applicable]

Year	Leonard Creek	Brownsworth Creek	Boulder Creek
	Electrofishing		
2010	7/9, 7/12, 7/13, 7/14, 7/15, 7/19	7/19, 7/20, 7/21	–
2011	6/15, 6/16, 6/17, 6/20, 6/21, 6/22, 6/27, 7/18, 8/8	6/27, 6/28, 6/29, 6/30, 7/19, 8/9	–
2012	6/27, 6/28, 7/9, 7/10, 7/12, 7/31	6/25, 6/26, 7/10, 7/11	7/18
2013	6/20, 6/25, 6/26, 6/27, 6/28, 7/1, 7/2, 7/3	6/17, 6/18, 6/19, 7/3	–
2014	7/9, 7/10	7/8, 7/9	–
2016	6/27, 6/29		–
	Portable antenna		
2010	10/4		–
2011	6/14, 6/15, 7/19, 7/20, 8/10, 8/11, 9/13, 9/14	6/14, 6/15, 7/19, 8/9, 9/12, 9/13	–
2012	7/10, 7/11, 7/16, 8/27, 8/28, 8/29, 9/17, 9/18, 9/20	7/11, 7/12, 7/16, 8/28, 9/17	7/20
2013	7/15, 7/16, 8/12, 8/13, 8/14, 9/9, 9/10, 9/11	7/15, 7/16, 8/12, 8/13, 9/9, 9/10	–

Table 2. Locations of study reaches based on distance (in meters) from culvert at Forest Service Road 34 (NF-34) and global position system (GPS).

Site	Meters above NF-34		GPS Start		GPS End	
	Start	End	Latitude	Longitude	Latitude	Longitude
Leonard Creek						
Leo5	1,690	2,000	42.442028	-120.852380	42.443548	-120.851025
Leo Control2	1,425	1,690	42.439930	-120.853357	42.442028	-120.852380
Leo4	1,275	1,425	42.439210	-120.853020	42.439930	-120.853357
Leo Trtmnt2	1,000	1,275	42.437445	-120.852335	42.439210	-120.853020
Leo3	655	1,000	42.435237	-120.852478	42.437445	-120.852335
Leo Trtmnt1	465	655	42.434082	-120.853268	42.435237	-120.852478
Leo2	200	465	42.432763	-120.855412	42.434082	-120.853268
Leo Control1	20	200	42.431382	-120.855822	42.432763	-120.855412
Leo1	0	20	42.431098	-120.855952	42.431382	-120.855822
LeoLower	-1,000	0	42.427654	-120.863158	42.431098	-120.855952
Brownsworth						
Brn3	1,000	825	42.432327	-120.836125	42.434142	-120.836008
Brn Control	585	825	42.430553	-120.837012	42.432327	-120.836125
Brn2	455	585	42.429765	-120.837317	42.430553	-120.837012
Brn Trtmnt	215	455	42.428482	-120.838722	42.429765	-120.837317
Brn1	0	215	42.427097	-120.839657	42.428482	-120.838722
Brn Lower	-130	0	42.425977	-120.840013	42.427097	-120.839657

Prior to the start of the study, the creeks did not have much large woody debris, and the large woody debris present was degraded. Furthermore, because the riparian forest was young, the likelihood of large woody debris recruited into the system was low. In an attempt to enhance habitat for bull trout, large woody debris was added to the treatment sections of Leonard and Brownsworth Creeks in September 2012. Large woody debris consisted of logs (20–30 centimeters [cm] in diameter and 1–3 m in length) that were covered with green limbs 10–15 cm in diameter (fig. 4). Seven of these log structures were added to the lower treatment section, and 10 were added to the upper treatment section in Leonard Creek, while 10 were added to the treatment section in Brownsworth Creek. Active detections of trout were compared by section before and after introductions of the large woody debris.

Remote Detections Using Stationary Passive Integrated Transponder (PIT) Tag Antennas

Stationary PIT tag antennas were generally deployed in late spring and removed in late autumn (table 3). A PIT tag antenna array was established in several unique locations within each creek (figs. 2 and 3) with each array containing up to three individual antennas that were placed 20–30 m apart (upstream to downstream). In Leonard Creek there were 9 antennas deployed during 2011 and 2012, 13 during 2013 and 2014, and 8 during 2015 and 2016 (table 4). In Brownsworth Creek, a total of nine antennas were deployed during 2011, 2012, and 2013. Antenna locations in Brownsworth Creek were consistent across years. Three each were located in the lower (below the culvert at road 34), middle (above the culvert at road 34), and upper portions of the creek (fig. 3).

All detections throughout the study were remotely recorded on Allflex (Madison, WI) Panel Readers at each station, except those at Leonard Creek in 2015 and 2016. Biomark (Boise, ID) IS1001 and Master controllers were used in 2015 and 2016 for the sites in Leonard Creek. One station controlled the antennas around the upper culvert, and one controlled the antennas around the lower culvert.

During this study, the culverts within the study area in Leonard Creek were replaced or modified to provide or improve fish passage (Upper Leonard replaced September 2013; Lower Leonard modified August 2014). We compared fish passage before and after replacement of the culverts. The Brownsworth Creek culvert was not replaced because it was assumed that the culvert did not impede fish passage, and we examined this assumption during this study.

Figure 4. Example of addition of large woody debris in Leonard Creek, Klamath Basin, Oregon. Photograph taken by Nolan Banish, U.S. Fish and Wildlife Service, September 2012.

Table 3. Dates antennas were deployed by creek and year, Klamath Basin, Oregon.

Year	Leonard Creek	Brownsworth Creek
2011	June 9 to November 15	June 13 to November 15
2012	June 13 to November 26	June 6 to November 26
2013	May 29 to November 18	May 31 to November 18
2014	June 18 to November 25	June 26 to November 25
2015	September 10 to December 7	None deployed
2016	June 7 to November 21	None deployed

Table 4. Number of antennas in each array by locations in Leonard Creek by year, Klamath Basin, Oregon.

[**Antenna locations**: **L11,** Lower 2011. **L,** Lower. **M,** Middle. **U,** Upper. **UBC,** Upper Below Culvert. **UAC,** Upper Above Culvert. All locations are shown in figure 2.]

Year	L11	L	M	U	UBC	UAC
2011	3	2	1	3	0	0
2012	0	3	3	3	0	0
2013	0	3	3	3	2	2
2014	0	3	3	3	2	2
2015	0	2	2	0	2	2
2016	0	2	2	0	2	2

Results

Trout Captured and Tagged

A total of 1,730 unique trout were captured and tagged during this study (1,023 bull, 516 redband, and 191 brown; table 5). Bull trout comprised the majority of trout captured at each of the three creeks (60 percent at Leonard, 56 percent at Brownsworth, and 67 percent at Boulder). The most trout, including recaptures, were captured during 33 sampling days in Leonard Creek (N=1,164), followed by Brownsworth Creek (N=640) over 19 sampling days, and then Boulder Creek (N=94) in a single sampling day. Number of trout captured per unit effort (CPUE), based on number of trout captured per minute of sampling, was greatest at Boulder Creek (0.40 CPUE), followed by Brownsworth Creek (0.22 CPUE), and then Leonard Creek (0.20 CPUE: table 5). Bull trout CPUE per creek followed the same order as overall trout CPUE; however, for redband trout the order of abundance was Brownsworth, Leonard, and then Boulder, with no redband trout captured in Boulder Creek. Brown trout CPUE was greatest at Boulder, followed by Leonard, and then Brownsworth creek. Sampling temperatures ranged from 3.4 to 15.4 °C (mean=10.3 °C) in Leonard Creek and 4.5 to 14.8 °C (mean=10.0 °C) in Brownsworth Creek.

Only a small proportion of trout (8.8 percent, N=153) were recaptured during the study (table 6). There were more trout recaptured in Leonard Creek; however, there was a higher proportion of trout recaptured in Brownsworth Creek. There were 141 trout recaptured once and 12 trout recaptured twice during the study (tables 7 and 8). Of the 141 trout recaptured once, 32 (23 percent) were recaptured in the same year as tagging, 98 (70 percent) were recaptured the following year, 9 were recaptured 2 years after tagging (6 percent), and 2 were recaptured 3 years after tagging (1 percent). Of the 12 trout that were recaptured twice, 7 (58 percent) were captured 3 years in a row, whereas 5 (42 percent) were recaptured twice in the year following tagging.

