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Effects of anesthetics on rainbow trout swimming ability and statisical comparison of the movements of acoustically tracked reband rainbow trout in Lake Roosevelt

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EFFECTS OF ANESTHETICS ON RAINBOW TROUT SWIMMING ABILITY AND STATISICAL COMPARISON OF THE MOVEMENTS OF ACOUSTICALLY TRACKED REBAND RAINBOW TROUT IN LAKE ROOSEVELT

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MASTER'S THESIS

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EXECUTIVE SUMMARY

The aims of this study were to:

(1) Determine which anesthetic, MS-222, AQUI-S 20E, CO_2, or Low Voltage Electro-Anesthesia (LVEA) is the most appropriate for anesthetizing fish for implanting acoustic or radio-transmitters based on five criteria:

a. induction (takedown) time;

b. recovery time;

c. critical swimming speed;

d. swimming behavior; and

e. mortality rate;

(2) Acoustically track Redband Trout, tagged in different spawning tributaries of Lake Roosevelt, to determine:

a. the utilization distribution , and compare these distributions spatially and temporally, for each tributary population;

b. if Redband Trout return to spawn in the tributary where they were originally tagged (homing); and

c. if entrainment events (i.e., passing over or through Grand Coulee Dam) of acoustically tagged fish was influenced by their age/size, proximity of tagging tributary to the dam, and dam operations.

Chapter 1 of this thesis describes the work that addressed the first aim. Both chemical and physical anesthetics induce a loss of feeling through the depression of the central and peripheral nervous system (Iwama and Ackerman 1994) and are commonly used by fisheries managers to immobilize and reduce stress on fish. Fisheries managers find it is important that these anesthetics are inexpensive, available, easy and safe to

use, and have a minimal impact on the fish (Marking & Meyer 1985; Ackerman et al. 2005).To test which anesthetic was most appropriate to use for implanting acoustic or radio-transmitters - 150 Coastal Rainbow Trout (*Oncorhynchus mykiss* var. *irideus*) were randomly divided into five treatments (30 per treatment): (1) AQUI-S anesthetic, (2) MS-222 anesthetic, (3) CO_2 anesthetic, (4) LVEA anesthetic, and (5) control(no anesthetic). Each fish was brought to stage IV anesthesia (complete loss of muscle tone, equilibrium, spinal reflexes, and regular opercular movements) confirmed by gently lifting the fish to check for responsiveness (Summerfelt and Smith 1990). Once the fish reached stage IV anesthesia, a small passive integrated transponder (PIT) tag was injected into the pelvic girdle of the fish for unique identification.

To determine the effect of the anesthetics, critical swimming speed (U_{crit}) was tested to assess the success of an individual fish to maintain and establish swimming speed. Each fish was allowed to recover in the swim tunnel so that once the fish recovered, the fish could be immediately swim tested to mimic a field release. Fish were tested in a Blazka type respirometer on loan from Battelle Pacific Northwest National Laboratory in Richland, WA. The fish were forced to swim as the water velocity was increased at a constant progression (0.071 m/s) with a constant time interval of 10 minute (Anderson et al. 1997). The test continued at increasing velocities until the fish failed to maintain swimming speed and was pushed against the posterior grid of the swimming tunnel. At this point the fish was considered exhausted and this was referred to as critical swimming speed (U_{crit}).

During the test, a behavior was observed where the fish was pushed against the rear grid of the tunnel, but was still able to continue swimming. This behavior was referred to as a "tire" and was counted during the swim test. For the mortality study there was a sixth group (procedural control), where the fish were held for 30 days under the same conditions and monitored for mortalities.

Rainbow Trout anesthetized by CO_2 had the longest average takedown and recovery time followed by AQUI-S, MS-222, and LVEA. Anesthesia with LVEA was nearly instantaneous and LVEA had the fastest takedown and recovery time compared to the other anesthetics ($F_4 = 10.35$; $p < 0.001$). During this study only 36 out of 149 fish reached critical swimming speed and the proportion of fish that reach the critical swimming speed in each anesthetic was not significantly different from each other ($F_4 = 0.054$, $p = 0.0637$). Of the group of fish that reached critical swimming speed, we performed an analysis of variance (ANOVA) to determine if there was a difference the critical swimming speed ($F_4 = 5.885$, $p = 0.002$). The test yielded significant variation among treatments, $F_4 = 5.885$, $p = 0.002$. A post hock Tukey's HSD test indicated that fish anesthetized with LVEA had significantly higher critical swimming speeds than fish anesthetized with MS-222 ($F_4 = 5.285$, $p = 0.007$) and CO_2 ($F_5 = 4.353$, $p =0.035$). An ANOVA performed on the tires yielded significant variation among treatments, $F_4 = 5.669$, $p = 0.00029$. The post hoc Tukey's HSD test showed that LVEA and Control fish had fewer tires then MS-222 and AQUI-S 20E treated fish ($p < 0.05$). The number of tires observed from fish treated with CO_2 was not significantly different from any of the other anesthetics ($p > 0.05$). A linear regression was used to look at the effect of tires over time and indicated there was an effect of time on the number of tires observed for AQUI-S 20E ($F_{225} = 4.747$; $p < 0.001$; adj R^2 =

0.0609), MS-222 ((F_{206} = 5.678; $p < 0.001$; adj $R^2 = 0.0786$), and CO_2 (F_{215} = 4.866; $p < 0.001$, adj $R^2 = 0.0824$). The number of tires observed over time did not change for the control (F_{246} = 3.054; $p = 0.43$; adj $R^2 = -0.0015$) and LVEA (F_{233} = 2.406; $p = 0.08$; adj $R^2 = 0.0085$). The control and LVEA treated fish had the most similar number of tires observed over time (~2 tires/ten minutes). There was no difference in mortality rates of the fish treated with different anesthetics and either of the controls (F_5 = 0.75; $p = 0.994$).

This study demonstrated that LVEA is an appropriate field anesthetic based on induction/recovery times, swimming behavior, and survival for Rainbow Trout. Further benefits of this technique include: low initial and sustained costs, ease of use, ability to be fine-tuned, and human safety (Hudson et al. 2011). The study in Chapter 1 revealed that LVEA was the most appropriate anesthetic. However, for the second study (Chapter 2), we used AQUI-S20E because the Redband tracking work was part of a three year study which began the year before we determined which anesthetic was most appropriate. We had used AQUI-S-20E in the first year of the study and so we continued to use it in this (the second year of the study) to remain consistent and not add an additional variable to our study.

Chapter 2 of this thesis describes the work that addresses the second aim. Since April of 2013, acoustic telemetry was used to identify long-term horizontal movements of Columbia River Redband Trout (*Oncorhynchus mykiss* var. *gairdneri*) within Lake Roosevelt, the reservoir formed by Grand Coulee Dam. The objectives of this study were to determine: (1) if Redband Trout occupy unique distributions based on their capture stream; (2) if Redband Trout home back to their tagging tributary; and (3) if entrainment rate of Redband Trout is affected by size class, proximity to dam, or reservoir operations.

In 2013, Redband Trout were collected in tributaries of Lake Roosevelt (Columbia River RKM 953.6 – 1,192.0), implanted with acoustic transmitters, and released at the site of capture in: (1) the Sanpoil River (enters Lake Roosevelt at Columbia River RKM 984.0) where the fish (*n* = 15) were collected about 12 – 13 km upstream from this point at the head of the Sanpoil River Arm of Lake Roosevelt; (2 – 3) the Spokane River (enters Lake Roosevelt at Columbia River RKM 1,022.2) where the fish were collected in Blue Creek at Spokane River RKM 19.2 (*n* = 13) and Spring Creek at Spokane River RKM 44.4 (*n* = 4), tributaries of the 45.2 km long Spokane River Arm of Lake Roosevelt; (4) Alder Creek at Columbia River RKM 1,058.8 (*n* = 5); and (5) Big Sheep Creek at Columbia River RKM 1,186.1 (*n* = 14).

