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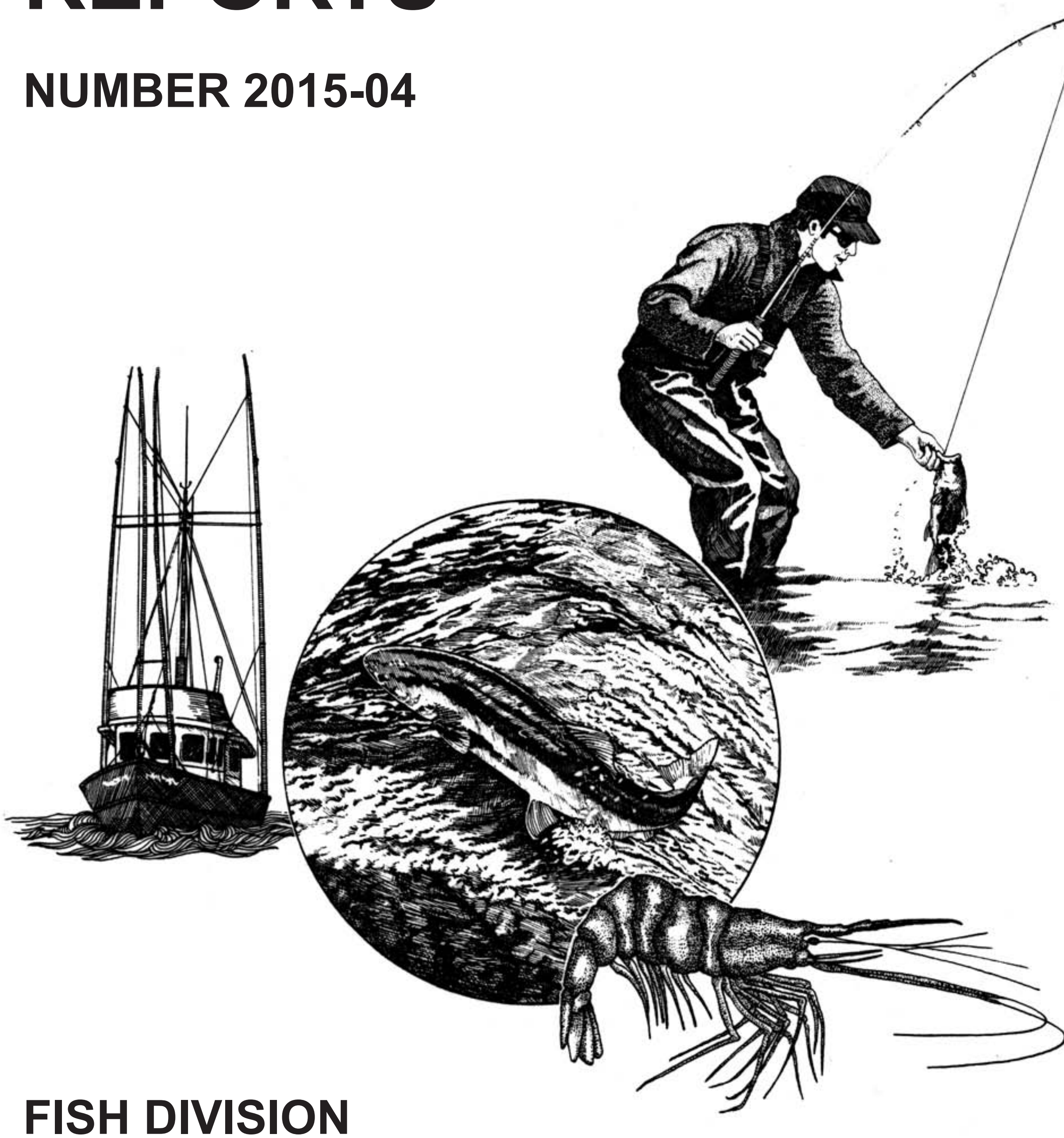

FISH DIVISION
Oregon Department of Fish and Wildlife

Bull Trout Conservation and Recovery in the Odell Lake Core Area: Distribution, Behavior, Ecology, and Fisheries Evaluations (2013-2014)

Bull Trout Conservation and Recovery in the Odell Lake Core Area: Distribution, Behavior, Ecology, and Fisheries Evaluations (2013—2014)

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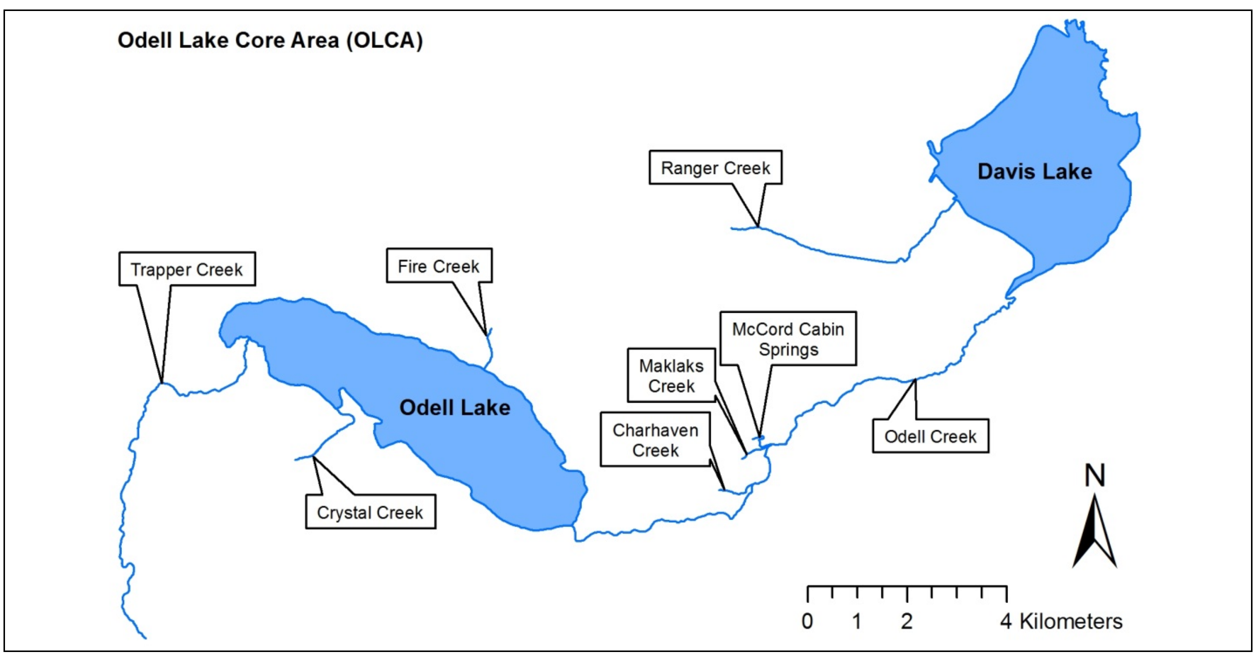
Executive Summary

Bull trout (*Salvelinus confluentus*) in the Odell Lake Core Area (hereafter OLCA; USFWS 2015) have been designated as critically at risk by Oregon Department of Fish and Wildlife (ODFW) and threatened under the US Endangered Species Act. The OLCA includes Odell Lake, Davis Lake, and their tributaries and bull trout in the Core Area represent the only extant, natural, lacustrine-adfluvial bull trout population in Oregon (ODFW 2005*a*). Currently, the only documented bull trout spawning site in the OLCA is the lowermost 1.3 km of Trapper Creek, a tributary to Odell Lake. The number of bull trout redds observed in Trapper Creek varied from 0 to 24 (median = 11) during annual redd surveys conducted from 1994 through 2012 (ODFW, *unpublished data*) and the number of adult bull trout in Odell Lake is assumed to be about 20-50 (ODFW 2005*b*).

Previous reports indicate that Crystal Creek was historically one of the the primary spawning tributary for bull trout in the OLCA (OSGC 1947); however, bull trout are believed to no longer spawn in Crystal Creek (USFS 1994). Historic records suggest that management practices and public perception towards bull trout in the OLCA have varied. For example, bull trout in the OLCA were referred to as a valuable recreational fishery in need of protection (OSGC 1950) and conversely as a species that may need to be controlled to boost introduced populations of kokanee (*Oncorhynchus nerka*) and lake trout (*S. namaycush*) (OSGC 1946, 1950).

The putative limiting factors for bull trout in the OLCA can be generally classified into three categories: 1) limited spawning and rearing habitat, 2) interactions with nonnative fishes, and 3) habitat degradation (USFWS 2015). Efforts have been ongoing to restore previously degraded habitat; for example, in-stream and riparian habitat enhancements have occurred in Trapper Creek in the last 15 years. However, uncertainty still exists regarding the current distribution of spawning and rearing bull trout and the nature of interactions with nonnative species in the OLCA. Additionally, the influence of recreational fisheries in Odell Lake has been identified as an area of concern (USFWS 2002; USFWS 2015). Therefore, the objectives of this work were to:

1) Document the current status of bull trout in the Odell Lake Core Area.
2) Document characteristics of the Odell Lake food web that may influence bull trout survival.
3) Determine the potential effect of the recreational fishery on bull trout in Odell Lake.



Current status of bull trout in the Odell Lake Core Area

Bull trout used to be widely distributed in the upper Deschutes River watershed and now are only extant in the small, isolated Odell Lake basin. This basin includes Odell Lake, Odell Creek, Davis Lake, and their tributaries; hereafter referred to as the Odell Lake Core Area (OLCA). In the OLCA, the current bull trout population is thought to be a small fraction of their abundance in the early 1900s; it is comprised of a single lacustrine-adfluvial spawning population and represents the only remaining natural example of this life history in Oregon. Most efforts to document the distribution and abundance of spawning and rearing bull trout have focused on the Odell Lake tributary, Trapper Creek. However, infrequent surveys elsewhere in the core area have occasionally detected bull trout, suggesting that an extensive investigation of the current distribution and relative abundance of all putative populations (i.e., status) in the OLCA, which is directly related to the core area recovery goals, is warranted.

To document the status of bull trout in the OLCA, we used a variety of methods. Fish passage stations were used to monitor fish movement in Trapper Creek, Odell Creek, and to-and-from the lakes. Snorkel surveys were used in Odell Creek to detect bull trout rearing that was unlikely to be detected by fish passage stations. Backpack electrofishing was used in smaller wadable streams to detect early rearing of bull trout. In the fish passage stations, we estimated that 43-51 unique bull trout entered Trapper Creek to spawn during 2013. At least two bull trout (60 and 95 cm total length [TL]) moved from Odell Lake to Odell Creek, including an allacustrine movement to the cold Odell Creek tributary, Charhaven Creek, potentially to spawn. We detected an outmigration of at least eight juvenile bull trout (14-18 cm; total length) from Charhaven Creek to Odell Creek, mainly in August, which was coincident with downstream movement of at least 11 more bull trout (12-25 cm TL) in the coldest reach of Odell Creek. In night snorkel occupancy surveys of the lower 9.2 km of Odell Creek, we did not observe any bull trout, suggesting that the bull trout rearing densities were low and below the detection power of our snorkel surveys. In occupancy surveys using backpack electrofishing, we documented bull trout occupancy in Crystal Creek and Charhaven Creek, but not in McCord Cabin Springs, Maklaks Creek, or Ranger Creek. However, the detection probability for bull trout was low ($p \leq 0.28$) when sampling by backpack electrofishing, which may account for lack of detection in some streams regardless of intensive sampling effort.

Our study shows that bull trout are present in the cold reach of Odell Creek and in Crystal Creek and that recovery actions should be evaluated for bull trout here along with those of the Trapper Creek local population. Improving our knowledge of potential passage barriers, negative interactions with brook trout, and the availability of refuge, feeding, and spawning habitats in Odell Creek would improve our understanding of limiting factors and where enhancement projects would most likely succeed. Finally, all of our sampling methods showed that robust populations of *Oncorhynchus mykiss spp.* and mountain whitefish (*Prosopium williamsoni*) are distributed throughout Odell Creek, which suggests that forage availability likely would not be a limiting factor for bull trout.

Characteristics of the Odell Lake food web that may influence bull trout survival

The food web in Odell Lake has likely been significantly altered by the introduction of several fishes, including lake trout, tui chub (*Gila bicolor*), kokanee, brook trout (*S. fontinalis*), and rainbow trout (*O. mykiss* ssp.). The historical fish assemblage in Odell Lake was thought to include bull trout, redband trout (*O. mykiss gairdneri*), and mountain whitefish; among these, bull trout were likely the apex predator. However, the bull trout population is believed to have declined significantly subsequent to introduction of large numbers of other species. The interactions between introduced and native species are poorly understood in this lake, and may help explain the decline of bull trout.

Establishment of nonnative lake trout populations has been implicated in the decline of bull trout populations in many systems (Donald and Alger 1993; Fredenberg 2002; Martinez et al. 2009). Interactions between bull trout and nonnative lake trout have been identified as one of the potential limiting factors for bull trout in Odell Lake (USFWS 2015); however, no data are available to evaluate how lake trout may influence the distribution or abundance of bull trout in Odell Lake. Therefore, we quantified characteristics of the aquatic food web in Odell Lake with an emphasis on interactions between bull trout and nonnative lake trout.

We used a combination of trap nets, benthic gill nets, and suspended gill nets to sample the fish assemblage in Odell Lake during the spring, summer, and autumn of 2013 and 2014. Captured fish were identified to species, counted, and measured for length. A muscle sample was collected from a subsample of captured fish for stable isotope analysis, and stomach contents were collected from a subsample of lake trout for food-habits analysis. Additionally, we evaluated the timing of age-0 salmonid movement in Trapper Creek and the presence of lake trout near Trapper Creek to examine if lake trout may use age-0 salmonids as a seasonal abundant prey source.

Lake trout were the most abundant apex predator sampled in Odell Lake and they preyed on a variety of salmonids (e.g., kokanee and mountain whitefish), non-salmonids (e.g., tui chub), and other seasonally available prey items (e.g., fish eggs, Diptera, etc.). Bull trout are also an apex predator in Odell Lake, but they were much less abundant than lake trout. Differences in isotopic values between bull trout and lake trout suggest incomplete overlap in prey use or variability in dietary composition between these species in Odell Lake; consequently, extirpation of bull trout from Odell Lake as a result of competition with lake trout (i.e., competitive exclusion, *sensu stricto*) would not be predicted. However, patterns of relative abundance, spatial overlap, and probable dietary overlap provide support that these species are competitors or intraguild predators. For example, bull trout made up only 3.7% of the combined bull trout and lake trout catch from our sampling, bull trout and lake trout were generally sampled from similar habitats, and stable isotope data suggest the probable use of similar prey items, but in different proportions.

Future studies may need to evaluate food-habits of bull trout in Odell Lake to more fully develop an understanding of competitive interactions between bull trout and lake trout because the resolution of stable isotope analyses may not be sufficient to base difficult management decisions on. Unfortunately, the apparent low abundance of bull trout in Odell Lake may preclude meaningful results from food-habits analysis of bull trout. Finally, reducing the putative influences of lake trout on bull trout may require actions that reduce the abundance of lake trout, increase the carrying capacity for bull trout, promote the expression of fluvial or resident life histories, or some combination of these.

Potential effect of the recreational fishery on bull trout in Odell Lake

Odell Lake has an important recreational fishery that may influence bull trout abundance (USFWS 2002; USFWS 2015). The recreational fishery is primarily composed of kokanee, lake trout, mountain whitefish, and *O. mykiss* sspp. (e.g., redband trout and rainbow trout); however, bull trout catch has been reported in creel surveys conducted in 1996, 1997, 1998, 1999, and 2004 (USFWS 2002; Oregon Department of Fish and Wildlife, *unpublished data*). Current regulations prohibit the take of bull trout; however, creel survey data may be useful for elucidating potential impacts to the bull trout population by recreational angling.

Boat access point creel surveys were conducted every other week beginning the week of June 24, 2013 and ending on October 6, 2013 (creel survey season) to determine if bull trout were part of the recreational fishery. Each two-week period was treated as an individual stratum and creel surveys were conducted on two randomly selected weekdays and both weekend days within the same week for each stratum. Creel surveys were conducted during one of two randomly selected survey periods on each survey day. Creel surveys were conducted by two independent creel clerks on each survey day and each creel clerk was randomly assigned to one of six possible access points (boat launch or marina). Angler counts were conducted three systematically spaced times per survey period and total harvest and release for each species was estimated for the creel survey season.

Greater than 90% of the fishing parties interviewed indicated that they were targeting kokanee. Less than 3% of the fishing parties indicated that they were targeting each of the following species or categories: lake trout, *O. mykiss*, mountain whitefish, some combination of these species, or unknown species. No fishing parties indicated that they were targeting bull trout. Estimated harvest during the creel survey season was 47,117 kokanee, 39 lake trout, 151 mountain whitefish, and 178 *O. mykiss*. Estimated release during the creel survey season was 2,482 kokanee, 166 lake trout, 98 mountain whitefish, and 165 *O. mykiss*.

One bull trout was reported during creel surveys on July 13. This bull trout was caught at a depth of about 19 m near the middle of the lake by an angler targeting kokanee. We estimated that about eight bull trout were caught during the entire creel survey season, which is likely a conservative estimate because we did not survey during the entire angling season (i.e., April 27-October 31, 2013). Although this number is small relative to the catch of other fishes in the recreational fishery, it may represent a large portion of the bull trout population in Odell Lake (see above). Therefore, we suggest that further creel surveys are warranted. If creel surveys are conducted in the future, the type of creel survey should be dictated by survey objectives, data needs, and logistical concerns. Regardless of creel survey methodology, future creel surveys may be enhanced by working with resort and marina owners because, on average, we surveyed 11 fishing parties per survey day when at one of the two resorts located on Odell Lake whereas we surveyed only 6 fishing parties per survey day when at one of the other access points. Additionally, research aimed at identifying spatio-temporal lacustrine habitat use by bull trout in Odell Lake may indicate when or where they are susceptible to incidental catch by anglers targeting other species.

Recovery and conservation of bull trout in the Odell Lake Core Area

Our research showed that bull trout are present at low abundance in the Odell Lake Core Area, and therefore may be at high risk of extinction. Substantial management intervention is likely needed to ensure the long term viability of bull trout in this core area. Management actions for this core area can be grouped into four major categories: habitat management, nonnative species management, recreational fishery management, and conservation translocation management.

Suggested habitat management and/or RME includes:

- Evaluate the extent of available spawning and rearing habitat in the Odell Lake Core Area, and identify areas that may support bull trout following habitat enhancement.
- Maintain habitat connectivity between Odell Lake and Odell Creek.
- Evaluate whether the railroad culvert on Crystal Creek is a barrier to upstream fish passage and mitigate for its effects if it is a barrier.

Suggested nonnative species management and/or RME includes:

- Evaluate brook trout management.
- Evaluate tui chub thiaminase activity.
- Quantify demographic characteristics of the lake trout population in Odell Lake.

Suggested recreational fishery management and/or RME includes:

- Develop a creel survey program that provides data regarding the inclusion of bull trout in the recreational fishery.

Suggested conservation translocation management includes:

- Identify biological and social conditions under which reinforcement of the existing bull trout population in the Odell Lake Core Area is deemed acceptable and explore strategies for conducting reinforcements using in and out of basin stock.

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Chapter 1: Current Status of Bull Trout in the Odell Lake Core Area

Abstract.—We conducted surveys using fish passage stations, snorkeling, and backpack electrofishing in streams within the Odell Lake drainage to identify the spatio-temporal extent of potential bull trout spawning and rearing. We estimated that 43-51 unique bull trout entered Trapper Creek to spawn during 2013. We documented two adult bull trout (60 and 95 cm) moving downstream from Odell Lake to Odell Creek, including a potential allacustrine spawning movement pattern to Charhaven Creek. We did not detect bull trout moving to or from Davis Lake. We detected seasonal movement of bull trout (12-20 cm) suggestive of migratory behavior in Charhaven Creek and the coldest reach of Odell Creek. We documented bull trout presence in Crystal Creek and Charhaven Creek, but not in McCord Cabin Springs, Maklaks Creek, or Ranger Creek. The detection probability for bull trout was low ($p \leq 0.21$) when sampling by backpack electrofishing. Assuming a 0.5 prior probability of bull trout occupying McCord Cabin Springs and Maklaks Creek, we estimated that our intensive surveys gave us high confidence (posterior probability >0.9) that bull trout currently did not occupy these streams. Our results show that multiple age-classes of bull trout occupy portions of the Odell Lake Core Area other than Trapper Creek and Odell Lake, albeit in relatively low abundance, and a better understanding of the factors influencing distribution and abundance throughout this core area would aid long-term management of this species.

In the last 60 years, bull trout (*Salvelinus confluentus*) have been extirpated from all of the Upper Deschutes River basin except for an extant population in the small watershed (302 km^2) that contains Odell Lake, Odell Creek, and Davis Lake (Figure 1.1), hereafter referred to as the Odell Lake Core Area (OLCA; USFWS 2015). Davis Lake was formed by a lava flow 5,500 years ago that blocked Odell Creek from its direct route to the Deschutes River. Water still flows to the river through cracks in the basalt, but it is a complete barrier to fish movement and has isolated native populations of bull trout, redband trout (*Oncorhynchus mykiss gairdneri*), and mountain whitefish (*Prosopium williamsoni*) in the OLCA for millennia.

A long history of human inhabitants in this high-elevation region and evidence of temporary settlements near the lakes dating back thousands of years attests to thriving fish populations in this region (USFS 1999). Bull trout, and the other native salmonids, in Odell Lake and in nearby Crescent Lake once supported seasonal subsistence fishing by Native Americans and early American homesteaders (Gray 1986, 1989). Bull trout and redband trout were part of a popular recreational fishery from 1910, when roads opened this region to motorized vehicles, through most of the 1940's (OGSC 1946, Gray 1986). Anglers reported catching bull trout as big as 6 kg and redband trout up to 3.5 kg in Odell Lake (Gray 1989).

Bull trout in this region have declined dramatically since then. The species disappeared from neighboring Crescent Lake basin in 1959 (ODFW 2005), shortly after US Bureau of Reclamation replaced the decrepit storage dam built in 1922 with a new dam. Access to historical spawning habitat in Crescent Creek, the lake's outlet stream, continued to be blocked and other spawning habitat was inundated when lake levels rose behind the taller dam. Recreational fishing for bull trout in Odell Lake was closed in 1992 to protect the species. Although, there are no direct estimates of bull trout abundance in Odell Lake basin from this early history, anecdotal evidence suggests bull trout are a remnant of their historical population size. For example, historically, bull trout reportedly spawned in the two largest inlet streams to Odell Lake, Trapper Creek and Crystal Creek (OGSC 1946). It is currently thought that bull trout were extirpated from Crystal Creek, leaving the lower 1.3 km of Trapper Creek as the only known area where bull trout spawning consistently occurs (USFWS 2004).

Previous efforts to document the distribution and abundance of spawning and rearing bull trout in the OLCA have primarily focused on Trapper Creek. Conservation actions proposed to address habitat and demographic threats to bull trout include the need to identify all suitable spawning and rearing habitat and assess the feasibility of establishing new populations in the core area (USFWS 2015). Bull trout have been documented

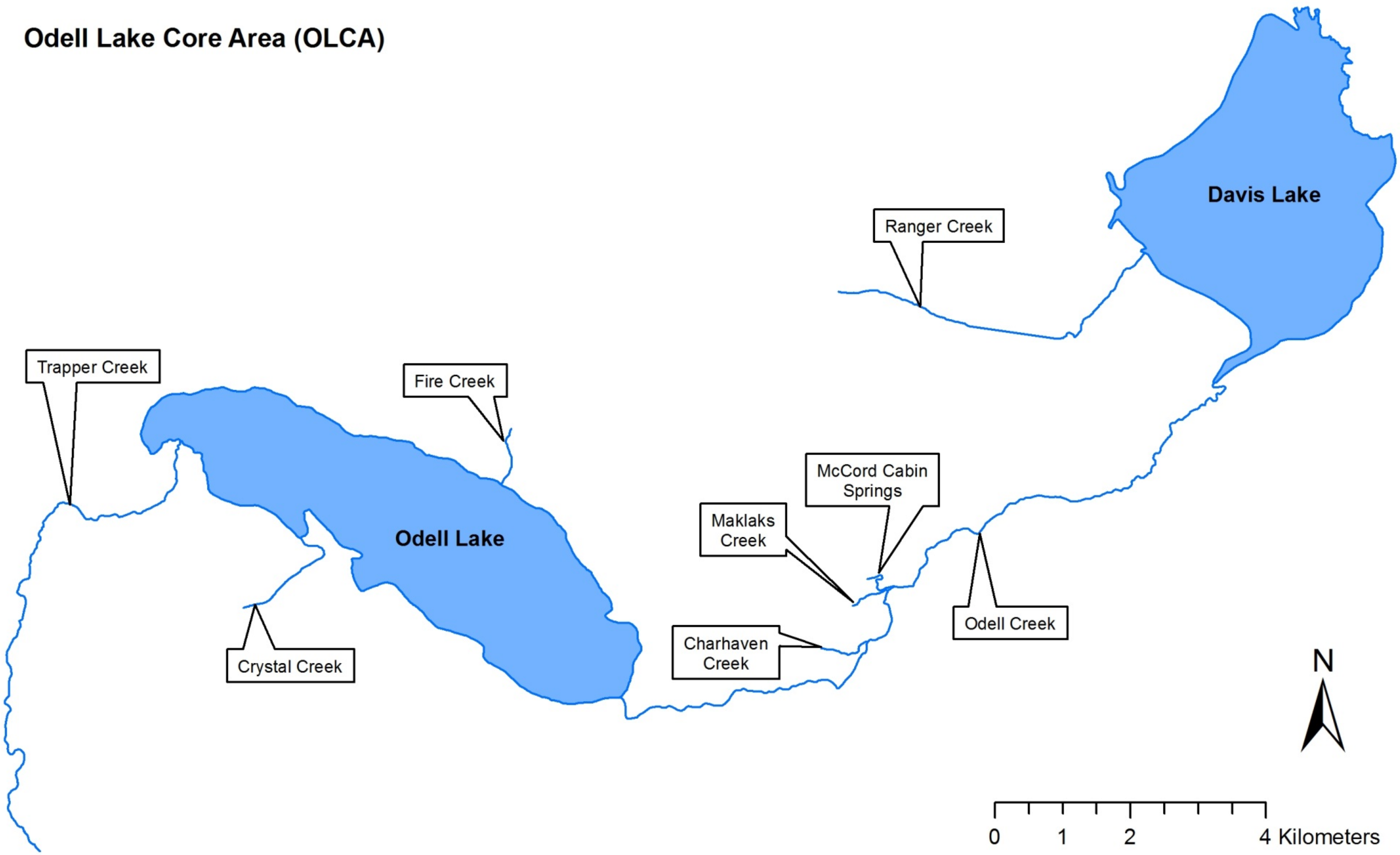


FIGURE 1.1—Map of the Odell Lake Core Area (OLCA) showing lakes and streams reference in this document. Charhaven Creek is known as Tributary #1 in USFWS (2015).

within the OLCA in areas other than Trapper Creek and Odell Lake (Figure 1.1); these areas may contain suitable spawning and rearing habitat, but they have not been surveyed intensively. For example, around Odell Lake, presence/absence surveys observed a single bull trout in Fire Creek in 2002 and Crystal Creek in 2005 and an angler caught two 200-mm bull trout in Odell Creek near the outlet of the lake (Paul Powers, USDA Forest Service, *personal communication*). In Davis Lake, bull trout were documented in the first biological investigation of the lake in 1932 and again in net surveys in 1966 and 1977 (Fies et al. 1996). In lower Odell Creek, six bull trout were observed during rotenone post-treatment surveys in 1961; daytime snorkel surveys in September, 1979, counted a few bull trout (350-460 mm) (Fies et al. 1996); in July, 2000, an angler reported catching a 965 mm bull trout in the creek inlet to Davis Lake (Steve Marx, ODFW, *personal communication*); and in 2003, two juvenile bull trout were observed during night snorkel surveys. In the middle section of Odell Creek, three bull trout were observed in 2003 during electrofishing and snorkel surveys in Maklaks Creek and nearby in Odell Creek and 18 bull trout were counted in one night of snorkel surveys in the largest Odell Creek tributary (Dachtler 2004); which is known as “Unnamed tributary #1” in the recovery unit implementation plan (USFWS 2015) and hereafter referred to as “Charhaven Creek”. These observations suggest that bull trout production may occur in locations other than Trapper Creek and an extensive investigation of the current status of bull trout in the OLCA is warranted. Therefore, we conducted intensive surveys in Charhaven Creek, Crystal Creek, Maklaks Creek, McCord Cabin Springs, Odell Creek, Ranger Creek, and Trapper Creek using a variety of sampling methods to help identify the spatio-temporal extent of bull trout spawning, rearing, and movement patterns within this core area.

Methods

Bull trout spawning, rearing, and movement can occur in a range of habitats and spatio-temporal scales. To investigate the status of bull trout in the range of habitats and scales relevant to their life history, we used a variety of methods. Fish passage stations were used to monitor fish movement in the largest streams in the OLCA (i.e., Trapper Creek, Odell Creek, and Charhaven Creek) and to-and-from the lakes. Snorkel surveys were used in Odell Creek to detect bull trout rearing that was unlikely to be detected by fish passage stations. Backpack electrofishing was used in smaller wadable streams to detect early rearing of bull trout.