The capture locations of trout were recorded from 2011 through 2016, and the number of trout captured differed by location sampled (table 9). In 2010, all trout from Leonard Creek were collected above Forest Service Road 34 without distinction as to which study location they were captured in, whereas in Brownsworth Creek 11 bull trout and 17 redband trout were captured from above the culvert, and 3 bull trout were captured from below the culvert. Although bull trout were found throughout Leonard Creek, captures in the upper sections of Leonard Creek included primarily bull trout. Redband and brown trout were mainly found in the lower sections of Leonard Creek. Within Brownsworth Creek, bull and redband trout were evenly distributed throughout the creek, and brown trout were only captured in the lower portion of the creek during a single year.

With the exception of brown trout in Boulder Creek, fish were generally similar in size (fig. 5). However, the modal groups of the fish species at the different creeks appear to show different age groups at length for the different species (fig. 6). Generally, bull trout appear to grow slower than redband and brown trout, as seen by the peaks in length frequency occurring at smaller lengths. However, since we did not age the trout but instead relied on length data, this observation may not be accurate for the individual age groups.

We examined the overall growth of individuals that were captured more than once during the study, and there was no difference in growth of trout between creeks or among species (figs. 7 and 8). Most of the recaptured trout appeared to be between age-0 and age-2 when growth was greatest; growth after assumed age-2 appeared to slow (fig. 8). Seven individual bull trout (three from Leonard and four from Brownsworth) were captured over 3 years and based on their initial capture size were assigned to a year class. Although our sample sizes were extremely small, we compared the slopes of the growth curves to see if growth was similar among individuals (fig. 9). Generally, growth rates were similar with some differences in year class growth within a year. One individual from Leonard Creek appeared to be an outlier with slower growth from presumed age-1 to age-2 and increased growth from presumed age-2 to age-3. There does not appear to be an influence of the year of capture for the four individuals from Brownsworth Creek captured in 2012–14, whereas each individual from Leonard Creek was collected in different consecutive years (one each 2010–12, 2011–13, and 2012–14).

Active Detection of Trout

Forty-four percent (N=472) of trout tagged from Leonard Creek from 2010 to 2013 were detected as free-swimming individuals at least once using portable PIT tag antennas from 2010 to 2013 (table 10). Per species tagged, there were more redband trout detected (53 percent; N=144) than bull (45 percent; N=290) or brown (25 percent; N=38) trout. The majority of tagged trout were only detected once (N=288, 61 percent), with 25 percent (N=117) detected twice, 7 percent (N=33) detected three times, and the remaining 7 percent (N=13) detected 4–8 times. Only 74 individuals (41 bull, 26 redband, and 7 brown) were detected over multiple years, with 6 of these individuals (3 each bull and redband) detected all 3 years (table 11). Thirty-four of the 74 individuals detected over multiple years were tagged in 2012 and therefore could not be detected in more than 2 years.

Table 5. Number of trout passive integrated transponder (PIT) tagged and catch per unit effort (in parenthesis) based on number of trout captured per minute for each year and species in each of the three creeks.

[**Bull**, bull trout (*Salvelinus confluentus*). Brown, brown trout (*Salmo trutta*). Redband, redband trout (*Oncorhynchus mykiss gairdnerii*). **Symbol**: —, not sampled]

Year	Leonard Creek			Brownsworth Creek			Boulder Creek		
	Bull	**Brown**	**Redband**	**Bull**	**Brown**	**Redband**	**Bull**	**Brown**	**Redband**
2010	61 (–)	9 (–)	28 (–)	14 (–)	0 (–)	17 (–)	–	–	–
2011	72 (–)	69 (–)	63 (–)	73 (–)	5 (–)	117 (–)	–	–	–
2012	150 (0.156)	52 (0.052)	125 (0.120)	110 (0.164)	0 (0.000)	64 (0.104)	63 (0.270)	31 (0.133)	0 (0.000)
2013	251 (0.119)	9 (0.004)	43 (0.021)	73 (0.122)	0 (0.000)	38 (0.057)	–	–	–
2014	73 (0.188)	11 (0.022)	8 (0.022)	47 (0.146)	0 (0.000)	10 (0.036)	–	–	–
2016	36 (0.141)	5 (0.018)	3 (0.014)	–	–	–	–	–	–
Total	643	155	270	317	5	246	63	31	0

Table 6. Number of trout and proportion of total trout recaptured per species in each of Leonard and Brownsworth Creeks, Klamath Basin, Oregon.

[**Bull**, bull trout (*Salvelinus confluentus*). **Brown**, brown trout (*Salmo trutta*). **Redband**, redband trout (*Oncorhynchus mykiss gairdnerii*)]

Species	Leonard Creek		Brownsworth Creek	
	Number	Percent	Number	Percent
Bull	69	10.7	40	12.6
Brown	7	4.5	0	0.0
Redband	13	4.8	24	9.8
All trout	89	8.3	64	11.3

Table 7. Number of trout only recaptured once separated by time frame (year) of recapture by species and creek, Klamath Basin, Oregon.

[**0** indicates recapture within the same year. **1, 2, 3**, indicate number of years after tagging that trout were recaptured. **Bull**, bull trout (*Salvelinus confluentus*). Brown, brown trout (*Salmo trutta*). Redband, redband trout (*Oncorhynchus mykiss gairdnerii*).]

Species	Leonard Creek				Brownsworth Creek		
	0	1	2	3	0	1	2
Bull	7	50	5	2	10	23	2
Brown	2	5	0	0	0	0	0
Redband	2	10	1	0	11	10	1
All trout	11	65	6	2	21	33	3

Table 8. Number of trout recaptured twice separated by time frame (year) of recapture by species and creek, Klamath Basin, Oregon.

[**Year** indicates the number of years after tagging that a trout was recaptured. **Bull**, bull trout (*Salvelinus confluentus*). Redband, redband trout (*Oncorhynchus mykiss gairdnerii*).]

Species	Leonard Creek		Brownsworth Creek	
	Year 1 (twice)	Years 1 and 2 (once each)	Year 1 (twice)	Years 1 and 2 (once each)
Bull	2	3	1	4
Redband	0	0	2	0
All trout	2	3	3	4

Table 9. Number of trout captured at preset locations at each creek separated by year sampled and species, Klamath Basin, Oregon.

[**Bull**, bull trout (*Salvelinus confluentus*). **Brown**, brown trout (*Salmo trutta*). **Redband**, redband trout (*Oncorhynchus mykiss gairdnerii*). Sections are listed from upstream to downstream. **Symbol**: –, not sampled]

Year	Bull					Redband					Brown				
	2011	2012	2013	2014	2016	2011	2012	2013	2014	2016	2011	2012	2013	2014	2016
Leonard Creek															
Leo5	19	23	93	0	32	0	2	2	0	1	1	1	0	0	0
Leo Control2	6	28	48	43	–	1	1	1	2	–	2	0	0	0	–
Leo4	9	13	29	0	–	0	1	0	0	–	1	0	0	0	–
Leo Trtmnt2	22	50	22	36	–	7	15	4	7	–	1	3	0	0	–
Leo3	5	13	17	0	–	11	41	16	0	–	1	4	1	0	–
Leo Trtmnt1	1	7	21	12	–	0	16	7	2	–	0	2	1	2	–
Leo2	2	9	35	0	–	3	14	13	0	–	1	3	2	0	–
Leo Control1	2	11	8	4	–	3	15	3	0	–	4	5	1	6	–
Leo1	0	3	0	0	6	0	2	2	0	0	0	2	0	0	4
Leo Lower	18	7	2	0	2	42	19	0	0	3	62	35	4	3	1
Brownsworth Creek															
Brn3	16	55	18	0	–	17	37	7	0	–	0	0	0	0	–
Brn Control	10	24	9	8	–	10	14	7	6	–	0	0	0	0	–
Brn2	7	8	18	0	–	7	8	2	0	–	0	0	0	0	–
Brn Trtmnt	11	10	18	22	–	20	3	14	3	–	0	0	0	0	–
Brn1	4	15	19	13	–	6	8	5	0	–	0	0	0	0	–
BrnLower	27	18	16	14	–	60	12	5	5	–	5	0	0	0	–