In 2014, fish were implanted with acoustic transmitters and released at: (1) the head of Sanpoil River Arm (*n* = 15); (2 – 3) The Spokane River in Blue (*n* = 6) and Spring (*n* = 5) creeks; (4)Wilmont Creek at Columbia River RKM 1,055.0 (*n* = 5); (5) Alder Creek (*n* = 11); (6) Onion Creek at Columbia River RKM 1,180.0 (*n* = 9); and (7) Big Sheep Creek (*n* = 9).

Fish were collected via stationary weir traps, boat electrofishing, backpack electrofishing, dip netting, and angling. Fifty fish were tagged (17 females, 10 males, and 23 unknown sex; average total length (TL) (± SD): 408 (± 148) mm from April to May in 2013, and 60 fish (21 females, 26 males, and 13 unknown sex; average TL: 457 (± 56) mm from March to May in 2014.

Tissue samples for genetics and scales for aging were collected and a PIT tag and acoustic transmitter were implanted into the coelomic cavity of the fish. All fish were anesthetized with AQUI-S 20E in 2013 and 2014 except fish tagged by the Colville Confederated Tribes (CCT) in the Sanpoil River in 2014. These fish were anesthetized using low voltage electroanesthesia (LVEA).

Fish were returned to the stream they were originally captured from and, following their release, were detected on an acoustic array of 71 automated receiver stations that extended from Columbia River RKM 940.0 in Rufus Woods Reservoir to Columbia River RKM 1,257.0 near Hugh Keenlyside Dam in British Columbia (B.C.). Four receivers were set in Rufus Woods Reservoir (between Columbia River RKM 940.0 and RKM 949.9 below Grand Coulee Dam), 37 receivers were set in Lake Roosevelt between Grand Coulee Dam (Columbia River RKM 953.6) and the international boundary (Columbia River RKM 1,192.0), 20 receivers were located in a free-flowing segment of the Columbia River in British Columbia between the international boundary and Hugh Keenlyside (Arrow Lakes) Dam (Columbia River RKM 1,257.0), four receivers were set in the Sanpoil River Arm of Lake Roosevelt between Sanpoil RKM 0 – 12.5, five receivers were in the Spokane River Arm of Lake Roosevelt between Spokane River RKM 0 – 43.2, and one receiver was in the Kootenay River, B. C. below Brilliant Dam. The Kootenay River enters the Columbia at Columbia RKM 1,239.0 and Brilliant Dam is located 2 km upstream of this point.

The movements were modeled using state-space modeling (dynamic Brownian Bridge Movement Model and utilization distribution modeling) in the statistical software R in order to create individual trajectories and utilization distributions (UDs).

Fish were grouped by capture stream (tributary group) and their movements spatially and temporally were compared to each other using a Mantel's test (Spearman's correlation). Homing was determined through the use of PIT tag data and acoustic receivers set near the home stream. The proportion of the fish that exhibited homing was determined by dividing the number that returned to their original tagging stream by the number of fish that were tagged there. Because the last date of downloads for this report occurred in April and did not encompass the entire 2014 spawning season, only 2013 fish were analyzed. Entrainment was detected by four buoys (three in 2014) 10.5 km below Grand Coulee Dam. Entrainment events were compared to reservoir operations by graphically displaying the reservoir operations (inflow, outflow, and elevation) as a function of time and plotting the entrainment events. The size class of the fish and proximity of tagging stream to the dam were also analyzed to determine if these variables influenced the fishes' likelihood of entrainment.

Trajectories of the fish were examined to determine the proportion of buoys missed by a single fish, termed "trajectory detection testing," and these data were used to identify holes within the array. Forty two receivers were tested. None of the receivers in B.C. were included in this analysis because there were not enough detections in B.C. to generate trajectories. The receivers in the north had the highest proportion of missed detections with one receiver missing nearly 55% of the detections. A comparison of the receivers maintained by the Spokane Tribe of Indians (STOI) and Eastern Washington University (EWU) using a Mann-Whitney rank sum test indicated that STOI receivers had a higher rate of missed detections than receivers maintained by EWU ($U = 108.5$ $T_{15,27} = 416.5$ $p = 0.014$). Based on the high proportion of missed detections it appears that the ability of the northern portion (above Alder/Wilmont Creek, Columbia River RKM 1,060.0) of the array is not as effective at detecting fish as the southern portion which may be the result of flow, geomorphology, tag collisions with sturgeon, or down time of receivers resulting from different maintenance schedules.

Fifty-eight comparisons of overall spatial and seasonal distributions were tested using the Mantel's test and Spearman's correlation. Comparisons were also made between years to determine year to year variability. Generally, when 2013 data were compared to 2014 data for fish from the same spawning tributary, no significant differences were found between years (Sanpoil 2013-2014 $r = 0.951$, $p = 0.999$; Spokane 2013-2014 $r = 1.000$, $p = 0.999$; Alder/Wilmont 2013-2014 $r = 0.836$, $p = 0.999$; Onion/Big Sheep $r = 0.990$, $p = 0.999$). The overall Sanpoil River fish distributions were similar to Spokane River and Alder/Wilmont Creek area fish, but different from the Big Sheep/Onion fish (Spokane 2013 $r = 0.789$, $p = 0.998$; Spokane 2014 $r = 0.910$, $p = 0.999$; Alder 2013 $r = 0.789$, $p = 0.999$; Alder/Wilmont 2014 $r = 0.973$, $p = 0.999$; Big Sheep 2013 $r = 0.045$, $p = 0.020$; Big Sheep/Onion 2014 $r = 0.064$, $p = 0.019$). The sample size associated with the overall distributions allows for a robust average of the UD.

Generally, there was significant overlap in the UDs of the fish spatially, but when breaking it down by season, fish from different areas of the reservoir had unique UDs. These data are not as robust as the overall distribution due to a relatively small and variable sample size at each tributary group (n = 1-13). Overall, the biggest differences in UDs were observed between the most geographically different groups (Sanpoil and Big Sheep/Onion) in agreement with the genetic findings by Small et al. (2014).

Only 38% of the fish from the 2013 tagging season were detected into 2014. Most detections of fish ended between June and August of 2013, which may indicate significant mortality from predators, anglers, or entrainment. Seven out of the seven fish (5 in the Sanpoil (33%); three in Big Sheep (33%); one in Alder (20%)) that migrated to a stream, homed back to the stream they were originally tagged in. Twelve of the tags in 2013 were the smallest tags (v-7) and only had a tag life of 336 days, so it is possible that these fish homed but were not detected moving back to the streams because the tag stopped working. The other fish did not show evidence of spawning in 2014 and thus no evidence of homing.

A total of seven fish were confirmed to have entrained out of the 112 fish tagged. Three of the seven fish (~ 43%) that entrained came from the Sanpoil, none of the fish tagged in the Spokane, two fish (~29%) tagged in Alder/Wilmont Creek entrained, and two fish (~ 29%) tagged in Big Sheep/Onion Creek entrained. Reservoir operations (inflow, outflow, and elevation) were graphed and entrainment events were plotted. Six of the fish that entrained showed some association with reservoir operations, specifically inflow. However, these dates reflected detections on a receiver below the dam and not the actual entrainment date. Fish can entrain at almost any time. All seven fish were larger than 400 mm TL, suggesting the fish were kelts that may have been too exhausted from spawning to stay within the reservoir. There was no evidence that proximity to the dam will increase the likelihood a fish entrains. Due to the small number (n = 7) of entrainment events it would be inappropriate to conduct statistical analysis on these data.