<u>Fish passage stations</u>

We used fish passage stations to monitor the movement of bull trout and other fishes at several locations in the OLCA (Figure 1.2). Each station consisted of a weir with a fish passage chute, a digital video system, light-emitting diode (LED) lighting, and a solar power source. A typical weir (Figure 1.3) consisted of upright and floating panels that were covered with welded wire fencing (2.5 x 5.0 cm mesh) affixed to the panel frame using hose clamps. Tall (1.2 x 3.0 m, H x W) and short (0.4 x 3.0 m) upright panel frames were made of aluminum chain-link fence rails (3.5 cm diameter, 17 ga) and gate elbows. These upright panels were fastened to fence posts sunk into the stream bed. Floating panel frames were constructed of 2.5-cm polyvinyl chloride (PVC) pipe. One side of the floating panel was attached underwater to the short panel frames and the other side floated on the surface with the aid of capped 10.2-cm PVC float tubes (3.0 m long). Floating panels prevented scouring under upright panels by reducing debris and ice build-up on the weir. To allow for voluntary fish passage and recording of passage events, each weir was fitted with a custom-built aluminum sheet-metal (16 ga, 1.6 mm) fish passage chute (1.0 x 0.5 x 0.8 m, L x H x W). The chute was fyked on one side to house a submersible digital camera (Sony Super HAD Color CCD, 400 TVL, 3.6 mm board lens; Jet Security USA, Inc.) and to create a 0.2 m wide passage slot (Figure 1.3). The camera was placed in a 5.1-cm PVC housing that was attached to the outside wall of the chute, with the camera extending into the fyked side of the chute and pointed through a plexiglass window toward the narrow fish passage slot. Measuring boards (5-cm graduations) were bolted to the floor and background wall of the passage slot so fish length could be estimated by the video analyst. The video feed was split and monitored by two motion-activated digital video recorders (DVRs) (mDVR-14, Supercircuits, Inc.). The DVRs were programmed to begin recording when 6% of the pixels in the video image were in flux and end recording 5 s after motion ended. The second DVR, with the same settings, was used as a backup and could be downloaded if the primary DVR malfunctioned. The DVRs saved video records on removable 8 GB secure digital high

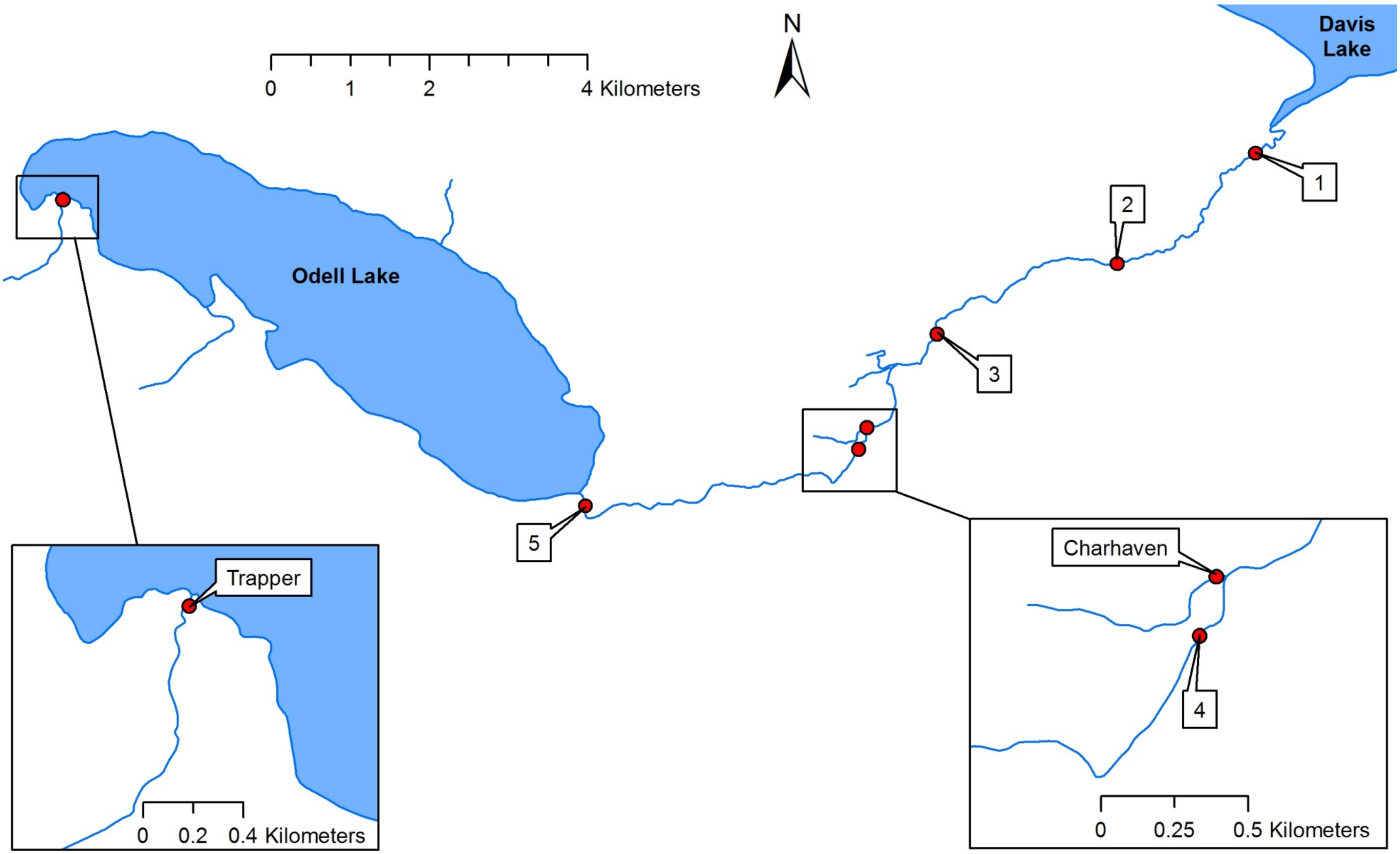


FIGURE 1.2—Map of seven fish passage stations monitored by underwater video systems in the Odell Lake basin. We maintained the Trapper Creek and Site 5 stations in 2012; sites 1, 3, 4, 5, and Charhaven in 2013; and all stations, except for the Trapper Creek station, in 2014.

FIGURE 1.3—Examples of fish passage stations *in situ* and an underwater view inside the fish passage chute.

capacity (Patriot SDHC) cards. Sunshades were suspended above the ends of the fish chute to reduce light noise in the fish chute during the day. To allow for recording fish passage events at night, submersible LEDs were affixed inside the fyked part of the chute and illuminated the passage slot. Each site was powered by three 12 V deep-cycle batteries that were charged by an 80 W solar panel (Kyocera) and solar controller (Sunsaver 20). In-line 12 V - 12 V DC power converters (Wall Industries, Inc.) were used to stabilize current to the cameras and LEDs and 12 V - 5 V converters were used to power the DVRs. All batteries and DVRs were housed in steel lockboxes.

The weirs and video systems were checked at least twice each week. Maintenance included thoroughly cleaning the weir panels and fish chute of debris, wiping algae off the plexiglass viewing window, checking the camera angle and video quality and making adjustment when necessary, ameliorating sources of video noise (e.g., debris, sunlight, small fish trapped in the fyke of the chute), and scanning the weir with an underwater viewfinder or by snorkeling to search for passage gaps, which were repaired immediately with sandbags or welded wire fencing. In Trapper Creek, the station was visited at least three times each week and maintenance included hiking the banks within 50 m of the station in search of signs of fish killed by otters. We found no evidence that bull trout were killed by otters during this study.

The memory card from the primary DVR was removed and replaced with an empty card usually once each week (depending on how much memory was left on the card). The memory cards were downloaded to a computer file folder and the folder was backed up on an external hard-drive and a network (if available). All video records were watched by a video analyst. Data from individual bull trout, brook trout (*S. fontinalis*), and lake trout (*S. namaycush*) video records were entered in a database. We entered the following characteristics for each record: species, estimated total length (TL; cm), passage direction, date, and time. When species was not identifiable, the data

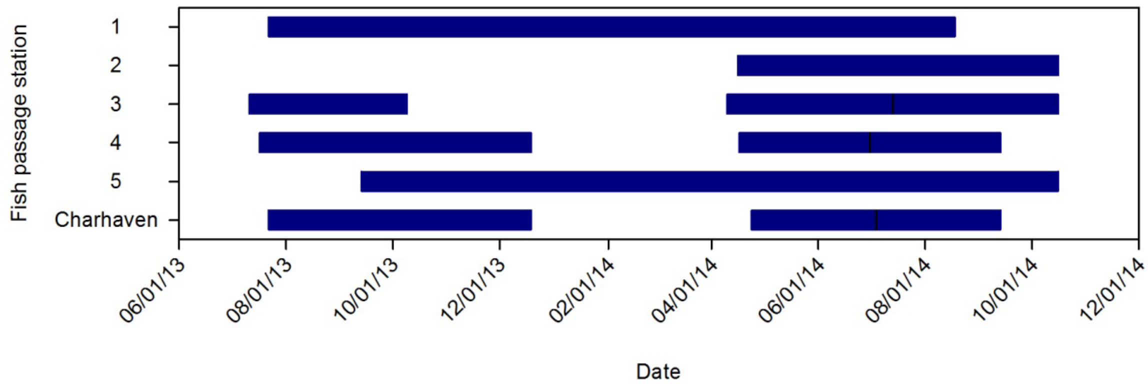


FIGURE 1.4—Time periods over which fish passage stations were operational in the Odell Lake Core Area.

record was entered as "unknown species." If the video analyst was uncertain about some aspect of a data record, the analyst clicked an "entry question" box and entered the question in the comment field in the database. All fish passage videos entered as a char species or "unknown species", or accompanied by an entry question, were reviewed by at least one other video analyst. The passage events of kokanee (*O. nerka*), *O. mykiss* spp., and mountain whitefish were tallied by species and passage direction and entered in the database as weekly counts.

In 2012, we maintained two fish passage stations. One station was located near the mouth of Trapper Creek, 10 m from Odell Lake, and was used to count adult bull trout using this stream for spawning. This station was maintained from August 15-November 26. The second station was located in Odell Creek, 200 m downstream from the lake, and was used to monitor bull trout movement between Odell Lake and Odell Creek. This station was maintained from August 16-November 11. In 2013 and 2014, we maintained the five stations in Odell Creek and one station in Charhaven Creek, 15 m from its confluence with Odell Creek (Figure 1.2), over varying time periods (Figure 1.4).

<u>Snorkel surveys</u>

We conducted night snorkeling surveys in Odell Creek in 2014 to determine detection and occupancy probabilities for bull trout. We delineated three segments in Odell Creek based on stream geomorphology, the presence of tributary streams, and vegetative cover. The first segment was 3.2 km long, started at Davis Lake and ended near fish passage station 2 (Figure 1.2), and was characterized by a relatively unconstrained floodplain channel, low gradient (0.3%), and a lack of mature riparian vegetation as a result of the 2003 Davis Lake forest fire. Mean maximum daily water temperature during July 2014 in this segment was 18.0 ± 0.4°C (mean ± sd) (ODFW, *unpublished data*). The second segment was 5.0 km long, started near fish passage station 2 and ended at the confluence with Charhaven Creek, was forested, constrained by narrow valley width, and had a higher gradient (1.1%). Near the upper end of this reach, several cold water tributaries (4.5°C) join Odell Creek and mean maximum daily water temperatures in July in this segment was 16.7 ± 1.2°C (ODFW, *unpublished data*). The third segment was 4.6 km from Charhaven Creek to the Odell Lake outlet (1.3% gradient); this segment mainly consists of surface water from Odell Lake and had a mean maximum daily water temperature in July of 22.0 ± 0.6°C (ODFW, *unpublished data*).

Each segment was divided into 100-m sample sites. The survey effort was allocated disproportionately to segments deemed more likely to be suitable for bull trout rearing. All 32 sample sites in the first segment and all 50 sites in the second segment were surveyed once between August 20 and September 4. Between September 15 and 29, all sites in the second segment and 14 sites in the upstream half of the first segment were surveyed a second time to determine the probability of detection at the site level. Only 12 sites were surveyed in the third segment, starting just upstream from the confluence of Charhaven Creek. These surveys were conducted on September 30.

Field crews usually consisted of two snorkelers and one data recorder; the data recorder walked on the bank or waded in the stream behind the snorkelers and recorded fish and habitat data, carried gear, located site start and end points, and ensured the safety of the snorkelers. All secondary channels were surveyed by one snorkeler accompanied by a data recorder. Start and end points of sites, determined using ArcGIS, were located using a GPS and flagged during daylight hours prior to the survey. Snorkel surveys, which were conducted between 20:00 and 02:00, began after nautical twilight to increase the likelihood that juvenile bull trout present in a sample site had emerged from cover (Jakober et al. 2000; Thurow et al. 2006). The two snorkelers split the stream along the midline of the channel and each snorkeler surveyed one side, working in the upstream direction. All slow-water habitat units (i.e., pools and glides) were surveyed thoroughly. In fast-water habitat units (i.e., riffles and rapids), snorkelers thoroughly surveyed all pockets (i.e., relatively deep and low velocity areas within the unit), areas with instream wood and boulders, deeper stream margins, backwaters, alcoves, and undercut banks. Habitat with relatively shallow uniform depth was spot-checked. Spot-checking entailed a stationary scan of an 180˚ angle upstream within a viewable range, picking out a spot at the upstream edge of that range, and then walking to that spot for another spot check. The goal of spot-checking was to survey all habitat in the unit, but to avoid crawling on elbows and knees through higher velocity areas, which was often too difficult or time-consuming for the snorkeler.

All individual bull trout, brook trout, and lake trout (i.e., the char species present in the core area) were counted, identified to species, measured for TL (cm), and data were entered on the field form by the data recorder. The presence of other fishes was noted for each site, but individuals were not counted. Large bull trout (> 30 cm) were digitally recorded using an underwater video camera. After measurements were recorded, snorkelers were instructed to attempt to capture bull trout and brook trout (< 30 cm) with a dipnet to confirm species identification and to calibrate measurement. The data recorder also measured pool length, pool tail crest depth, and maximum pool depth for all pools in each survey site and measured the temperature at the beginning and end of each survey; stream slope was measured using ArcGIS.

Electrofishing surveys

Electrofishing surveys were conducted in Charhaven Creek, Maklaks Creek, McCord Cabin Springs, and Ranger Creek in 2013 and in Crystal Creek in 2014; each stream was divided into contiguous sample sites that were about 100-m long. Nine sample sites were established in Charhaven Creek from its confluence with Odell Creek to an upstream point where the channel became braided and entered a meadow. There were 19 sample sites in Crystal Creek starting from its mouth (i.e., Odell Lake) and continuing upstream to its headwaters; the 10 upstream-most sample sites in Crystal Creek were upstream from a railroad culvert. Eight sample sites were established in Maklaks Creek from its confluence with Odell Creek to an upstream point where the channel became braided and the size and gradient of the individual braids were deemed unlikely to harbor bull trout. Seven sample sites were established in McCord Cabin Springs starting at its confluence with Odell Creek and continuing upstream to its headwaters. Twenty-three sample sites were established in Ranger Creek starting at its mouth (i.e., Davis Lake) and continuing upstream. The sample sites in Ranger Creek comprised about the lowermost 65% of available habitat (measured in length); additional sites were not sampled because of time constraint.

Bull trout are highly cryptic and typically difficult to capture. Additionally, we expected the density of bull trout, if present, to be very low. To account for this, we used a repeat visit sampling design with a maximum of five visits per site; however, limitations were placed on the number of visits at sites where we detected bull trout. For any site, if a bull trout was detected, subsequent visits were not conducted unless it was the first visit to the site, in which case only one subsequent visit was conducted. This sampling design resulted in all sites being visited at least two times and up to five times. We chose this design based on a power analysis suggesting that failure to detect bull trout on 5 repeat visits to a site would result in us being about 50% certain that the site was unoccupied, or 95% confident that there were < 4 bull trout (see Box 1.1). Ranger Creek was the only exception, where each site was only visited once because of time constraints and we considered this tributary to be the least suitable for bull trout based on local knowledge of these streams. For each site visit, block nets were placed at the downstream and upstream boundaries of the site

Box 1.1—Power analysis, assuming a 0.05 capture probability with standard deviation of 0.01, that shows the posterior mean number (*N*) of fish in a tributary, the upper 95% confidence limit for the mean number of fish in a tributary, and the probability that no fish are present in a tributary as a function of the number of times each sample site is electrofished within a tributary (right). Script (implemented in Program R) used to conduct the power analysis (below). The script was provided by J. Peterson and requires JAGS 3.4 software and the R package R2JAGS to run.

Visit	Posterior mean *N*	Upper 95% CL for *N*	Probability *N* = 0
1	5.66	18	0.10
3	1.78	6	0.29
5	0.99	4	0.45
7	0.62	3	0.60
9	0.40	2	0.71
11	0.26	1	0.79
13	0.19	1	0.84
15	0.14	1	0.88
17	0.10	1	0.91
19	0.07	1	0.94
21	0.05	1	0.95
23	0.04	0	0.97
25	0.03	0	0.97

```
####################################################################################################
##     Calculates posterior abundance for zero catch data
##     Assumes uniform fistribution 0,2000 as prior mean abundance per sample unit
##      >>>>>> NOTE REQUIRES R PACKAGE R2JAGS AND JAGS SOFTWARE INSTALLED
##     >>>>>> (available: http://mcmc-jags.sourceforge.net/)
####################################################################################################

#### BEGINNING OF FUNCTION

post.abun <- function(no.sites, cap.p, cap.p.sd){
 if(is.element("R2jags",installed.packages()[,1]) == 0) {print("ERROR: Package R2jags is not installed"); break}
 require(R2jags)
 #   no.sites = 10
 #   cap.p.sd = 0.1
 #   cap.p = 0.3

 v<-cap.p.sd**2
 x<-cap.p
 alpha<-x*(x*(1-x)/v-1)
 beta<-(1-x)*(x*(1-x)/v-1)

 if(alpha < 0 | beta < 0) stop("capture probability std dev is too high or low")

 jag.model<- function(){
  for(v in 1:sites){
   # number caught is catch
   # estimated capture probability is p
   catch[v]~dbin(p,est.N)
  }
  ## estimated abundance
  est.N<-round(N)
  N~dunif(0,2000)
  p~dbeta(alpha,beta)
  nz<- 1- step(est.N-1)
 }

 params<- c("est.N","nz")
 jdata<- list(catch=rep(0,no.sites), sites=no.sites,alpha=alpha,beta = beta)
 inits<-function(){list(p=0.25,N=10)}
 ZZ<-jags(data =jdata, inits=inits, parameters.to.save=params,
      model.file=jag.model, n.thin=1, n.chains=2, n.burnin=2000, n.iter=100000)

 return(c(ZZ$BUGSoutput$summary[2,1:2],ZZ$BUGSoutput$summary[3,1]))
}

##### Example use, output is posterior mean abundance and SD, and probability that mean abundance is 0
post.abun(no.sites= 10, cap.p=0.05, cap.p.sd= 0.01)
```

to prevent fish from moving into or out of the site during sampling, a two-person field-crew electrofished in an upstream direction through the entire sample site, and all fish encountered were netted and placed in a bucket filled with stream water. We assumed that Charhaven Creek was too wide to effectively sample with one field crew; therefore, two, two-person field-crews electrofished side-by-side in Charhaven Creek. Fish were identified to species, measured for fork length (FL; mm) and returned to the stream within the sample site; fish were anesthetized when necessary using 25 mg/L Aqui-S 20E, and a small tissue sample was collected from the caudal fin of bull trout for genetic analysis.

Length frequency histograms, spatial distribution, and electrofishing counts for each visit were plotted for each species and stream where the species was encountered. A single-season occupancy model (Mackenzie et al. 2005) was used to estimate occupancy (ψ, Greek letter "psi"), and detection (*p*) probabilities of bull trout, brook trout, and redband trout for the sampled streams in the study area. Detection and occupancy probabilities were modeled separately for each species. For bull trout, Charhaven Creek and Crystal Creek data were combined in the analysis and stream was treated as an attribute group (i.e., indicator variable). Brook trout were only detected in Charhaven Creek so their detectability and occupancy were estimated only for this stream. Redband trout were detected in all streams sampled so these data were combined for analysis with streams treated as attribute groups. Prior to the occupancy analysis, the influence of sampling effort on bull trout detection probability was evaluated. Site length and the amount of time each site was surveyed (i.e., electrofishing seconds) were positively correlated (Pearson product moment correlation; R = 0.80; 0.62–0.90, 95% confidence interval; P < 0.001, df = 28); therefore, we used only electrofishing seconds to represent site sampling effort and evaluated its influence on bull trout detection. We found that our sampling effort did not influence bull trout detection probability at individual sites (R^2 = 0.14, P = 0.36, df = 10) so it was not included as a covariate in the occupancy analysis.

The models evaluated included *p*- and ψ-intercepts and all combinations of the stream attribute group. Markov Chain Monte Carlo methods were used to estimate parameters. Deviance Information Criterion (DIC) was used for model selection. Deviance Information Criterion ranks the deviance of individual models while penalizing for additional parameters (i.e., model complexity), producing a DIC score for each model. The model with the lowest DIC score represents the "best" model, and models with scores within 1-2 DIC values of the best model also merit consideration (Spiegelhalter et al. 2002). Since a method of model averaging in DIC has not been developed (Spiegelhalter et al. 2002), we report the detection and occupancy probabilities of the best model and report the DIC scores of models within 2 DIC values of the best model. The analysis was conducted using Program MARK.

In streams where bull trout were not detected, we used a Bayesian approach (Bayley and Peterson 2001; Peterson and Dunham 2003) to estimate the posterior probability that bull trout were actually present at two spatial scales (Box 1.2). We simulated the range of prior probabilities of species presence at the site level to produce posterior probabilities at the stream level in Maklaks Creek and McCord Cabin Springs, where bull trout were not detected. Posterior probabilities were estimated using bull trout detection probabilities estimated from Charhaven Creek (P=0.28), Crystal Creek (P=0.10), and the two streams combined (P=0.21) (this study).

<u>eDNA survey</u>

Organisms are constantly shedding DNA into the environment through processes such as excretion of feces and urine and loss of skin cells and saliva. DNA that can be sampled from the environment (e.g., water, soil, etc.) is called environmental DNA (eDNA) and research has shown that it is possible to detect the presence of organisms based on the presence of eDNA; see Rees et al. (2014) for review.

Environmental DNA surveys were conducted June 9 and 23, 2014, in Crystal Creek coincident with electrofishing surveys, and on June 10, 2014 in Trapper Creek. Field samples were collected from eight locations along Crystal Creek that were spaced about every 250 m from Odell Lake to 1.77 km upstream from Odell Lake. Paired control samples (i.e., distilled water) were also prepared at each location. This sample design consisted of four samples collected downstream from the railroad culvert and four samples collected upstream from the railroad culvert. One field sample (and paired control sample) was collected from Trapper Creek about 25 m upstream from

BOX 1.2—Equations for estimating the posterior probability that bull trout were present in streams where they were not detected based on backpack electrofishing surveys.

Equation 1. Probability of presence given no detection in a site:

$$p_{site}(\psi = 1|y = 0) = \frac{p(\psi = 1)p(y = 0|\psi = 1)^{visits}}{p(\psi = 1)p(y = 0|\psi = 1)^{visits} + p(\psi = 0)p(y = 0|\psi = 0)}$$

Equation 2. Probability of presence given no detection (after five site visits) in a stream:

$$p_{trib}(\psi = 1|y = 0) = \frac{p(\psi = 1)p_{site}(y = 0|\psi = 1)^{sites}}{p(\psi = 1)p_{site}(y = 0|\psi = 1)^{sites} + p(\psi = 0)p(y = 0|\psi = 0)}$$

where $p(\psi = 1)$, at the site-scale, is the prior probability the species is present in a site; $p(y= 0|\psi = 1)$ is the probability of not detecting the species during a single visit when present in a site, which is the complement of the detection probability we estimated for occupied streams [i.e., $1 - p(y= 1|\psi = 1)$]; $p(\psi = 0)$ is the probability that the species is absent from the site, which is the complement of the probability of species presence [i.e., $1 - p(\psi = 1)$]; and $p(y= 0|\psi = 0)$, which necessarily equals 1, is the probability that the species is not detected when not present in the site. At the site-scale, the probability of not detecting the species when it is present [i.e., $p(y= 0|\psi = 1)$] is compounded by the number of visits to a site. At the stream-scale, equation (2) is the same except we used the posterior probability estimated in equation (1) for $p_{site}(y= 0|\psi = 1)$ and this was compounded by the number of sites sampled in the stream

Odell Lake. Samples were collected following Carim et al. (2014) and were sent to the US Forest Service—Rocky Mountain Research Station (Missoula, Montana) for analysis of bull trout and brook trout eDNA; see Carim et al. (2015) for a detailed description of laboratory methods.

Results

<u>Fish passage stations</u>

Trapper Creek fish passage station—The fish passage station at Trapper Creek monitored bull trout movement from August 15 to November 26, 2012. Bull trout were present in 340 of the fish passage video records. From these records, we identified 43 unique bull trout (21 females, 22 males) passing upstream through the station between August 18 and September 21 (Figure 1.5). These fish had at least one distinctive characteristic that allowed them to be individually identified during video evaluation. Distinctive characteristics included sex, coloration, scratches, fin damage, opercle markings and deformities, jaw shape, and body shape and size (Figure 1.6). A memory card from the primary DVR was accidentally erased prior to its download to a computer and the backup DVR malfunctioned, leading to a 4-d data loss from September 15-19. Also, 14 video records of bull trout (5 female, 9 males) could not be uniquely identified because either no distinctive characteristics were found or poor resolution of video records prevented their evaluation.

The behavior of males and females differed substantially (Figure 1.7). Males accounted for 70% of the bull trout passage records, with individual males passing upstream and downstream through the fish chute on average five times. One male passed back-and-forth 18 times. In contrast, females only passed back-and-forth on average two times and a maximum of three times. Both males and females were moving in and out of Trapper Creek during night and day hours.

Odell Creek and Charhaven Creek fish passage stations—In 2012, a single fish passage station was maintained in Odell Creek from August 21 to November 26. No bull trout were observed in the video records from this site. A six-week long algal bloom in the lake reduced visibility in the fish chute and produced poor quality video records until late September. Two high water events in October and November preceded by a large wood addition in August at the Odell Lake outlet led to

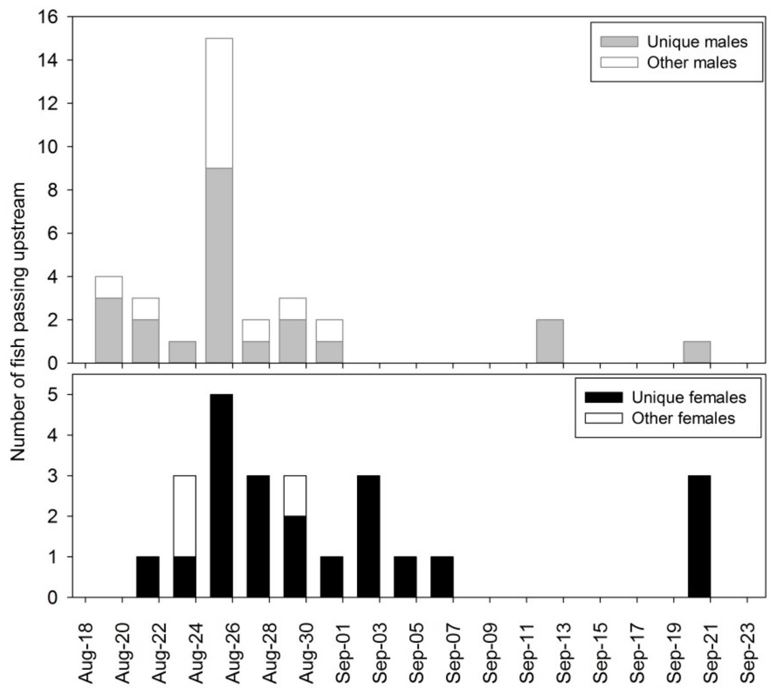


FIGURE 1.5—Temporal distribution of the initial upstream passage of 43 unique bull trout through a fish passage station on Trapper Creek. The bull trout in 14 video records were not individually identifiable, shown here as “other”. The station was maintained from August 15 to November 26, 2012; however, there was a 4-d data loss from September 15-19.

FIGURE 1.6—Still photos from selected video records from the fish passage station near the mouth of Trapper Creek, 10 m from Odell Lake. Individuals from this small adult population were identified by unique combinations of characteristics such as sex (males in left column, females on right), coloration, scratches, fin damage, opercle markings and deformities, jaw shape, body shape, and length.

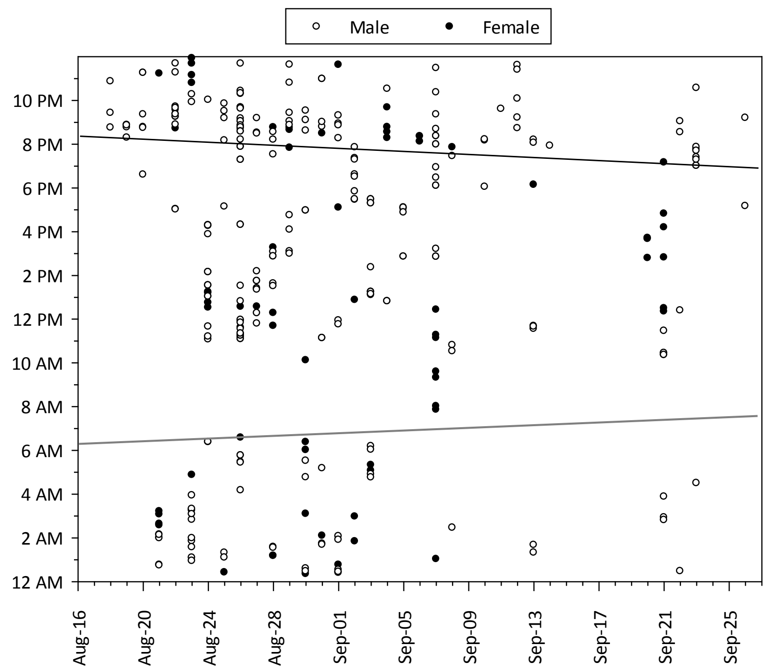


FIGURE 1.7— Diel distribution of all male and female bull trout passage events (upstream and downstream) at the fish passage station in Trapper Creek. Diagonal lines represent the time of sunrise and sunset. There was a 4-d data loss from September 15-19, 2012.

station damage. Weir panels were damaged such that fish could pass the station without going through the fish chute.

In 2013 and 2014, bull trout passage events were recorded at stations 5, 4, 3, and Charhaven Creek. At station 5, in 2013, two large bull trout (estimated 60 and 95 cm TL) were recorded moving downstream in Odell Creek on September 25 and November 28, respectively (Figure 1.8). The 60 cm bull trout male was subsequently recorded passing repeatedly through the Charhaven Creek station starting on October 2, 2013 (Figure 1.9). This fish went upstream into Charhaven Creek during several nights and back to Odell Creek during the day, passing through this station 35 times, until it was last recorded on October 24, 2013. Another char species (i.e., bull trout, brook trout, or lake trout) passed downstream on December 14, 2013; this fish had bull trout characteristics, but the video quality was too poor for species to be identified with certainty.

Most of the bull trout passage events that occurred downstream from Odell Lake were recorded by fish passage stations in Charhaven Creek, located 15 m from Odell Creek, and at station 3 in Odell Creek, 1 km downstream from the confluences of several cold tributaries (Table 1.1). At both sites, most of the movement was in the downstream direction and occurred in July and August in both 2013 and 2014 (Figure 1.10). In 2014, only one bull trout was recorded at station 3 in Odell Creek; this 18 cm TL fish moved downstream on July 14 at 16:53. Bull trout were not recorded at the downstream most stations (1 or 2) in Odell Creek.

In 2013, a brook trout (17 cm TL) was recorded passing through station 1 on September 25 and three largemouth bass were recorded passing through station 1 between September 2 and October 19. In 2014, a brook trout (35 cm TL) was recorded passing upstream through stations 3 and 4 between May 13 and 19.

Kokanee and redband trout were recorded passing upstream and downstream through all stations. Mountain whitefish were recorded at all the stations in Odell Creek, but were not recorded in Charhaven Creek (Table 1.2). The total count of upstream passes recorded at all the stations was 9,970 kokanee, 26,504 redband trout, and 15,603 mountain whitefish. These numbers should not be considered estimates of abundance since we did not quantify how many individuals passed through a station more than one time.

FIGURE 1.8—Still photos from video records of adult bull trout moving downstream through station 5 (Odell Lake outlet) in Odell Creek. One male, 60 cm TL (left), was recorded moving through the Charhaven Creek station 7 days later. The other male (right) was an estimated 95 cm TL.

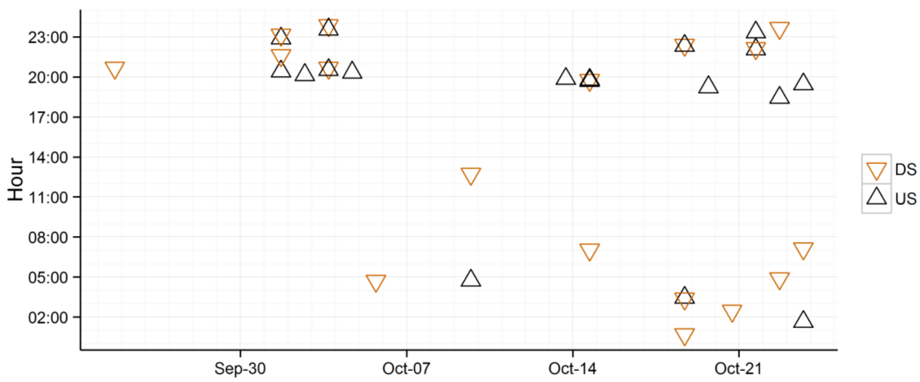


FIGURE 1.9—Video record history of upstream (black triangle) and downstream (orange) passage events of a 60 cm male bull trout in 2013. The first video record, corresponding to 25 September, was of the fish moving downstream through station 5 in Odell Creek, near the Odell Lake outlet. All October records were from the Charhaven Creek station located 15 m from its confluence with Odell Creek.