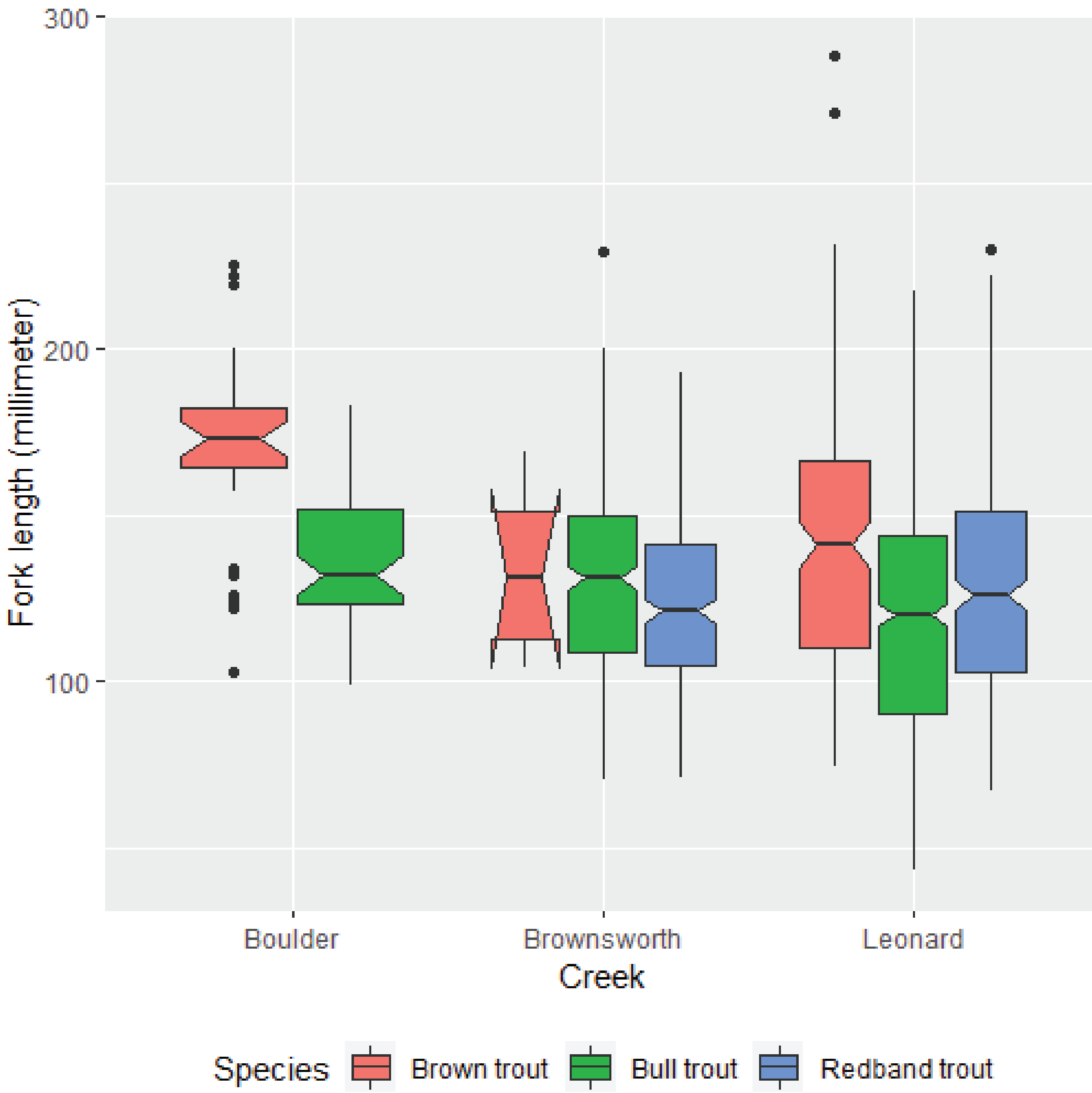

Figure 5. Comparisons of fork lengths of brown trout (*Salmo trutta*), bull trout (*Salvelinus confluentus*), and redband trout (*Oncorhynchus mykiss gairdnerii*) at Boulder, Brownsworth, and Leonard Creeks, Klamath Basin, Oregon, 2010–16. [Black lines within boxes represent the median of data, boxes represent the 1st and 3rd quartiles, and whiskers represent minimums and maximums determined by (quartile – 1.5 * interquartile range). Circles represent outliers determined by points outside the whisker range.]

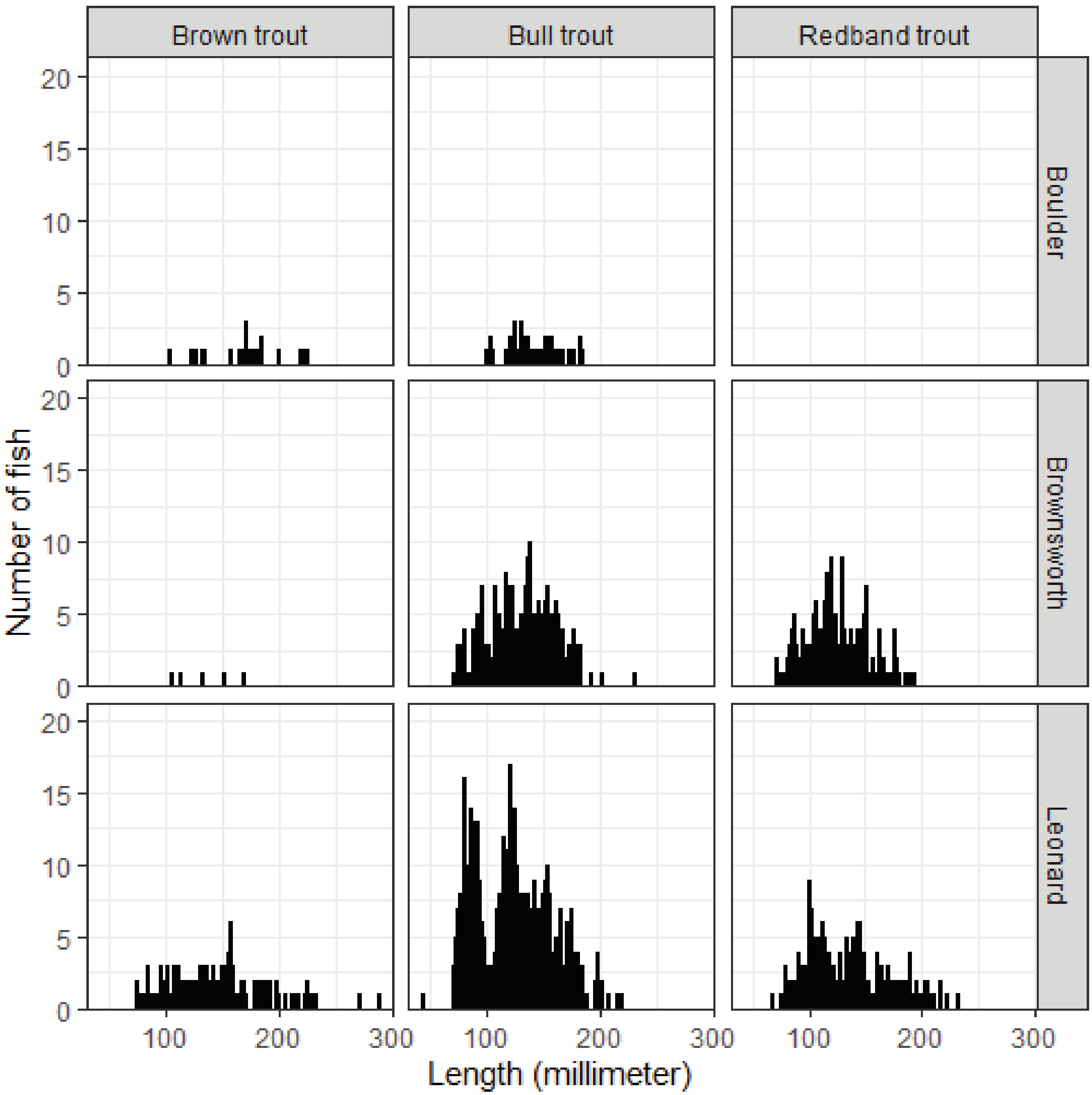

Figure 6. Length frequency of brown trout (*Salmo trutta*), bull trout (*Salvelinus confluentus*), and redband trout (*Oncorhynchus mykiss gairdnerii*) by creek in Klamath Basin, Oregon, 2010–16.