CHAPTER 1. The short-term effect of different field anesthetics on Rainbow Trout (*Oncorhynchus mykiss* var. *irideus*) swimming performance

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Introduction

Handling and tagging of fish for research can cause physical injuries (Ross and Ross 2008). Experimental procedures often involve the surgical implantation of tags that require the use of an anesthetic that will bring about a deep level of sedation. This study compared the effect of four anesthetics that are available and approved for use with fish (MS-222, AQUI-S 20E, CO_2, and LVEA) on the short-term swimming ability of Rainbow Trout. During the induction or initial exposure to an anesthetic the fish will go through a series of stages before full anesthesia (stage IV) is reached. Stage IV, deep sedation, is characterized by loss of equilibrium and no response to external stimuli (McFarland 1959; Yoshikawa et al. 1988; Iwama et al. 1989; Summerfelt and Smith 1990).

Local regulations limit the use of some anesthetics, especially in fish that are entering the human food chain (food fish; Sattari et al. 2009). Chemical anesthetics are mostly absorbed through the gills and have the potential to buildup in tissues and must be either excreted or metabolized from the fish before the fish enters the human food chain (Markings and Meyers 1985). Alternative methods, such as Low Voltage Electroanesthesia (LVEA) or CO_2 allow fish to be anesthetized without the use of a chemical anesthetic and are generally regarded as safe for use in food fish (USOFR 1990).

MS-222

Tricaine methanesulfonate (MS-222) is a common anesthetic that is approved for use in food fish in the United States (Marking and Meyer 1985; Sato et al. 2000; Carter

2011) with a 21-day holding period (to allow the compound to metabolize) prior to release because of its carcinogenic effects (USOFR 1990).

AQUI-S 20E

Clove oil has frequently been used as a fish anesthetic and is made up of 85-95% eugenol. However, clove oil is not accepted for use in the United States because two components of clove oil (methyleugenol and isoeugenol) are known carcinogens (USDHHS 2007, 2008, 2010). To date eugenol, the main component of clove oil, is considered safe and no studies have shown evidence of carcinogenicity as a result of the consumptions of eugenol (USDHHS 2010). AQUI-S 20E, a pharmaceutical that contains 10% eugenol [2-methoxy-4-(propenyl) phenol; $C_{10}H_{12}O_2$] (the active ingredient), was first reported by Endo et al. (1972) as a possible anesthetic. This method is registered for use with food fish in Australia and New Zealand with a 21-day holding period prior to release (Marking and Meyer 1985; Ackerman 2005) and is currently under review by the FDA (Food and Drug Administration) for use with food fish in the United States.

CO_2

CO_2 is an odorless, colorless gas that is soluble in water and was introduced directly into the water from gas (Loch 1991; Peake 1998). It is recognized as generally safe and does not require a holding period prior to being released for food fish (Summerfelt and Smith 1990). The gaseous form of CO_2 is the most widely used method as it leaves no residues in the tissues (Ackerman 2005; Iwama et al. 1989). Anesthesia with CO_2 can result in an incomplete level of sedation or cause asphyxiation as CO_2 competes with O_2 for binding sites on hemoglobin (Iwama et al 1989).

LVEA

Low voltage non-pulsed DC current electroanesthesia is a physical method of anesthesia that is available for immediate release in food fish and is used to immobilize adult fish for tagging (Marking and Meyer 1985; Barham et al. 1987 Hudson et al. 2011; Ackerman et al. 2005; Anderson et al. 1997) and has been successfully used to anesthetize brown Trout for telemetry studies (Gosset et al. 2006). This method requires the fish to remain within the electrical field to stay under anesthesia.

Treshenki et al. (2012) compared the induction and recovery times and hematological profiles following sedation of striped bass using MS-222, eugenol, CO_2, and LVEA. Results indicated that all four anesthetics were effective at sedating the fish and each anesthetic elicited a generalized stress response (i.e., cortisol, glucose, hematocrit, osmolality, and lactate levels were similar among each group tested).

Despite extensive studies assessing physiological impacts of anesthetics, there appears to be a lack of understanding of the short-term effect of anesthetics on swimming ability immediately after the fish recovers. Fish suffering from a short-term effect as a result of the anesthetic may be more susceptible to predation due reduced swimming ability. The fish's behavior may also be altered so that the anesthetic negatively affects its migration, feeding, and spawning behavior. It is important to understand this especially when some studies require the fish to be released immediately after exposure to the anesthetic.

To determine the effect of the anesthetic on swimming ability, this study used a swim tunnel to determine critical swimming speed. Critical swimming speed (U_{crit}) was first established by Brett in 1964 and was used to assess the success of an individual fish to maintain and establish swimming speed. U_{crit} is commonly used as a physiological measurement to assess the impacts of toxicants, disease, hypoxia, and temperature on fish (Thomas and Rice 1987; Ye and Randall 1991). Alternatively, fish whose behavior indicates a reduced ability to swim (pushed against the current) but have not reached U_{crit} were recorded in this study.

It is important that wild fish maintain a high swimming performance to avoid predators, feed, migrate, and spawn (Ye and Randall 1991). Past studies that tested the effect of anesthetics on swimming performance waited at least an hour prior to the test to acclimate the fish to the tunnel (Anderson et al. 1997). However, other studies have observed that fish are no longer affected by chemical anesthetics (MS-222 or AQUI-S 20E) one hour after administration (Trushenki et al. 2012) and because of this, this study immediately swim tested the fish after recovery. The aim of this study was to determine which anesthetic (MS-222, AQUI-S 20E, CO_2, and LVEA) is the most appropriate based on five criteria: (1) induction (takedown) time; (2) recovery time (3) critical swimming speed, (4) swimming behavior, and (5) mortality rate.

Methods

Rainbow Trout were obtained from Washington State Department of Fish and Wildlife hatchery at Sherman Creek, WA (n=180; average TL= 224 ±34.54 mm)). We used thirty fish for each treatment and an additional 30 fish were kept as controls for the mortality study (these fish were not swim tested). Fish were held in flow-through 300-gal tanks for four weeks prior to the experiment to acclimate to laboratory conditions. Fish were fed ab libitum with commercial Trout pellets. The tanks were maintained at 11^{o}C +/- 1 ^{o}C and were well aerated. One hundred and fifty Rainbow Trout were randomly divided into five treatments (30 per treatment): (1) AQUI-S anesthetic, (2) MS-222 anesthetic, (3) CO_2 anesthetic, (4) LVEA anesthetic, and (5) control or no anesthetic.

Each fish was removed from the tank and placed into the "anesthetic bath," (described below) until stage IV anesthesia was reached. Each anesthetic bath was in a 10 gallon glass aquarium with five gallons of water. The anesthetic (excluding LVEA) was placed in the water, thoroughly mixed, and then a fish at random was added to the tank by net. Once the fish reached stage IV anesthesia (complete loss of muscle tone, equilibrium, spinal reflexes, and regular opercular movements, confirmed by gently lifting the fish to check for responsiveness; Summerfelt and Smith 1990), a small passive integrated transponder (PIT) tag was injected into the pelvic girdle of the fish using an injection needle (Fish 1999). The specific location of the tag placement, in accordance with the PIT tag manual, was in the "ventral area of the abdominal cavity somewhere between the pyloric ceca and the pelvic girdle, generally in the fatty tissue just posterior to the pyloric ceca" (Fish 1999). PIT tags were encoded with a unique identification number that was read using a PIT tag reader, enabling us to identify each fish (Fish 1999).