TABLE 1.1—Fish passage station summary for selected fish species, including total downstream (DS) and upstream (US) passage direction, minimum counts of unique individuals, and estimated total lengths of individuals.

			Fish passage		Minimum	Total length (cm)		
Year	Species	Station	DS	US	count	Mean	Min	Max
2013	Bull trout	Charhaven	6	1	5	15	14	16
	Bull trout	3	9	3	10	20	12	25
	Bull trout	4	1	0	1	15	NA	NA
	Bull trout	5	2	0	2	78	60	95
	Brook trout	1	1	0	1	17	NA	NA
	Largemouth bass	1	0	3	NA	15	14	15
2014	Bull trout	Charhaven	3	0	3	17	17	18
	Bull trout	3	1	0	1	18	NA	NA
	Brook trout	3	0	1	1	35	NA	NA
	Brook trout	4	0	1	1	35	NA	NA
	Lake trout	5	2	1	2	64	60	68

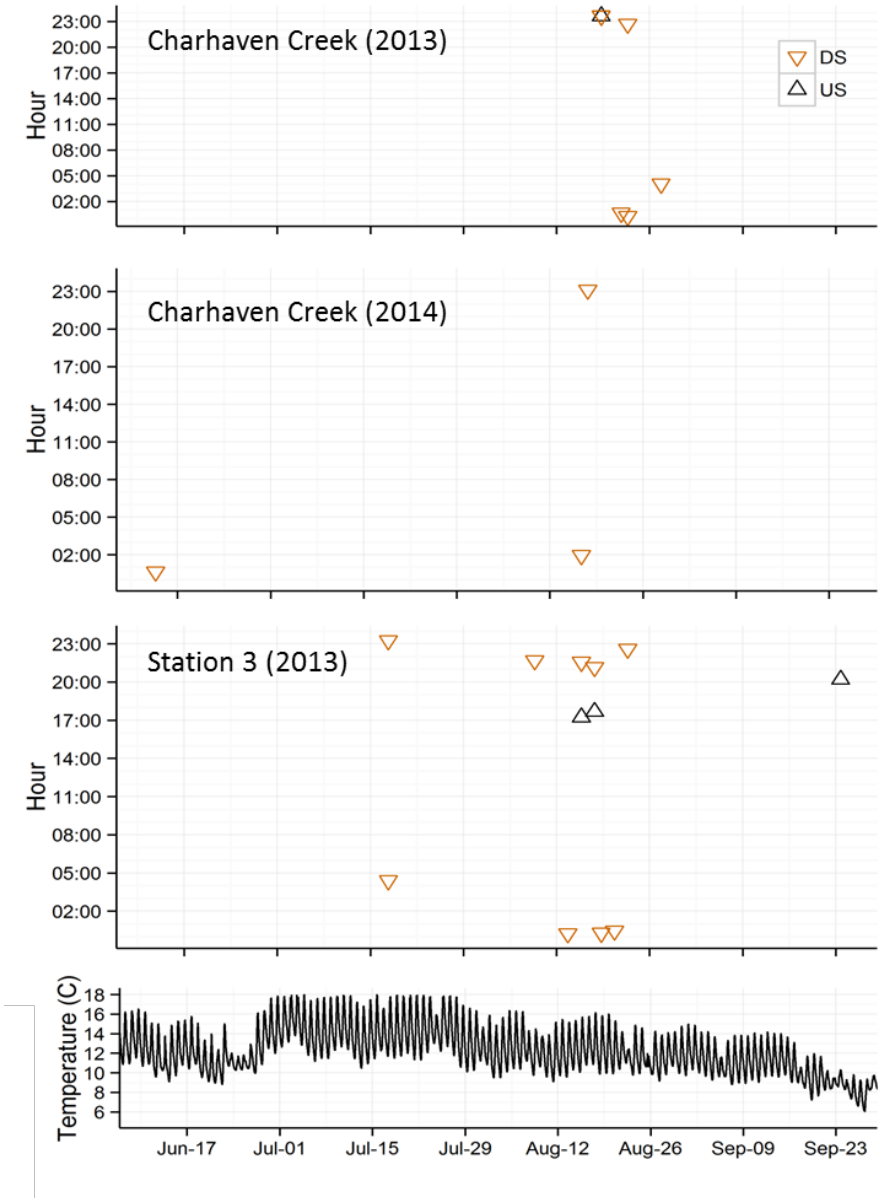


FIGURE 1.10—Video record history of upstream (black triangle) and downstream (orange) passage events of bull trout through the Charhaven Creek station and station 3 in Odell Creek. Station 3 water temperature for 2013 is also shown.

TABLE 1.2—Total count of video records of upstream (US) and downstream (DS) passes at each station for kokanee, redband trout, and mountain whitefish. These counts represent relative abundance because some individuals passed through a station more than one time and the average number of passes by an individual was not quantified. The time period of the count was about one year for Charhaven station and Odell Creek stations 1 and 5, and six months for the others.

	Kokanee		Redband trout		Mountain whitefish		
Station	US	DS	US	DS	US	DS	Time period
Charhaven	28	22	172	345	0	0	22 July 2013 – 21 July 2014
1	9,291	1,295	3,199	2,374	11,722	3,333	22 July 2013 – 25 July 2014
2	159	64	3,792	4,781	2,840	1,155	24 April – 15 October 2014
3	64	46	6,373	6,830	767	368	15 April 2014 – 15 October 2014
4	15	17	5,908	6,459	108	123	24 April 2014 – 15 September 2014
5	413	315	7,060	5,304	166	63	25 November 2013 – 2 December 2014

Snorkel surveys

No confirmed observations of bull trout, brook trout, or lake trout were recorded during snorkel surveys of 94 100-m sites in Odell Creek (0.0-9.8 km from Davis Lake). We did not observe any of these species in repeat snorkel surveys to 66 of these sites (1.0-8.2 km from Davis Lake). One potential observation of a bull trout was noted in the second segment, near its downstream end. The snorkeler did not get close enough to the fish to take a measurement, and the observation lasted less than 5 s before the fish darted upstream. Both snorkelers searched for 20 minutes for the fish, but it was not seen again and the observation could not be confirmed as a bull trout. Water temperatures during snorkel surveys averaged 9.2°C (range, 8-11°C; September 10 - 29) in the first segment, 9.7°C (range, 8 - 13°C; August 20-September 24) in the second segment, and 12.3°C (range, 10 - 17.5°C; September 30) in the third segment.

Redband trout and mountain whitefish were present in every sample unit and kokanee were observed in the first 10 sample units upstream from Davis Lake and then infrequently in the remainder of the study area.

Electrofishing surveys

Bull trout—Bull trout were detected in Charhaven Creek and Crystal Creek. In Charhaven Creek, seven bull trout were captured (range: 147-185 mm FL) and they were distributed throughout most of the sample sites (Figure 1.11). One individual was captured in two different sites on consecutive days. In Crystal Creek, five bull trout (110-212 mm FL) were captured, and were distributed among the downstream-most nine sample sites (Figure 1.12). Additive models that included the stream attribute had the lowest DIC score for bull trout (Table 1.3). The estimated occupancy (ψ) and detection (p) probabilities for bull trout were 0.85 and 0.28 in Charhaven Creek and 0.85 and 0.10 in Crystal Creek, respectively (Table 1.4). In other words, there was an 85% chance that bull trout occupied any individual site in Charhaven Creek and there was 28% chance of detecting a bull trout present at a site on any individual visit.

Bull trout were not detected in Maklaks Creek, McCord Cabin Springs, or Ranger Creek. The simulated posterior probability that bull trout were present and not detected in Maklaks Creek and McCord Cabin Springs was dependent on the assumed prior probability of occupancy and the range of detection probabilities estimated in streams occupied by bull trout in this study (Figure 1.13). For example, if we assume a prior bull trout occupancy probability the same as that estimated for Charhaven and Crystal creeks (i.e., ψ=0.85) and a moderate detection probability at the site-scale (i.e., p=0.21), then the estimated posterior probability of bull trout occupancy at the tributary-scale would be 0.28 for Maklaks Creek and 0.32 for McCord Cabin Springs. In another example, if we assume these tributaries were less likely than the known occupied tributaries to harbor bull trout (i.e., prior ψ=0.50) and the site-scale detection probability were relatively low (i.e., p=0.10), then the estimated posterior probability of occupancy would be 0.20 for Maklaks Creek and 0.22 for McCord Cabin Springs. Put another way, and using the complement, we estimated that there was 80% and 78% likelihood that bull trout did not occupy Maklaks Creek and McCord Cabin Springs, respectively, at the time of our sampling. The small difference in posterior probabilities between these two tributaries was because a greater number of sites were sampled in Maklaks Creek (N=8) than in McCord Cabin Springs (N=7). Ranger Creek, as a tributary of Davis Lake, was disjunct from the cold reach in the Odell Creek basin where bull trout were observed during electrofishing surveys and in video records. As such, if we assume low prior probability of bull trout occupancy (i.e., ψ=0.20), and low detection probability (i.e., p=0.10), after surveying the first 23 sample sites, we estimated the posterior probability of bull trout being present in this part of the tributary without detection was 0.02. In other words, if we take its complement, there was 98% likelihood that bull trout were not present in the sampled part of Ranger Creek during our sampling.

Brook trout—Brook trout were detected in Charhaven Creek and Ranger Creek. In Charhaven Creek, 116 brook trout were captured. We did not mark individual brook trout; therefore, we cannot determine the proportion of brook trout that may have been re-captured among sites and site visits. Brook trout ranged from 41-181 mm and were distributed in the upper 4 sites in Charhaven Creek (Figure 1.11). The mean number of brook trout caught per survey visit in these four sites was 9 (SD=6). The occupancy model failed to converge for brook trout in Charhaven Creek due to the combination of small sample size (i.e., nine sites) and high detection

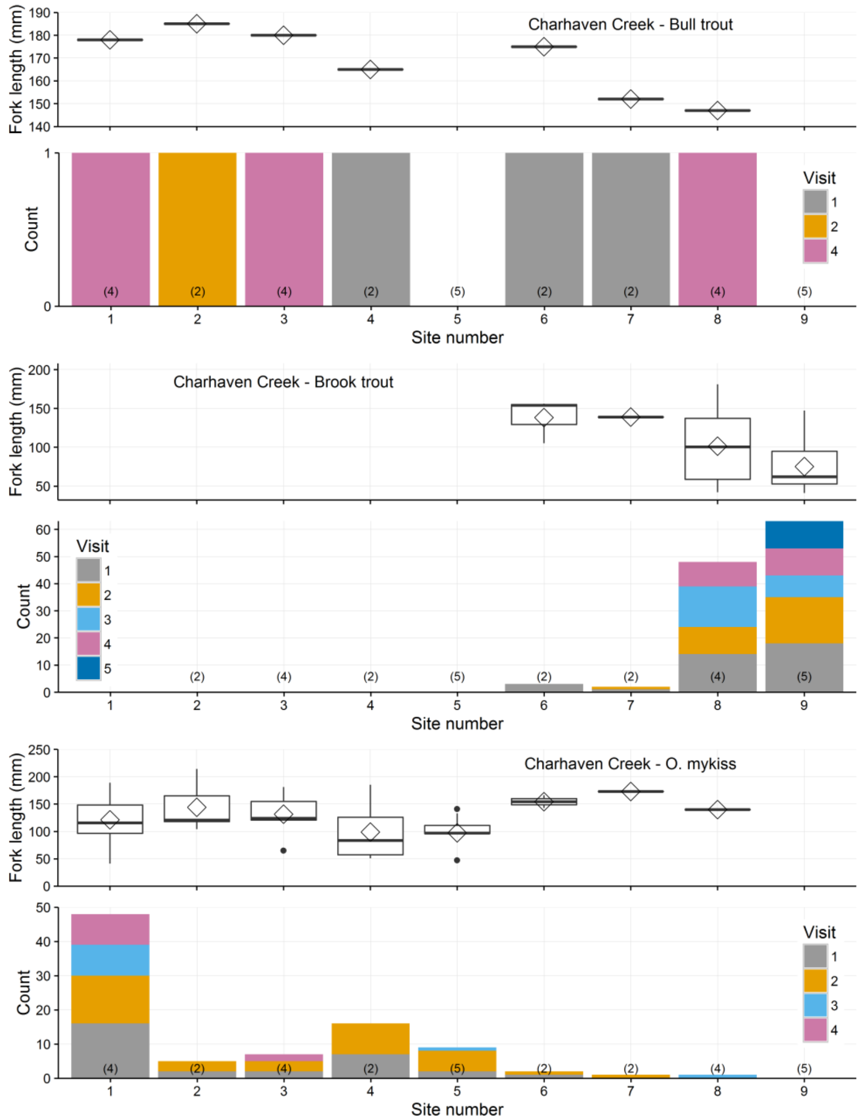


FIGURE 1.11—Electrofishing count by visit (colored bars) and site and fork length distribution by site for bull trout (upper pair), brook trout (middle pair), and *O. mykiss* ssp. (bottom pair) in Charhaven Creek. Nine sites were surveyed 2-5 times between October 22 and November 11, 2013. The number of survey visits per site is in parentheses. Boxplots describe median (bold line), mean (diamond), inner quartiles (boxes), 95% confidence interval (whiskers), and outliers (points).

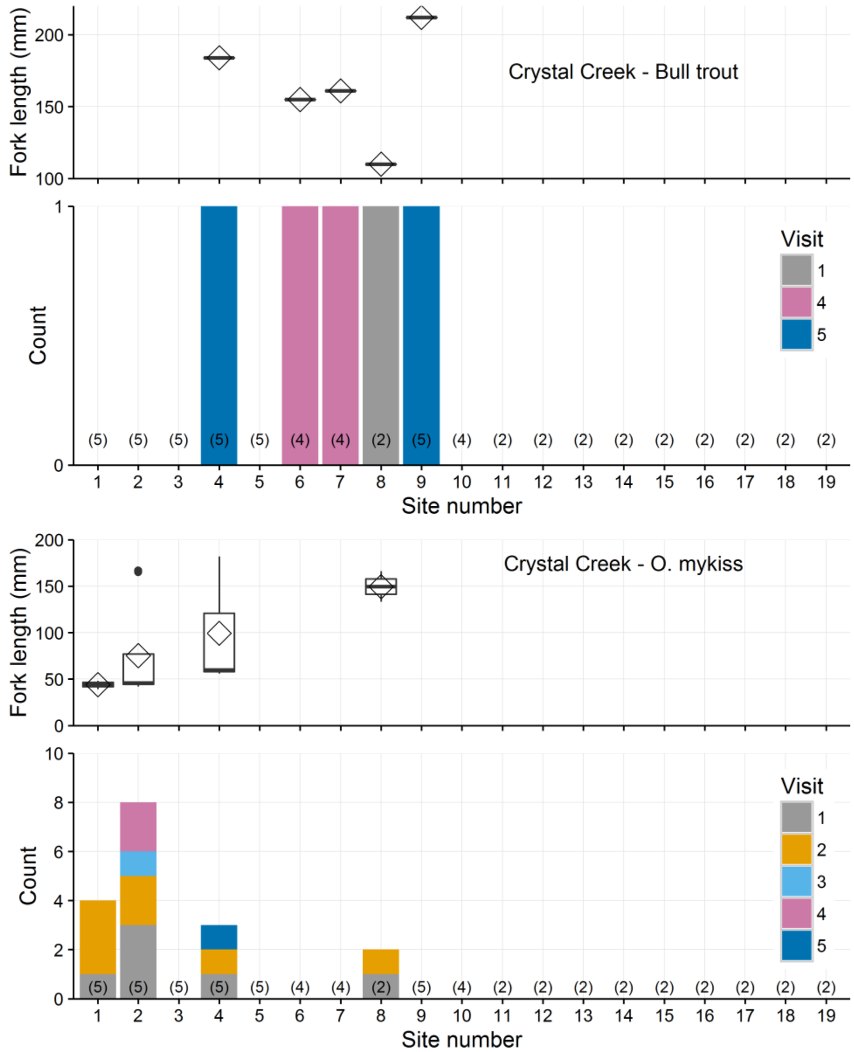


FIGURE 1.12—Electrofishing count by visit (colored bars) and site and fork length distribution by site in Crystal Creek for bull trout (upper pair) and *O. mykiss* (bottom pair). Nineteen sites were surveyed 2-5 times from June 9 to August 11, 2014. The number of survey visits per site is in parentheses. Boxplots describe median (bold line), mean (diamond), inner quartiles (boxes), 95% confidence interval (whiskers), and outliers (points).

TABLE 1.3—Occupancy (ψ) and detection (p) modeling results for bull trout and redband trout in tributary streams in the OLCA. Bull trout data were from Charhaven (9 sample sites) and Crystal (19 sites) creeks; redband trout data were from these two creeks and Maklaks (8 sites) and McCord Cabin Springs (7 sites) creeks. Results were based on 2-5 visits to each site, over a 3-5 week period, using blocknets and a backpack electrofisher in 2013-2014. The "stream" attribute group represents an indicator variable for each stream and all combinations were modeled.

Species	Models	Parameters	DIC
Bull trout	p + stream, ψ + stream	4	73.0
	p, ψ + stream	3	74.5
	p, ψ intercepts only	2	75.0
Redband trout	p + stream, ψ + stream	8	170.6
	p, ψ + stream(Charhaven=Maklaks=McCord)	3	170.9
	p + stream(Charhaven=Maklaks), ψ + stream(Charhaven=Maklaks)	6	171.7
	p + stream(Charhaven=Maklaks=McCord), ψ + stream(Charhaven=Maklaks=McCord)	4	172.5

TABLE 1.4—Detectability and occupancy estimates with 95% confidence intervals (CI) for three species in tributary streams in the OLCA. Detection and occupancy probabilities were estimated using the model with the lowest DIC score. Brook trout had high detection probability at a small number of occupied sites (9 sites) which prevented obtaining estimates.

		Naïve	Est.		95% CI		Naïve	Est.		95% CL	
Species	Stream	p	p	SE	Lower	Upper	ψ	ψ	SE	Lower	Upper
Bull trout	Charhaven Creek	0.35	0.28	0.09	0.11	0.47	0.78	0.85	0.11	0.62	1.00
	Crystal Creek	0.25	0.10	0.05	0.02	0.20	0.26	0.85	0.16	0.50	1.00
Brook trout	Charhaven Creek	0.92	NA	NA	NA	NA	0.44	NA	NA	NA	NA
Redband trout	Charhaven Creek	0.72	0.71	0.09	0.54	0.87	0.89	0.83	0.11	0.62	1.00
	Crystal Creek	0.65	0.60	0.12	0.36	0.82	0.21	0.25	0.10	0.07	0.46
	Maklaks Creek	0.47	0.45	0.09	0.27	0.62	0.75	0.75	0.15	0.48	0.99
	McCord Cabin Springs	0.60	0.58	0.12	0.34	0.79	0.46	0.52	0.14	0.25	0.79

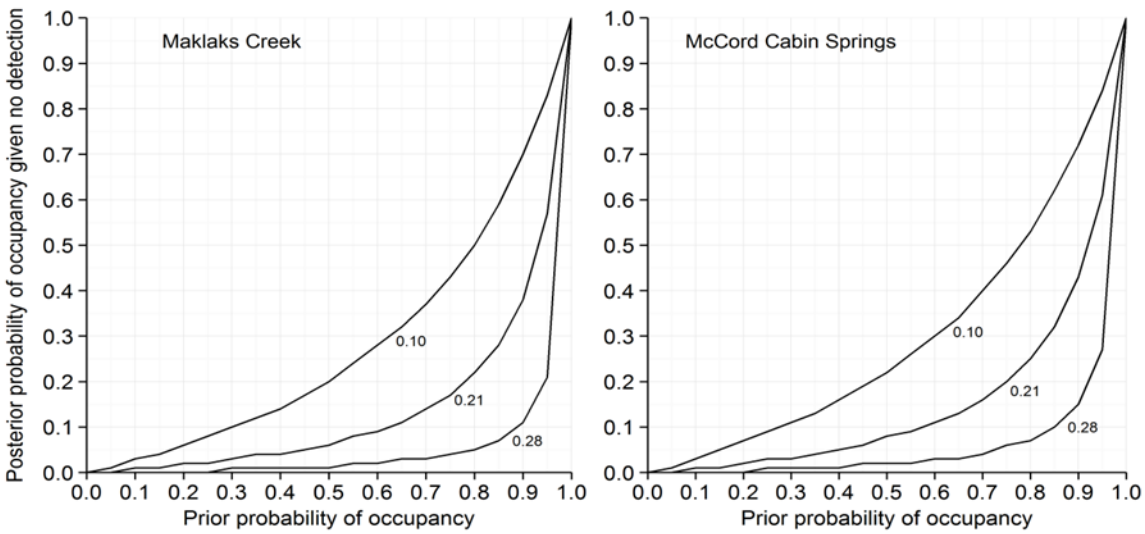


FIGURE 1.13—Simulations estimating the posterior probability of bull trout occupancy for tributaries where bull trout were not detected during electrofishing surveys in the Odell Creek basin, using three detection probabilities (labeled in the graph) estimated for Crystal Creek and Charhaven Creek. Backpack electrofishing with blocknets was used to survey 100-m sample sites in Maklaks Creek (*N*=8) and McCord Cabin Springs (*N*=7) and each site was sampled 5 times during 3-week periods from August to October, 2012.

probability (naïve *p*=0.92). Naïve occupancy, defined as the ratio of sites where the species was present to the total number of sites sampled) was 0.44 (Table 1.4). In Ranger Creek, a total of 438 brook trout were captured during a single visit to each of 23 sample sites. Brook trout were captured at all sample sites (mean *N*=19 fish/site; SD=16), and ranged in length from 52-211 mm (Figure 1.14).

Redband trout—Redband trout were captured in all five streams (Figure 1.11; Figure 1.12; Figure 1.14; Figure 1.15; Figure 1.16). Total catch of redband trout ranged from 89 in Charhaven Creek to 13 in McCord Cabin Springs. Fish lengths ranged from 39-214 mm and maximum single-visit counts varied from five fish in McCord Cabin Springs Creek to 57 in Ranger Creek. The best occupancy and detection models included the stream attribute (Table 1.3). Detection and occupancy probabilities for redband trout ranged from 0.45-0.71 and 0.25-0.83, respectively (Table 1.4).

Other fishes—In Crystal Creek, four tui chub, four kokanee, and four unidentified trout (< 30 mm FL) were captured in the site adjacent to Odell Lake. No other fishes were captured in the other four tributaries sampled.

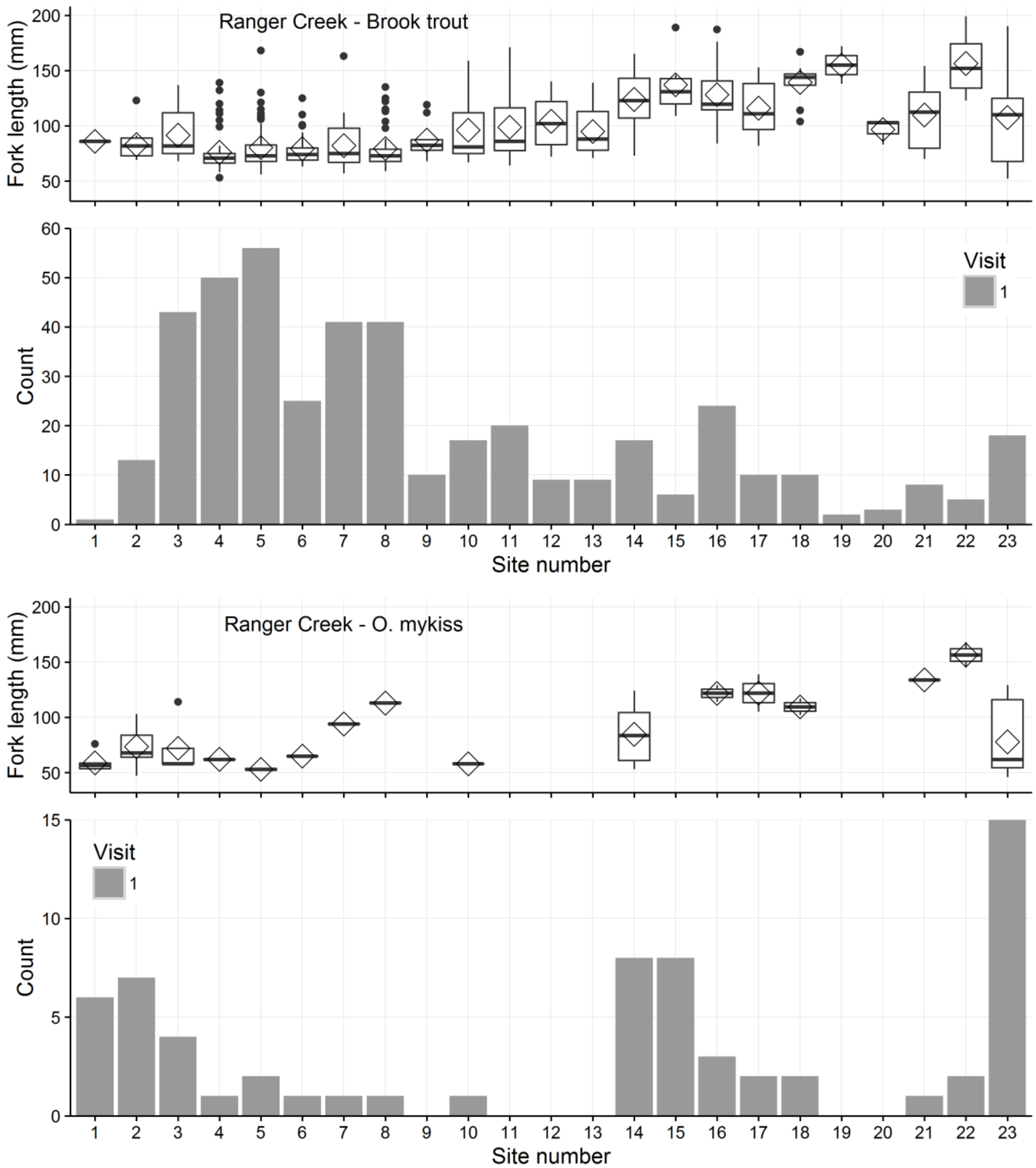


FIGURE 1.14—Electrofishing count and fork length distribution by site in Ranger Creek for *O. mykiss* ssp. and brook trout. Twenty-three sites were each surveyed once from October 8 to November 14, 2013. Boxplots describe median (bold line), mean (diamond), inner quartiles (boxes), 95% confidence interval (whiskers), and outliers (points).

<u>eDNA survey</u>

All control samples from Crystal Creek were negative for both bull trout and brook trout eDNA. Bull trout eDNA was detected in the four field samples collected downstream from the railroad culvert in Crystal Creek. Bull trout eDNA was not detected in the four field samples collected upstream from the railroad culvert in Crystal Creek. Brook trout eDNA was not detected in any of the field samples from Crystal Creek.

The control sample from Trapper Creek was negative for both bull trout and brook trout eDNA. Both bull trout and brook trout eDNA was detected in the single sample from Trapper Creek.

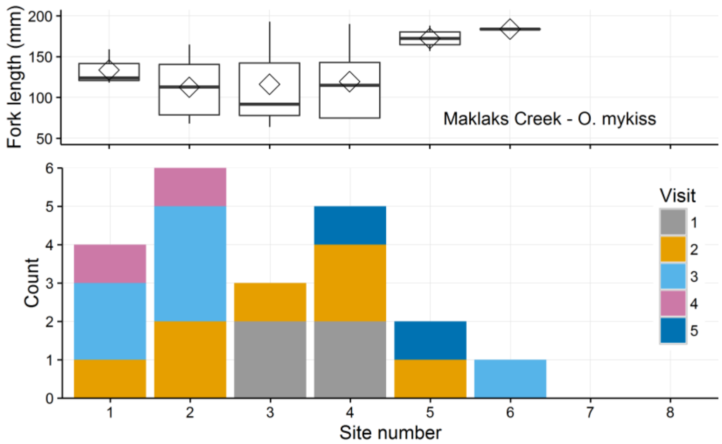


FIGURE 1.15—Electrofishing capture history by visit (colored bars) and site and fork length distribution by site in Maklaks Creek for *O. mykiss*. Nine sites were surveyed 5 times from September 17 to October 2, 2013. Boxplots describe median (bold line), mean (diamond), inner quartiles (boxes), 95% confidence interval (whiskers), and outliers (points).

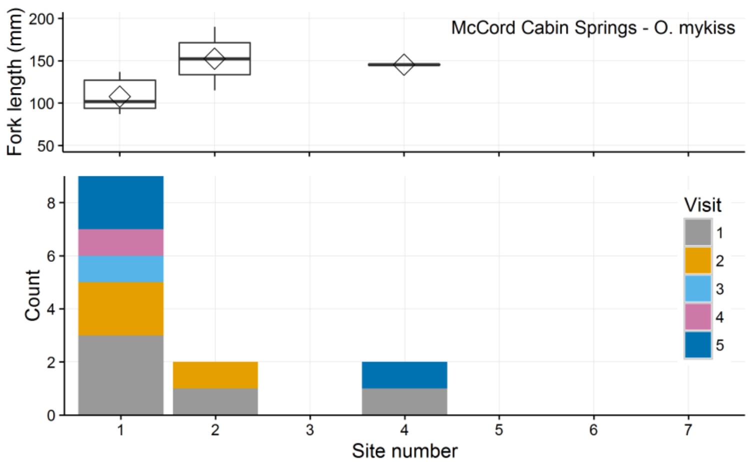


FIGURE 1.16—Electrofishing count by visit (colored bars) and site and fork length distribution by site in McCord Cabin Springs for *O. mykiss* ssp. Seven sites were surveyed 5 times from August 5-28, 2013. Boxplots describe median (bold line), mean (diamond), inner quartiles (boxes), 95% confidence interval (whiskers), and outliers (points).

Discussion

The presence of bull trout spawning in Trapper Creek and Crystal Creek was recorded in early reports in this region. At the time, these were considered to be the only two local populations (i.e., independent reproductive units; Rieman and McIntyre 1995) in the OLCA (OSGC 1947). More recently, Trapper Creek has been considered the only extant local population in the core area (USFWS 2002). Although Trapper Creek constitutes the largest local tributary population, our data suggest that bull trout are present in Crystal Creek and Odell Creek and at least one of its tributaries.

<u>Trapper Creek</u>

Trapper Creek currently supports the greatest number of spawning and rearing bull trout among the tributary streams in the OLCA. We identified 43 individual adult bull trout in our video records, including 21 females and 22 males. These fish entered Trapper Creek and exhibited pre-spawning behavior between August 18 and September 21, 2012. Our observations were consistent with those of a prior study that used a weir and fyke trap near the mouth of Trapper Creek during the spawning season in 1999 and 2000 to count spawning bull trout and describe run timing (ODFW, unpublished data). In 1999, the trap caught 48 adult bull trout (23 females, 22 males, 3 unknown sex) and the run timing was between August 19 and September 26. In 2000, the trap captured 39 bull trout (20 females and 19 males) between August 6 and September 21.

The video monitoring count in 2012 was possibly an underestimate of the actual number of adults attempting to spawn because video records from September 15-19 were accidentally erased from the memory card prior to its download to a computer and individual fish were not identifiable in 4% (*N*=14) of the video records of passing bull trout (*N*=340). However, three factors suggest that few unique bull trout were missed from these two sources of error. First, similarities in the count and peak run timing between the trapping and video monitoring suggest that it is likely few adults were entering Trapper Creek in the latter half of September. In both trapping years, 85% of adults were captured prior to September 15. Second, analysis of video passage records suggest that, by September 8, both the number of unique individual arrivals at the station and fish passes through the station had declined sharply. Third, females and males passed through the station on average two and five times, respectively; this behavior provided multiple chances to identify unique individuals. Therefore, adult bull trout that first entered Trapper Creek during the 4-day data-loss period may have passed through the station again from September 19-21, during which time four unique individuals were identified and the bull trout run ended.