Figure 7. Comparison of growth of trout that were recaptured during this study, Klamath Basin, Oregon, 2010–16. Brown, brown trout (*Salmo trutta*); bull, bull trout (*Salvelinus confluentus*); redband, redband trout (*Oncorhynchus mykiss gairdnerii*). [Black lines within boxes represent the median of data, boxes represent the 1st and 3rd quartiles, and whiskers represent minimums and maximums determined by (quartile – 1.5 * interquartile range). Circles represent outliers determined by points outside the whisker range.]

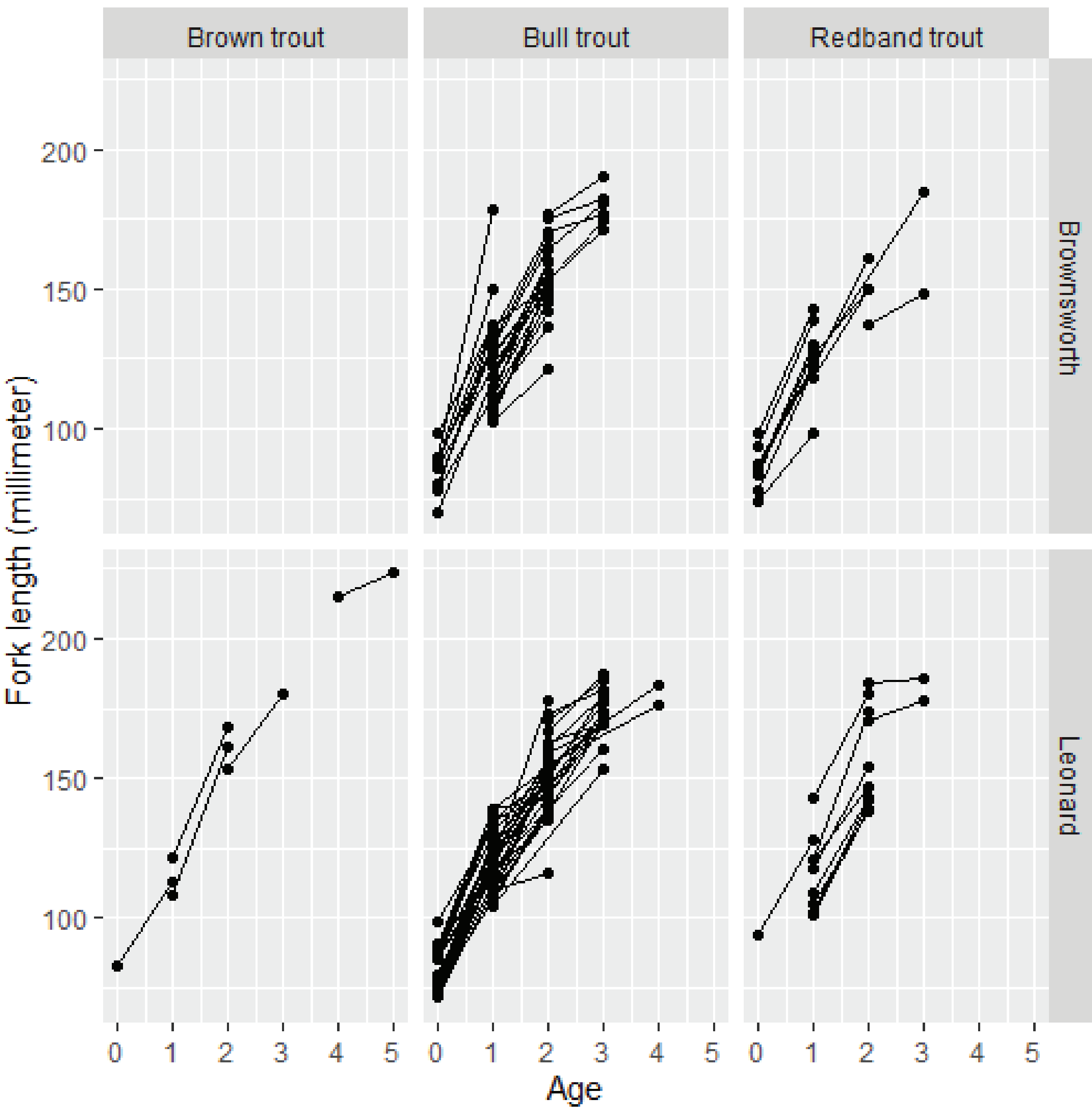

Figure 8. Comparison of growth of trout that were recaptured over multiple years in three creeks in Klamath Basin, Oregon, 2010–16. Year class was assigned based on length of initial capture. Brown, brown trout (*Salmo trutta*); bull, bull trout (*Salvelinus confluentus*); redband, redband trout (*Oncorhynchus mykiss gairdnerii*).

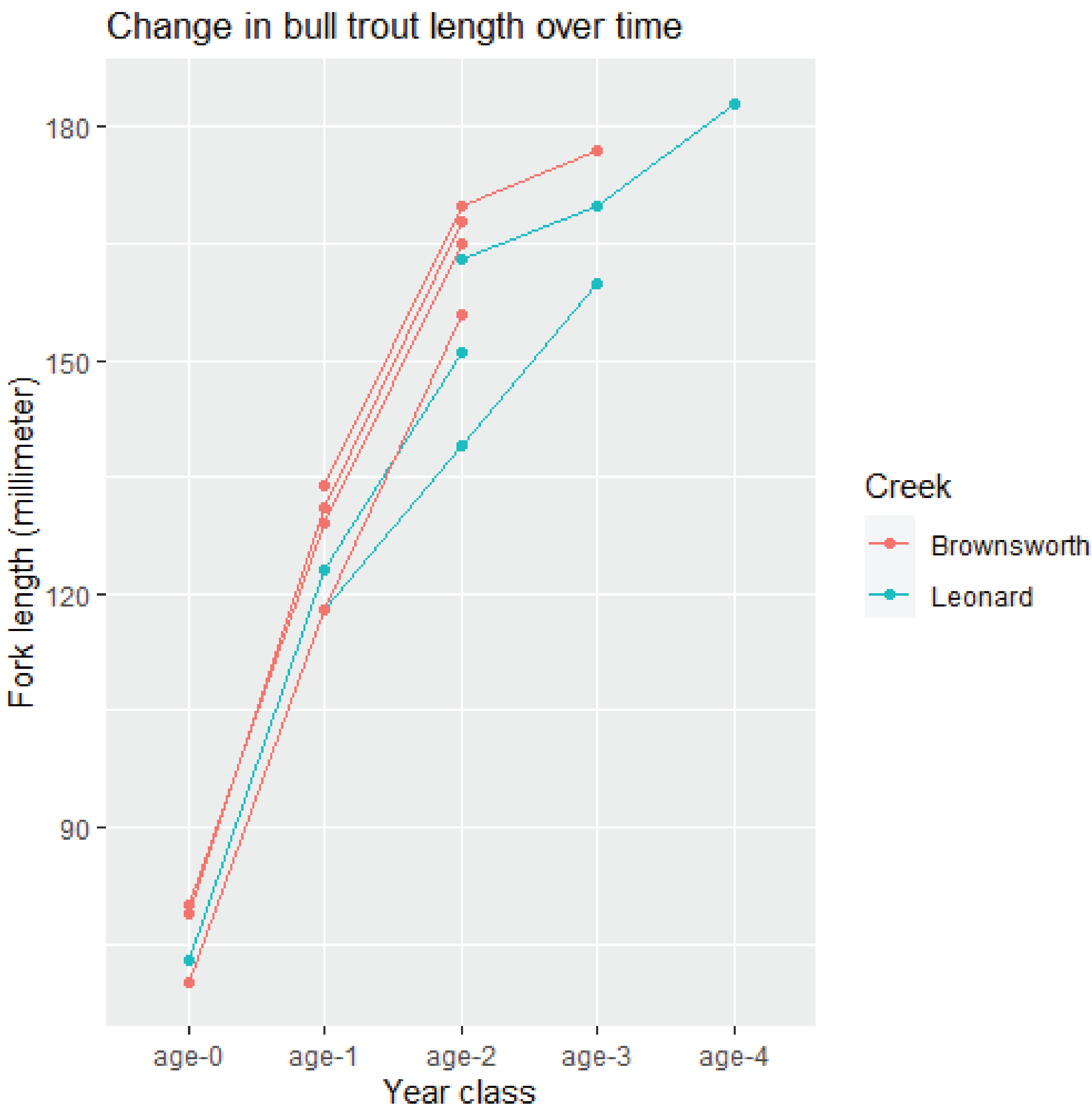

Figure 9. Comparison of growth of seven bull trout that were each captured 3 consecutive years in Klamath Basin, Oregon, 2010–16. Year class was assigned based on length of initial capture.