The fish were held under a 50% solution of the takedown anesthetic for three minutes (average field surgery times) to maintain consistency. Total and fork length (mm) and weight (g) were collected while the fish was anesthetized. The fish was placed in the swim tunnel to recover (upright and responsive to external stimuli) and for swim testing. Each fish was allowed to recover in the swim tunnel so that once the fish recovered, the fish could be immediately swim tested to mimic an immediate field release.

Anesthetic Concentration

AQUI-S 20E and MS-222 was added directly to the water at a concentration of 28 mg/L and 80 mg/L, respectively (Hill 2002; AFS 2004). The water was mixed thoroughly before the fish was added.

Fish were anesthetized with 253 mg/L of CO_2 buffered with sodium bicarbonate until stage IV anesthesia (Loch 1991). A carbon air stone (3 x 5 cm) was placed in the water and the flow was regulated with a gauge. The bubbling rate was 2.9 m^3/second for 80 seconds in five gallons of water. This anesthetic exposes fish to hypercapnia to induce respiratory acidosis in fish and decreases the blood pH. The risk of hypercapnia requires the water to be buffered with sodium bicarbonate to maintain a near neutral pH (Marking and Meyer 1985; Ackerman 2005). The pH level was maintained by adding 30 grams of sodium bicarbonate to the charged water (Loch 1991).

To anesthetize fish with LVEA, a single fish was placed in a cooler with two metal plates attached to a Protek 6003 L DC power supply. The suggested upper limit is 0.56 v/cm and lower limit is 0.25 v/cm (Hudson and Johnson 2011) and these limits were used in this study to ensure no harm was done to the fish. LVEA is more fined tuned to the biomass of each fish and the conductivity of the water, hence the reason for the range (Hudson and Johnson 2011). Each fish was held under continual anesthesia (non-pulsed direct current) for three minutes to mimic the time it generally takes us to complete surgical implantation of radio or acoustic transmitters for biotelemetry studies. The induction (takedown) and recovery times of the fish under the various anesthesia methods were measured with a stopwatch to the nearest second.

Once the fish recovered to field standards (upright and swimming) (Summerfelt and Smith 1990), the fish was immediately swim tested. Fish were tested in a Blazka type respirometer on loan from Battelle Pacific Northwest National Laboratory in Richland, WA. The tunnel was placed in a climate controlled room with a live streaming camera to monitor the fish movements. The video streamed live to a computer located in an adjacent office. This kept the fish undisturbed during the test. The fish were not allowed to acclimate to the tunnel in an effort to mimic immediate release in a field setting.

Trials began with a low initial water flow equating to 0.5-body lengths/second (bl/s) for 2 minutes to allow the fish to adjust. Initial velocity was sustained for 1 minute at 1.75 bl/s before testing critical speed (Anderson et al. 1997). The process we used was outlined by Anderson et al. (1997). The fish were forced to swim as the water velocity was increased at a constant progression (0.071 m/s) with a constant time interval of 10 minute (Anderson et al. 1997). The test continued at increasing velocities until the fish failed to maintain swimming speed and was pushed against the posterior grid of the swimming tunnel. At this point the fish was considered exhausted and this was referred to as critical swimming speed (U_{crit}). The critical swimming speed was determined for each fish using equation 1 (Brett 1964):

$$U_{crit} = V + (t\Delta t^{-1})\ \Delta vi$$

Where:

U_{crit} = Critical Swimming Speed in (m/s)

V= highest velocity maintained for the incremental period (m/s)

Δt = time increment (1 minute)

Δv_i = velocity increment (m/s)

t = time elapsed at the final velocity (min)

During the test, a behavior was observed where the fish was pushed against the rear grid of the tunnel, but was still able to continue swimming. This behavior was referred to as a “tire” and was counted during the swim test. Each swim test was video recorded and these videos were watched a total of three times. Each time the observer would count the tires observed at each time step. The measurements were averaged and the averages were used in the analysis. The reason for this was to reduce the subjectivity associated with the observations.

Mortality

For the mortality study there was a sixth group (procedural control), where the fish were held for 30 days under the same conditions and monitored for mortalities. Fish were monitored for mortalities for 30 days after the swim test was completed (i.e. 30 days after the fish test was completed, the mortalities were no longer recorded).

Statistical Analysis

Five (# 1, 2, 3, 4, and 6) of following six null hypotheses were tested using analysis of variance (ANOVA) ($p \leq .05$) and post hoc Tukey’s HSD ($p \leq .05$) if necessary. Null hypothesis # 5 was tested using a linear regression and ANOVA (alpha level of 0.05).

(1) Length of fish was uniform among the treatments.

(2) Number of fish that reached critical swimming speed was uniform among the treatments.

(3) Critical swimming speed was uniform among the treatments.

(4) Total number of tires observed was uniform among the treatments.

(5) Number of tires observed over time was uniform among the groups.

(6) Number of mortalities was uniform among the groups.

Results

Length

Length did not differ significantly among the groups (F_5 = 0.2.105; p = 0.716; Table 1).

Induction and Recovery

Rainbow Trout anesthetized with CO_2 often resulted in the fish thrashing around and an incomplete level of anesthesia. Rainbow Trout anesthetized by CO_2 had the longest average takedown and recovery time followed by AQUI-S, MS-222, and LVEA (Table1). Anesthesia with LVEA was nearly instantaneous and LVEA had the fastest takedown and recovery time compared to the other anesthetics (F_4 = 10.35; p < 0.001; Figure 1).

Critical Swimming Speed

During this study only 36 out of 149 fish reached critical swimming speed and the proportion of fish that reach the critical swimming speed in each anesthetic was not significantly different from each other (Table 1, F_4 = 0.054, p = 0.0637). There was a very low proportion of fish that reached critical swimming speed. Of the group of fish that reached critical swimming speed, we performed an analysis of variance (ANOVA) to determine if there was a difference the critical swimming speed (F_4 = 5.885, p = 0.002). The test yielded significant variation among treatments, F_4 = 5.885, p = 0.002. A post hock Tukey's HSD test indicated that fish anesthetized with LVEA had significantly

Table 1. Summary of the sample size (n), mean total length and weight and (standard deviation), mean (SD) takedown and recovery time in seconds for each anesthetic, number that reached critical swimming speed, total number of tires (SD), and the number of mortalities observed 30 day after treatment.