Bull trout rearing in Trapper Creek has been documented annually through night snorkel counts of juveniles (i.e., 80-225 mm fork length) and periodic capture-mark-recapture (CMR) estimates of juvenile abundance since more intensive monitoring efforts began in 1996. Annual counts have ranged from 22-168 juveniles (ODFW, unpublished data), and CMR estimates of juvenile abundance in Trapper Creek have ranged from 163 to 253 (Moore 2005; Richardson and Jacobs 2010). Even though night-time snorkel surveys generally have a lower detection probability for bull trout relative to electrofishing surveys (Peterson et al. 2004; Thurow et al. 2006), these counts have detected juvenile bull trout in all three sample reaches in the lower 1.3 km of the stream almost every year since surveys began in 1996 (ODFW, unpublished data).

The Trapper Creek local population has been considered vulnerable to extirpation because of low adult abundance, potential isolation from other local populations, and the presence of brook trout in Trapper Creek (USFWS 2002). Rieman and Allendorf (2001) estimated that a local population of bull trout needs at least 50-100 spawners each year to minimize potential inbreeding effects and a core area needs between 500-1,000 spawners to minimize the potential effects of genetic drift. Adult abundance, based on trap and video monitoring counts, has been consistently below 50 in Trapper Creek and previous genetic analysis suggested this population has experienced a recent genetic bottleneck and estimated an effective population size of 11.8 fish (95% CI of 4.7 – 32.8) (Ardren et al. 2007). Although we found evidence of other potential local populations, these appeared to be substantially smaller than the Trapper Creek population. These factors increase the vulnerability of this local population to potential deleterious effects of both inbreeding and genetic drift and the risk to its long-term persistence.

Brook trout have been observed every year during the annual snorkel survey in relatively small numbers (range, 1-23) in the lower 1.3 km of Trapper Creek and a larger breeding population of brook trout exists upstream of a putative passage barrier in the upper 10.1 km of the stream (USFWS 2002). During these surveys, a few fish were identified in the field by their phenotype as bull trout/brook trout hybrids (USFWS 2002). However, genetic analysis of 61 samples from Trapper Creek juveniles identified 58 bull trout and 3 brook trout, some of which were misidentified in field as hybrids (Ardren et al. 2007). Trapping data and video monitoring records did not detect any brook trout from Odell Lake entering Trapper Creek to spawn. This suggests that in Trapper Creek brook trout have been either inconsistent or unsuccessful in developing a lacustrine-adfluvial life history and that the upstream breeding population is likely the main source of brook trout in the lower reach. Nevertheless, the consistent presence of brook trout in the main bull trout spawning and rearing area in the OLCA is a concern and an additional threat to the long-term persistence of this local population (USFWS 2002).

Crystal Creek

In Crystal Creek, we captured five bull trout during electrofishing surveys in 2014. This is the largest number of bull trout observed in this stream in recent history. The bull trout caught during our survey represented multiple age classes (size range, 110-212 mm), which suggested either spawning success in multiple years in Crystal Creek, consistent movement into the stream by fish spawned elsewhere, or some combination of the two. Annual surveys of Crystal Creek from 1994-1999, using a variety of methods (e.g., electrofishing, day and night snorkeling) did not detect any bull trout and suggested that bull trout had been extirpated from this stream (USFWS 2002). In 2005, three-pass electrofishing was conducted in the lower 1 km of Crystal Creek and a single bull trout (150 mm) was detected (Paul Powers, USFS, *personal communication*). Our occupancy sampling design of five sampling visits to each site was the most intensive survey of this creek to date and the first to estimate the detection probability. We estimated there was only a 10% chance of detecting the species during a single visit in any occupied site in Crystal Creek. With this low detection probability, and after five visits to a site, there was still about a 60% chance of not detecting the species in any given occupied site in this creek. Previous surveys likely had even lower detection because of the sampling method (i.e., snorkeling) and relatively less sampling effort (e.g., fewer visits or passes at a site) and therefore previous surveys would have had a much higher probability of not detecting a bull trout population similar to what we detected in 2014.

Crystal Creek was once identified as the main spawning stream for bull trout (OSGC 1947) in this core area. Several factors have been identified as potentially limiting bull trout in Crystal Creek (USFWS 2002). One factor identified was a partial passage barrier at the railroad crossing culvert about 1 km from the mouth of the stream (Figure 1.17) (USFWS 2002). Prior to 1994, fish access to the downstream end of the culvert was considered poor, but habitat restoration activities in 1994 raised the stream level to that of the culvert (USFS 1994). Although we did not formally evaluate whether this culvert currently impedes bull trout passage, we did not detect any fish in the 0.9 km upstream from the culvert during electrofishing surveys. Furthermore, eDNA analysis detected bull trout downstream from the culvert and did not detect bull trout or brook trout upstream from the culvert, adding supporting evidence that this culvert currently marks an end to bull trout distribution in Crystal Creek. When the nine sites upstream from the culvert were removed, and the occupancy analysis was re-done, the detection and occupancy probabilities for this stream changed to a 21% chance of detecting a bull trout during a single sampling visit to an occupied site (a large increase) and 77% chance bull trout occupying any given site (a slight decrease) downstream from the culvert.

FIGURE 1.17—Railroad culvert (27 m long) on Crystal Creek; upper panel looking upstream, lower panel looking downstream.

Odell Creek and tributaries

In the Odell Creek basin (i.e., downstream from Odell Lake), bull trout have been repeatedly observed in low densities during management activities and surveys since 1932 (Fies et al. 1996) and as recently as 2003 (Dachtler 2004). We found additional evidence of bull trout persistence in this part of the core area and new evidence of actual spawning; however, bull trout abundance appeared to be substantially lower relative to the Trapper Creek local population. In Charhaven Creek, we captured seven bull trout during occupancy surveys in 2013 ranging in size from 147-185 mm. Genetic analysis of these seven bull trout revealed very little genetic variation, suggesting these fish were the progeny of some combination of three adult bull trout (P. DeHaan, US Fish and Wildlife Service, *personal communication*), that spawned near the capture site. We estimated a 28% chance of detecting bull trout during a single visit to an occupied site and an 85% chance any given site was occupied. In a two-week period in August, two months prior to the occupancy surveys, we recorded five unique bull trout (140-150 mm) moving downstream through the Charhaven Creek fish passage station and presumably into Odell Creek. Because the fish passage station may not have detected fish in this size range or smaller with 100% efficiency, this number is likely only a minimum count of the bull trout moving downstream. Potamodromous salmonids often exhibit directed movements between spawning, feeding, and refuge habitats; and when these movements result in an alternation between two or more well-separated habitats, occur with regular periodicity, and involve a large proportion of the population, then the movements can be defined as migrations (Northcote 1997). Therefore, in Charhaven Creek this movement from a small stream to a large stream, by a substantial proportion of the population, over a discrete period in two consecutive years may represent a migration to an area of greater food availability or more suitable rearing habitat. This apparent outmigration also likely reduced the detection probability and the number of bull trout caught during the occupancy surveys in Charhaven Creek.

In Odell Creek, downstream from the confluences of the cold tributaries (i.e., Charhaven Creek, Maklaks Creek, and McCord Cabin Springs), at least 10 individual bull trout were recorded passing through fish passage station 3. Most of these passes were in the downstream direction during August, similar to the timing and directionality of the Charhaven Creek outmigrants. However, size differences among the bull trout passing the Odell Creek and Charhaven Creek stations suggest they were different individuals. The relatively synchronous downstream movement of bull trout through this station could suggest a migration from thermal refuge to feeding habitats, or possibly a resident spawning migration. Odell Creek is fed by warm epilimnetic water from Odell Lake in the summer. During July (i.e., the hottest calendar month), most of Odell Creek exceeded water temperatures required for bull trout rearing. The estimated mean maximum daily stream temperature in July in the cold reach of Odell Creek was 16.7°C. The concordance of a thermal tolerance study of juvenile bull trout (45-135 mm, Selong et al. 2001), an evaluation of empirical studies (Rieman and Chandler 1999), and a landscape temperature model for juvenile bull trout (≤150 mm, Dunham et al. 2003) strongly suggest that stream reaches with maximum daily temperatures above the 14-16°C range have a low probability of being occupied by rearing bull trout. Maximum temperatures were, of course, not uniformly distributed in this reach of Odell Creek; rather, daily maximum temperatures declined as one neared the confluences of the cold tributaries (7-9°C in July) and other patches of thermal refuge likely exist in Odell Creek. The downstream movement of bull trout in late August (by which date thermal maximums were in decline) in the cold reach of Odell Creek may represent a trophic migration from thermal refuge near the cold tributaries to habitat better suited for foraging and growth. However, several factors suggest that this movement may instead represent a fluvial or resident life history spawning migration. For example, most of the bull trout passing Odell Creek station 3 had attained a size (>200 mm) characteristic of resident spawners elsewhere (McPhail and Baxter 1996), the timing of the movement pattern corresponded to the spawning period typical of bull trout in this region (Starcevich et al. 2012), and minimum stream temperatures at the cold reach fish passage station were approaching 9°C, the temperature that generally characterizes the onset of bull trout spawning (Fraley and Shepard 1989; Pratt 1992; Rieman and McIntyre 1993).

Odell Lake was another source of adult bull trout in Odell Creek. We recorded two large male bull trout passing downstream through the fish passage station in Odell Creek near the Odell Lake outlet. The largest fish (95 cm) passed downstream on November 28, 2013, and was not observed again. The skin of this fish was infected with the oomycete *Saprolegnia parasitica*, often seen in spawned-out salmon and indicative of a breakdown in the immune system. The other male (60 cm) passed downstream through this fish passage station on September 25, 2013, which corresponds with the end of the spawning period in Trapper Creek. A week later, this fish was observed at the Charhaven Creek fish passage station and recorded repeatedly moving from Odell Creek into Charhaven Creek and back again over the next four weeks. These movements were unlikely to be for feeding or refuge since more food and space is available in Odell Creek and water temperatures are relatively uniform by October. This movement pattern bears a close resemblance to the spawning behavior of male bull trout recorded in Trapper Creek during the August-September spawning period in 2012 and therefore may represent an allacustrine life history pattern.

Our surveys represent the most intensive sampling and monitoring to date in Odell Creek and its tributaries. The total number of bull trout observed also represents the highest abundance of this species recorded in this part of the OLCA. Nevertheless, the abundance of this population is likely much lower than that of the Trapper Creek local population. In contrast to single-pass snorkel surveys in which hundreds of juvenile bull trout were counted in lower Trapper Creek (a 1.3 km reach), two-visit occupancy snorkel surveys in Odell Creek from the Davis Lake inlet to 1 km upstream from the Charhaven Creek confluence (a 9.2 km reach) did not detect any bull trout. Fish passage stations showed bull trout were moving into the coldest segment of Odell Creek prior to occupancy snorkel surveys and at least some fish were moving (rather than hiding) during the time of night when snorkel surveys typically occurred. Non-detection during occupancy surveys suggests bull trout densities were below those of Trapper Creek and the power of our night snorkel surveys to detect. Furthermore, we found no evidence of the lacustrine-adfluvial life history from Davis Lake to Odell Creek. Although bull trout historically were present in Davis Lake (OSGC 1950; Gray 1986; Fies et al. 1996), this species was not recorded passing through the fish passage station during the full year it was in place in Odell Creek near the Davis Lake inlet.

We confirmed that Trapper Creek is the primary spawning and rearing habitat in the Odell Lake Core Area. The importance of this stream to bull trout persistence in this core area warrants a continued focus on improving spawning and rearing habitat, ameliorating the threat of hybridization and negative interactions with nonnative brook trout, and development of an accurate, precise, and low-risk monitoring protocol for tracking trend in adult abundance. This study also showed that bull trout rearing habitat and potentially spawning habitat exists in other parts of the core area, including Crystal Creek, Odell Creek, and its largest tributary Charhaven Creek. We documented movement of adult bull trout from the lake downstream into Odell Creek, potentially to spawn; therefore, impediments to movement would limit expression of an allacustrine life history. Brook trout were detected in high relative abundance in the upper section of Charhaven Creek and moving in low relative abundance in Odell Creek. The potential for hybridization as a limiting factor and ways to reduce the risk to bull trout in this part of the core area should be explored. We found suggestive evidence of bull trout movement corresponding to seasonal change in water temperature in Charhaven Creek and Odell Creek; however, we could not determine how, or if, these movements were related to the availability of thermal refuge, feeding, or spawning habitats. In fact, little is known about the spatial and temporal availability of these habitats in Odell Creek; therefore, we suggest improving our knowledge in this regard, which would improve our understanding of how habitat may be limiting bull trout in this part of the core area and where enhancement projects would be most likely to succeed. Finally, all our sampling methods showed that robust populations of redband trout and mountain whitefish are distributed throughout Odell Creek, which suggests that forage availability likely would not be a limiting factor for bull trout.

Chapter 2: Characteristics of the Odell Lake Food Web that may Influence Bull Trout Survival

Abstract.—Introduced species can have significant effects on food-webs, which can result in changes in the abundance of native species. Odell Lake has been the site of numerous nonnative species introductions and the influence of these introductions on native bull trout is unknown. We quantified characteristics of the aquatic food web in Odell Lake with an emphasis on interactions between bull trout and nonnative lake trout. Lake trout were the most abundant apex predator sampled in Odell Lake and they preyed on a variety of salmonids (e.g., kokanee and mountain whitefish), non-salmonids (e.g., tui chub), and other seasonally available prey items (e.g., fish eggs, dipterans, etc.). Bull trout are also an apex predator in Odell Lake, but they were much less abundant than lake trout. Differences in isotopic values between bull trout and lake trout suggest incomplete overlap in prey use or variability in dietary composition between these species in Odell Lake; consequently, extirpation of bull trout from Odell Lake as a result of competition with lake trout (i.e., competitive exclusion, *sensu stricto*) would not be predicted. However, patterns of relative abundance, spatial overlap, and probable dietary overlap provide support that these species are competitors or intraguild predators; therefore, reducing the putative influences of lake trout on bull trout may require actions that reduce the abundance of lake trout, increase the carrying capacity for bull trout, promote the expression of fluvial or resident life histories, or some combination of these.

The historical fish assemblage in Odell Lake was thought to include bull trout (*Salvelinus confluentus*), redband trout (*Oncorhynchus mykiss gairdneri*), and mountain whitefish (*Prosopium williamsoni*); among these, bull trout were likely the apex predator. However, the bull trout population is believed to have declined significantly subsequent to introduction of large numbers of other species. Fishes intentionally stocked into Odell Lake include lake trout (*Salvelinus namaycush*), brook trout (*Salvelinus fontinalis*), Arctic grayling (*Thymallus arcticus*), kokanee (*O. nerka*), and Atlantic salmon (*Salmo salar*) (ODFW 1996). Fisheries managers ceased stocking Odell Lake in the late 20th century; however, some nonnative species are still present. Currently, nonnative species present in Odell Lake include lake trout, tui chub (*Gila bicolor*), kokanee, brook trout, and rainbow trout. The interactions between introduced and native species are poorly understood in this lake, and may help explain the decline of bull trout.

The introduction and proliferation of lake trout in lakes within western North America has occurred concurrently with local extirpations or decreases in abundance of some bull trout populations (Donald and Alger 1993; Fredenberg 2002). The causal mechanism by which lake trout affect bull trout populations is unknown; however, interspecific competition, predation, and intraguild predation have been suggested or empirically evaluated (Donald and Alger 1993; Fredenberg 2002; Guy et al. 2011; Meeuwig et al. 2011*a*; *b*).

Bull trout and lake trout exhibit dietary overlap in some systems where they are sympatric (Donald and Alger 1993; Guy et al. 2011). Because of this overlap and other biological similarities (e.g., body size and gape limitation), interspecific competition for food resources has been proposed as a mechanism to explain the displacement of bull trout following the establishment of lake trout (Donald and Alger 1993). Interspecific competition may result in extirpation of one of the competing species if the species occupy the same ecological niche (Hardin 1960). For example, bull trout were extirpated from Bow and Hector lakes, Alberta, following the establishment of nonnative lake trout (Donald and Alger 1993). However, both of these lakes had relatively simple food webs (i.e., ≤ 2 other fishes; Donald and Alger 1993), and complete exclusion of bull trout following the establishment of lake trout has not been observed in lakes with more diverse prey bases (e.g., see Vidergar 2000; Fredenberg 2002; Meeuwig et al. 2008).

Bull trout have been shown to persist for decades in many western lakes following the establishment of lake trout, but at decreased abundance (Donald and Alger 1993; Fredenberg 2002; Meeuwig et al. 2008; Martinez et al. 2009). This pattern is indicative of species that coexist despite competition. Fundamental ecological theory predicts that two competing species may coexist at a stable equilibrium if their influence on each other is insufficient to result in extirpation (Gotelli 1995*a*); however, neither species will reach abundances that could be achieved in the absence of competition. Although under this scenario competition is not predicted to result in exclusion of either species, the equilibrium abundance of one or both species may be at levels low enough that extinction risks associated with demographic, genetic, or environmental stochasticity may be elevated.

Although it is generally accepted that bull trout and nonnative lake trout are likely competitors (Donald and Alger 1993; Fredenberg 2002; Martinez et al. 2009; Guy et al. 2011), other ecological interactions may have an influence on bull trout populations that are sympatric with nonnative lake trout. Lake trout are opportunistic predators that have the potential to consume large quantities of fish (Ruzycki et al. 2003), and predation can directly influence the size and stability of a prey population (Ricklefs 1990). Predation on juvenile bull trout by lake trout is a potentially important ecological interaction that may have negative, population-level effects on bull trout. Lake trout may prey on juvenile bull trout at various times and locations. For example, in some systems juvenile bull trout emigrate from rearing habitat into lake environments in large numbers (Downs et al. 2006). This type of migration may provide a seasonally abundant resource pulse (Yang et al. 2008) that piscivores can exploit.

The combined influences of competition and predation (i.e., intraguild predation; Polis et al. 1989) may help explain empirical data related to sympatric bull trout and nonnative lake trout populations. Intraguild predation is characterized by predatory interactions between species that use similar, potentially limiting, resources (Polis et al. 1989). Intraguild predation can provide direct energetic gains for the predator while decreasing the magnitude of exploitation competition (Polis et al. 1989). Additionally, some theoretical predictions associated with intraguild predation allow for the coexistence of species that would not coexist under a competitive exclusion scenario.

Odell Lake, located in the Cascade Mountain Range in central Oregon, is occupied by the only natural, lacustrine-adfluvial bull trout population in Oregon. Historically, fishery managers considered Odell Lake to support an important recreational bull trout fishery (OSGC 1946, 1947, 1950); however, the population is currently depressed. For example, the spawning population size was estimated to be about 43-51 individuals in 2012 (this document). Odell Lake also provides a popular lake trout sport fishery. Although currently unevaluated, ecological interactions between bull trout and nonnative lake trout are considered to be a factor that potentially limits the population growth of bull trout in the Odell Lake Core Area (USFWS 2015). The purpose of this study was to quantify characteristics of the aquatic food web in Odell Lake with an emphasis on interactions between bull trout and lake trout. Sampling was performed to address four objectives:

1) Characterize the Odell Lake fish assemblage including the relative abundance and size distribution of fishes in Odell Lake.
2) Quantify characteristics of the aquatic food web and trophic overlap between bull trout and lake trout in Odell Lake.
3) Quantify the food-habits of lake trout in Odell Lake.
4) Evaluate juvenile salmonid drift patterns in Trapper Creek associated with the presence and relative abundance of lake trout near Trapper Creek.

Methods

<u>Odell Lake fish assemblage</u>

We used a combination of trap nets, benthic gill nets, and suspended gill nets to sample the fish assemblage in Odell Lake. Sampling was generally stratified by season (i.e., spring, summer, or autumn), where seasons were based on astronomical events (i.e., delineated by an equinox or a solstice). However, sample seasons roughly corresponded to the time period prior to maximum thermal stratification (spring), the period of maximum thermal stratification (summer), and the period after maximum thermal stratification of Odell Lake (Figure 2.1)

We used three different types of trap nets in 2013 (small modified fyke nets, large modified fyke nets, and Oneida trap nets) and one type of trap net in 2014 (Oneida trap net). Small modified fyke nets were constructed of 19-mm mesh (bar) multifilament, had a 15-m long x 0.9-m tall leader, a 1.8-m wide x 0.9-m tall opening, and four 0.8-m diameter hoops (Hubert 1996). Large modified fyke nets were constructed of 6-mm mesh

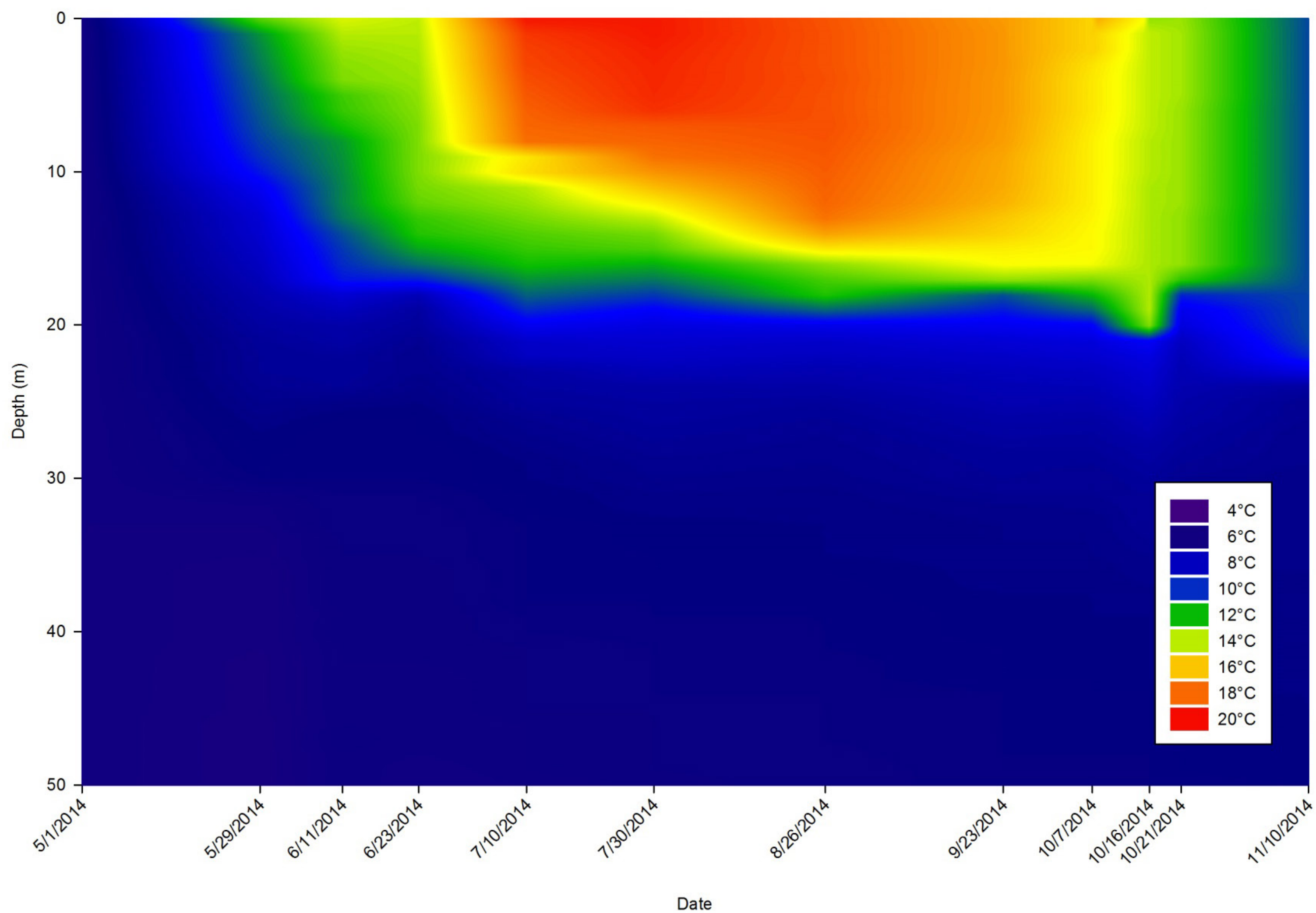


FIGURE 2.1—Odell Lake, Oregon, seasonal temperature profile. Dates shown represent days that temperature data were recorded, with the exception that temperature data were not recorded on May 1, 2014; we assumed that the lake was isothermal at 6°C on May 1, 2014. Vertical temperature profiles were recorded at one or two sampling locations on each sampling occasion; the two sampling locations corresponded to the deepest portions of the lake on the northwest and southeast ends of the lake. Temperature data were recorded at 1-m depth increments from the surface of the lake to a depth of 50-m using a handheld temperature meter (YSI Pro20, YSI Inc.) with a 50-m probe line. We estimated temperature by day and depth using linear interpolation between sampling occasions and plotted vertical temperature data as a function of day.

multifilament, had a 15-m long x 1.2-m tall leader, two 8-m long x 1.2-m tall wings, a 1.8-m wide x 1.2-m tall opening, and five 1.2-m diameter hoops (Hubert 1996). Oneida Lake trap nets were constructed of 6-mm mesh multifilament, had a 30.5-m long x 1.8-m tall leader, two 8.0-m long x 1.8-m tall wings, and a 2.1-m wide x 1.8-m tall x 1.8-m deep trap box. We set small modified fyke nets during the period June 17-July 3, 2013 (*N* = 27), large modified fyke nets during the period June 3-June 13, 2013 (*N* = 18), and Oneida Lake trap nets during the periods May 20-22, 2013 (*N* = 4), July 15-August 1, 2013 (*N* = 16), and May 27-October 29, 2014 (*N* = 26). For ease of analysis, we treated all trap nets similarly despite potential differences in gear selectivity and efficiency. See Table 2.1 for a summary of net characteristics and Supplemental Figure 2.1, Supplemental Figure 2.2, Supplemental Figure 2.3, and Supplemental Figure 2.4 for the spatial distribution of nets set in Odell Lake.

In 2013, trap nets were set following a judgment sample design (*N* = 37 net sets) to evaluate presence of lake trout near Trapper Creek and a convenience sample design (*N* = 28 net sets) to provide general information about the fish assemblage in Odell Lake. In the spring of 2014, trap nets were set following a systematic sample design with two random starting points (Hansen et

TABLE 2.1—Sample design, sample season, depth strata, mean soak time, and mean nearshore and offshore depths for nets used to sample the fish assemblage in Odell Lake, Oregon, during 2013 and 2014. Trap nets were generally set with the nearshore end of the leader on shore; therefore, nearshore depths were generally 0.0 m. Suspended gill nets were set at discrete depths (depth strata) so mean nearshore and offshore depths are not provided. GRTS = Generalized Random-Tessellation Stratified.

Net type	Year	Sample Design	Season	Depth strata	*N*	Mean soak time ± std (h)	Mean depth ± std (m) Nearshore	Mean depth ± std (m) Offshore
Trap net	2013	Judgment	Spring and summer	NA	37	22.25 ± 2.29	0.0 ± 0.1	4.6 ± 4.9
		Convenience	Spring and summer	NA	28	21.25 ± 2.72	0.0 ± 0.1	4.9 ± 7.1
	2014	Systematic	Spring	Shallow	6	19.90 ± 2.36	0.0 ± 0.0	5.5 ± 6.7
		GRTS	Summer	Shallow	12	22.33 ± 1.98	0.0 ± 0.0	4.1 ± 1.3
		GRTS	Autumn	Shallow	8	21.20 ± 1.32	0.0 ± 0.0	2.8 ± 0.7
Benthic gill net	2013	Systematic	Summer	Deep	25	0.53 ± 0.05	24.4 ± 3.6	32.0 ± 5.4
		Systematic	Autumn	Shallow	10	0.59 ± 0.05	2.8 ± 0.7	11.2 ± 4.1
				Deep	23	0.57 ± 0.03	21.8 ± 6.5	29.4 ± 9.6
	2014	Systematic	Spring	Shallow	30	0.51 ± 0.03	3.1 ± 0.4	9.1 ± 3.6
				Deep	40	0.52 ± 0.04	24.9 ± 0.7	32.9 ± 5.6
		Systematic	Summer	Shallow	20	0.52 ± 0.03	3.3 ± 0.4	12.7 ± 5.5
				Deep	20	0.52 ± 0.02	25.5 ± 1.4	34.0 ± 7.2
		Systematic	Autumn	Shallow	20	0.52 ± 0.02	3.3 ± 0.4	10.1 ± 4.2
				Deep	20	0.55 ± 0.11	23.7 ± 5.0	30.9 ± 4.8
Suspended gill net	2014	GRTS	Spring	0-6 m	4	1.00 ± 0.00		
				12-18 m	4	1.01 ± 0.02		
				24-30 m	4	1.00 ± 0.00		
				36-42 m	3	1.04 ± 0.05		
		GRTS	Summer	0-6 m	4	1.08 ± 0.02		
				12-18 m	4	0.80 ± 0.51		
				24-30 m	4	1.15 ± 0.10		
				36-42 m	4	1.13 ± 0.14		
		GRTS	Autumn	0-6 m	3	1.04 ± 0.04		
				12-18 m	3	1.01 ± 0.05		
				24-30 m	3	1.04 ± 0.05		
				36-42 m	4	1.05 ± 0.03		

al. 2007). To identify random starting points, we used ArcGIS (ArcGIS 10.2, Esri Inc.) to convert the perimeter of the Odell Lake polygon (National Hydrography Dataset; http://nhd.usgs.gov/) into a polyline. Forty equally-spaced points were constructed along the polyline, and X-Y coordinates were generated for the points. A random number generator was used to select multiple random starting locations from the first four points along the polyline. Trap nets were set in groups of four nets such that each group consisted of a point selected by the random number generator and every subsequent fourth point along the polyline. Many of the systematically spaced points were in locations that were not ideal for setting trap nets (e.g., deep steep bathymetry, etc.), and when this occurred we set the net at the next appropriate point along the polyline. Consequently, in the summer and autumn of 2014 trap nets were set following a generalized random-tessellation stratified (GRTS) sample design (Stevens and Olsen 2004). The 40 equally-spaced points (see above) were overlaid on available bathymetric data in ArcGIS and the suitability of sample sites for trap nets was visually assessed based on bathymetry. The subset of suitable trap net locations was treated as a finite resource and GRTS site selections were conducted separately for summer and autumn sampling.

Each benthic gill net consisted of two North American standardized core gill nets (Beauchamp et al. 2009) ganged together. Therefore, benthic gill nets were constructed of monofilament, had a top float line and a bottom lead line, were 1.8 m tall and 48.8 m long, and consisted of 16 equal length panels (38-, 57-, 25-, 44-, 19-, 64-, 32-, 51-, 38-, 57-, 25-, 44-, 19-, 64-, 32-, and 51-mm mesh bar). Benthic gill nets were set during distinct sample seasons in 2013 and 2014. Sample seasons consisted of summer (September 9-12) and autumn (November 17-26) in 2013 and spring (May 5-23), summer (July 28-August 13), and autumn (October 6-19) in 2014. Benthic gill nets were set during the night with the exception of nets set during the summer of 2013, which were set during the day. Benthic gill nets were set perpendicular to the lake shoreline (Beauchamp et al. 2009) at two depth strata (shallow and deep), which were selected to sample above and below the depth of the mid-summer thermocline in Odell Lake (see Figure 2.1).