Table 10. Number of detections for each of the three trout species by creek, Klamath Basin, Oregon.

[**Bull**, bull trout (*Salvelinus confluentus*). **Redband**, redband trout (*Oncorhynchus mykiss gairdnerii*). **Brown**, brown trout (*Salmo trutta*)]

Number of detections	Leonard Creek			Brownsworth Creek		
	Bull	Redband	Brown	Bull	Redband	Brown
1	178	84	26	82	64	1
2	74	34	9	38	26	1
3	20	13	0	17	2	0
4	7	6	2	1	4	0
5	7	4	1	2	2	0
6	4	2	0	1	1	0
7	0	0	0	1	1	0
8	0	1	0	0	0	0
All	290	144	38	142	100	2

Table 11. Years in which multiple detections occurred for each of the three trout species by creek, Klamath Basin, Oregon.

[**Bull**, bull trout (*Salvelinus confluentus*). **Redband**, redband trout (*Oncorhynchus mykiss gairdnerii*). **Brown**, brown trout (*Salmo trutta*)]

Years detected	Leonard Creek			Brownsworth Creek		
	Bull	Redband	Brown	Bull	Redband	Brown
2010/2011	0	1	0	0	0	0
2011/2012	12	3	3	1	3	1
2011/2013	1	4	1	0	2	0
2011/2012/2013	3	3	0	3	3	0
2012/2013	25	15	3	9	6	0
All	41	26	7	13	14	1

Forty-seven percent (N=244) of the trout tagged from Brownsworth Creek from 2010 to 2013 were detected as free-swimming individuals at least once using portable antennas from 2011 to 2013 (table 10). Per species tagged, there were slightly more bull trout detected (52 percent; N=142) than redband (42 percent; N=100) or brown (40 percent; N=2). The majority of tagged trout were only detected once (N=147, 60 percent), with 27 percent (N=65) detected twice, 8 percent (N=19) detected three times, and the remaining 5 percent (N=13) detected 4–7 times. Only 28 individuals (13 bull, 14 redband, and 1 brown) were detected over multiple years, with 6 of these individuals (3 each bull and redband) detected all 3 years (table 11). Nine of the 28 individuals detected over multiple years were tagged in 2012 and therefore could not be detected in more than 2 years.

Thirty-nine percent (N=37) of the trout tagged in Boulder Creek were detected 2 days after tagging. All trout were detected in the same section they were tagged. A higher proportion of brown trout were detected (55 percent, N=17) than bull trout (32 percent, N=20).

In Leonard Creek the majority of initial fish detections were in the uppermost section (table 12). Bull trout were primarily detected in the uppermost sections of the creek, whereas redband trout were primarily found in the middle portion of the creek, and brown trout were mainly found in the lower portion of the creek. Of fish detected with the portable antennas in Leonard Creek, 420 of the 472 fish (89 percent) had a tagging location recorded. Seventy-three percent (N=305) of these fish were initially detected in the same study reach where they were tagged, with 92 of the remaining 115 trout (80 percent) detected in the adjacent study reach. The majority of individuals detected at least twice were found in the same study reach on subsequent detections (N=142, 77 percent) with similar proportions among the three species (table 13). Additionally, 26 of the 32 fish (81 percent) that were located in adjacent study reaches on subsequent detections were initially recorded in 100 m stream segments that were converted to study reaches and therefore may have actually been from the same study reach as identified in table 2 and figure 1.

Table 12. Number of trout and percentage detected at initial detection locations within Leonard and Brownsworth Creeks separated by species, Klamath Basin, Oregon.

[Sections are listed from upstream to downstream. **Bull**, bull trout (*Salvelinus confluentus*). **Redband**, redband trout (*Oncorhynchus mykiss gairdnerii*). **Brown**, brown trout (*Salmo trutta*)]

Site	Bull		Redband		Brown	
	Number	Percent	Number	Percent	Number	Percent
Leonard Creek						
Leo5	80	28	5	3	1	3
Leo Control2	62	21	6	4	2	5
Leo4	38	13	5	3	2	5
Leo Trtmnt2	28	10	14	10	0	0
Leo3	31	11	39	27	2	5
Leo Trtmnt1	16	5	21	15	2	5
Leo2	25	9	25	18	4	11
Leo Control1	6	2	6	4	4	11
Leo1	4	1	23	16	21	55
Brownsworth						
Brn3	40	28	28	28	0	0
Brn Control	18	13	14	14	0	0
Brn2	14	9	7	7	0	0
Brn Trtmnt	34	24	25	25	0	0
Brn1	18	13	9	9	0	0
Brn Lower	18	13	17	17	2	100

Table 13. Distance (in creek segments) between subsequent detections for bull trout (*Salvelinus confluentus*), redband trout (*Oncorhynchus mykiss gairdnerii*), and brown trout (*Salmo trutta*) by creek.

Creek segment	Leonard Creek			Brownsworth Creek		
	Bull	Redband	Brown	Bull	Redband	Brown
Same	89	44	Same	89	44	Same
1 apart	16	13	1 apart	16	13	1 apart
2 apart	3	2	2 apart	3	2	2 apart
3 apart	1	1	3 apart	1	1	3 apart
4 apart	0	0	4 apart	0	0	4 apart
Various	3	0	Various	3	0	Various
All	112	60	All	112	60	All

In Brownsworth Creek the highest proportion of initial detections were in the uppermost section (table 12). Ranking of study reaches where bull and redband trout were detected were similar between species. Of the 244 fish detected with the portable antennas in Brownsworth Creek, 230 (94 percent) had a tagging location recorded. Seventy-five percent (N=173) of these fish were detected in the same study reach as where they were tagged, with 48 of the remaining 57 trout (84 percent) detected in the adjacent study reach. The majority of individuals detected at least twice were found in the same study reach on subsequent detections (N=69, 71 percent; table 13). Additionally, 6 of the 13 fish (46 percent) that were located in adjacent study reaches on subsequent detections were initially recorded in 100 m stream segments that were converted to study reaches and therefore may have actually been from the same study reach as identified in table 2 and figure 2.

The proportion of bull trout or redband trout in the treatment sections of Leonard Creek did not increase the year following the addition of large woody debris in September 2012 (table 14). Whereas, in 2012 the majority of brown trout captured within Leonard Creek were in the LeoTrtmnt 2 study reach or the adjacent study reaches which was an increase of brown trout represented in this area compared to the previous two years. However, in the treatment section of Brownsworth Creek the proportion of bull trout decreased while the proportion of redband trout increased the year following the addition of large woody debris to the treatment section of Brownsworth Creek in September of 2012 (table 14).

Remote Detection of Trout in Leonard Creek

A little over one third (N=381; 36 percent) of the trout captured in Leonard Creek were detected on the stationary PIT tag antennas. First detection on an antenna occurred anywhere from the day of tagging to 1,136 days post tagging, whereas the last day of detection occurred anywhere from the day after tagging to 1,208 days post tagging. Almost half of the trout were only detected on antennas at a single array (N=188; 49 percent; table 15). Of the remaining 192 trout, the majority (N=115, 60 percent) were detected only in the upper section of the creek (arrays: U, UBC, and UAC; table 16), whereas 64 (33 percent) trout were detected only in the lower portion of the creek (arrays: L11, L, and M). The remaining 13 (7 percent) trout were detected throughout the creek. Very few trout were detected at both ends of the sample area within the creek (N=13, 3 percent). Most of the bull trout (N=195, 63 percent) were found primarily in the upper portion of the creek, whereas most of redband trout (N=43, 83 percent) and brown trout (N=57, 92 percent) were primarily located in the lower portion of the creek (tables 15 and 16).