Anesthetic	***n***	**Mean TL in mm (SD)**	**Takedown (sec) Mean (SD)**	**Recovery (sec) Mean (SD)**	**Number that reached U_{crit}**	**Total # of Tires (SD)**	**Mortalities (after 30 days)**
AQUI-S 20E©	30	233 (35)	182.1 (97.4)	662.9 (301.3)	11	29 (22)	2
MS-222	30	236 (38)	145.0 (50.7)	657.4 (390.4)	11	24 (24)	1
CO_2	29	236 (42)	302.3 (93.3)	905.4 (627.6)	9	23 (20)	2
LVEA	30	227 (32)	5.1 (3.4)	6.27 (4.9)	5	10 (12)	2
Control (swim)	30	225 (35)	-	-	0	11 (13)	1
Control (not swim tested)	30	229 (33)	-	-	-		2

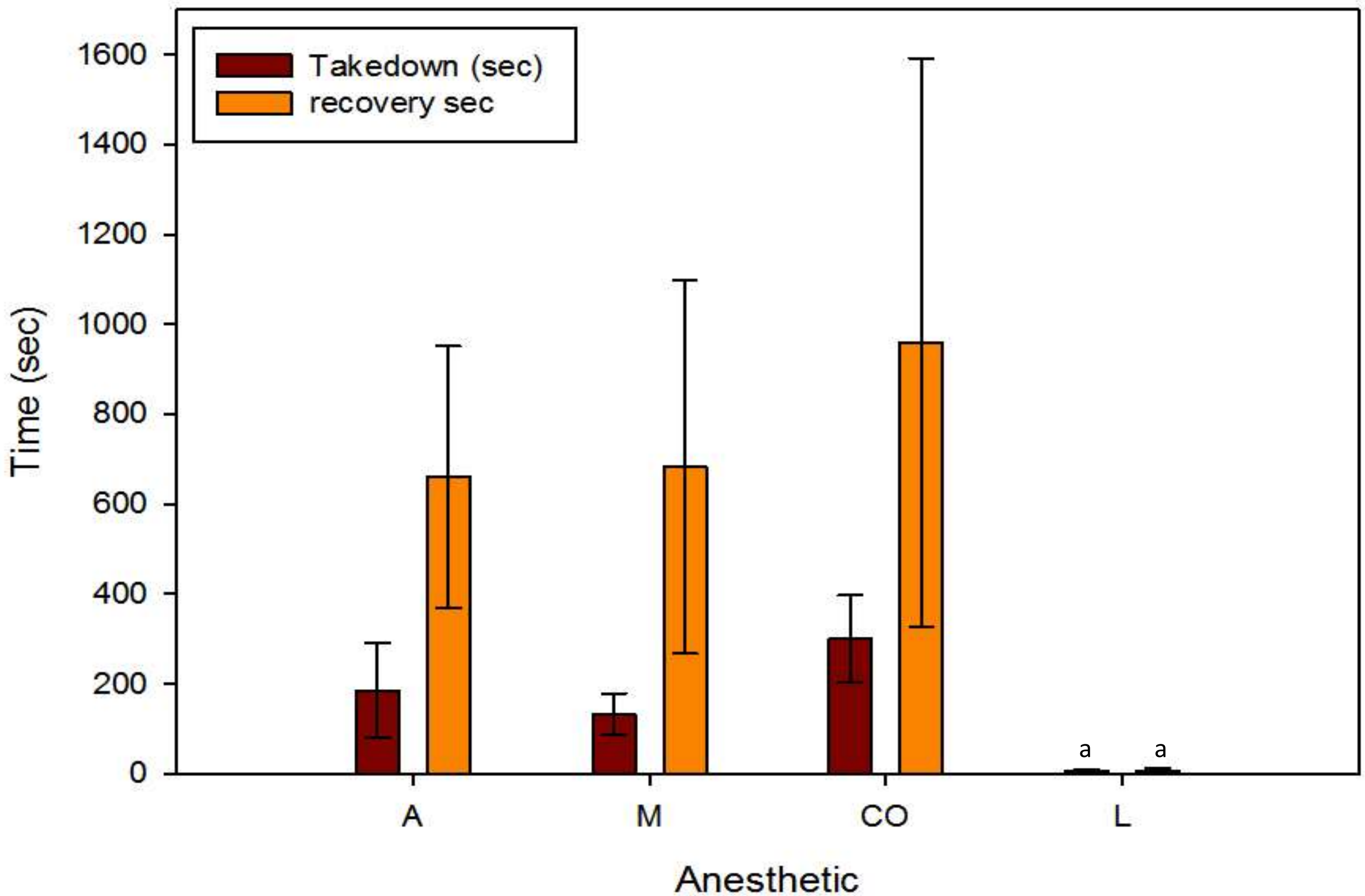

Figure 1. Induction and recovery times of fish anesthetized with different anesthetics. A = AQUI-S 20E, L = LVEA, CO = Carbon Dioxide, M = MS-222, and “a” denotes significance. The error bars denote one standard deviation.

higher critical swimming speeds then fish anesthetized with MS-222 (F_4 = 5.285, p = 0.007) and CO_2 (F_5 = 4.353, p = 0.035).

Tires

An ANOVA performed on the tires yielded significant variation among treatments, F_4 = 5.669, p = 0.00029. A post hoc Tukey's HSD test showed that LVEA and Control fish had fewer tires then MS-222 and AQUI-S 20E treated fish ($p < 0.05$, Figure 2, Table 2). The number of tires observed from fish treated with CO_2 was not significantly different from any of the other anesthetics ($p > 0.05$, Table 2).

A linear regression was used to look at the effect of tires over time (Figure 3). There was an effect of time on the number of tires observed for AQUI-S 20E (F_{225} = 4.747; $p < 0.001$; adj R^2 = 0.0609), MS-222 ((F_{206} = 5.678; $p < 0.001$; adj R^2 = 0.0786), and CO_2 (F_{215} = 4.866; $p < 0.001$, adj R^2 = 0.0824). The number of tires observed over time did not change for the control (F_{246} = 3.054; p = 0.43; adj R^2 = -0.0015) and LVEA (F_{233} = 2.406; p = 0.08; adj R^2 = 0.0085). The control and LVEA treated fish had the most similar number of tires observed over time (~2 tires/ten minutes). The remaining anesthetics showed a decrease in the number of tires observed over time.

Mortality

There was no difference in mortality rates of the fish treated with different anesthetics and either of the controls (F_5 = 0.75; p = 0.994).

Discussion

Both chemical and physical anesthetics induce a loss of feeling through the depression of the central and peripheral nervous system (Iwama and Ackerman 1994) and