In 2013 and 2014, benthic gill nets were set following a systematic sample design with multiple random starting points (Hansen et al. 2007); starting points were selected separately for each sample period and depth strata. For shallow benthic gill nets, ArcGIS was used to convert the perimeter of the Odell Lake polygon into a polyline, 100 equally-spaced points were constructed along the polyline, and X-Y coordinates were generated for the points. A random number generator was used to select multiple random starting locations from the first ten points along the polyline. Shallow benthic gill nets were set in groups of 10 nets such that each group consisted of a point selected by the random number generator and every subsequent tenth point along the polyline. For deep benthic gill nets, a polyline was created along the 30-m bathymetric contour of Odell Lake in ArcGIS, 100 equally-spaced points were constructed along the polyline, and X-Y coordinates were generated for the points. Random starting locations and groups of nets were selected as above. Shallow benthic gill nets were set with the nearshore end of the net near the selected point, but at a depth of about 3 m. Deep benthic gill nets were set with the nearshore end of the net near the selected point, but at a depth of about 24 m. Benthic gill nets were allowed to soak for about 0.5 h.

Suspended gill nets were constructed of monofilament, had a top float line and a bottom lead line, were 6.1 m tall and 48.8 m long, and consisted of eight equal length panels (38-, 57-, 25-, 44-, 19-, 64-, 32-, and 51-mm mesh bar) (Beauchamp et al. 2009). Suspended gill nets were set during the spring (June 2-6), summer (August 25-28), and autumn (October 19-22) of 2014. Suspended gill nets were set during the night at four depth strata (0-6 m, 12-18 m, 24-30 m, and 36-42 m). Suspended gill nets were allowed to soak for about 1.0 h.

Suspended gill nets were set following a GRTS sample design; GRTS site selections were performed separately for each sample season. ArcGIS was used to create a polygon along the 45-m bathymetric contour of Odell Lake, to create a fishnet with cell dimensions of 200-m x 200-m based on the extent of the polygon, and to generate the X-Y coordinates for the centroid of each cell in the fishnet. The list of X-Y locations was replicated four times and each replicate was assigned to one of the four depth strata. The X-Y locations were treated as a finite resource and the GRTS site selection provided an ordered list in which to set suspended gill nets by depth strata.

Fish captured using trap nets, benthic gill nets, and suspended gill nets were identified to species and counted; we categorized all *O. mykiss* subspecies as *O. mykiss* because of the uncertainty associated with discrimination of native redband trout, introduced rainbow trout, and their potential hybrids in the field. All captured bull trout, brook trout, and lake trout were measured for length (fork length, mm). Haphazard subsamples of kokanee (*N* = 624; 33% of the kokanee captured), mountain whitefish (*N* = 1,064; 57% of the mountain whitefish captured), *O. mykiss* (*N* = 206; 81% of the *O. mykiss* captured), and tui chub (*N* = 796; 4% of the tui chub captured) were measured for length due to logistical constraints, but we assumed that the measured subsample was representative of the species. Length-frequency histograms were plotted by species for all measured fish; additionally, the median and first and third quartile lengths were calculated by species to provide a trimmed estimate for qualitatively assessing differences in size distributions among species. Catch per unit effort (C/*f*; fish·h^{-1}) was calculated for each net by fish species.

<u>Characteristics of the aquatic food web in Odell Lake</u>

Muscle samples were collected from the dorsal musculature from a subsample of fish (Table 2.2) captured during fish assemblage sampling in Odell Lake (see above). Muscle samples were collected using a 5-mm soft-tissue biopsy punch and were frozen in the field in a cryo-express vapor shipper (CX100, Taylor-Wharton International LLC); muscle samples were subsequently stored at -20°C. Crayfish were opportunistically sampled from trap nets or using minnow traps set haphazardly (Table 2.2). Crayfish were measured from the anterior end of the rostrum to the posterior end of the cephalothorax, sacrificed, and a portion of their abdominal muscle was collected for stable isotope analysis; storage procedures were as above. Zooplankton was opportunistically sampled using a number 25 mesh, closing, Wisconsin-style plankton net (Table 2.2). Zooplankton was sampled from two depth strata (> 10 m and < 3 m; see Vander Zanden and Rasmussen 1999) and was stored as above.

Muscle samples and composite zooplankton samples were dried at 60°C for about 48 h (Jardine et al. 2003) and sent to the Colorado Stable Isotope Laboratory for stable isotope analysis ($\delta^{13}C$ and $\delta^{15}N$). Briefly, stable isotope analysis provides an indirect, time-integrated method for examining trophic characteristics. The $\delta^{15}N$ value of a consumer is generally greater than that of its diet (e.g., + 3.4‰; Post 2002) due to isotopic discrimination (Martínez del Rio et al. 2009); therefore, $\delta^{15}N$ is useful for examining the trophic position of species in a food web. Differences in $\delta^{13}C$ between a consumer and its diet are generally very small (e.g., + 0.4‰; Post 2002) (France and Peters 1997; McCutchan et al. 2003; Martínez del Rio et al. 2009), and $\delta^{13}C$ values are often greater for benthic-littoral primary producers and consumers than for planktonic-pelagic primary producers and consumers (France 1995; Vander Zanden and Rasmussen 1999). Therefore, $\delta^{13}C$ may be used to infer where or on what group of species a consumer is feeding (Vander Zanden and Rasmussen 1999).

Tissue lipid content can influence $\delta^{13}C$ values; therefore, $\delta^{13}C$ values were normalized for lipid content following Post et al. (2007). Post et al. (2007) did not evaluate the relationship between lipid content and C:N ratio for samples with C:N ratios greater than 7.0. Therefore, we omitted samples with C:N ratios greater than 7.0 from all analyses, which resulted in omission of < 5% of the samples that we processed.

Within species isotopic differences may occur as a result of size-related shifts in diet. Therefore, preliminary analyses were conducted to determine if any within species groups existed based on size-related isotopic clusters or trends. Isotopic data ($\delta^{13}C$ and $\delta^{15}N$ analyzed separately) were plotted as a function of individual length by species; with the exception of zooplankton, for which length data were not recorded. These plots were visually evaluated for 1) clustering and 2) curvilinear trends. Individuals were placed into appropriate size-based groups if clusters were observed; length frequency data were used to aid in interpretation of appropriate groups. An approximating linear regression model (PROC REG; SAS software) was applied to the data to evaluate the significance (α = 0.05) of curvilinear trends. For species that exhibited a curvilinear trend in isotopic values as a function of individual length, the topology of the trend and length frequency data (Figure 2.2; Supplemental Figure 2.5) were used to separate individuals into distinct size-based groups.

Bull trout were split into two species by size groups based on apparent size-related differences

TABLE 2.2—Year, season, sample size (*N*), and length range (fishes = fork length; crayfish = from the anterior end of the rostrum to the posterior end of the cephalothorax) for species sampled for stable isotope analysis in Odell Lake, Oregon. Length data were not recorded for zooplankton.

Year	Season	Species	*N*	Length range (mm)
2013	Spring	Bull trout	1	119
		Kokanee	5	117 – 252
		Mountain whitefish	22	132 – 383
		Oncorhynchus mykiss	11	149 – 419
		Tui chub	16	51 – 222
	Summer	Bull trout	1	358
		Kokanee	5	168 – 328
		Lake trout	2	403 – 497
		Mountain whitefish	34	60 – 444
		Oncorhynchus mykiss	16	121 – 342
		Tui chub	13	49 – 210
	Autumn	Kokanee	4	329 – 362
		Lake trout	27	311 – 875
		Mountain whitefish	11	238 – 431
		Oncorhynchus mykiss	1	265
2014	Spring	Bull trout	1	746
		Crayfish	4	35 – 40
		Kokanee	17	94 – 319
		Lake trout	32	245 – 845
		Mountain whitefish	27	124 – 433
		Oncorhynchus mykiss	15	155 – 321
		Tui chub	12	22 – 276
		Zooplankton – shallow	2	
		Zooplankton – deep	5	
	Summer	Crayfish	12	29 – 39
		Kokanee	27	145 – 350
		Lake trout	14	220 – 867
		Mountain whitefish	33	65 – 450
		Oncorhynchus mykiss	22	122 – 456
		Tui chub	17	82 – 224
		Zooplankton – shallow	4	
		Zooplankton – deep	4	
	Autumn	Bull trout	1	665
		Crayfish	10	27 – 58
		Kokanee	30	160 – 443
		Lake trout	39	425 – 904
		Mountain whitefish	37	98 – 454
		Oncorhynchus mykiss	27	162 – 459
		Tui chub	9	163 – 227
		Zooplankton – shallow	8	
		Zooplankton – deep	4	

in $\delta^{13}C$ and $\delta^{15}N$ values (small bull trout = 119 mm and large bull trout ≥ 358 mm; Figure 2.3). Kokanee were split into two species by size groups based on apparent size-related differences in $\delta^{13}C$ and $\delta^{15}N$ values (small kokanee ≤ 107 mm and large kokanee ≥ 117 mm; Figure 2.3). Lake trout were split into three species by size groups. Small lake trout (≤ 245 mm) were distinguished from other lake trout based on an apparent difference in δ13C values (Figure 2.3). A significant quadratic relationship was observed between length and δ13C for lake trout ≥ 311 mm (adjusted R^2 = 0.55, P < 0.0001). Based on this relationship (Figure 2.3), and on trimmed length frequency data (Figure 2.2), we further separated lake trout into medium lake trout (lake trout ≥ 311 mm and ≤ 596 mm) and large lake trout (≥ 597 mm). Crayfish, mountain whitefish, *O. mykiss*, and tui chub were not split into separate species by size groups.

For each species by size group with sufficient sample sizes, we used analysis of variance (ANOVA) (PROC GLM; SAS software) to evaluate the influence of sample year, sample season (predictor variable), and length (i.e., fork length;

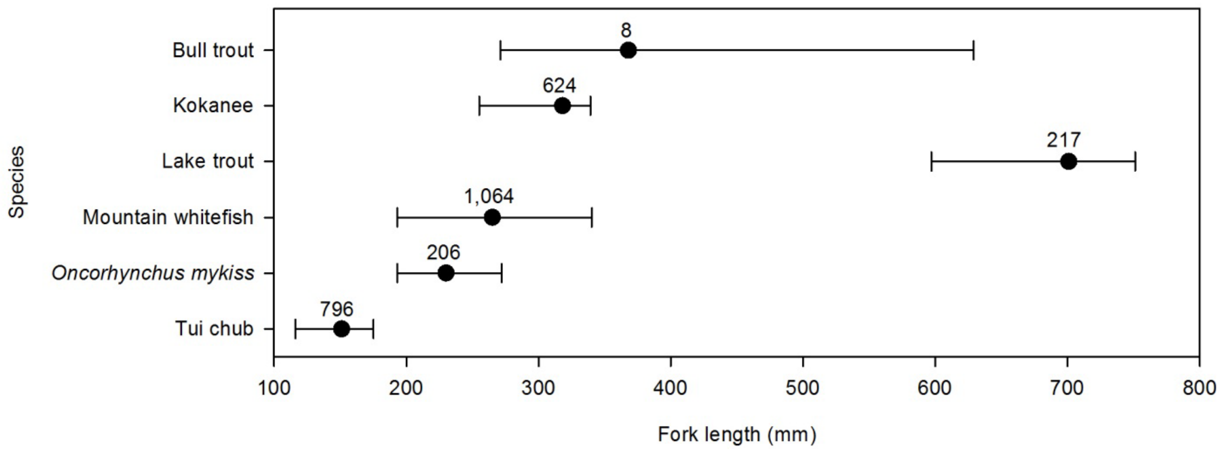


FIGURE 2.2—Trimmed length distributions for fishes sampled during 2013 and 2014 using trap nets, benthic gill nets, and suspended gill nets in Odell Lake, Oregon. Filled circles represent median lengths, bars represent the 25th and 75th percentiles of lengths, and the number represents the sample size used to estimate the distribution.

quantitative predictor variable) on $\delta^{13}C$ and $\delta^{15}N$ (analyzed separately); analyses were performed at $\alpha = 0.05$. Each ANOVA model was initially fit with all first order interactions terms (i.e., year x season, year x length, and season x length). Interaction terms were removed from the model if they were not significant and the model was re-fit. Least squares means were calculated for the main effects of sample year and sample season. Because of small sample sizes, these analyses were not performed for small bull trout (N = 1), large bull trout (N = 3), small kokanee (N = 4), and small lake trout (N = 2). In general, we observed few interactions between year and length and between season and length for $\delta^{13}C$ and $\delta^{15}N$ among species by size groups (Table 2.3). Additionally, differences in mean isotopic values were generally greater between species by size groups than they were between years or seasons within species by size groups (Table 2.3). Therefore, mean $\delta^{13}C$ and $\delta^{15}N$ for each species by size group were plotted to depict characteristics of the Odell Lake food web.

To evaluate trophic overlap between bull trout and lake trout, we performed *t*-tests (PROC TTEST; SAS software) to test for differences in isotopic values ($\delta^{13}C$ and $\delta^{15}N$ analyzed separately) between large bull trout and large lake trout and between large bull trout and medium lake trout. We performed similar *t*-tests on baseline-corrected $\delta^{15}N$ values. Baseline corrections can be used to adjust the $\delta^{15}N$ value of a consumer based on $\delta^{13}C$-specific $\delta^{15}N$ values of primary consumers (Vander Zanden and Rasmussen 1999). Primary consumer samples collected in this study (i.e., zooplankton) exhibited significant among season variation in both $\delta^{13}C$ and $\delta^{15}N$, but little within-season variation (see below); consequently, we considered zooplankton to be less than desirable to use for developing a baseline correction (e.g., Post 2002; Matthews and Mazumder 2003). However, exploratory analyses showed a significant quadratic relationship between $\delta^{13}C$ and $\delta^{15}N$ for all putative forage fish combined (i.e., kokanee, mountain whitefish, *O. mykiss*, and tui chub; Figure 2.4). Therefore, we used the relationship between $\delta^{13}C$ and $\delta^{15}N$ of forage fish as a reference point for calculating $\delta^{13}C$-specific $\delta^{15}N$ values (hereafter relative $\delta^{15}N$) for large bull trout, large lake trout, and medium lake trout following the methods of Vander Zanden and Rasmussen (1999).

We calculated standard ellipses (Package SIAR; R-software; Jackson et al. 2011) from bivariate isotope data for large bull trout, large lake trout, and medium lake trout. Standard ellipses were used as a qualitative means for assessing trophic-niche overlap among large bull trout, large lake trout, and medium lake trout, such that no overlap of standard ellipses was considered no-or-low trophic-niche overlap, some overlap of standard ellipses was considered low-or-moderate trophic-niche overlap, and substantial overlap of standard ellipses was considered moderate-or-high trophic-niche overlap (e.g., Eloranta et al. 2014); the magnitude of overlap was visually assessed.

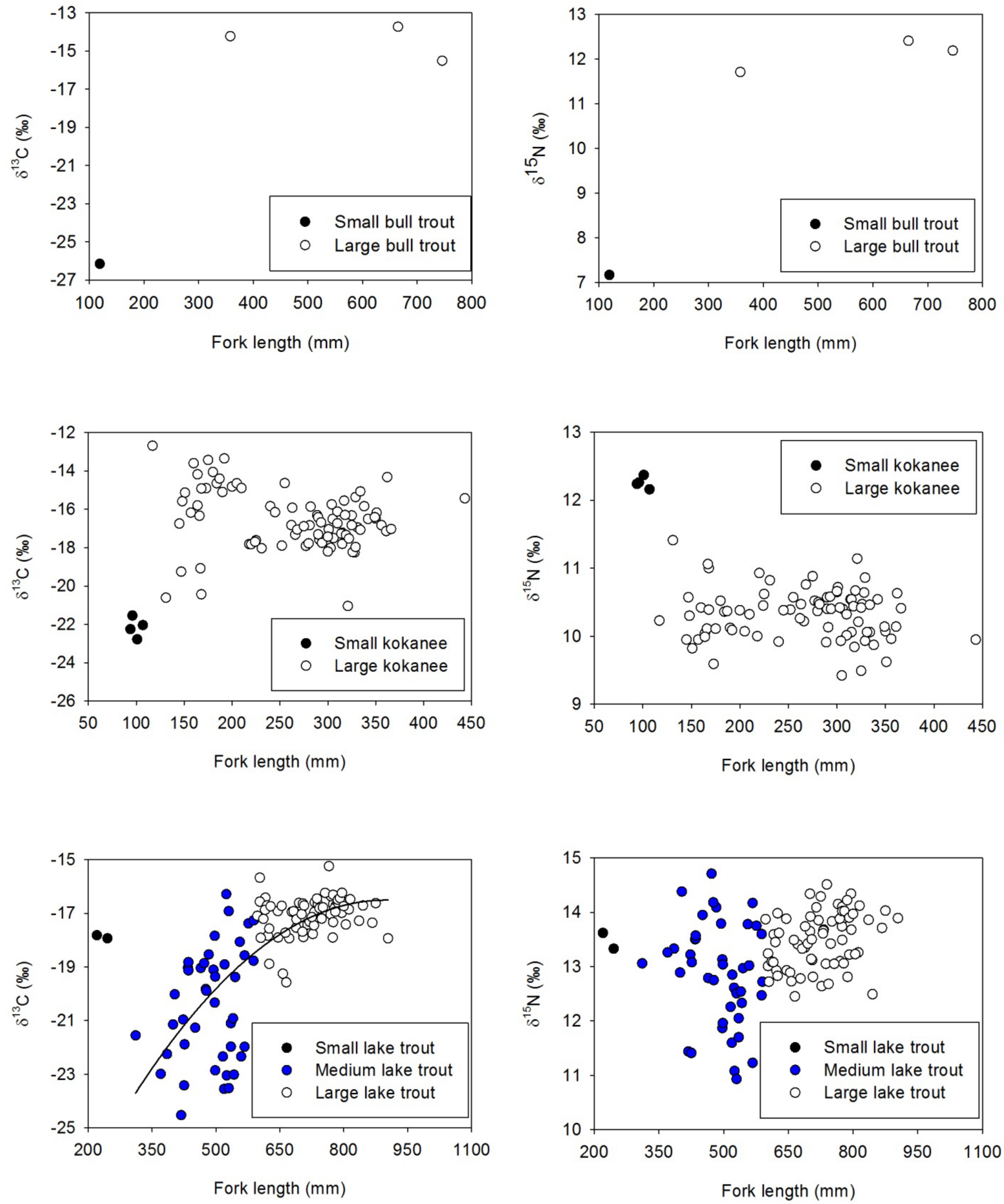


FIGURE 2.3—$\delta^{13}C$ (left panel) and $\delta^{15}N$ (right panel) as a function of length for bull trout (top panel), kokanee (middle panel), and lake trout (bottom panel) sampled in Odell Lake, Oregon. A significant quadratic relationship was observed between length and $\delta^{13}C$ for the combined sample of medium and large lake trout (R^2 = 0.54, P < 0.0001).

Table 2.3—Analysis of variance model effects and mean isotope values for stable isotope analysis ($\delta^{13}C$ and $\delta^{15}N$) conducted on different species by size groups of fish and crayfish sampled from Odell Lake, Oregon. Model effects include sample year (2013 and 2014), sample season (spring, summer, and autumn), length (fork length of species examined), and the interaction between year and season, year and length, and season and length; an X indicates a significant effect ($\alpha = 0.05$). Mean isotope values are the overall mean for all samples in a group within years and within seasons. Crayfish were not sampled during 2013. Bull trout, small kokanee, and small lake trout were not analyzed by season due to small sample sizes; one small bull trout was sampled with isotope values of $\delta^{13}C = -26.15$ and $\delta^{15}N = 7.17$, large bull trout isotope values (mean ± SD) were $\delta^{13}C = -14.50 \pm 0.92$ and $\delta^{15}N = 12.10 \pm 0.36$, small kokanee isotope values were $\delta^{13}C = -22.16 \pm 0.51$ and $\delta^{15}N = 12.26 \pm 0.09$, and small lake trout isotope values were $\delta^{13}C = -17.88 \pm 0.08$ and $\delta^{15}N = 13.48 \pm 0.21$. NS = Not Sampled.

		Model effects						Mean (± SE) isotope value				
Species by size group	Isotope	Year	Season	Length	Year x season	Year x length	Season x length	2013	2014	Spring	Summer	Autumn
Crayfish	$\delta^{13}C$			X				NS	-12.56 ± 0.38	-14.68 ± 1.19	-12.94 ± 0.49	-11.94 ± 0.54
	$\delta^{15}N$			X				NS	7.32 ± 0.14	7.85 ± 0.33	7.34 ± 0.14	7.08 ± 0.15
Large kokanee	$\delta^{13}C$		X	X				-16.93 ± 0.36	-16.65 ± 0.17	-17.51 ± 0.34	-17.13 ± 0.28	-15.74 ± 0.28
	$\delta^{15}N$					X		10.24 ± 0.09	10.35 ± 0.04	10.36 ± 0.09	10.23 ± 0.07	10.30 ± 0.07
Medium lake trout	$\delta^{13}C$	X		X				-18.78 ± 0.62	-20.57 ± 0.38	-19.34 ± 0.72	-19.19 ± 0.76	-20.50 ± 0.37
	$\delta^{15}N$							13.28 ± 0.30	12.74 ± 0.18	12.89 ± 0.35	13.23 ± 0.37	12.91 ± 0.18
Large lake trout	$\delta^{13}C$			X				-16.88 ± 0.22	-17.18 ± 0.11	-17.08 ± 0.19	-17.13 ± 0.27	-16.88 ± 0.11
	$\delta^{15}N$						X	13.73 ± 0.11	13.39 ± 0.05	13.20 ± 0.09	13.71 ± 0.14	13.78 ± 0.06
Mountain whitefish	$\delta^{13}C$			X				-16.44 ± 0.39	-16.57 ± 0.31	-15.89 ± 0.44	-16.63 ± 0.37	-17.00 ± 0.46
	$\delta^{15}N$						X	10.00 ± 0.11	9.97 ± 0.09	9.94 ± 0.12	9.87 ± 0.10	10.14 ± 0.13
O. mykiss	$\delta^{13}C$							-14.38 ± 0.31	-14.77 ± 0.20	-14.51 ± 0.30	-15.06 ± 0.25	-14.15 ± 0.35
	$\delta^{15}N$			X				9.43 ± 0.14	9.44 ± 0.09	9.54 ± 0.14	9.41 ± 0.11	9.36 ± 0.16
Tui chub	$\delta^{13}C$					X		-14.91 ± 0.42	-14.01 ± 0.32	-13.91 ± 0.34	-15.27 ± 0.32	-14.21 ± 0.64
	$\delta^{15}N$	X	X	X				9.47 ± 0.13	9.04 ± 0.10	8.98 ± 0.11	9.35 ± 0.10	9.43 ± 0.20

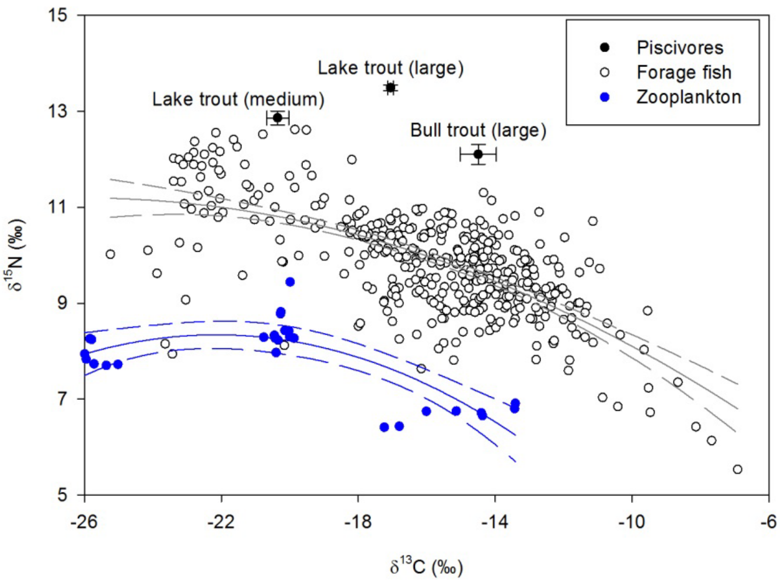


FIGURE 2.4—Quadratic relationships between $\delta^{15}N$ and $\delta^{13}C$ for all forage fish combined (gray symbols) (i.e., kokanee, mountain whitefish, *O. mykiss*, and tui chub) ($\delta^{15}N = 3.03 - 0.63*\delta^{13}C - 0.01*\delta^{13}C^2$; adjusted $R^2 = 0.47$, $P < 0.0001$) and for zooplankton (blue symbols) ($\delta^{15}N = -5.08 - 1.21*\delta^{13}C - 0.03*\delta^{13}C^2$; adjusted $R^2 = 0.58$, $P < 0.0001$) sampled in Odell Lake, Oregon. Solid lines represent the fitted quadratic regressions and the dashed lines represent 95% confidence limits for the fitted regression. We considered zooplankton to be a poor indicator of baseline $\delta^{15}N$ values because of their clumped distribution; therefore we used forage fish to establish baseline $\delta^{15}N$ values for comparing $\delta^{15}N$ among large bull trout, large lake trout, and medium lake trout (shown as black symbols; mean ± SE).

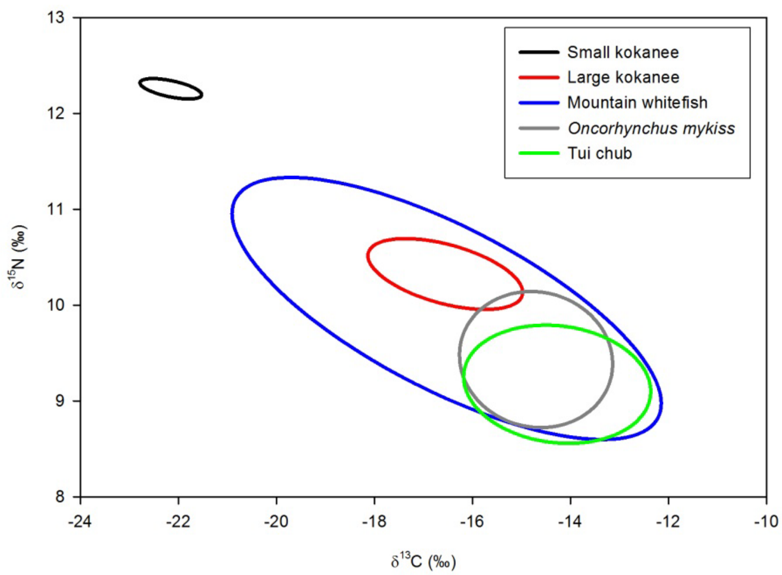


FIGURE 2.5—Standard ellipses (Jackson et al. 2011) calculated from bivariate isotope data ($\delta^{13}C$ and $\delta^{15}N$) for small kokanee, large kokanee, mountain whitefish, *Oncorhynchus mykiss*, and tui chub sampled in Odell Lake.

To evaluate probable dietary overlap between bull trout and lake trout we conducted a mixture analysis using a Bayesian isotopic mixing model (Parnell et al. 2010). Mixture analyses can be used to estimate probable contribution of various sources (i.e., prey items) to a mixture (i.e., predator). For this analysis we made the simplifying assumption that large lake trout and large bull trout in Odell Lake primarily prey on small kokanee, large kokanee, mountain whitefish, *O. mykiss*, and tui chub; this assumption was based on the results of our food-habits analysis (see below) and published data on the diets of bull trout and lake trout (e.g., Vidergar 2000; Beauchamp and Van Tassell 2001; Guy et al. 2011). Prior to conducting the mixture analysis, we calculated standard ellipses (Package SIAR; R-software; Jackson et al. 2011) from bivariate isotope data for each putative prey group and visually assessed isotopic-niche overlap among prey groups. *O. mykiss* and tui chub had similar isotopic-niche areas (*O. mykiss* = 3.26; tui chub = 3.55) and substantial isotopic-niche overlap (Figure 2.5); therefore, these species were grouped into one prey group to simplify analyses (Phillips et al. 2005). Although the isotopic-niche of mountain whitefish overlapped with large kokanee, *O. mykiss*, and tui chub (Figure 2.5), these species were not grouped together because the area of the isotopic-niche for mountain whitefish (13.32) was much larger than that of large kokanee (1.34), *O. mykiss* (3.26), and tui chub (3.55). Finally, we assumed that isotopic discrimination was 0.4 ± 1.3‰ (mean ± sd) for $\delta^{13}C$ and 3.4 ± 1.0‰ for $\delta^{15}N$ (Post 2002). We qualitatively assessed the 50, 70, and 90% credibility intervals for probable contributions of the different prey groups to the diets of bull trout and lake trout.

Food-habits of lake trout in Odell Lake

Stomach contents were collected from a subsample of lake trout for food-habits analysis. Lake trout were captured using experimental gill nets and Oneida Lake trap nets and samples were collected from lake trout that varied in length from 220-904 mm; however, the majority (73%) of the sample was from fish greater than 600 mm.

In 2013, we removed whole stomachs from a subsample of lake trout that were sacrificed during the autumn sample season. In 2014, we performed gastric lavage and removed whole stomachs from a subsample of lake trout that were captured during spring, summer, and autumn (Table 2.4). Lake trout were anesthetized in a water bath containing 25 $mg{\cdot}L^{-1}$ AQUI-S 20E. Once lake trout reached a handleable level of sedation, an 11.35 L handheld sprayer fitted with a piece of flexible vinyl tubing was inserted down the esophagus and into the stomach of the fish and lake water was pumped into the stomach with a starting pressure of about 2.5 bar. The belly of the fish was massaged and the head and mouth were held over a 500 μm sieve to catch regurgitated contents. After gastric lavage was completed, fish were sacrificed and whole stomachs were removed. Whole stomachs were also removed from lake trout that were dead upon removal from gill nets or trap nets; however, gastric lavage was not performed on these individuals. All gastric lavage and whole stomach samples were individually stored in WHIRL-PAK bags (Nasco) filled with 70% ethanol until they could be processed.

All samples were brought back to the lab for identification. Whole stomachs were cut longitudinally and contents were rinsed from the stomach tissue into a 500 μm sieve. Gastric lavage samples were individually drained into a 500 μm sieve. All sample contents were sorted, identified, and measured for wet weight with a digital scale. Organisms were identified to the lowest possible or convenient taxonomic level and placed in one of fourteen categories: fingernail clam, flat worm, Amphipoda, Diptera, Megalotera, crayfish, fish eggs, kokanee, mountain whitefish, unknown salmonid, tui chub, unknown fish, vegetation, and unknown material. Additionally, intact prey fish recovered from samples were measured for length.

TABLE 2.4—Number of lake trout stomach content samples collected from Odell Lake, Oregon. Samples from lake trout with empty stomachs were not included in the food-habits analysis.

Season and year	Number collected	Number empty	Number used in analysis
Autumn 2013	27	18	9
Spring 2014	36	1	35
Summer 2014	17	5	12
Autumn 2014	80	37	43
Total	160	61	99

For each prey category, percent by weight (%W), frequency of occurrence (%O), percent by number (%N), and index of relative importance (IRI) were calculated by sample year and sample season (Chipps and Garvey 2007; Zacharia and Abdurahiman 2010); additionally, %W was calculated for all seasons combined. Only stomachs containing prey were included in these analyses (Table 2.4). For individual lake trout that had gastric lavage and whole stomach samples collected, calculations were based on the combined contents. Percent weight was also calculated for each dietary category by season based only on the results from the gastric lavage sample, and Schoener's index (Schoener 1970; Hurlbert 1978) was used to evaluate percent agreement between gastric lavage samples and the combined gastric lavage and whole stomach samples by season.

The ratio of prey fish length to predator length was calculated to evaluate the size of fish that lake trout in Odell Lake are capable of consuming. This measure did not account for material that was already missing or digested (e.g., caudal fins, snouts, head, etc.); therefore, it must be considered a minimum ratio of prey to predator size.