Almost half (N=187, 49 percent) of the trout detected on the Leonard antennas passed through a culvert at least one time, with the majority of these being bull trout (N=158, 84 percent; table 17). Most of the bull trout (N=108, 68 percent) remained in the upper portion of the creek regardless of the direction they were traveling, whereas most of the redband trout (N=13, 76 percent) and all of the brown trout remained in the lower portion of the creek. Almost half (N=91, 49 percent) of the trout that passed through culverts did so on multiple occasions. However, there were differences among species with the proportion of bull trout crossing multiple times (N=79, 50 percent), more often than redband trout (N=8, 47 percent) or brown trout (N=4, 33 percent).

A total of 75 trout (50 bull, 13 redband, and 12 brown) traversed the culvert located between the lower and middle array sites from 2011 through 2016, with the most crossings in 2012 (table 18). Two of these bull trout also traversed the upper culvert. An additional 112 trout (108 bull and 4 redband) traversed the upper culvert from 2013 through 2016, with the most crossing in 2014 (table 18). After the upper culvert was replaced in September of 2013, there was an increased proportion of both bull and redband trout crossing the upper culvert (table 18). Percentage of detected bull trout crossing the lower culvert was variable by year ranging from 13 percent to 34 percent with no discernable increase or decrease of crossings after the lower culvert was modified in August of 2014. Although there were not many redband and brown trout passing the lower culvert after its modification, the proportion did increase.

Thirty-one percent of the trout (N=118) were last detected on the farthest upstream (N=47) or downstream (N=71) antenna and therefore could have left the study area (table 19). The majority of these fish were bull trout (N=82; 69 percent) with only four (5 percent) detected at both ends. Half of the bull trout (N=41) were last detected on each of the farthest upstream and downstream antennas, with similar sizes exiting in each direction (mean±SD; upstream 116±31mm, downstream 120±37mm). The four bull trout that were detected at both culverts moved from upstream to downstream exiting at the downstream culvert. Sixteen percent (N=19) of the trout suspected of leaving the study area were redband trout. The majority of the redband trout (N=15) were last detected at the farthest downstream antenna, these fish had only been detected on the lower and middle arrays. The four redband trout last detected on the farthest upstream antenna had only been detected at the Upper Below Culvert (UBC) and Upper Above Culvert (UAC) arrays. The remaining 13 percent (N=15) of trout suspected of exiting the study area were brown trout with the majority (N=13; 87 percent) last detected on the farthest downstream antenna and 11 of these fish only detected at the lower array. The two brown trout that were last detected on the farthest upstream antenna were only detected on the UAC array. The bull trout exiting via the downstream culvert were primarily detected on the farthest downstream antenna in July (N=26), whereas bull trout exiting via the upstream culvert were primarily detected on the farthest upstream antenna in October N=20 (table 19). Fifty-three percent (N=8) of the redband trout and 69 percent (N=9) of the brown trout exited via the farthest downstream antenna during autumn (N=8).

Table 14. Number and percentage of trout detections in Leonard and Brownsworth Creeks in the 2 years prior (2011 and 2012) and the year after (2013) addition of large woody debris to the treatment sections.

[Sections are listed from upstream to downstream. Parenthetical numbers are percentages. **Bull**, bull trout (*Salvelinus confluentus*). **Redband**, redband trout (*Oncorhynchus mykiss gairdnerii*). **Brown**, brown trout (*Salmo trutta*)]

Site	Bull			Redband			Brown		
	2011	2012	2013	2011	2012	2013	2011	2012	2013
Leonard Creek									
Leo5	42 (42)	16 (11)	62 (28)	2 (4)	2 (2)	3 (4)	2 (18)	0 (0)	0 (0)
Leo Control2	16 (16)	47 (32)	60 (27)	5 (10)	5 (4)	4 (5)	1 (9)	1(3)	0 (0)
Leo4	4 (4)	28 (19)	16 (7)	3 (6)	2 (2)	2 (2)	0 (0)	3 (8)	2 (29)
Leo Trtmnt2	11 (11)	20 (13)	12 (5)	8 (16)	14 (12)	10 (12)	0 (0)	1 (3)	2 (29)
Leo3	18 (18)	15 (10)	25 (11)	12 (24)	27 (23)	25 (29)	0 (0)	6 (15)	2 (29)
Leo Trtmnt1	6 (6)	10 (7)	17 (8)	1 (2)	24 (20)	14 (16)	1 (9)	2 (5)	0 (0)
Leo2	4 (4)	8 (5)	18 (8)	1 (2)	25 (21)	24 (28)	1 (9)	4 (10)	0 (0)
Leo Control1	0 (0)	1 (1)	5 (2)	4 (8)	1 (1)	2 (2)	1 (9)	4 (10)	0 (0)
Leo1	0 (0)	4 (3)	6 (3)	14 (28)	19 (16)	1 (1)	5 (45)	18 (46)	1 (14)
Brownsworth									
Brn3	16 (43)	24 (31)	26 (22)	20 (32)	15 (28)	3 (7)	0 (0)	0 (0)	0
Brn Control	4 (11)	11 (14)	16 (13)	7 (11)	8 (15)	5 (11)	0 (0)	0 (0)	0
Brn2	0 (0)	9 (12)	24 (20)	6 (10)	3 (6)	4 (9)	0 (0)	0 (0)	0
Brn Trtmnt	12 (32)	20 (26)	22 (18)	9 (15)	14 (26)	23 (52)	0 (0)	0 (0)	0
Brn1	2 (5)	9 (12)	15 (13)	4 (6)	5 (9)	6 (14)	0 (0)	0 (0)	0
Brn Lower	3 (8)	5 (6)	16 (13)	16 (26)	9 (17)	3 (7)	2 (100)	1 (100)	0

Table 15. Number of bull trout (*Salvelinus confluentus*), redband trout (*Oncorhynchus mykiss gairdnerii*), and brown trout (*Salmo trutta*) detected on a single array in Leonard or Brownsworth Creeks, Klamath Basin, Oregon.

Trout	Leonard Creek						Brownsworth Creek		
	Lower 2011 (L11)	Lower (L)	Middle (M)	Upper (U)	Upper below culvert (UBC)	Upper above culvert (UAC)	Lower (L)	Middle (M)	Upper (U)
Bull	0	13	9	71	6	6	17	8	49
Redband	11	9	10	4	0	0	9	5	24
Brown	14	16	15	4	0	0	0	2	0
Total	25	38	34	79	6	6	26	15	73

Table 16. Detection of bull trout (*Salvelinus confluentus*), redband trout (*Oncorhynchus mykiss gairdnerii*), and brown trout (*Salmo trutta*) located at multiple arrays located by stream section in Leonard and Brownsworth Creeks.

[Since Brownsworth Creek only had one array in the upper section, those fish are recorded in the previous table and not this table.]

Trout	Leonard Creek			Brownsworth Creek	
	Lower Section	Both Sections	Upper Section	Lower Section	Both Sections
Bull	40	12	110	34	9
Redband	13	0	5	14	1
Brown	11	1	0	0	0
Total	64	13	115	48	10

Table 17. Bull trout (*Salvelinus confluentus*), redband trout (*Oncorhynchus mykiss gairdnerii*), and brown trout (*Salmo trutta*) that passed through at least one of the two culverts (lower or upper) on Leonard Creek and the direction they were traveling (up or downstream).

Trout	Lower down	Lower up	Lower both directions	Lower and Upper up to down	Lower and Upper both directions	Upper down	Upper up	Upper both directions
Bull	30	3	9	4	4	4	38	66
Redband	6	1	6	0	0	0	2	2
Brown	4	4	4	0	0	0	0	0
Total	40	8	19	4	4	4	40	68

Table 18. Year that a bull trout (*Salvelinus confluentus*), redband trout (*Oncorhynchus mykiss gairdnerii*), and brown trout (*Salmo trutta*) passed through a culvert (lower or upper) on Leonard Creek and total number of trout detected in a year.