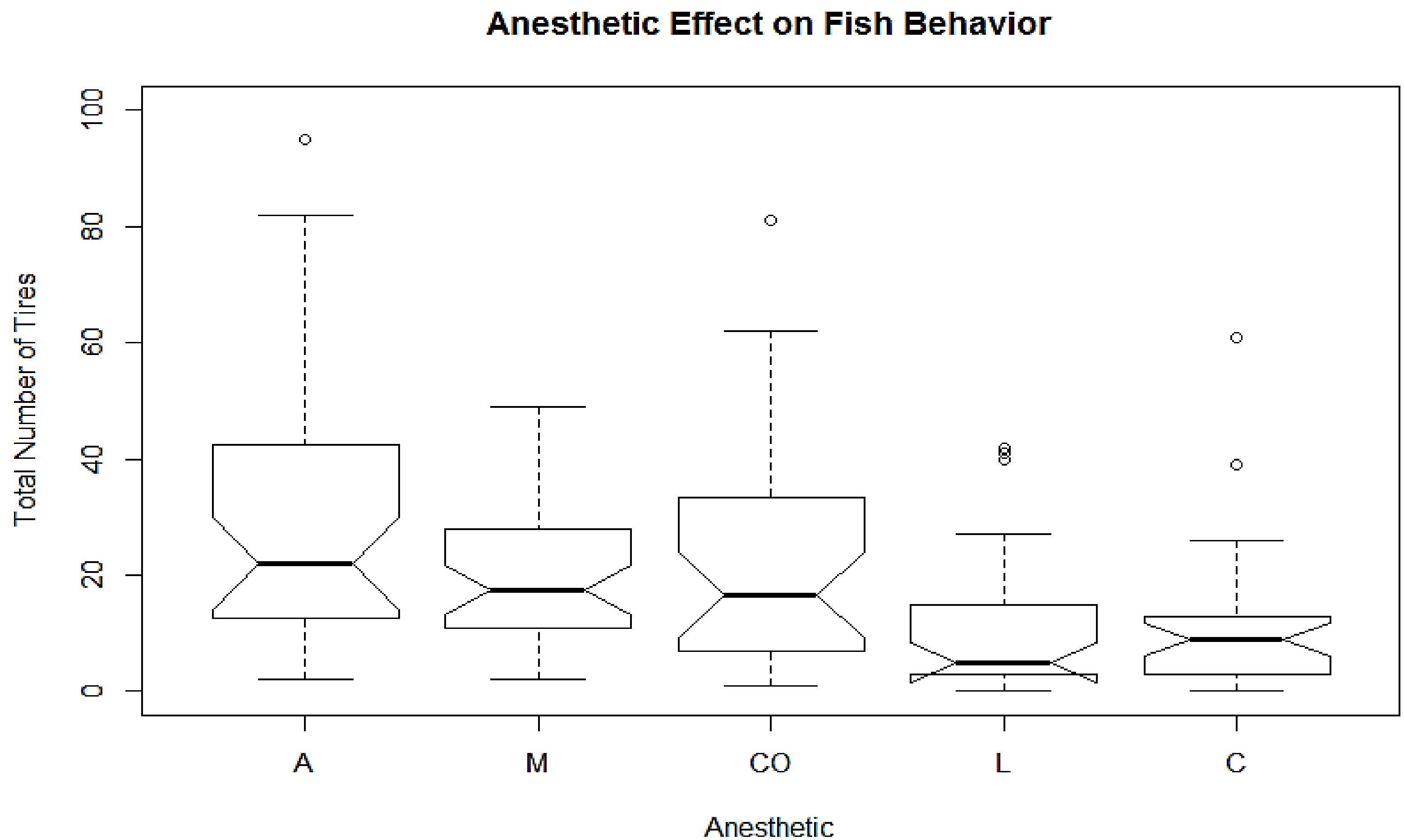

Figure 2. Anesthetic effect on fish behavior. Box plot of the total number of tires observed over the entire swim test for fish anesthetized with different anesthetics (A=AQUI-S 20E, C=Control, CO=CO2, L=LVEA, M=MS-222). The bottom and top of the box represents the first and third quartiles and the box shows the second quartile (median). The thick black line represents the mean and the lines extending from the box show one standard devaition above and below the mean of the data. The hollow circles indicate outliers. The notch displays the 95% confidence interval around the median.

Table 2. Post hoc Tukey's HSD multiple comparison of means (95% family-wise confidence level) comparing the effect of each anesthetic on the total number of tires observed for the entire swim test, where A=AQUI-S 20E, C=Control, CO=CO2, L=LVEA, M=MS-222 and * indicates significance at an alpha of 0.05.

Treatment Comparisons	Difference	adjusted p-value
C-A	18.83	0.003*
C-M	-13.97	0.046*
C-CO	-12.5	0.118
C-L	0.39	0.999
L-A	19.32	0.003*
L-M	-14.36	0.046*
L-CO	12.89	0.104
A-M	4.86	0.878
A-CO	6.33	0.739
M-CO	-1.47	0.999

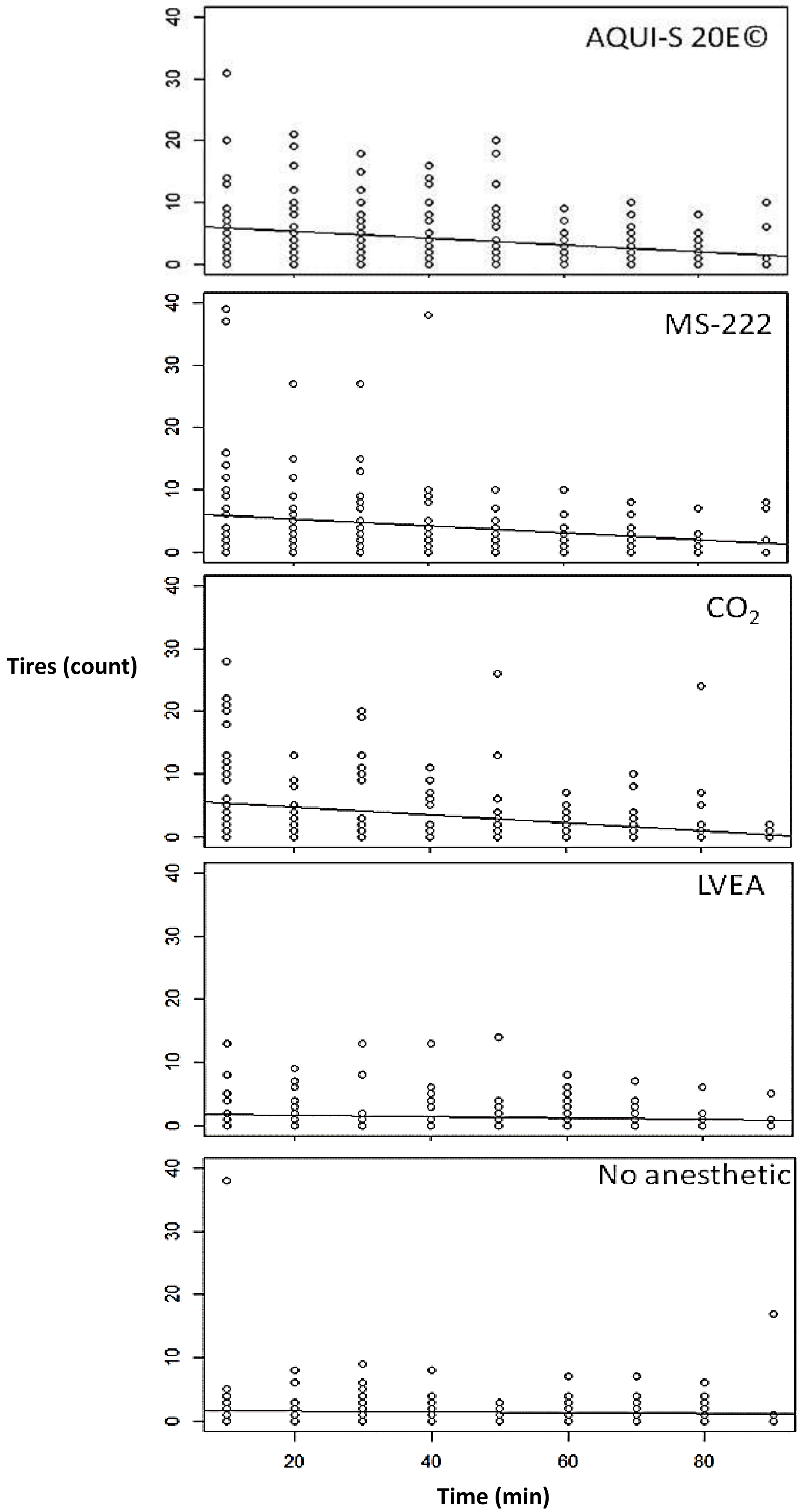

Figure 3. Linear regression for each anesthetic showing the relationship of tires observed during the swim test for each anesthetic over time.

are commonly used by fisheries managers to immobilize and reduce stress on fish. Fisheries managers find it is important that these anesthetics are inexpensive, available, easy and safe to use, and have a minimal impact on the fish (Marking & Meyer 1985; Ackerman et al. 2005).