Bull trout drift and the presence of lake trout near Trapper Creek

We used drift nets to evaluate the timing and magnitude of age-0 salmonid drift in Trapper Creek during the spring and summer of 2013. Two drift nets were located about 0.1 km upstream from the mouth of Trapper Creek. Drift net A was constructed of 1.6-mm mesh (bar) and had a 1.2-m wide x 1.2-m tall opening, a 3-m long net that constricted towards a trap box, and a 0.5-m high x 0.8-m wide x 0.35-m deep trap box. This drift net was used to sample drift about three days per week from May 20-September 9, 2013. Drift net B was constructed of 1.6-mm mesh (bar) and had a 1-m wide x 0.75-m tall opening, a 3-m long net that constricted towards a trap box, and a 0.75-m high x 0.75-m wide x 0.75-m deep trap box. This drift net was used to sample drift about two days per week from July 17-September 9, 2013. Drift nets were set during the daylight hours, were allowed to soak for about 24-h, and then the contents of the trap box were sorted and salmonids were counted and measured for length (fork length; mm). We did not identify salmonids to species because of the difficulty in differentiating among age-0 bull trout, brook trout (*S. fontinalis*), and other salmonids potentially present in Trapper Creek (e.g., kokanee and *O. mykiss*).

Drift net discharge ($m^3 \cdot sec^{-1}$) (i.e., the volume of water filtered by the drift nets per unit time) was measured periodically during the sample season. Drift net discharge was measured following standard methods (see Gallagher and Stevenson 1999) using water depth and velocity measurements that were recorded at six equally spaced increments starting at one side of the drift net frame and ending at the other side of the drift net frame. Stream discharge for Trapper Creek was measured periodically (see Gallagher and Stevenson 1999) starting on May 15, 2013; stream discharge was measured from water depth and velocity measurements recorded at 25 equally spaced increments. A water-level data logger (HOBO U20 Water Level Data Logger; Onset Computer Corporation) was installed on June 4, 2013 in Trapper Creek.

The relationship between water level and stream discharge was estimated using simple linear regression (water level = 0.13 + 0.30*stream discharge; $P < 0.01$, $R^2 = 0.99$); this relationship was used to estimate water level and stream discharge throughout the sample period. The relationship between drift net discharge and stream discharge was estimated using simple linear regression for drift net A (drift net discharge = 0.00 + 0.40*stream discharge; $P < 0.01$, $R^2 = 0.97$); this relationship was used to estimate the proportion of the stream discharge associated with the area sampled by drift net A for the portion of the sample period that this net was used. The relationship between drift net discharge and stream discharge for drift net B was not significant ($P = 0.10$); therefore, the mean discharge measured at drift net B ($0.19\ m^3 \cdot sec^{-1}$) was used to calculate the proportion of the stream discharge associated with the area sampled by drift net B for the portion of the sample period that this net was used.

For each sample day and drift net, the total salmonid catch was divided by the total estimated volume of water sampled by the net to provide an estimate of catch$\cdot m^{-3}$. For sample days that only one drift net was in operation this value was multiplied by the estimated discharge of Trapper Creek and the number of seconds in a day to provide an estimate of the abundance of daily salmonid drift for Trapper Creek. For sample days that both drift nets were operated a similar procedure was used with the exception that salmonid catch was the sum of catch for both drift nets and the estimated volume of water sampled was the sum of the volumes of water sampled for both drift nets.

Greater than 99% of the salmonids sampled were less than 30 mm; therefore, the biomass of drifting salmonids in Trapper Creek was estimated using the formula: estimated abundance of daily salmonid drift (see above) multiplied by 5×10^{-4} kg (average weight of bull trout less than 30 mm; M.H. Meeuwig, *unpublished data*). We used linear interpolation to estimate the biomass of drifting salmonids for days when the drift nets were not operated, and cumulative biomass of drifting salmonids was calculated for the duration of the sample period.

We used data from 37 trap nets set during the spring and summer of 2013 to evaluate the presence and relative abundance of lake trout and other fishes in close proximity to Trapper Creek. The locations of these nets were based on a judgment sample design such that the nets were located within 15-294 m (Euclidean distance) from the mouth of Trapper Creek (73 ± 68 m; mean ± std). Catch per unit effort (C/*f*; fish$\cdot h^{-1}$) of lake trout and other fishes was calculated for each trap net and mean C/*f* was calculated by day.

Results

Odell Lake fish assemblage

The combination of trap nets, benthic gill nets, and suspended gill nets sampled brook trout (*N* = 2), bull trout (*N* = 8), kokanee (*N* = 1,868), lake trout (*N* = 217), mountain whitefish (*N* = 1,871), *O. mykiss* (*N* = 254), and tui chub (*N* = 21,453) (see Table 2.5, Table 2.6, and Table 2.7 for catch by gear type, year, season, and depth strata). Lake trout varied in length from 120 to 910 mm and bull trout varied in length from 100 to 740 mm; other fishes generally did not exceed about 400 mm (Supplemental Figure 2.5). Trimmed length distributions show that most lake trout sampled varied in length from 597 to 751 mm with a median length of 701 mm (Figure 2.2). With the exception of bull trout, trimmed length distributions of other fishes varied from about 110 mm through 350 mm.

Trap nets set during 2014 sampled mountain whitefish, *O. mykiss*, and tui chub during all seasons, kokanee during the spring and autumn, and lake trout during the autumn (Table 2.5). Relative abundance of tui chub in trap nets was greatest during the summer and relative

TABLE 2.5—Number of nets set (*N*), total number of individuals sampled (catch), median, first quartile, and third quartile catch per unit effort by depth strata, season, year and species for fishes sampled using trap nets in Odell Lake, Oregon.

					Total	Catch per unit effort (fish·h^{-1})		
Species	Year	Season	Depth strata	*N*	catch	Median	First quartile	Third quartile
Brook trout	2013	Spr/Sum[1]	NA	37	2	0.00	0.00	0.00
		Spr/Sum[2]	NA	28	0	0.00	0.00	0.00
	2014	Spring	Shallow	6	0	0.00	0.00	0.00
		Summer	Shallow	12	0	0.00	0.00	0.00
		Autumn	Shallow	8	0	0.00	0.00	0.00
Bull trout	2013	Spr/Sum[1]	NA	37	3	0.00	0.00	0.00
		Spr/Sum[2]	NA	28	2	0.00	0.00	0.00
	2014	Spring	Shallow	6	0	0.00	0.00	0.00
		Summer	Shallow	12	0	0.00	0.00	0.00
		Autumn	Shallow	8	0	0.00	0.00	0.00
Kokanee	2013	Spr/Sum[1]	NA	37	9	0.00	0.00	0.00
		Spr/Sum[2]	NA	28	4	0.00	0.00	0.00
	2014	Spring	Shallow	6	9	0.00	0.00	0.06
		Summer	Shallow	12	0	0.00	0.00	0.00
		Autumn	Shallow	8	1160	4.25	1.92	6.05
	2013	Spr/Sum[1]	NA	37	0	0.00	0.00	0.00
		Spr/Sum[2]	NA	28	1	0.00	0.00	0.00
Lake trout	2014	Spring	Shallow	6	0	0.00	0.00	0.00
		Summer	Shallow	12	0	0.00	0.00	0.00
		Autumn	Shallow	8	28	0.00	0.00	0.05
Mountain whitefish	2013	Spr/Sum[1]	NA	37	139	0.08	0.00	0.14
		Spr/Sum[2]	NA	28	545	0.27	0.02	0.93
	2014	Spring	Shallow	6	37	0.13	0.00	0.52
		Summer	Shallow	12	399	0.38	0.04	2.12
		Autumn	Shallow	8	206	0.14	0.00	1.37
Oncorhynchus mykiss	2013	Spr/Sum[1]	NA	37	14	0.00	0.00	0.00
		Spr/Sum[2]	NA	28	29	0.00	0.00	0.11
	2014	Spring	Shallow	6	22	0.00	0.00	0.49
		Summer	Shallow	12	110	0.08	0.00	0.47
		Autumn	Shallow	8	71	0.48	0.00	0.70
Tui chub	2013	Spr/Sum[1]	NA	37	7807	3.45	0.53	10.82
		Spr/Sum[2]	NA	28	7199	3.48	0.66	16.09
	2014	Spring	Shallow	6	162	0.78	0.29	0.98
		Summer	Shallow	12	6103	15.07	2.84	39.11
		Autumn	Shallow	8	15	0.00	0.00	0.07

[1] Trap nets set during the spring and summer following a judgment sample design.
[2] Trap nets set during the spring and summer following a convenience sample design.

TABLE 2.6—Number of nets set (*N*), total number of individuals sampled (catch), median, first quartile, and third quartile for number of individuals sampled by depth strata, season, year and species for fishes sampled using benthic gill nets in Odell Lake, Oregon.

					Total	Catch per unit effort (fish·h^{-1})		
Species	Year	Season	Depth strata	*N*	catch	Median	First quartile	Third quartile
Bull trout	2013	Autumn	Shallow	10	1	0.00	0.00	0.00
			Deep	22	0	0.00	0.00	0.00
	2014	Spring	Shallow	30	1	0.00	0.00	0.00
			Deep	40	0	0.00	0.00	0.00
		Summer	Shallow	13	0	0.00	0.00	0.00
			Deep	20	0	0.00	0.00	0.00
		Autumn	Shallow	20	1	0.00	0.00	0.00
			Deep	20	0	0.00	0.00	0.00
Kokanee	2013	Autumn	Shallow	10	69	1.79	0.00	18.57
			Deep	22	25	0.00	0.00	1.82
	2014	Spring	Shallow	30	46	0.94	0.00	4.00
			Deep	40	2	0.00	0.00	0.00
		Summer	Shallow	13	11	0.00	0.00	1.94
			Deep	20	15	0.00	0.00	2.94
		Autumn	Shallow	20	258	8.00	5.46	28.27
			Deep	20	58	1.67	0.00	6.57
Lake trout	2013	Autumn	Shallow	10	11	0.79	0.00	1.76
			Deep	22	24	1.76	0.00	1.82
	2014	Spring	Shallow	30	13	0.00	0.00	1.88
			Deep	40	26	0.00	0.00	2.00
		Summer	Shallow	13	0	0.00	0.00	0.00
			Deep	20	5	0.00	0.00	0.94
		Autumn	Shallow	20	26	0.00	0.00	2.94
			Deep	20	43	1.52	0.00	5.90
Mountain whitefish	2013	Autumn	Shallow	10	66	9.43	5.14	12.35
			Deep	22	11	0.00	0.00	0.00
	2014	Spring	Shallow	30	77	2.43	0.00	7.50
			Deep	40	30	0.00	0.00	2.00
		Summer	Shallow	13	29	2.00	1.67	5.63
			Deep	20	22	0.94	0.00	4.78
		Autumn	Shallow	20	95	7.50	2.79	12.00
			Deep	20	6	0.00	0.00	0.00
Oncorhynchus mykiss	2013	Autumn	Shallow	10	1	0.00	0.00	0.00
			Deep	22	0	0.00	0.00	0.00
	2014	Spring	Shallow	30	1	0.00	0.00	0.00
			Deep	40	0	0.00	0.00	0.00
		Summer	Shallow	13	1	0.00	0.00	0.00
			Deep	20	0	0.00	0.00	0.00
		Autumn	Shallow	20	4	0.00	0.00	0.00
			Deep	20	0	0.00	0.00	0.00
Tui chub	2013	Autumn	Shallow	10	1	0.00	0.00	0.00
			Deep	22	2	0.00	0.00	0.00
	2014	Spring	Shallow	30	26	0.94	0.00	2.00
			Deep	40	0	0.00	0.00	0.00
		Summer	Shallow	13	74	10.00	4.00	14.00
			Deep	20	0	0.00	0.00	0.00
		Autumn	Shallow	20	11	0.00	0.00	1.94
			Deep	20	13	0.00	0.00	1.91

abundance of kokanee in trap nets was greatest during the autumn. A small number of bull trout (*N* = 5) and brook trout (*N* = 2) were sampled using trap nets in 2013, but these species were not sampled using trap nets in 2014. Small numbers of bull trout were sampled from shallow benthic gill nets in the autumn of 2013 (*N* = 1), spring of 2014 (*N* = 1), and autumn of 2014 (*N* = 1) (Table 2.6). Kokanee were sampled from both shallow and deep benthic gill nets during all sample seasons, but were most abundant in shallow benthic gill nets during the autumns of 2013 and

TABLE 2.7—Number of nets set (*N*), total number of individuals sampled (catch), median, first quartile, and third quartile for number of individuals sampled by depth strata, season, year and species for fishes sampled using suspended gill nets in Odell Lake, Oregon.

					Total	Catch per unit effort (fish·h^{-1})		
Species	Year	Season	Depth strata	*N*	catch	Median	First quartile	Third quartile
Kokanee	2014	Spring	0–6	4	22	0.50	0.00	11.00
			12–18	4	0	0.00	0.00	0.00
			24–30	4	3	0.50	0.00	1.50
			36–42	3	0	0.00	0.00	0.00
		Summer	0–6	4	0	0.00	0.00	0.00
			12–18	4	57	22.06	10.92	64.00
			24–30	4	9	1.83	0.87	3.06
			36–42	4	9	1.52	0.00	3.69
		Autumn	0–6	3	18	6.89	2.77	7.87
			12–18	3	9	2.81	0.00	6.00
			24–30	3	6	2.03	0.00	3.75
			36–42	4	20	3.33	1.91	7.68
Lake trout	2014	Spring	0–6	4	0	0.00	0.00	0.00
			12–18	4	0	0.00	0.00	0.00
			24–30	4	2	0.00	0.00	1.00
			36–42	3	1	0.00	0.00	0.98
		Summer	0–6	4	0	0.00	0.00	0.00
			12–18	4	3	0.50	0.00	1.40
			24–30	4	2	0.45	0.00	0.93
			36–42	4	1	0.00	0.00	0.51
		Autumn	0–6	3	0	0.00	0.00	0.00
			12–18	3	0	0.00	0.00	0.00
			24–30	3	1	0.00	0.00	0.94
			36–42	4	0	0.00	0.00	0.00
Mountain whitefish	2014	Spring	0–6	4	0	0.00	0.00	0.00
			12–18	4	0	0.00	0.00	0.00
			24–30	4	0	0.00	0.00	0.00
			36–42	3	0	0.00	0.00	0.00
		Summer	0–6	4	0	0.00	0.00	0.00
			12–18	4	0	0.00	0.00	0.00
			24–30	4	0	0.00	0.00	0.00
			36–42	4	0	0.00	0.00	0.00
		Autumn	0–6	3	0	0.00	0.00	0.00
			12–18	3	1	0.00	0.00	1.00
			24–30	3	0	0.00	0.00	0.00
			36–42	4	0	0.00	0.00	0.00
Tui chub	2014	Spring	0–6	4	0	0.00	0.00	0.00
			12–18	4	0	0.00	0.00	0.00
			24–30	4	0	0.00	0.00	0.00
			36–42	3	0	0.00	0.00	0.00
		Summer	0–6	4	0	0.00	0.00	0.00
			12–18	4	0	0.00	0.00	0.00
			24–30	4	0	0.00	0.00	0.00
			36–42	4	0	0.00	0.00	0.00
		Autumn	0–6	3	0	0.00	0.00	0.00
			12–18	3	2	0.00	0.00	2.00
			24–30	3	0	0.00	0.00	0.00
			36–42	4	0	0.00	0.00	0.00

2014. Lake trout were sampled from both shallow and deep benthic gill nets during all sample seasons with the exception that they were not sampled from shallow benthic gill nets in the summer of 2014. Mountain whitefish were present in samples from shallow and deep benthic gill nets during all sample seasons, but they were generally most abundant in shallow benthic gill nets. Small numbers of *O. mykiss* were present in samples from shallow benthic gill nets during all sample seasons. Tui chub were present in samples from shallow benthic gill nets during all sample seasons, in deep benthic gill nets during the autumn of 2013 and autumn of 2014, and

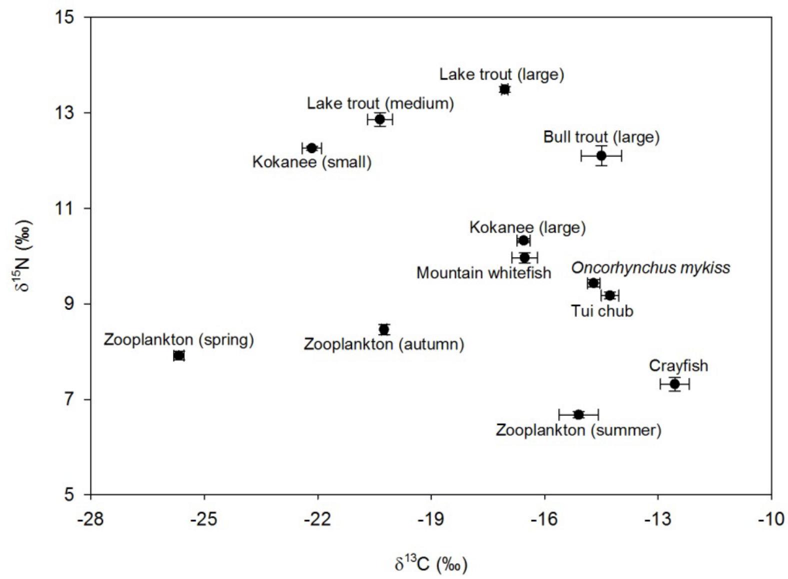


FIGURE 2.6—Graphical representation of the Odell Lake food web based on mean (± SE) δ^{13}C and δ^{15}N values of species sampled in Odell Lake.

were most abundant in samples from shallow benthic gill nets in the summer of 2014.

Kokanee where the most abundant fish sampled using suspended gill nets. Kokanee were present in samples from suspended gill nets in most depth strata by season combinations and were most abundant in the 12-18 m depth strata in the summer of 2014 (Table 2.7). Lake trout were not detected in samples from suspended gill nets in the 0-6 m depth strata, but where present in samples from at least one other depth strata by season combination. Additionally, one mountain whitefish was sampled using suspended gill nets (12-18 m depth strata) in the autumn of 2014 and two tui chub were sampled using suspended gill nets (12-18 m depth strata) in the autumn of 2014.

Characteristics of the aquatic food web in Odell Lake

The interaction between sample year and length (i.e., fork length) had a significant effect on δ^{13}C of tui chub ($F_{1,61}$ = 4.49, P = 0.0382) and on δ^{15}N of large kokanee ($F_{1,78}$ = 7.48, P = 0.0077) (Table 2.3).The interaction between sample season and length had a significant effect on δ^{15}N of large lake trout ($2_{2,62}$ = 5.07, P = 0.0091) and mountain whitefish ($F_{2,157}$ = 5.16, P = 0.0068). Length had a significant negative effect on δ^{13}C of crayfish ($F_{1,20}$ = 6.82, P = 0.0167), large kokanee (F_{179} = 11.57, P = 0.0011), and mountain whitefish ($F_{1,159}$ = 161.52, P < 0.0001). Length had a significant positive effect on δ^{13}C of medium lake trout ($F_{1,38}$ = 8.19, P = 0.0068) and large lake trout ($F_{1,64}$ = 4.17, P = 0.0452). Length had a significant positive effect on δ^{15}N of crayfish ($F_{1,20}$ = 30.95, P < 0.0001), *O. mykiss* ($F_{1,87}$ = 6.81, P = 0.0107), and tui chub ($F_{1,62}$ = 8.10, P = 0.0060). Medium lake trout differed significantly in δ^{13}C between sample years ($F_{1,38}$ = 7.00, P = 0.0118), with greater δ^{13}C values observed in 2013. Tui chub differed significantly in δ^{15}N between sample years ($F_{1,62}$ = 7.12, P = 0.0097), with greater δ^{13}C values observed in 2013. Large kokanee differed significantly in δ^{13}C among sample seasons ($F_{2,79}$ = 12.49, P < 0.0001), with δ^{13}C values greatest in the autumn (-15.74‰) followed by the summer (-17.13‰) and spring (-17.51‰). Tui chub differed significantly in δ^{15}N among sample seasons ($F_{2,62}$ = 3.69, P = 0.0306), with δ^{15}N values greatest in the autumn (9.43‰) followed by the summer (9.35‰) and spring (8.98‰). The interaction between sample season and depth strata had a significant effect on δ^{13}C of zooplankton ($F_{1,2}$ = 16.19, P < 0.0001) and zooplankton differed significantly in δ^{15}N among sample season ($F_{2,23}$ = 81.21, P < 0.0001), with δ^{15}N values greatest in the autumn (8.45‰) followed by the spring (7.94‰) and summer (6.68‰). Although significant differences were observed between years and among seasons for some species, mean differences were generally greater between species than within species (Table 2.3).

Large bull trout, medium lake trout, and large lake trout had the greatest δ^{15}N values; small kokanee also had high δ^{15}N values (Figure 2.6). Large

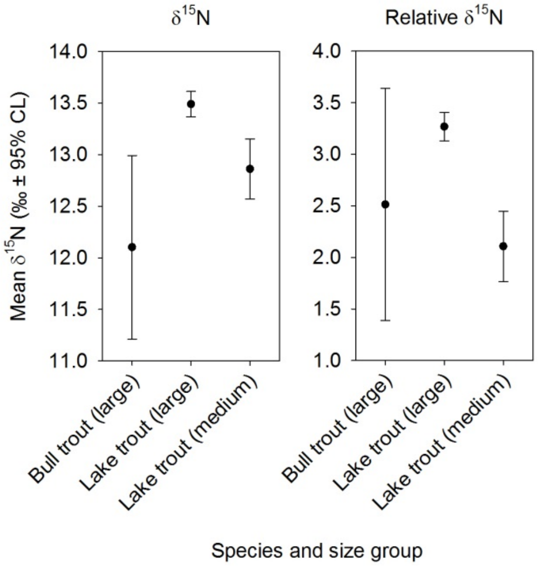


FIGURE 2.7—$\delta^{15}N$ and relative $\delta^{15}N$ for large bull trout, large lake trout, and medium lake trout sampled in Odell Lake, Oregon. Relative $\delta^{15}N$ was calculated using $\delta^{13}C$-specific $\delta^{15}N$ values (Figure 2.4) as a reference point (*sensu* Vander Zanden and Rasmussen 1999).

kokanee and mountain whitefish had similar $\delta^{13}C$ and $\delta^{15}N$ values, and *O. mykiss* and tui chub had similar $\delta^{13}C$ and $\delta^{15}N$ values. Large lake trout $\delta^{13}C$ values where generally similar to those of large kokanee and mountain whitefish and large bull trout $\delta^{13}C$ values were generally similar to those of *O. mykiss* and tui chub. Crayfish had low $\delta^{15}N$ values and high $\delta^{13}C$ values. Zooplankton varied considerably among seasons in $\delta^{13}C$ values, and in $\delta^{15}N$ values to a lesser degree. Small lake trout and large lake trout had similar $\delta^{13}C$ and $\delta^{15}N$ values (Table 2.3), and the one small bull trout sampled had the lowest $\delta^{13}C$ value and among the lowest $\delta^{15}N$ values (Table 2.3).

Large bull trout differed significantly in $\delta^{13}C$ from large lake trout (t = 6.01, df = 70, P < 0.0001) and medium lake trout (t = 4.69, df = 44, P < 0.0001). Large bull trout differed significantly in $\delta^{15}N$ from large lake trout (t = -4.64, df = 70, P < 0.0001), but not from medium lake trout (t = -1.38, df = 44, P =0.1752). Similarly, large bull trout differed significantly in relative $\delta^{15}N$ from large lake trout (t = -2.24, df = 70, P = 0.0286), but not from medium lake trout (t = 0.63, df = 44, P = 0.5343). However, the magnitude and effect size (i.e., the mean difference) differs among large bull trout, large lake trout, and medium lake trout when evaluating differences in $\delta^{15}N$ and relative $\delta^{15}N$ (Figure 2.7).

No-or-low trophic niche overlap was observed among large bull trout, large lake trout, and medium lake trout (Figure 2.8). However, isotopic mixture analyses suggested that small kokanee, large kokanee, mountain whitefish, and the combination of *O. mykiss* and tui chub all had some probable contribution to the diets of large bull trout and large lake trout (Figure 2.9). Probable contributions to the diet of large bull trout were slightly skewed towards the combination of *O. mykiss* and tui chub. Additionally, the probable contributions of all four assumed dietary categories generally overlapped. However, the probable contribution of small kokanee to the diet of bull trout included zero in the 90% and 70% credible intervals. Conversely, probable contributions of the different prey groups to the diet of large lake trout were all greater than zero. The probable contribution of small kokanee and large kokanee to the diet of large lake trout was about 0.25 and 0.30, respectively; or about 0.55 for all sizes of kokanee combined. The probable contribution of the combination of *O. mykiss* and tui chub to the diet of large lake trout was about 0.43. The probable contribution of mountain whitefish to the diets of lake trout and bull trout should not be underestimated despite results of the isotopic mixture analyses. The isotopic niche of mountain whitefish was large and overlapped all the assumed prey groups except small kokanee (Figure 2.5), as such it is plausible that some contribution to the diets of lake trout and bull trout that were attributed to large kokanee, *O. mykiss*, and tui chub are coming from mountain whitefish.

Food-habits of lake trout in Odell Lake

In spring 2014, Diptera was the most numerous prey group and was found in 80% of the stomachs examined; all Diptera were aquatic life stages. Although Diptera made up a small fraction (1.5%) by weight, it had the greatest IRI (68.3%) (Figure 2.10). Kokanee made up 60.8% by weight and had the second greatest IRI (22%). In summer 2014, kokanee and unknown salmonids combined to made up over 93% by weight and had a combined IRI of 92.2%. Macroinvertebrates combined (i.e., Diptera, Megaloptera, flat worm, and Amphipoda) were found in 8.3% of stomachs and had an IRI of 4.1%.

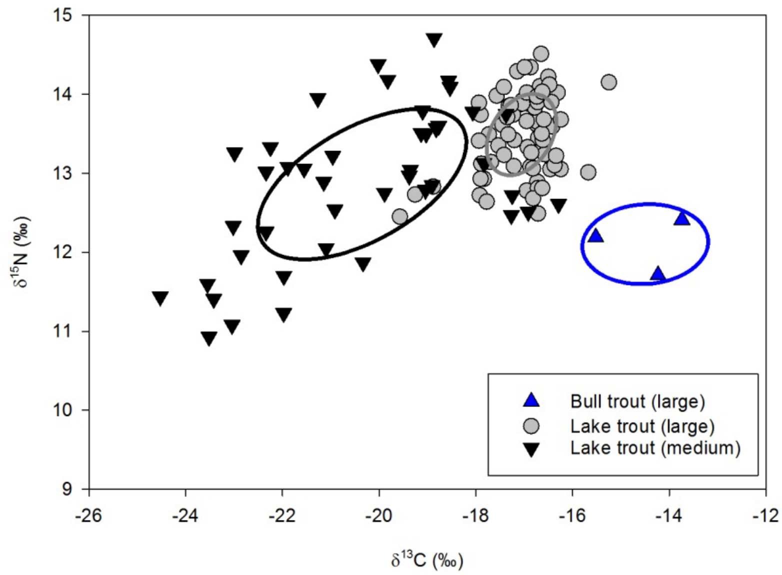


FIGURE 2.8—Standard ellipses (Jackson et al. 2011) calculated from bivariate isotope data ($\delta^{13}C$ and $\delta^{15}N$) for large bull trout, large lake trout, and medium lake trout sampled in Odell Lake. Symbols represent bivariate isotope data for individual large bull trout (blue triangles), large lake trout (gray circles), and medium lake trout (black triangles) used to calculate standard ellipses.

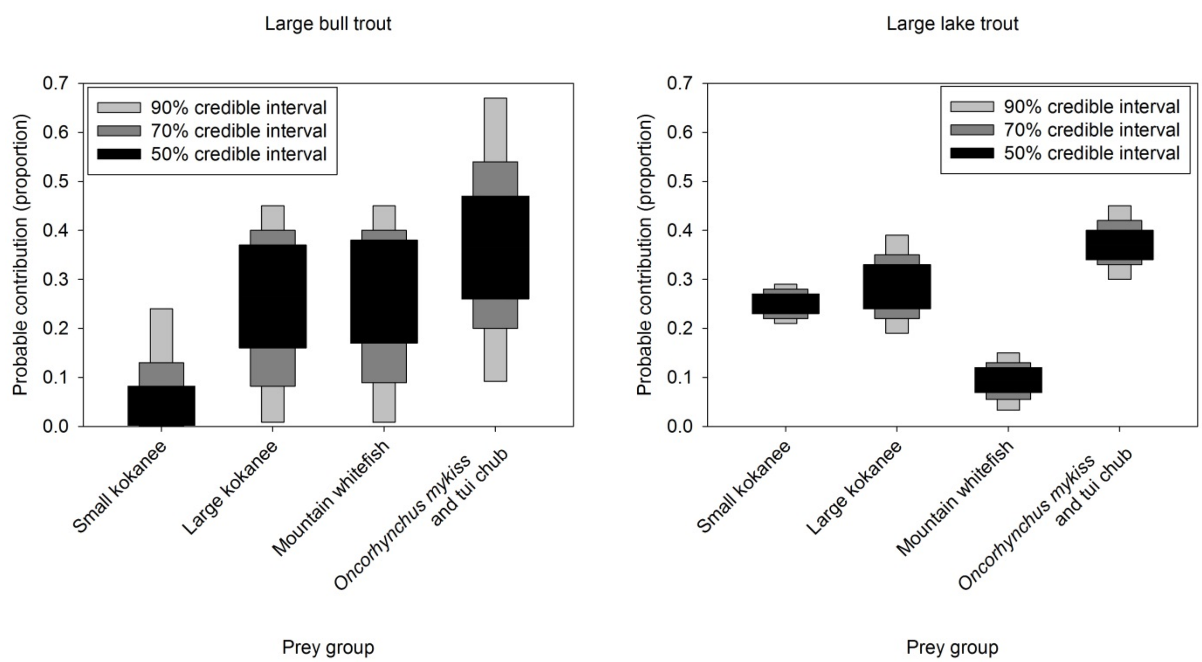


FIGURE 2.9—Probable dietary contributions to large bull trout (left panel) and large lake trout (right panel) based on a Bayesian isotope mixture analysis.