[Bold numbers indicate these fish passed the culvert after the culvert was replaced or modified. Numbers in parenthesis are the percent of detected trout that passed through the culvert. Individuals are counted multiple times if they were detected in multiple years, crossed multiple culverts or crossed culverts in multiple years. **Symbol:** –, not sampled]

Year	Lower			Upper			Total		
	Bull	Redband	Brown	Bull	Redband	Brown	Bull	Redband	Brown
2011	0 (0)	3 (15)	2 (7)	–	–	–	25	20	28
2012	21 (34)	3 (19)	3 (16)	–	–	–	62	16	19
2013	11 (15)	4 (50)	2 (22)	32 (44)	0 (0)	0 (0)	72	8	9
2014	18 (15)	2 (22)	2 (22)	**70 (58)**	**3 (33)**	**0 (0)**	121	9	9
2015	**2 (13)**	**1 (100)**	**1 (100)**	**9 (60)**	**0 (0)**	**0 (0)**	15	1	1
2016	**5 (22)**	**1 (33)**	**2 (67)**	**14 (61)**	**1 (33)**	**0 (0)**	23	3	3

Table 19. Month that bull trout (*Salvelinus confluentus*), redband trout (*Oncorhynchus mykiss gairdnerii*), and brown trout (*Salmo trutta*) were last detected on the farthest downstream or upstream antenna in Leonard and Brownsworth Creeks, Klamath County, Oregon

Month	Leonard Creek						Brownsworth Creek			
	Farthest downstream			Farthest upstream			Farthest downstream		Farthest upstream	
	Bull	Redband	Brown	Bull	Redband	Brown	Bull	Redband	Bull	Redband
June	5	4	0	0	0	0	0	1	7	0
July	26	1	0	3	1	0	4	3	7	4
August	6	1	0	4	1	1	5	4	6	2
September	3	1	4	5	1	1	4	0	4	0
October	1	4	3	20	0	0	3	0	0	1
November	0	4	6	9	1	0	2	1	0	0
All	41	15	13	41	4	2	18	9	24	7

Of the 381 trout that were detected on the stationary antennas in Leonard Creek, 365 (96 percent) had tagging locations associated with them, and the majority (N=258; 71 percent) were bull trout (table 20). Most of the bull trout (N=185; 72 percent) with capture locations were only detected in the upper section of the study area at the upper 3 arrays (U, UBC, and UAC). There were 61 (24 percent) bull trout that were only detected in the lower section of the study area at the lower and middle arrays. Bull trout captured at LeoTrtmnt1 and above (N=218) were primarily detected on the antennas in the upper section of the creek (N=175; 80 percent), whereas those captured from Leo2 and below (N=40) were primarily detected at the lower and or middle arrays (N=29; 73 percent). Of the bull trout with tagging locations, there were 39 that were last detected on the farthest upstream antenna, and 41 that were last detected on the farthest downstream antenna; these fish were primarily captured from LeoTrtmnt1 and above (upstream N=34, 87 percent; downstream N=30, 73 percent). There was a total of 49 redband trout that had capture locations associated with them (table 20). The majority (N=41; 84 percent) of redband trout with capture locations were only detected in the lower section of the study area. Eight (16 percent) redband trout were only detected in the upper section of the study area. Redband trout captured at LeoTrtmnt2 and above (N=7) were primarily detected on the antennas in the upper section of the study area (N=6; 86 percent), whereas those captured from Leo3 and below (N=42) were primarily detected at the lower and (or) middle arrays (N=40; 95 percent). Of the redband trout with tagging locations, there were 4 that were last detected on the farthest upstream antenna, and 14 that were last detected on the farthest downstream antenna; these fish were primarily captured from LeoTrtmnt2 and above (upstream N=3, 75 percent) or LeoLower (downstream N=10, 71 percent). Of the 58 brown trout with known capture locations, the majority (N=55) were captured in the lower section of the study area (Leo2 and below), with only 3 captured in the upper section (Leo4 and above). All brown trout were only detected on antennas closest to their capture locations (table 20). Of the brown trout with tagging locations, 2 were last detected on the farthest upstream antenna, and 12 were last detected on the farthest downstream antenna. The brown trout last detected on the farthest downstream antenna were all originally captured at LeoLower below the farthest downstream antenna, whereas one of the brown trout exiting via the farthest upstream antenna was captured at LeoLower and the other from Leo4.

Remote Detection of Trout in Brownsworth Creek

Only 30 percent (N=172) of the trout captured in Brownsworth Creek were detected on the stationary antennas. First detection on an antenna occurred anywhere from the day of tagging to 1,093 days after tagging, whereas the last day of detection occurred anywhere from the day of tagging to 1,192 days post tagging. The majority of trout were only detected at antennas on a single array (N=114; 66 percent; table 15). Seventy-three trout were only detected on the upper array, 15 trout were only detected on the middle array, and 26 trout were only detected on the lower array. An additional 48 trout (34 bull and 14 redband) were only detected in the lower section of Brownsworth Creek on both the lower and middle arrays (table 16). Ten trout were detected at both ends of the study area.

Table 20. Detection of bull trout (*Salvelinus confluentus*), redband trout (*Oncorhynchus mykiss gairdnerii*), and brown trout (*Salmo trutta*) on antennas located by stream section and capture location within Leonard Creek, Klamath County, Oregon.

Capture location	Lower section			Both sections			Upper section		
	Bull	Redband	Brown	Bull	Redband	Brown	Bull	Redband	Brown
Leo5	1	0	0	7	0	0	81	2	1
LeoControl2	7	0	0	3	0	0	37	2	1
Leo4	3	0	0	0	0	0	15	0	1
LeoTrtmnt2	14	1	0	1	0	0	27	2	0
Leo3	5	4	0	0	0	0	10	2	0
LeoTrtmnt1	2	1	0	0	0	0	5	0	0
Leo2	5	1	2	1	0	0	1	0	0
LeoControl1	10	5	9	0	0	0	2	0	0
Leo1	7	4	4	0	0	0	0	0	0
LeoLower	7	25	39	0	0	0	7	0	1
Total	61	41	54	12	0	0	185	8	4

In total there were 58 (34 percent) trout that were last detected on the farthest upstream (N=31) or farthest downstream (N=27) antenna and could have left the study area (table 19). The majority of these fish were bull trout (N=42; 72 percent) with only one (2 percent) detected at both ends of the study area and exiting at the lower end. Of the trout that were only detected on the upper array, 24 bull trout and 7 redband trout were last detected at the farthest upstream antenna (table 19). Of the trout that were only detected on the lower array, nine bull trout and five redband trout were last detected on the farthest downstream antenna. An additional 12 trout (8 bull and 4 redband) that were detected in the lower section (lower and middle arrays) were last detected on the farthest downstream antenna. The one bull trout that was detected at both ends of the study area moved from up to downstream passing through the downstream culvert and then was detected on the farthest downstream antenna. Although species differences were not evident, the trout exiting the system were primarily detected in July (upstream N=11; downstream N=7) and August (upstream N=8; downstream N=9) (table 19).

A total of 53 trout (38 bull and 15 redband) traversed the culvert located between the lower and middle arrays from 2011 through 2014, with the most crossings in 2013. The majority of trout that crossed the culvert did so in both directions (N=27; 51 percent). However, a greater proportion of redband trout (N=12; 80 percent) traveled in both directions than bull trout (N=15; 39 percent). There were more trout that traveled in the upstream direction (N=16; 30 percent) than in the downstream direction (N=10; 19 percent). There was a greater proportion of bull trout (N=23, 61 percent; upstream N=14, 37 percent; downstream N=9, 24 percent) that traveled in a single direction than redband trout (N=3, 20 percent; upstream N=2, 13 percent; downstream N=1, 7 percent).