Chemical anesthetics, like MS-222 and AQUI-S, have shown to reduce heart rates in Chinook salmon (Hill et al. 2002) and alter the pathways in the brain (Arnolds et al. 2002). There is also evidence that MS-222 and eugenol do not completely suppress stress-induced cortisol and glucose responses in Rainbow Trout (Wagner et al. 2002; Palić et al. 2006). Alternative forms of anesthesia like LVEA have been reviewed by Ackerman (2005) and concluded that when used appropriately, there are few, if any long-term effects on the fish. It is also considered to have effects that are similar to or reduced when compared to other chemical anesthetics (MS-222, AQUI-S 20E, and CO_2; Madden and Houston 1976; Barham et al. 1988; Jenning and Looney 1998; Henyey et al. 2002; Robb and Roth 2013).

Takedown and Recovery

Our results of the induction and recovery times were consistent with previous studies (Barham et al. 1987; Anderson et al 1997; Carter et al. 2011). Marking and Meyer (1985) described several attributes necessary for field applicability of an anesthetic in fisheries management. One requirement included induction in less than three minutes and recovery in less than five minutes. In our experiment, LVEA was the only anesthetic that met both of these requirements (Table 1). LVEA was the only anesthetic that allowed for recovery in less than five minutes (Table 1) and because of this it appears that LVEA is the only anesthetic to meet both induction and recovery requirements set forth by

Marking and Meyer (1985). CO_2 was the only anesthetic that took longer than three minutes to bring to stage IV anesthesia and had a mean recovery time that was three times more than the recommendation by Marking and Meyer (1985; Table 1).

Critical Swimming Speed

Our study observed just 24% of the fish reaching their critical swimming speed. This may be because the swim tunnel used in the study had a maximum sustained speed of 50.9 cm/sec. It is likely that we did not observe a higher proportion of fish reaching their critical swimming speed because the tunnel could not sustain a speed that would allow this. Despite this, there was a trend from the fish that reached critical swimming speed (n = 36) that LVEA had the highest U_{crit} indicating that these fish were not affected by the method of anesthesia. Critical swimming speed is a commonly used method to assess the impacts of toxicants, disease, hypoxia, and temperature on fish (Thomas and Rice 1987; Ye and Randall 1991) and in the future a study should evaluate this more effectively. Despite this, there was a trend that fish exposed to CO_2, AQUI-S 20E, and MS-222 were more likely to reach a critical swimming speed than LVEA and the control over the course of the test (Table 1, p = 0.0637).

Tires

Despite the apparent issues with the swim tunnel, this study observed some important behavioral responses in during the swim test. Fish that were exposed to AQUI-S 20E, CO_2, and MS-222 had a higher number of tires than the control fish or those anesthetized by LVEA (Figure 2). When using the number of tires observed, it was apparent that LVEA was most similar to the control (Figure 2 and 3).

The tires observed over time were most similar for LVEA and the control. Both of these treatments had on average 1.5 tires (SD = 2.3) at each time step and did not show a significant change over time (Figure 3; *p* = 0.08 and 0.43 respectively). This is evidence that LVEA does not impact the short-term swimming ability of the fish. The tires observed for the other three anesthetics were higher on average and show a general decrease over time (Figure 3). CO_2 had the most dramatic decrease over time and this may be because CO_2 asphyxiates the fish (Treshenki et al. 2012), so as the fish is swimming it is able to take in oxygen and recover during the test. The other two anesthetics, MS-222 and AQUI-S 20E, bind to the gills (Frazier and Narahashi 1975; Neumcke et al. 1981) causing the fish to experience residual effects of the anesthetic even after the fish is deemed recovered. Basically, the fish is still affected by the anesthesia during the swim test and this was apparent by the number of tires observed during the swim test.

Mortality

Mortality rates were not significantly different ($p = 0.994$) for fish exposed to each anesthetic and the control, so the anesthetic did not increase the likelihood of death which is in agreement with work done by Anderson et al. (1997) and Trushenki et al. (2012).

The present study has demonstrated that LVEA has the least impact on Rainbow Trout swimming ability and allows for induction and recovery times that make it a perfect candidate for field studies. LVEA has been successfully implemented in field studies for Rainbow Trout, bull Trout, brown Trout, walleye, and striped bass (Vandergoot et al. 2011; Trushenki et al. 2012) and is an approved technique by

Washington State Department of Fish and Wildlife (WDFW). WDFW has successfully tagged Bull Trout and brood stock with this form of anesthesia (Hudson et al. 2011; WDFW 2012). Marking and Meyer (1985) suggested that field anesthetics not only allow for swift induction/recovery times but also should not disturb the physiological balance of the fish. Since this study did not observe a difference in the survival of the fish it is likely that the anesthetic methods do not disturb the physiological balance (Anderson et al. 1997). It important that more studies should be conducted to investigate the effects of these anesthetics as it relates to physiological processes (i.e. stress, long-term survival, growth and reproduction). Before an anesthetic is used it is important that the anesthetic is validated for the size and species of interest.

The present study has clearly demonstrated that LVEA is an appropriate field anesthetic based on induction/recovery times, swimming behavior, and survival for Rainbow Trout. Further benefits of this technique include: low initial and sustained costs, ease of use, ability to be fine-tuned, and human safety (Hudson et al. 2011). There are some drawbacks to this method as it requires the fish to be in electrical field (i.e., water) to remain immobilized and because this collection of length and weight measurements can be difficult. Despite these drawbacks, it appears that LVEA may be the most useful field technique for its time saving abilities, cost, and low impact on swimming ability of fish.

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CHAPTER 2. A comparison of the movements of Columbia River Redband Rainbow Trout (*Onchorhynchus mykiss* var. *gairdneri*) tagged with acoustic transmitters in several spawning tributaries of Lake Roosevelt, Washington: A synopsis of fish tagged in 2013 and 2014.

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Introduction

We acoustically tracked Columbia River Redband Rainbow Trout (*Oncorhynchus mykiss* var. *gairdneri*) that were tagged in different tributaries of Lake Roosevelt to determine:

1. The utilization distribution for each tributary population and statistically compare these distributions both spatially and temporally;
2. If fish returned to spawn in the tributary where they were originally tagged (homing); and
3. If entrainment events (i.e., passing over or through Grand Coulee Dam) of acoustically tagged fish was influenced by their size, proximity of tagging tributary to the dam, and dam operations.

Rainbow Trout are divided into five subspecies in North America: coastal rainbow (*O. mykiss* var. *irrideus*), golden Trout (*O. mykiss* var. *aguabonita*), Klamath Lake Redband Trout (*O. mykiss* var. *newberrii*), Sacramento River Redband Trout (*O. mykiss* var. *stonei*) and the Columbia River Redband Trout (*O. mykiss* var. *gairdneri*) (Behnke 1992; Scholz and McLellan 2010; Blackenship et al. 2011; Scholz 2014). Coastal Rainbow Trout are genetically uniform throughout their native range, which extended from the Aleutian Islands, Alaska to southern California. Interior Rainbow Trout (collectively called Redband Trout) are sufficiently different genetically throughout their range to warrant separation into distinctive subspecies (Behnke 1992). The subspecies, known as Columbia River Redband Trout, hereafter referred to as Redband Trout, are endemic to the Columbia River and Fraser River watersheds (Behnke 1992; Scholz and McLellan 2010; Scholz 2014). A connection between the

Columbia and Fraser Rivers occurred at the end of the Ice Ages, which accounts for the considerable overlap in distributions of various fish species that occupy both rivers (Macphail and Lindsey 1986; Scholz 2014). Columbia River Redbands were historically the most widely distributed salmonid within the Columbia River Basin, occupying roughly 73 percent of the watersheds, but today they only occupy 47 percent of those watersheds (Lee et al. 2006; Parametrix 2005). These fish are considered species of concern or classified as sensitive by several agencies as a result of threats to the population from habitat degradation and introduced species (Thurow et al. 1997; Lee et al. 2006; Lee et al. 2012).