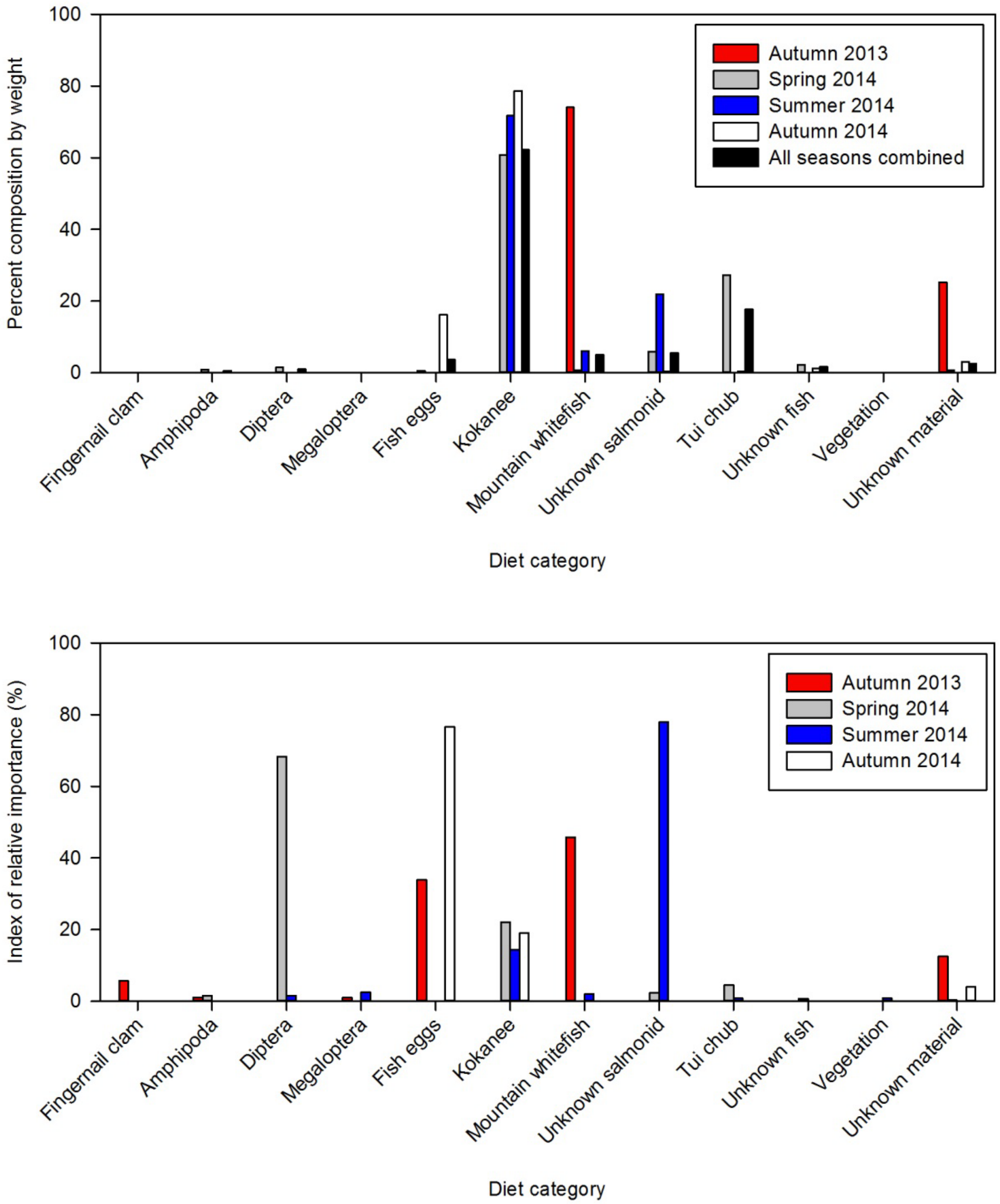


FIGURE 2.10—Percent composition by weight (top panel) and index of relative importance (bottom panel) for lake trout stomach contents. Diet categories representing less than 1% by weight (i.e., crayfish and flatworms) were omitted from this figure.

During the autumn, fish eggs were an important dietary item. Although representing a small portion of the weight (Figure 2.10), they were one of the most commonly found prey items and had high IRI scores in both 2013 (second greatest at 33.8%) and 2014 (greatest at 76.6%). In autumn 2013, no kokanee were identified from stomach contents and mountain whitefish had the highest IRI (45.8%). Conversely, kokanee made up 78.7% of the stomach content by weight and had the second greatest IRI (19%) in autumn 2014. However, this difference should be interpreted carefully because only 9 lake trout stomachs contained prey items in autumn of 2013 whereas 90 lake trout stomachs contained prey items in 2014; therefore, this may be a result of the small sample size as opposed to differences in prey use between 2013 and 2014.

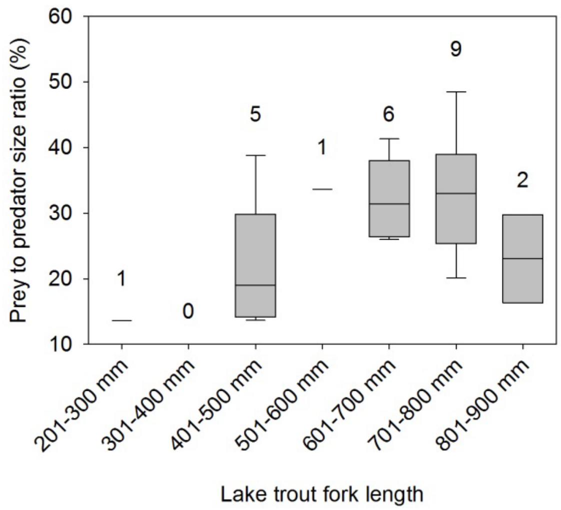


FIGURE 2.11—Prey to predator size for lake trout sampled in Odell Lake. Upper and lower boundaries of boxes represent the 25th and 75th percentiles, the line in the box represents the 50th percentile, and the whiskers represent the 10th (lower) a 90th (upper) percentiles; numbers above boxes represent the number of lake trout sampled for each length category. (Prey consisted of 35 kokanee, 3 tui chub, 4 mountain whitefish, and 1 unknown salmonid).

TABLE 2.8—Number of gastric lavage samples (GL), number of stomachs completely emptied by GL, and % of contents recovered from Odell Lake lake trout.

Season and year	GL samples	Stomachs completely emptied by GL	Percent by weight of contents removed with GL
Autumn 2013	0	N/A	N/A
Spring 2014	36	20	42.14
Summer 2014	7	6	99.86
Autumn 2014	56	54	90.17
Total	99	80	77.39

Prey fish that were recovered from the stomach contents of lake trout were measured for length. The largest prey item recovered was 48.5% of the length of the lake trout that consumed it and the smallest measurable prey fish was 13.6% (Figure 2.11).

Combined sample contents were compared to the gastric lavage contents. There was 99.9% and 98.4% percent agreement between the combined sample contents and the gastric lavage contents in summer and autumn 2014, respectively; indicating little to no difference in the composition of the diet based on the method used to collect stomach contents. The overlap between methods was slightly lower in spring 2014 (76.3%); only 20 out of 36 gastric lavage samples completely emptied the stomach, and only 42% by weight of the total contents were removed. For both summer and autumn 2014 over 90% of the total stomach contents were recovered with the gastric lavage technique (Table 2.8).

Bull trout drift and the presence of lake trout near Trapper Creek

At the location of our drift nets in Trapper Creek, age-0 salmonid drift was low from May 20-June 11, 2013, was higher and variable from June 12-July 24, 2013, and was low from July 29-September 9, 2013 (Figure 2.12). We estimated that about 1.7 kg of age-0 salmonids drifted past the point of our drift nets during the duration of sampling. Lake trout were not sampled from trap nets set near the mouth of Trapper Creek during the sample season (Figure 2.12). The most abundant fishes sampled from trap nets during the sample season were tui chub (*N* = 7,807) and mountain whitefish (*N* = 139); smaller numbers of bull trout (*N* = 3), brook trout (*N* = 2), kokanee (*N* = 9) and *O. mykiss* (*N* = 14) were also sampled.

Discussion

Lake trout were the most abundant apex predator sampled in Odell Lake. Stable isotope data indicate that lake trout occupy a high trophic position, and food-habits analysis suggest that lake trout prey on salmonids (e.g., kokanee and mountain whitefish), non-salmonids (e.g., tui chub), and a variety of other seasonally available prey items (e.g., fish eggs, dipterans, etc.). However, we found no evidence to suggest that lake trout prey on age-0 salmonids during putative periods of emigration from rearing sites in Trapper Creek. Stable isotope data indicate that bull trout are also an apex predator in Odell Lake, but they were much less abundant than lake trout based on gill net and trap net data. Differences in isotopic values between bull trout and lake trout suggest incomplete overlap in prey use or variability in dietary composition between these species; therefore, extirpation of bull trout from Odell Lake as a result of competition with lake trout (i.e., competitive exclusion, *sensu stricto*) would not be predicted. However, exclusion is only one outcome that results from competition, and both classic competition theory (e.g., Lotka-Volterra; Gotelli 1995) and intraguild predation (Polis et al. 1989) can help explain the contemporary pattern of bull trout abundance in Odell Lake.

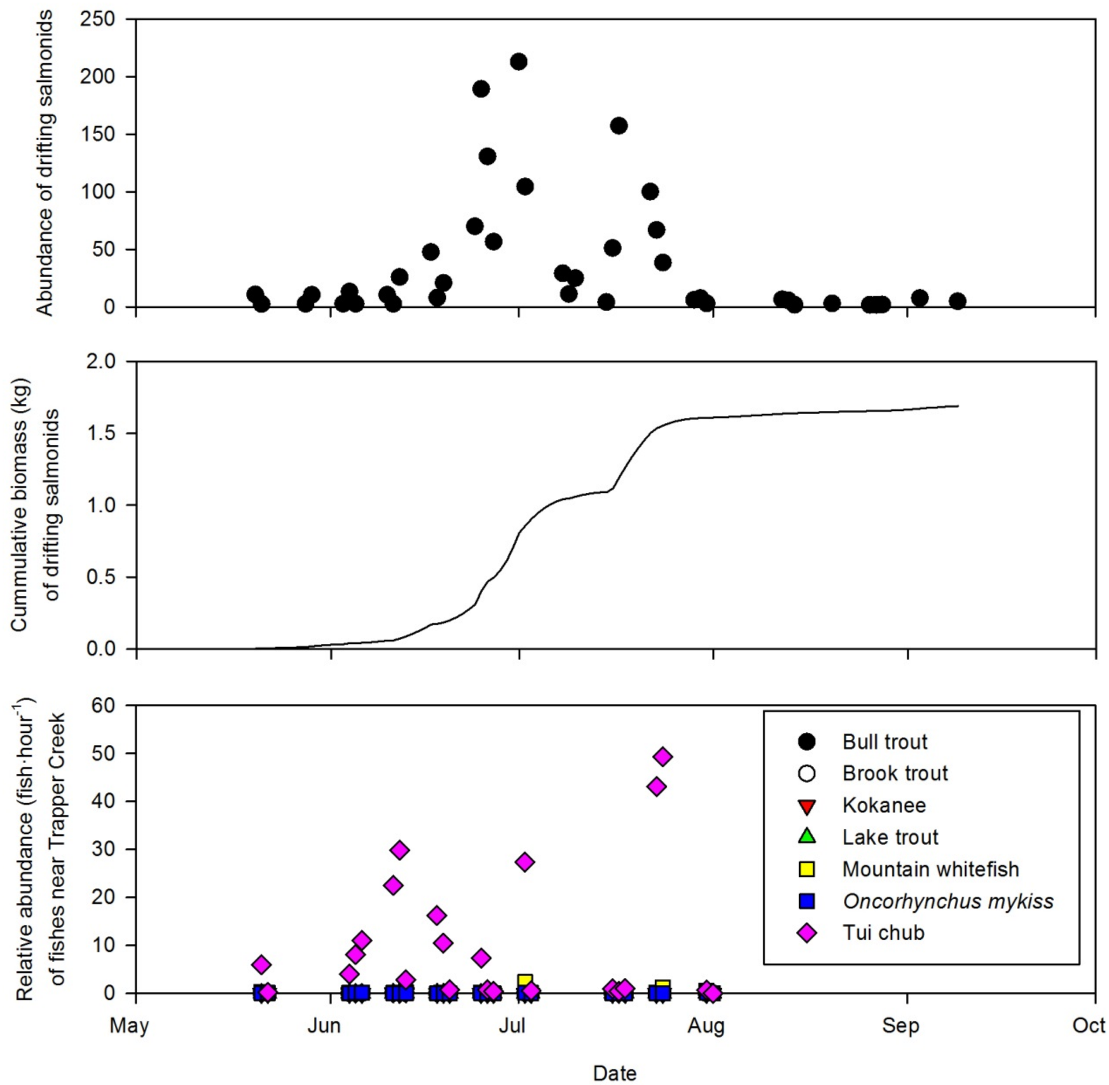


FIGURE 2.12—Abundance of drifting age-0 salmonids in Trapper Creek (top panel), cumulative biomass of drifting age-0 salmonids in Trapper Creek (middle panel), and relative abundance of fishes sampled using trap nets set near the mouth of Trapper Creek, Odell Lake, Oregon (bottom panel). Abundance and biomass estimates for drifting age-0 salmonids where calculated from drift samples collected about 0.1 km upstream from the mouth of Trapper Creek and relative abundance estimates for fishes sample near Trapper Creek where calculated from a sample of trap nets (*N* = 37) set near the mouth of Trapper Creek (i.e., within 15-294 m from the mouth).

Competitive interactions negatively influence the population growth rates and population sizes of two competing species, and may or may not result in exclusion of one of the species (Hardin 1960; Gotelli 1995*a*). The Lotka-Volterra model forms the foundation of competition theory in ecological systems (Gotelli 1995*a*), and this relatively simple model predicts four possible outcomes from competition between two species: 1) species A wins in competition and species B is excluded, 2) species B wins in competition and species A is excluded, 3) coexistence occurs between species A and species B at a stable equilibrium, and 4) an unstable equilibrium exists such that competitive exclusion occurs, but it is difficult to predict which species will win in competition. Currently, bull trout in Odell Lake coexist with nonnative lake trout, but at a putatively decreased abundance based on anecdotal information and empirical data. For example, bull trout in Odell Lake provided an important sport fishery in the past (OSGC 1946, 1947, 1950), but our conservative estimate suggest that only about 8 bull trout were captured by anglers during the 2013 fishing season compared to 205 lake trout (Chapter 3; this document). Additionally, during our gill net and trap net sampling, a total of 8 bull trout were captured in Odell Lake compared to 217 lake trout. Therefore, bull trout represent 3.7% of the combined bull trout and lake trout catch from our sampling. Although these numbers may not be entirely indicative of patterns in abundance, they differ enough to warrant concern. For example, in four northwestern Montana lakes, where decreases in relative abundance of bull trout have been documented concurrently with increases in relative abundance of lake trout (Fredenberg 2002), the percent of bull trout in the combined bull trout and lake trout catch varied from 20–26% (Meeuwig et al. 2008). Therefore, the pattern of relative abundance of bull trout and lake trout in Odell Lake (i.e., fewer bull trout relative to lake trout) is similar to that observed in other systems where bull trout relative abundance has declined and plausibly represents coexistence at a stable or unstable equilibrium for two competing species.

In addition to patterns of relative abundance, other biological characteristics of bull trout and lake trout in Odell Lake suggest the potential for competition between these species. Spatial overlap and use of similar prey may predispose bull trout and lake trout to compete under conditions of limited prey resources. Bull trout and lake trout were both sampled from shallow water habitat in the spring and autumn in Odell Lake. Lake trout were generally restricted to habitats below the thermocline during the summer in Odell Lake. Although bull trout were not sampled during the summer in Odell Lake, acoustic telemetry data from Ross Lake, Washington (Eckmann 2014), indicate that lacustrine-adfluvial bull trout may avoid shallow or warm-water habitats in thermally stratified lakes during summer months. These data indicate that spatial overlap likely occurs between bull trout and lake trout during most of the year in Odell Lake.

Our study indicates that lake trout (generally greater than about 600 mm) in Odell Lake prey extensively on fishes. Kokanee comprised the greatest percent (by weight) of the lake trout diet among sample seasons; followed by mountain whitefish. Bull trout were the only fish sampled in Odell Lake that achieved maximum sizes similar to lake trout, and therefore would have similar abilities to capture large prey (i.e., similar gape limitations; Donald and Alger 1993). Bull trout food-habits were not evaluated during this study; however, bull trout have been shown to prey on a variety of fishes once they have reached sufficient size (Beauchamp and Van Tassell 2001; Guy et al. 2011). The Oregon State Game Commission speculated that kokanee and mountain whitefish comprise the majority of the diet of bull trout in Odell Lake (OSGC 1946, 1947). Additionally, large bull trout (i.e., > 450 mm) in Lake Billy Chinook, Oregon, prey extensively on kokanee. Therefore, it is plausible that there is dietary overlap between bull trout and lake trout in Odell Lake. Indeed, studies have documented substantial dietary overlap between piscivorous bull trout and lake trout where these species are sympatric. For example, kokanee comprised 86% and 88% of the diets of bull trout and nonnative lake trout, respectively, in Swan Lake, Montana (Guy et al. 2011), and kokanee comprised 64% and 87% of the diets of bull trout and nonnative lake trout (≥ 406 mm), respectively, in Lake Pend Oreille, Idaho (Vidergar 2000).

Observed patterns of relative abundance, spatial overlap, and putative dietary overlap between bull trout and lake trout in Odell Lake all suggest competition for food resources may occur between these species; however, stable isotope values differed between these species. We urge that caution should be taken before interpreting this as evidence for lack of dietary overlap or lack of competition. First, the difference in $\delta^{15}N$ between large bull trout and large lake trout was 1.39‰ (0.75‰ measured as relative $\delta^{15}N$) (Figure 2.7); a relatively small difference. Meta-analyses indicate that $\delta^{15}N$ isotopic fractionation of about 3.4‰ is indicative of a one trophic level difference for a variety of taxa (Minagawa and Wada 1984; Post 2002). Additionally, mean $\delta^{15}N$ isotopic fractionation was greater than 3.42‰ for field studies, for aquatic environments, and for carnivores, and variance in these fractionation values was less than 0.99 (Post 2002). Consequently, the differences in $\delta^{15}N$ observed between large bull trout and large lake trout represent substantially less than a one trophic level difference. Therefore, large bull trout and large lake trout in Odell Lake should be considered to occupy the same trophic guild; despite having significantly different $\delta^{15}N$. Second, stable isotope analysis is a powerful tool for inferring trophic characteristics of species and whole food-webs (Martínez del Rio et al. 2009); however, as food-webs become more complex the ability of stable isotope analyses to accurately and precisely identify trophic linkages diminishes. Mixture analyses can be used to estimate the contribution of various sources (i.e., prey items) to a mixture (i.e., predator); however, a unique solution describing the contribution of each source to a mixture can only be achieved if the number of potential sources does not exceed one plus the number of isotopes examined (Phillips et al. 2005), and if simplifying assumptions are made regarding isotopic discrimination. Given some simplifying assumptions (see above), it is probable that bull trout and lake trout in Odell Lake use similar prey resources, but in different proportions. These results indicate that care must be taken when interpreting the strength of competition based solely on the significance of differences in mean isotopic values between two species. Specifically, it is probable that the differences in $\delta^{13}C$ and $\delta^{15}N$ values between bull trout and lake trout are a result of differences in the proportional use of a single prey item (e.g., small kokanee) as opposed to general differences in dietary composition. Future research may need to be conducted to more precisely quantify bull trout food-habits in Odell Lake through direct observation of stomach contents.

Although most studies that have evaluated interactions between bull trout and lake trout have focused on competition as a mechanism for displacement (e.g., Donald and Alger 1993; Guy et al. 2011; Meeuwig et al. 2011*a*; *b*), intraguild predation (Polis et al. 1989) may better represent interactions between bull trout and lake trout. Intraguild predation occurs when competing species also interact as predator and prey (either symmetrically or asymmetrically). Intraguild predation can provide direct energetic gains for the predator while simultaneously decreasing the magnitude of exploitation competition (Polis et al. 1989). Additionally, some theoretical predictions associated with intraguild predation allow for the coexistence of species that would not coexist under a competitive exclusion scenario. There is strong support suggesting that bull trout and lake trout compete in other systems (Donald and Alger 1993; Guy et al. 2011) and competition between these species should not be ruled out in Odell Lake. Additionally, both bull trout and lake trout are apex predators, and highly piscivorous, in Odell Lake and other systems (Guy et al. 2011; Meeuwig et al. 2011*a*); consequently, it is likely that they would prey on each other if given the opportunity. We hypothesized that lake trout may prey on bull trout and other salmonids during putative periods of outmigration from rearing areas in Trapper Creek. However, we did not observe lake trout congregating near Trapper Creek during extensive surveys in 2013. Additionally, we did not observe bull trout in the stomach contents of lake trout sampled from Odell Lake. This is not surprising given the presumed low abundance of bull trout in Odell Lake, the apparent high abundance of other prey fishes available to lake trout (e.g., kokanee, mountain whitefish, etc.), and the assumption that predation rate is often negatively related to prey abundance (Gotelli 1995*b*). In fact, dietary studies of bull trout and lake trout in sympatry generally fail to show bull trout as a prey item for lake trout (Donald and Alger 1993; Guy et al. 2011); however, bull trout have been documented in the diet of lake trout in Lake Pend Oreille, Idaho (Vidergar 2000), and in Flathead Lake, Montana (Beauchamp et al. 2006). Therefore, although we did not detect predation on bull trout by lake trout, we suggest that intraguild predation be considered as a potential mechanism to explain the current patterns of relative abundance and coexistence for these species in Odell Lake.

If competition or intraguild predation between bull trout and lake trout is occurring, it is likely that fishery management intervention will be necessary to realize an increase in the abundance of bull trout. Activities that increase the carrying capacity of bull trout or decrease the influence of lake trout on bull trout may result in an increase in abundance of bull trout. Without accurately knowing the nature of the interaction between these species it is difficult to identify any one management action that may benefit bull trout; however, various potential scenarios are worth considering.

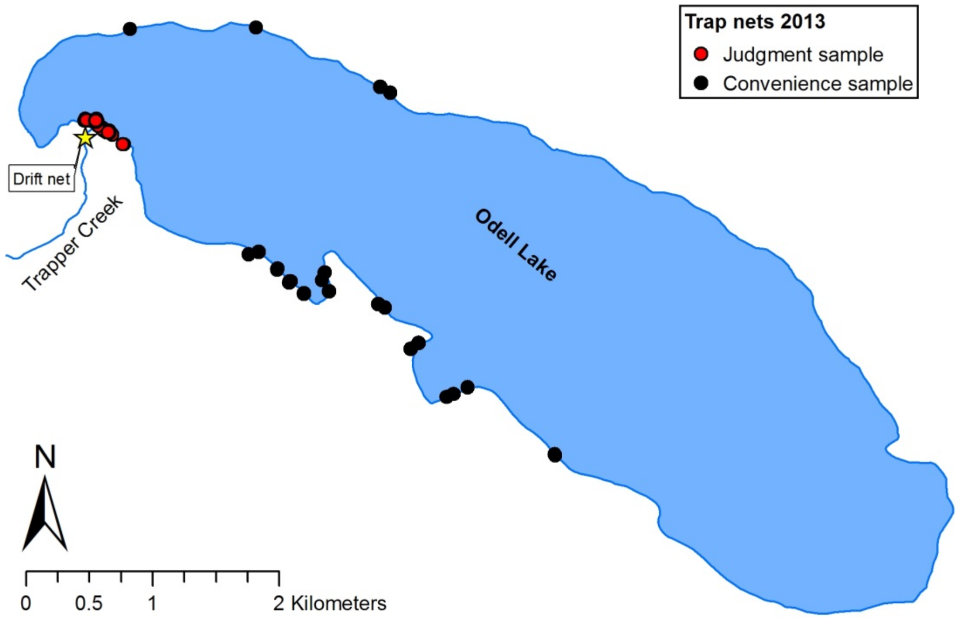
If competition is occurring for food resources between piscivorous bull trout and lake trout, as is suggested by many studies (Donald and Alger 1993; Fredenberg 2002; Guy et al. 2011), then activities that increase the abundance of prey types available to bull trout or activities that reduce lake trout abundance may positively benefit bull trout. It is unlikely that increasing the abundance of prey available to bull trout would differentially benefit bull trout because lake trout in Odell Lake and other systems exhibit generalist food-habits, and would therefore also benefit from activities that increase prey abundance. Mechanical removal of lake trout (e.g., increased harvest or active suppression programs) may decrease the influence of lake trout on bull trout and putatively benefit bull trout; however, removal efforts must be substantial to have a population-level effect on lake trout (Hansen et al. 2008; Syslo et al. 2011; Cox et al. 2013).

If intraguild predation is occurring then activities that reduce the predatory impact of lake trout on bull trout may result in an increase in abundance of bull trout. Spatial segregation of piscivorous lake trout and juvenile bull trout may reduce predator-prey interactions. Lacustrine-adfluvial bull trout are often cited to emigrate from natal streams to lake environments primarily at age-2, and also at age-1, age-3, and older (see Pratt 1992). However, other studies and anecdotal information suggest that large numbers of age-0 bull trout may emigrate from natal streams to lake environments (Downs et al. 2006), very few lacustrine-adfluvial bull trout may remain in stream environments past age-1 (Tennant et al. 2015), and that age-0, age-1, and age-2 bull trout may rear in lake environments (Meeuwig and Guy 2007); in fact, we sampled a 119 mm (likely age-1 or age-2) bull trout from Odell Lake during our trap net sampling. Activities that increase the availability of high-quality stream-rearing habitat may increase the stream residency of bull trout in the Odell Lake Core Area, and may promote the expression of a resident or fluvial life-history. Currently bull trout in the Odell Lake Core Area are believed to primarily occupy the lower 1.3 km of Trapper Creek during their stream residency. This short section of stream remains relatively cold even during the hottest portions of the year (see Chapter 1 - Figure 1.2, this document) and is likely not very productive. However, we detected bull trout (< 220 mm) in other portions of the Odell Lake Core Area (see Chapter 1, this document); including Crystal Creek, Charhaven Creek, and Odell Creek. Management activities that promote the use of these streams by bull trout may decrease the spatial overlap between bull trout and piscivorous lake trout and thereby reduce predatory impacts on at least some portion of the bull trout population. Additionally, mechanical removal of lake trout may also reduce the predatory impact of lake trout on bull trout, but certain caveats apply (see above).

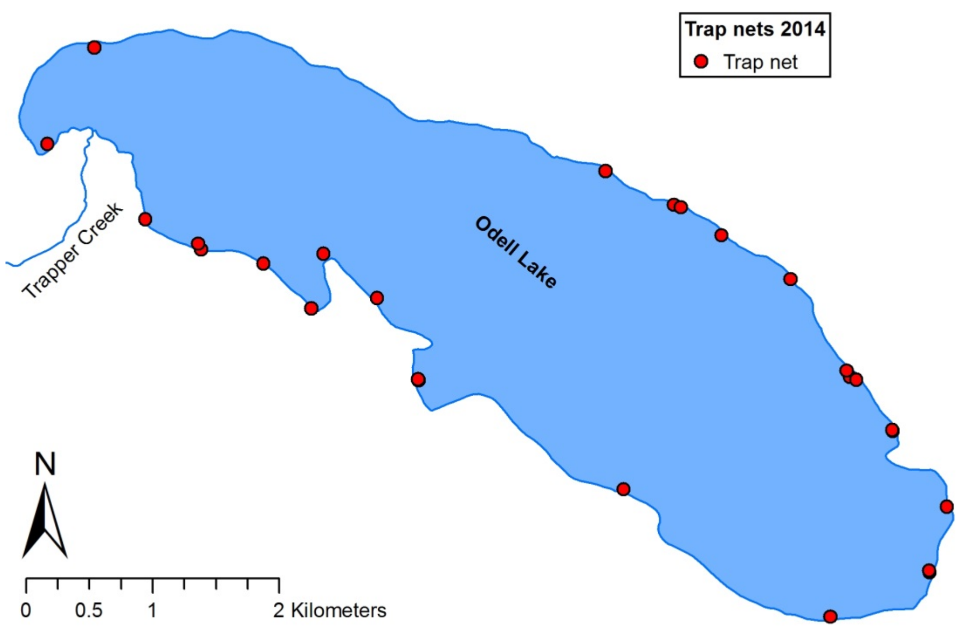
Although our focus was on interactions between bull trout and lake trout, other findings of this study should be of interest to resource managers. Tui chub were extremely abundant in the near-shore littoral zone of Odell Lake as evidenced by our trap net catch data, and tui chub have been cited as being abundant in Odell Lake in the past (OSGC 1946). Tui chub sampled from East Lake, Oregon, exhibited elevated thiaminase activity (S. Clements, *unpublished data*), and stable isotope data suggest that tui chub may be an important dietary source for bull trout in Odell Lake. Studies have shown that fish fed diets high in thiaminase produce eggs with low thiamine levels; furthermore, the incidence of early mortality syndrome is negatively related to thiamine levels (Honeyfield et al. 2005). As such, evaluating thiaminase activity in tui chub from Odell Lake is warranted, and, if thiaminase levels are found to be high, a more thorough evaluation of the predator-prey relationship between bull trout and tui chub, or egg thiaminase levels in bull trout eggs, or both may be necessary.

Mountain whitefish have been cited as being abundant, but stunted in length in Odell Lake (OSGC 1947). Mountain whitefish were very abundant in Odell Lake during our study as evidenced by trap net and benthic gill net (shallow and deep) catch data. However, our sampling did not suggest that mountain whitefish in Odell Lake are stunted. We observed mountain whitefish up to 480 mm in our sample; Scott and Crossman (1973) suggest that the average length of mountain whitefish is 203-305 mm. Additionally, mountain whitefish appear to be an important component in the Odell Lake food web. The estimated standard deviation of $\delta^{13}C$ for mountain whitefish was relatively small, partially due to the large sample size available for this species (N = 114). However, $\delta^{13}C$ values for mountain whitefish varied from -25.24 to -6.91‰; a range that essentially spans the entire extent of $\delta^{13}C$ values observed among all other species examined (Figure 2.6), and $\delta^{13}C$ values for mountain whitefish were significantly related to individual length. Therefore, mountain whitefish likely exhibited a directed shift in dietary resources associated with individual length that likely spans the entire width of the food web. Additionally, mountain whitefish were shown to be an important part of the diet of lake trout and a probable dietary source for bull trout in Odell Lake.

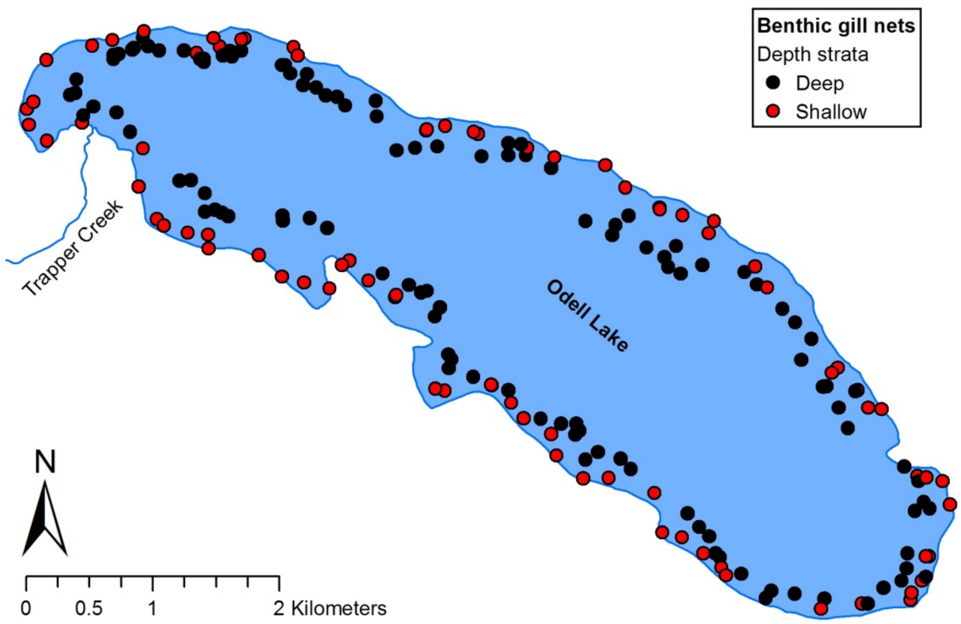
We have shown that both lake trout and bull trout occupy a high trophic position in the Odell Lake food web, but we did not observe direct predation on bull trout by lake trout or complete trophic overlap between bull trout and lake trout. Therefore, theoretical models of competition and intraguild predation would not predict extirpation of bull trout from Odell Lake as a result of interactions with lake trout. However, patterns of relative abundance, habitat use, and probable dietary overlap are indicative of coexistence at reduced abundance. Future studies may need to evaluate food-habits of bull trout in Odell Lake to more fully develop an understanding of competitive interactions between bull trout and lake trout because the resolution of stable isotope analyses may not be sufficient to base difficult management decisions on. Unfortunately, the apparent low abundance of bull trout in Odell Lake may preclude meaningful results from food-habits analysis of bull trout. Regardless, reduced abundance of bull trout may indirectly lead to an increased probability of extirpation as a result of stochastic environmental, demographic, and genetic processes. Finally, reducing the putative influences of lake trout on bull trout may require actions that reduce the abundance of lake trout, increase the carrying capacity for bull trout, promote the expression of fluvial or resident life histories, or some combination of these.