Of the 172 trout that were detected on the stationary antennas, 169 (98 percent) had tagging locations associated with them (table 21). Slightly over half of these fish (N=86; 51 percent) were only detected in the lower section of the study area on the lower and middle arrays, with the majority (N=64) originally captured within two study reaches of these arrays. These fish were detected anywhere from the day of capture to 1,192 days post capture with the fish composed of 57 bull trout, 27 redband trout, and 2 brown trout. Twenty-six of these trout were last detected on the farthest downstream antenna (17 bull trout and 9 redband trout). Only 6 percent of the trout (N=10) were detected at both ends of the study area (9 bull trout and 1 redband trout). One of the bull trout and the redband trout tagged at Brn3 traversed the study area from upstream to downstream within a day, after having been tagged for at least a month. The remainder of the trout (N=73; 43 percent) were only detected at the upper antenna site, with 31 of the trout last detected on the farthest upstream antenna (24 bull trout and 7 redband trout). Most of the trout that were last detected on the farthest upstream antenna were tagged at Brn3 (N=19; 61 percent).

Table 21. Detection of bull trout (*Salvelinus confluentus*), redband trout (*Oncorhynchus mykiss gairdnerii*), and brown trout (*Salmo trutta*) on antennas located by stream section and capture location within Brownsworth Creek, Klamath Basin, Oregon.

Capture Location	Lower section			Both sections			Upper section		
	Bull	Redband	Brown	Bull	Redband	Brown	Bull	Redband	Brown
Brn3	1	1	0	1	1	0	25	11	0
BrnControl	1	1	0	1	0	0	9	2	0
Brn2	1	0	0	1	0	0	2	2	0
BrnTrtmnt	9	6	0	0	0	0	3	1	0
Brn1	12	4	0	2	0	0	5	0	0
BrnLower	33	15	2	4	0	0	5	8	0
Total	57	27	2	9	1	0	49	24	0

Discussion

The Klamath Recovery Unit mainly supports resident forms of bull trout, with fluvial forms located in Long Creek within the Sycan River area and in North Fork Sprague River at its confluence with Boulder Creek in the Upper Sprague River area (USFWS, 2015). Culverts and other structures have been shown to be an impediment to the movement of bull trout and may be one reason that resident forms are more prevalent in the Klamath Recovery Unit where road culverts and low-head dams are common for forestry and agricultural practices, respectively. Although a priori assumptions were that trout could easily pass through the culvert located at the lower portion of Brownsworth Creek but not those at the upper and lower sections of Leonard Creek, our study found that trout easily passed through all the culverts associated with these creeks. However, during this study the culverts on Leonard Creek were replaced or altered to allow for more efficient fish passage. During this study there was increased bull trout passage at the upper culvert in Leonard Creek after the culvert was replaced. The lower culvert on Leonard Creek had variable passage both before and after the upgrades took place, indicating that the upgrades may not have affected fish passage through this culvert. It appears that the improvements to fish passage on the upper culvert on Leonard Creek were the most successful with the greatest increase in proportion of bull trout passage. Consequently, the culverts found on Leonard and Brownsworth creeks are currently not enough of an impediment to prevent the fish from migrating. Although these culverts are not an impediment towards short distance migrations, our study areas were only 1 km for Brownsworth Creek and 2 km for Leonard Creek. Such distances are considered to be within the typical migrations for resident forms of bull trout (Nelson and others, 2002; Jakober and others, 1998), whereas fluvial forms of bull trout usually travel more than 10 km (Al-Chokhachy and Budy, 2008) and can travel as much as 250 km.

The majority of trout detected on multiple occasions during this study appeared to show site fidelity, indicating a lack of migration. Furthermore, none of the tagged trout were detected in both Brownsworth and Leonard creeks, which are close in proximity and within the distance expected for typical migration of fluvial forms of bull trout. During our study approximately one third of the bull trout in Leonard Creek appeared to leave the study area, migrating past the lowermost or uppermost antennas, and therefore could have migrated distances longer than the study areas. The majority of these fish were bull trout with equal numbers of similar sized trout migrating upstream and downstream. Bull trout migrated out of the study area going upstream in autumn, whereas they exited downstream during the summer. Redband and brown trout appeared to migrate downstream in Leonard creek during the fall, whereas redband trout migrated downstream in Brownsworth Creek in the summer. Consequently, these were likely considered migrations of resident forms and may have been associated with spawning migrations. However, other barriers may have been present outside of our study area that could have prevented the adult bull trout from migrating out of the system. Nelson and others (2002) found that physical barriers were not the only impediment to migration of bull trout. They found that elevated temperatures and non-native species also prevented migration of bull trout, although they were mainly looking at outmigration of yearlings. The limited temperature data we collected did not indicate that temperatures were different between the two creeks. However, temperatures were likely increased downstream with decreased elevation. Furthermore, in our study, non-native brown trout were not numerous enough in the study area to prevent migration; however, if they were more numerous downstream of our study area, they may have prevented bull trout from migrating downstream.

Similar to Nelson and others (2002), we found brown trout in the lower portions of the creeks, whereas bull trout occupied the upper portions of the creeks. This phenomenon of partitioning the stream is common when native and non-native trout occupy the same stream (Paul and Post, 2001; Korsu and others, 2007). However, when either species is in allopatry, they occupy the entire range of habitats within the stream (Korsu and others, 2007). In Brownsworth Creek, where we found very few brown trout, we found that bull trout did occupy the entire stretch of the study area. Benjamin and others (2016) found that bull trout and brown trout rarely occurred in sympatry, and when they did occur together, water temperatures were generally at the upper tolerance of the bull trout. Both Leonard and Brownsworth creeks had maximum daily temperatures at the upper tolerance level of bull trout. Gunckel and others (2002) indicated that closely related species that naturally do not exist in sympatry but that occupy similar environments have the greatest potential for interference competition, whereas native species found together have shown a partition of resources to allow coexistence (Nakano and others, 1998; Paul and Post, 2001). Since bull trout and redband trout are both native species that naturally occur in sympatry, it is not surprising that they overlap in the habitat they occupy while maintaining separate niches within both Leonard and Brownsworth creeks. Although we saw increased overlap in the use of stream segments with redband and brown trout, these two species likely showed interference competition as found by these species in other streams (Hasegawa, 2016). Fausch (2008) made the argument that native trout species at their southernmost range (furthest from their evolutionary origin) where the habitat is not ideal for the species are more likely to be replaced by introduced trout species that are better suited for the habitat. This might be one reason that the southern bull trout in the Klamath Recovery Unit are the most imperiled. Furthermore, brown trout distribution is likely to expand upstream if stream temperatures increase as expected with climate change.

One concern for the decline of bull trout is the decline in suitably complex habitat. Bull trout use complex stream habitat cover such as deep pools, overhanging banks, large woody debris, root wads, or large boulders (Rieman and McIntyre, 1995; Watson and Hillman, 1997; Jakober and others, 1998; Rich and others, 2003). During this study, in an attempt to enhance habitat for bull trout, large woody debris, consisting of logs (up to 30 cm in diameter) covered with green limbs that were 10–15 cm in diameter, was added to the treatment sections of Leonard and Brownsworth creeks. Although Rich and others (2003) and Jakober and others (1998) considered these to be suitable parameters for large woody debris used by bull trout, Dunham and others (2003) indicated that large woody debris of this size range would likely contribute little to bull trout habitat. They indicated that the best large woody debris habitat consists of initial log structures greater than 50 cm in diameter with associated debris jams. We did not find an increased use of areas that were enhanced with large woody debris, consistent with Dunham and others (2003). Furthermore, we found that individuals were often redetected in the same segment of the creek where they were initially captured, indicating that the area may have been a preferred area for the individual and that these bull trout have a small home range with limited migration during the time frame of our study.

Bull trout are considered threatened due to three major factors: lack of connectivity, degraded habitat, and introduction of non-native species (USFWS, 2015). Although our study did not show that there was a lack of connectivity due to the present road culverts, it did not preclude that there were no barriers preventing the migration of bull trout in other portions of Leonard or Brownsworth creeks outside of the study area. Distribution of bull trout within these creeks did appear to be altered by the presence of the non-native brown trout; however, distribution did not appear altered by the native redband trout. Temperature was similar among Leonard and Brownsworth creeks suggesting that the increased presence of brown trout in Leonard Creek was not due to higher temperatures. Although habitat enhancements are likely to provide bull trout with refugia, these enhancements need to provide the proper complexity in order to be useful to the species. Further research is warranted to determine what enhancements would provide bull trout with the additional habitat they need.

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