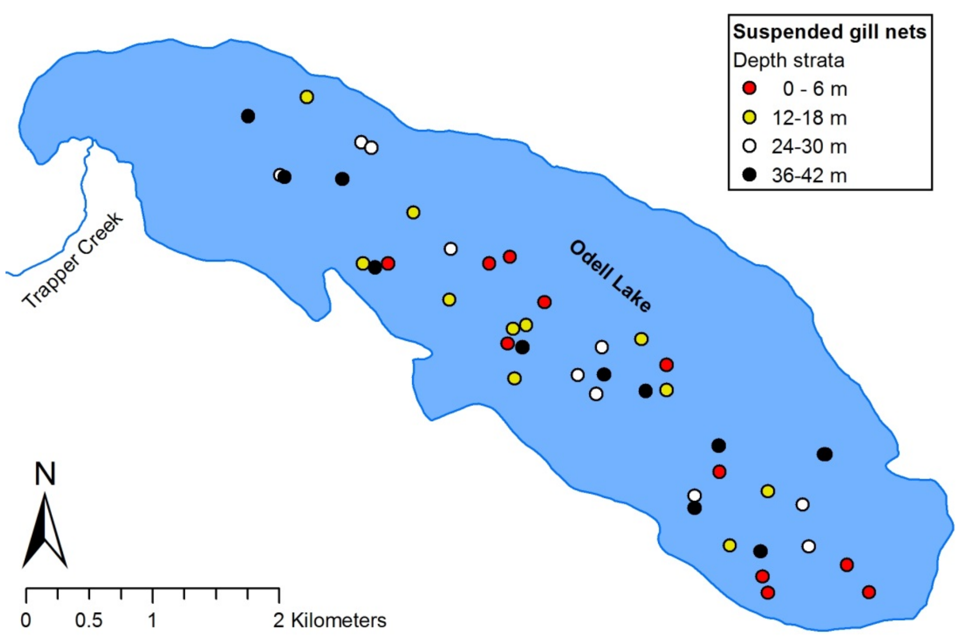
SUPPLEMENTAL FIGURE 2.1—Spatial distribution of trap nets set following a judgment sample design and a convenience sample design during the spring and summer of 2013 in Odell Lake, Oregon



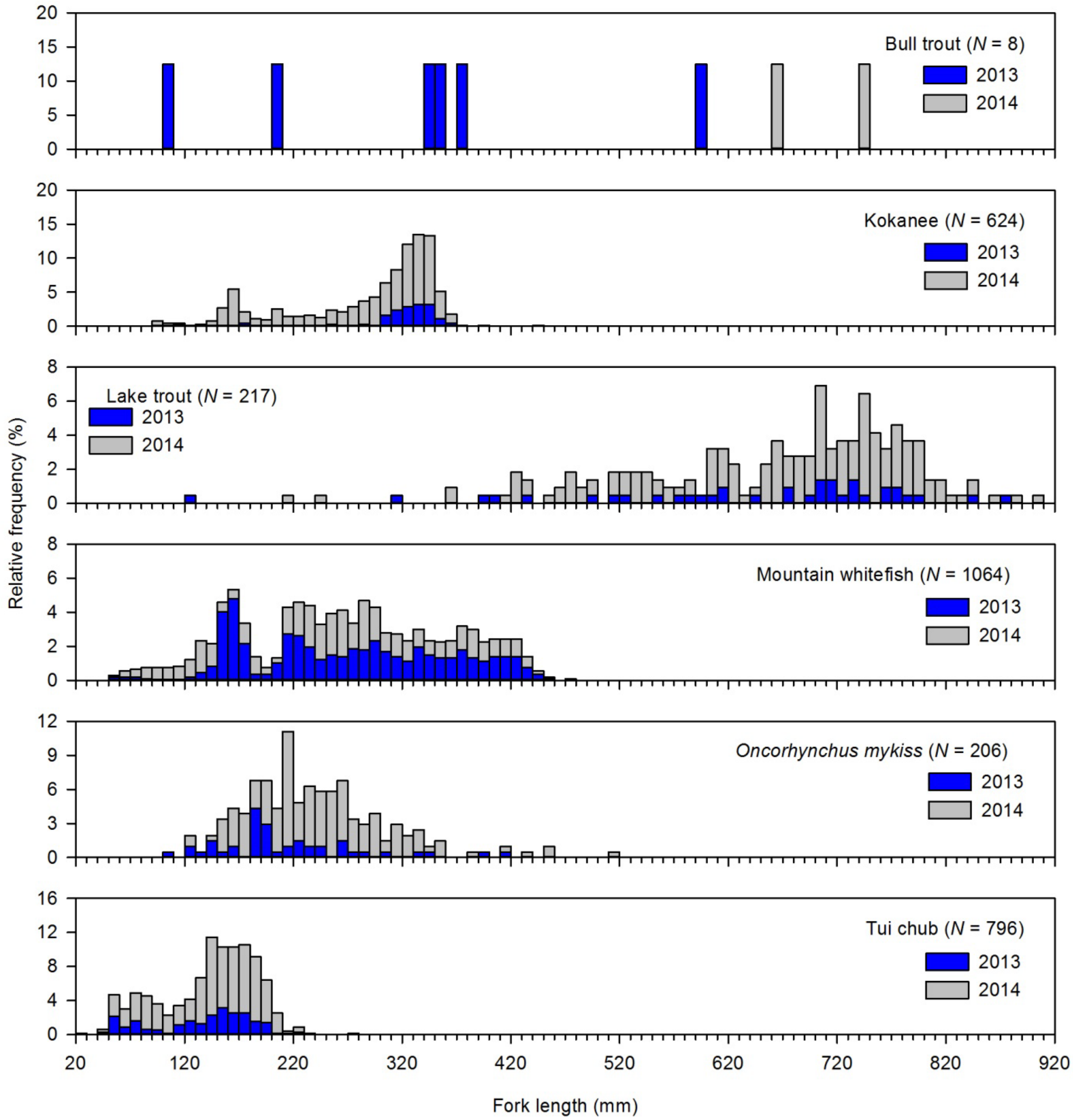
SUPPLEMENTAL FIGURE 2.2—Spatial distribution of trap nets set following a systematic sample design and a generalized random-tessellation stratified sample design (combined) during 2014 in Odell Lake, Oregon



SUPPLEMENTAL FIGURE 2.3—Spatial distribution of benthic gill nets set at two depth strata following a systematic sample design during the autumn of 2013 and the spring, summer, and autumn of 2014 in Odell Lake, Oregon.



SUPPLEMENTAL FIGURE 2.4—Spatial distribution of suspended gill nets set following a generalized random-tessellation stratified sample design at four depth strata during 2014 in Odell Lake, Oregon.



SUPPLEMENTAL FIGURE 2.5—Length-frequency histograms for fishes sampled during 2013 and 2014 using trap nets, benthic gill nets, and suspended gill nets in Odell Lake, Oregon.

Chapter 3: Potential Effect of the Recreational Fishery on Bull Trout in Odell Lake

Abstract.—Creel surveys were conducted on Odell Lake from the week of 24 June 2013 through the week of 30 September 2013 to determine if bull trout (*Salvelinus confluentus*) were part of the recreational fishery. One bull trout was reported during creel surveys on 13 July. This bull trout was caught at a depth of about 19 m near the middle of the lake by an angler targeting kokanee. We estimated that about eight bull trout were caught during the entire creel survey season. Although this number is small relative to the catch of other fishes in the recreational fishery, it may represent a large portion of the bull trout population in Odell Lake. Therefore, we suggest that further creel surveys are warranted; however, use of voluntary on-site creel survey cards or some other alternative survey method may be more cost effective than the methods we employed. Additionally, research aimed at identifying spatio-temporal lacustrine habitat use by adfluvial bull trout may indicate when or where they are susceptible to incidental catch by anglers targeting other species.

Odell Lake has an important recreational fishery. The estimated number of angler·hours during the summer months for bank anglers was 2,602 in 1999 and 1,142 in 2004 and for boat anglers was 118,438 in 1996, 64,831 in 1999 and 62,245 in 2004 (Oregon Department of Fish and Wildlife, unpublished data). The recreational fishery primarily includes kokanee (*Oncorhynchus nerka*), lake trout (*Salvelinus namaycush*), mountain whitefish (*Prosopium williamsoni*), and *O. mykiss* sspp. (e.g., redband trout, rainbow trout). However, bull trout (*S. confluentus*) catch was reported in creel surveys in 1996, 1998, 1999, and 2004 (USFWS 2002; Oregon Department of Fish and Wildlife, *unpublished data*). Current regulations prohibit the take of bull trout; however, the influence of incidental catch (and any associated mortality) on bull trout in this recreational fishery is unknown.

Creel surveys are useful for identifying the characteristics of a fishery, including time of catch, total catch, species, and size class. Creel surveys can provide information on the use and efficiency of different gear types for different species and life stages of fish, and can provide insight into the behavior of anglers. These data are valuable for developing fishing regulations that minimize the impact of recreational angling on sensitive species. We conducted a creel survey on Odell Lake during 2013 to determine if bull trout were present in the recreational fishery.

Methods

Access point creel surveys were conducted every other week beginning the week of 24 June 2013 and ending the week of 30 September 2013 (creel survey season). Each two-week period was treated as an individual stratum and creel surveys were conducted on two randomly selected weekdays and both weekend days within the same week for each stratum. Creel surveys were conducted during one of two randomly selected survey periods on each survey day; survey periods were either the morning or afternoon half of the fishing day where the fishing day was defined as the period of time from 1-h before sunrise to 1-h after sunset. Creel surveys were conducted by two independent creel clerks on each survey day with the exception that only one creel clerk conducted surveys during the week of 30 September 2013. Each creel clerk was randomly assigned to one of six possible access points (Odell Lake Lodge & Resort, Princess Creek boat launch, the boat launch at Shelter Cove Resort & Marina, the marina at Shelter Cove Resort & Marina, Sunset Cove boat launch, Trapper Creek boat launch) for each survey period.

Creel clerks surveyed fishing parties as they returned from fishing excursions; only fishing parties using boats were surveyed. The following data were recorded during each survey:

1) Number of anglers in the fishing party
2) Target species
3) Hours fished
4) Number and species caught and kept
5) Number and species caught and released

If a member of a fishing party indicated that they caught a bull trout the following data were recorded:

1) Bull trout length
3) Fishing depth
4) Hooking location on the body
6) If the bull trout was held out of water
7) Condition of the bull trout upon release

Angler counts were conducted at three systematically spaced times per survey period. Each angler count was conducted by one of the creel clerks who drove to two different vantage points (Chinquapin Point, Princess Creek boat launch) where they could count the number of boats that were currently on the lake.

Total daily angling effort $\hat{e}$ for each day that was sampled was estimated as:

$$\hat{e} = T\bar{I},$$

where *T* is the total number of hours in the fishing day, and $\bar{I}$, is the mean of the angler counts (Pollock et al. 1994). Mean daily harvest and release rate of each species was estimated using the ratio-of-means estimator (Jones et al. 1995; Hoenig et al. 1997; McCormick et al. 2012):

$$\hat{r} = \frac{\sum_{i=1}^{n} f_i}{\sum_{i=1}^{n} h_i},$$

where f_i is the number of fish harvested or released by the *i*th party and h_i is the number of hours fished by the *i*th party. Daily harvest and release $\hat{c}$ of each species was estimated as (Pollock et al. 1994; Bernard et al. 1998);

$$\hat{c} = \hat{e} \times \hat{r}.$$

Within strata harvest and release $\hat{C}_j$ of each species was estimated as;

$$\hat{C}_j = \sum_{j=1}^{L} \bar{c}_j N_j,$$

where *j* represents the strata, $\bar{c}_j$ is the average daily catch estimate in the *j*th strata, and N_j is the number of days in the *j*th strata and *L* is the total number of strata. Total season harvest and release of each species was estimated as the sum of all strata estimates.

Ninety-five percent non-parametric confidence intervals were estimated for each species using the percentile method (Efron and Tibshirani 1993). Because there was no replication of secondary sampling units (i.e., shifts within days), confidence intervals were based on the catch variance among days, which provided a conservative estimate of variance (Bernard et al. 1998; Su and Clapp 2013).

Results

Greater than 90% of the fishing parties indicated that they were targeting kokanee and other species were each targeted by ≤ 3% of the fishing parties surveyed (Figure 3.1); bull trout were not targeted by any of the fishing parties surveyed. One bull trout was reported caught during our creel surveys on 13 July near the middle of the lake at a depth of about 19 m. The bull trout was about 250 mm, was hooked in the lip, was not held out of water, and it swam off alive.

We estimated that no bull trout were harvested and that eight were released (Figure 3.2). We estimated that over 47,000 kokanee were harvested from the end of June to the beginning of October and about 2,500 kokanee were released. More lake trout were released (166) than were harvested (39) and about 100-200 mountain whitefish and *O. mykiss* were released and were harvested during the creel survey season.

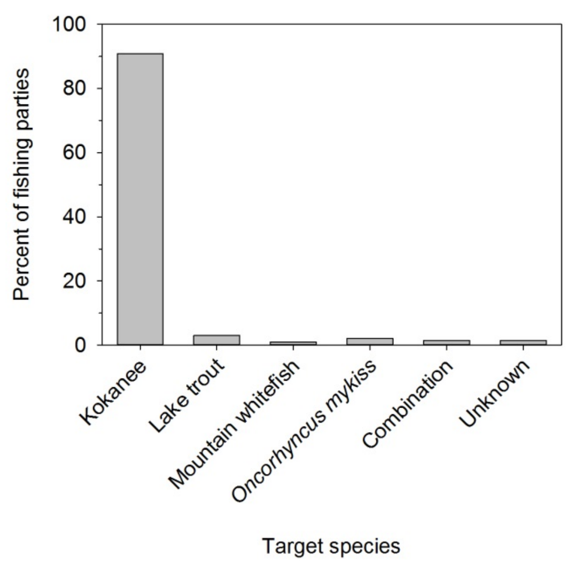


FIGURE 3.1—Percent of fishing parties on Odell Lake, Oregon, that reported targeting kokanee, lake trout, mountain whitefish, *Oncorhynchus mykiss*, a combination of fishes, or did not have a specific target species (unknown); no fishing parties reported targeting bull trout.

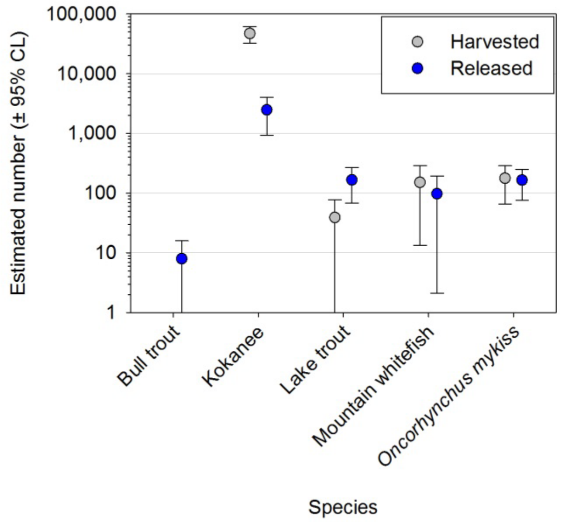


FIGURE 3.2—Estimated number of bull trout, kokanee, lake trout, mountain whitefish, and *Oncorhynchus mykiss* harvested and released during the creel survey period of 24 June through 6 October 2013 on Odell Lake, Oregon.

Discussion

We estimated that eight bull trout were captured and released and that no bull trout were harvested from 24 June 2013 through 6 October 2013. Although this number is small relative to the catch (i.e., released + harvested) of other fishes it may represent a large number relative to the total adult population of bull trout in Odell Lake. The total number of adult bull trout in Odell Lake is unknown, but estimates vary from 20-50 individuals (ODFW 2005*b*) to 43–51 individuals (see Chapter 1). Consequently, our estimated bull trout catch may represent from about 14-19% of the spawning population.

Our bull trout catch estimate is conservative as we did not survey the entire fishing season. The creel survey season began on 24 June 2013; however, the fishing season began two months earlier on 27 April 2013. Previous creel surveys on Odell Lake began about the last week of April and lasted through July (1996-1999) or began in June and lasted through about the first week in September (2004). Bull trout catch was reported by anglers in May, June, and July of 1996 (N = 316; estimated bull trout catch) and 1998 (N = 43), April, May, June, and July of 1999 (N = 281), and in July and August of 2004 (N = 33); no bull trout catch was reported by anglers in 1997. Consequently, it is likely that we would have surveyed more anglers that caught bull trout if we had surveyed a greater portion of the fishing season, which lasted from 27 April through 31 October in 2013.

Relatively few fishing parties indicated that they were targeting lake trout and no fishing parties were targeting bull trout, whereas > 90% of the fishing parties indicated that they were targeting kokanee. The low percentage of fishing parties targeting species other than kokanee was likely influenced by the time period over which creel surveys were conducted (see above), and it is likely that a greater percentage of fishing parties would have been targeting lake trout earlier in the fishing season. Additionally, it is plausible that incidental catch of bull trout may be greater in a lake trout driven fishery than in a kokanee driven fishery because bull trout and lake trout share some common phenotypic and trophic characteristics (Donald and Alger 1993). However, kokanee are an important prey species for lake trout in Odell Lake (Chapter 2, this document) and both bull trout and lake trout prey extensively on kokanee in other lakes (Vidergar 2000; Clarke et al. 2005; Guy et al. 2011). Therefore, bull trout and lake trout likely exhibit spatial overlap with kokanee in Odell Lake and thus may be subject to incidental catch in the kokanee fishery. For example, the single bull trout reported in the recreational creel was caught near the middle of the lake at a depth of about 19 m by an angler targeting kokanee and 53% of the lake trout reported in the recreational creel were caught by anglers targeting kokanee. It is unknown how angler behavior may influence incidental catch of bull trout in Odell Lake. Specifically, there may be times, or locations, or both that bull trout are more likely to be incidentally caught by anglers targeting other species. Data describing lacustrine habitat use by adfluvial bull trout are extremely limited, but see Eckmann (2014). Consequently, research to better understand spatio-temporal habitat use by bull trout in Odell Lake or an appropriate surrogate lacustrine system warrants consideration.

In general, our creel survey indicated that the majority of anglers surveyed were targeting kokanee and that kokanee were the dominant fish in the recreational harvest; other species reported included lake trout, *O. mykiss*, and mountain whitefish. Additionally, one bull trout was reported, which resulted in an estimate of about 8 bull trout caught during the creel survey season. This sample size is too small to provide valid inference regarding aspects of angler behavior that may influence bull trout catch; however, it is large enough to warrant concern given the putative small size of the bull trout population in Odell Lake and the possible effects associated with catch-and-release fisheries. For example, even short term handling of fishes can cause an endocrine response and metabolic disturbances (Mazeaud et al. 1977), and both immediate and delayed mortality commonly occur in catch-and-release fisheries (Muoneke and Childress 1994). Therefore, fishery managers may consider continuing creel surveys in order to better understand potential effects of the recreational fishery on bull trout.

If creel surveys are conducted in the future, the type of creel survey should be dictated by survey objectives, data needs, and logistical concerns. Creel surveys as conducted in 2013 and previously on Odell Lake have the benefits of providing valuable data as well as angler outreach and education. However, these types of surveys require a fairly large investment of time and money. Alternative creel survey designs, such as voluntary on-site angler survey cards, may require fewer resources to implement; however, the quality of data collected using alternative methods must be considered relative to savings in time, or money, or both. Regardless of creel survey methodology, future creel surveys may be enhanced by working with resort and marina owners because, on average, we surveyed 11 fishing parties per survey day when at one of the two resorts located on Odell Lake whereas we surveyed only 6 fishing parties per survey day when at one of the other access points.

Chapter 4: Recovery and Conservation of Bull Trout in the Odell Lake Core Area

Our research showed that bull trout are present at low abundance in the Odell Lake Core Area, and therefore may be at high risk of extinction. Substantial management intervention is likely needed to ensure the long term viability of bull trout in this core area, and research, monitoring, and evaluation should be conducted prior to, or in conjunction with, management activities. Management actions for this core area can be grouped into four major categories: habitat management, nonnative species management, recreational fishery management, and conservation translocation management. Based on our research, we outline some potential actions and the research, monitoring, and evaluation that could accompany or precede these actions.

Habitat Management

Spawning and rearing habitat.

Bull trout spawning and rearing is known to occur in Trapper Creek and video monitoring stations have shown bull trout moving through portions of Odell Creek. Additionally, electrofishing surveys have shown that bull trout occupy Charhaven Creek and Crystal Creek. However, observations associated with surveys on some streams (e.g., Charhaven Creek, Crystal Creek, etc.) suggest a lack of high-quality spawning substrate and rearing habitat. Therefore, we recommend that the extent of spawning and rearing habitat in the Odell Lake Core Area should be quantified, and that areas that may benefit bull trout with habitat enhancement (e.g., substrate augmentation) should be identified. Additionally, knowledge about the extent of spawning and rearing habitat may be used to estimate location-specific and stage-specific carrying capacity of streams in the Odell Lake Core Area.

Action: Quantify the extent of available (and potential) spawning and rearing habitat in the Odell Lake Core Area.

Research, Monitoring, and Evaluation: Comprehensive habitat surveys (e.g., Baxter and McPhail 1999; Baxter and Hauer 2000; Bowerman et al. 2014) can be used to estimate the extent of suitable bull trout spawning and rearing habitat in the Odell Lake Core Area. These surveys should be conducted in a way that also identifies where habitat enhancements may increase available spawning and rearing habitat or bull trout carrying capacity. Results and synthesis of these surveys should be used to inform habitat enhancement and comprehensive monitoring should accompany any habitat enhancements that are enacted.

Habitat connectivity.

Our research revealed that adult, migratory bull trout will move between Odell Lake and Odell Creek and that small bull trout (i.e., < 200 mm) occupy tributaries to Odell Creek and move through portions of Odell Creek. Therefore, any structures that hinder connectivity between Odell Lake and Odell Creek may restrict demographic and genetic connectivity and fragment the Odell Lake Core Area.

Action: Maintain connectivity between Odell Lake and Odell Creek.

Research, Monitoring, and Evaluation: This action requires no research; however, conservation plans and agreements should ensure that any structure located at the outlet of Odell Lake allows fish passage under all foreseeable environmental conditions (e.g., lake levels, seasons, etc.).

Oregon State Game Commission reports suggest that Crystal Creek, a tributary to Odell Lake, was one of the primary bull trout spawning streams (OSGC 1946, 1947, 1950). It is unknown whether bull trout currently use Crystal Creek for spawning; however, we documented bull trout in this stream during electrofishing surveys. Five bull trout were sampled among the lower nine sample sites in Crystal Creek, which corresponds to the portion of the stream that is located downstream from a railroad culvert. No bull trout, or any other fishes, were observed in the upper 10 sample sites in Crystal Creek located upstream from the railroad culvert. Additionally, eDNA samples collected in Crystal Creek corroborate that bull trout are present downstream from the railroad culvert, but not upstream. These data suggest that the railroad culver on Crystal Creek may hinder upstream fish passage. Therefore, we suggest that a formal analysis should be conducted to determine if this culvert has the potential to limit fish passage.

<u>Action</u>: Evaluate whether the railroad culvert on Crystal Creek is a barrier to upstream fish passage.

<u>Research, Monitoring, and Evaluation</u>: Literature synthesis and use of algorithms, such as those employed by FishXing (available: www.stream.fs.fed.us/fishxing/), may provide a rapid method for assessing whether the railroad culvert on Crystal Creek is likely a barrier to fish passage. If this culvert is identified as a likely passage barrier, then the habitat upstream of the culvert should be evaluated based on suitability for bull trout. If upstream habitat is deemed suitable, the culvert should be modified to allow fish passage and the distribution of fishes in Crystal Creek should be quantified at some regular interval following modification of the culvert.

Nonnative Species Management

Brook trout.

Brook trout have a negative influence on the distribution and abundance of bull trout in some systems (Rieman et al. 2006) where they are sympatric, either by competition or hybridization (Gunckel 2002; DeHaan et al. 2010). Brook trout have been documented in Charhaven Creek, Ranger Creek, Trapper Creek, Odell Creek, and Odell Lake; additionally they may be present in other areas in the Odell Lake Core Area. Hybridization between brook trout and bull trout has not been shown to be substantial in the Odell Lake Core area (Ardren et al. 2007 and this study). Despite this, consideration of brook trout control in the Odell Lake Core Area is warranted given: 1) the potential for brook trout to negatively influence bull trout genetic integrity, distribution, and abundance, 2) the known presence of brook trout in Trapper Creek, and 3) our observations of relatively large numbers of brook trout in Ranger Creek and in sympatry with bull trout in Charhaven Creek. Implementation of brook trout control or eradication in all or parts of the core area would require 1) identifying the distribution of brook trout and evaluating the complexity of the habitats occupied by brook trout, 2) evaluating the risk to bull trout, and 3) evaluating the socio-political implications and resource availability for such activities.

<u>Action</u>: Evaluate the distribution of brook trout in the Odell Lake Core Area.

<u>Research, Monitoring, and Evaluation</u>: Past surveys and our research has shown that brook trout occupy Yoran Lake, Trapper Creek, Odell Lake, Odell Creek, Charhaven Creek, and Ranger Creek. Evaluating the efficacy of brook trout control or eradication will require identifying other potentially occupied habitats and quantifying habitat complexity in occupied habitats. Environmental DNA surveys may be a rapid way to assess the distribution of brook trout in the Odell Lake Core Area. Habitat surveys should be conducted in areas occupied by brook trout with the aim of identifying the ease of applying standard control and eradication techniques.

Action: Evaluate the socio-political implications and resource availability for brook trout control or eradication.

Research, Monitoring, and Evaluation: The Odell Lake Core Area supports and important recreational fishery. Much of the fishing effort is focused on Odell Lake and Davis Lake; however, general angling rules apply to Yoran Lake and catch-and-release angling is allowed in Odell Creek (ODFW 2016). Therefore, prior to any brook trout control or eradication activities, consideration should be given to the socio-political implications of such activities. Additionally, control or eradication of fish is often not 100% effective. In the Odell Lake Core Area, brook trout occupy Odell Lake (albeit, likely in low numbers) and certain habitats where control or eradication activities may be difficult to perform. If less than 100% effective, or if only certain habitats are targeted for control or eradication, then sources for recolonization of treated areas will persist. Therefore, prior to initiation of control or eradication efforts, the long-term maintenance of such activities should be considered.

Action: Brook trout control or eradication.

Research, Monitoring, and Evaluation: If brook trout control or eradication is deemed feasible and has acceptable socio-political implications then appropriate techniques should be used to remove brook trout and to avoid negative impacts to bull trout. Any control or eradication activities should be followed with sufficient monitoring to evaluate the adequacy of removal efforts.

Tui chub.

Our research has shown that tui chub are in Odell Lake in relatively high abundance. As such, they may be an important contribution to the diet of bull trout. Tui chub in nearby East Lake, Oregon, have been shown to have high levels of thiaminase. Thiaminase can be transferred to offspring from parents that consume fishes high in thiaminase, and thiaminase has been linked to early mortality in lake trout and other fishes (Honeyfield et al. 2005). Therefore, tui chub from Odell Lake should be evaluated for thiaminase activity. If they show high levels of thiaminase activity then adult bull trout and their offspring should be evaluated for thiaminase activity.

Action: *Evaluate tui chub thiaminase activity*.

Research, Monitoring, and Evaluation: Tui chub should be sampled from Odell Lake and analyzed for thiaminase activity. If thiaminase activity is high in tui chub in Odell Lake then research should be conducted to determine 1) if adult bull trout and their offspring have high levels of thiaminase and 2) the effect of thiaminase on survival of young bull trout. If a link between tui chub thiaminase activity and bull trout abundance is identified, then eradication or suppression of tui chub in Odell Lake will need to be considered.

Lake trout.

Our study showed that patterns of abundance, spatial distribution, and probable dietary contributions between bull trout and lake trout are consistent with competition or intraguild predation. As such, actions to increase the carrying capacity of bull trout in the Odell Lake Core Area (see above; Habitat Management) may increase the abundance of bull trout. Alternatively, actions that decrease the abundance of lake trout may also increase the abundance of bull trout in the Odell Lake Core Area. However, decreasing the abundance of lake trout can be a costly and long-term commitment (Hansen et al. 2008; Syslo et al. 2011; Rosenthal et al. 2012; Cox et al. 2013). Therefore, if lake trout suppression efforts are considered, we recommend that they be preceded by a comprehensive demographic assessment of lake trout in Odell Lake. This assessment will allow researchers and managers to identify expected population level outcomes from various lake trout suppression strategies.

Action: Quantify demographic characteristics of the lake trout population in Odell Lake.

Research, Monitoring, and Evaluation: Sampling should be conducted to estimate the abundance, birth rate, death rate, and other demographic characteristics of the lake trout population in Odell Lake. These data can be used to predict the population growth rate of lake trout under various harvest scenarios (e.g., Syslo et al. 2011; Cox et al. 2013), and a formal understanding of the effort necessary to reduce the lake trout population to some desired level will allow natural resource managers to make informed decisions on if and how to proceed with suppression.

Recreational Fishery Management

Creel survey.

Our study showed that bull trout are part of the recreational fishery and previous creel surveys have indicated that potentially large numbers of bull trout may be handled in a given year; although, the number of bull trout reported among creel survey years is variable. Given the apparent high angler use of Odell Lake and the potential for delayed effects associated with capture and handling of bull trout, we recommend that some form of angler survey (i.e., creel survey) be conducted at Odell Lake. The methods we employed in our study and the methods used during previous creel surveys are relatively costly, but provide valuable data and also provide the opportunity for angler outreach and education. Alternative creel survey methods that require fewer resources may also be considered, but the applicability of the data generated from alternative survey methodologies should be considered relative to savings in time, or money, or both.

Action: Develop and implement a creel survey program that provides reliable data regarding the inclusion of bull trout in the recreational fishery in the Odell Lake Core Area.

Research, Monitoring, and Evaluation: If creel surveys are implemented, they should be developed in a way that allows efficient estimation of the number of bull trout handled by recreational anglers during a fishing season. Creel surveys may be made more efficient by working in conjunction with resort owners and operators who have daily contact with the angling public. Additionally, creek surveys may provide real-time assessment of current recreational fishing regulations.

Conservation Translocation Management

Translocation.

Conservation translocations are increasingly being used to conserve populations of species of concern (e.g., threatened or endangered species). Conservation translocations generally fall under two categories (IUCN 2013): 1) reinforcements and reintroductions within a species native range and 2) conservation introductions. Conservation introduction relates to establishment of a species outside of its recorded range, and therefore does not apply to bull trout in the Odell Lake Core Area. Reintroduction does not currently apply to bull trout in the Odell Lake Core Area because bull trout are currently extant; although, at low abundance. Reinforcement, the addition of individuals to an existing population, is often used to correct skewed demographic characteristics or improve genetic characteristics of populations. Reinforcement may benefit depressed populations, but can also pose risks to local populations. Therefore, this type of activity requires critical forethought as to whether it is an acceptable strategy, and if so, how reinforcement should proceed. We recommend that conditions under which reinforcement is deemed acceptable should be identified. Additionally, strategies for conducting reinforcements should be explored.

Action: Identify conditions under which reinforcement of the existing bull trout population in the Odell Lake Core Area is deemed acceptable and explore strategies for conducting reinforcements.

Research, Monitoring, and Evaluation: All appropriate stakeholders should be involved in a transparent and structured decision-making process with the aim of identifying when and if bull trout population reinforcement should be conducted in the Odell Lake Core Area. If conditions exist under which reinforcement is deemed acceptable, then appropriate strategies should be explored for conducting reinforcements. Existing guidelines (e.g., IUCN 2013) may provide a template for this process.

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