Life History

Redband Trout exhibit multiple life history strategies including: non-migratory (resident of the same water body their entire lives), anadromous (also called steelhead that migrate from freshwater into the ocean before returning to their natal stream to spawn), and three forms of potadromous life histories including fluvial-adfluvial (rear in natal tributary before migrating to a river and eventually returning to their natal tributary to spawn), lacustrine-adfluvial (rear in natal tributary and migrate to a lake before returning to their natal tributary to spawn), and secondary lacustrine-adfluvial (fish that once exhibited fluvial life history but, as a result of dam construction, which converted fluvial habitat into a lacustrine reservoir, migrate to a reservoir before returning to their natal tributary (Northcote 1997; Scholz and McLellan 2010; McLellan et al 2015; Brown et al. 2013; Scholz 2014). Since the construction of Grand Coulee Dam, it has been hypothesized that the majority of the Redbands within Lake Roosevelt are secondary lacustrine-adfluvial and that some of these populations of Redband Trout may be

potential remnants of, and still retain the traits of, once anadromous steelhead runs (McLellan et al.
2015).

These fish are iteroparous, i.e., spawn more than once in their lifetime (Narum et al. 2008). Spawning timing in Rainbow Trout is triggered by changes in both flow and water temperature in close association with the spring freshet (reviewed by Scholz and McLellan 2010; Scholz 2014). Columbia River Redband Trout spawn in late spring or early summer (Muhlfeld 2002) from February to May each year in the Sanpoil River, tributaries of the Spokane River, Alder and Wilmont creeks (McClellan et al. 2015), and typically spawn from mid-March to early June in Big Sheep and Onion creeks (Lee et al. 2012).

After one to three years within the natal stream, juveniles with anadromous or potadromous life histories will migrate downstream to the ocean, lake, or river, and continue to grow and mature in environments in accordance with their respective life histories until they return to spawn (Kwain 1983; Parametrix 2005).

As a result of the construction of Grand Coulee Dam without fish ladders, anadromous fishes have been blocked from over 1,038 km of habitat. Grand Coulee Dam extirpated steelhead from the upper Columbia (Mullen et al. 1992; Scholz and McLellan 2010; Scholz 2014) and shifted the life history strategies of Columbia River Redband Trout from being mainly anadromous and fluvial to one that is secondary lacustrine-adfluvial and reliant upon large lentic portions of the reservoir. Grand Coulee Dam also poses a threat to Redband Trout in Lake Roosevelt as they have the potential to entrain over or through the dam into Rufus Woods Reservoir. Of 2,075 Redband Trout that were implanted with PIT tags in the Sanpoil River between 2010 and 2012, 46 (2.2%) have been detected in the Columbia River at locations downstream of Grand Coulee Dam at juvenile bypass facilities (Rocky Reach, Rock Island and McNary dams) and from a piscivorous bird colony at East Sand Island located in the Columbia River estuary near the mouth of the Columbia River (McLellan et al. 2015).

McLellan et al. (2008) constructed a model of the relationship between various reservoir operations in Lake Roosevelt and hatchery Rainbow Trout success, and verified that deep drawdown events, short water retention time, and low reservoir elevation resulted in fewer rainbow trout tag recoveries in Lake Roosevelt and more tag recoveries downstream from Grand Coulee Dam (McLellan et al. 2008).

Part of the mitigation for the loss and damage to the fish stocks as a result of hydropower in the upper Columbia are hatchery programs that boost fish production. These efforts have increased the number of fish available for harvest, but have also introduced non-native variants of Rainbow Trout to Lake Roosevelt. Despite this, naturally spawning native stocks of Redband still exist. Genetic analysis has already determined (1) that unique stocks of Redband Trout exist within the Sanpoil River (confluence with the Columbia River at Columbia River RKM 984.0), (2) that Redband Trout from the Spokane River (confluence with the Columbia mainstem at Columbia River RKM 1,022.2) and tributaries like Alder Creek (confluence with the Columbia River at Columbia River RKM 1,058.8 in the central part of the reservoir) share a common genetic ancestry with the Sanpoil River Redbands, and (3) Redbands from Big Sheep Creek (confluence with the Columbia at Columbia River RKM 1,186.1) were genetically distinctive from those in the Sanpoil, Spokane, and tributaries of the central reservoir (Small and Dean 2006, 2007; Small et al. 2007, 2014). Part of the goal of the present study was to determine if the distributions of fish implanted with acoustic transmitters from different tributaries overlapped with tributaries where the genetics were similar and if the distributions were unique for tributaries with distinctive genetic populations.

The introduction of exotic species has increased the risk of predation on Redbands by predators such as Smallmouth Bass (*Micropterus dolomieu*), Largemouth Bass (*Micropterus salmoides*) and Walleye (*Sander vitreus*) that prey on juvenile salmonids (Zimmerman 1999; Baldwin and Polacek 2002; Baldwin et al 2003; Simmons et al. 2006; Stroud et al. 2010, 2012). Baldwin et al. (2003) determined that predation by Walleye on Rainbow Trout released at Sherman Creek was substantial based on population estimates of Walleye in the study area using Program CAPTURE. The Wisconsin Bioenergetics Model was then used to determine how many Rainbow Trout were consumed by individual Walleye during a 41-day period following their release. In 2000, a population of 12,333 Walleye consumed 7.3% of the total released Rainbow Trout at Sherman Creek (Baldwin et al. 2003). In 2010, populations, based on using Program MARK, of Smallmouth Bass (n = 49,291) and Walleye (n = 12,257) occupying the Sanpoil River Arm of Lake Roosevelt, combined, consumed (Wisconsin Bioenergetics Model) 24.0% of the Rainbow Trout yearlings (n = 3,499 of 14,587) and 27.4 % of two- and three- year old Rainbow Trout (n = 6,504 of 23,738) that made secondary lacustrine-adfluvial migrations out of the Sanpoil River into Lake Roosevelt between the middle of March and the first week in July (Stroud et al. 2012). The populations of 14,587 one-year old and 23,738 two- and three- year old Rainbow Trout were estimated by employing a rotary screw trap and conducting studies to determine trap efficiency. Due to pressures impacting the Redband Trout populations, it is important that mangers understand the movements, distribution, and entrainment rates of these fish in Lake Roosevelt to manage the species more appropriately. Maintaining native Redband populations is essential for the future survival of Columbia River Redband Trout and the potential return of anadromous fish to the upper Columbia.

Methods

Study Area

Lake Roosevelt (Figure 1), a reservoir of the Columbia River, was created by Grand Coulee Dam at river kilometer (RKM) 953.6. The dam blocked anadromous fish migration in 1939 and changed a once free-flowing riverine habitat to more lacustrine habitat. The dam became operational in 1941. At full pool the reservoir has a maximum depth of 122 m, average depth of 114 m, surface area of 33,490 hectares, total active water storage of 5.2 million acre feet, and maximum length of 243 km and extends to the Canadian border at Columbia River RKM 1,192.0 (U.S. Bureau of Reclamation 2013; Ferrari 2012). The main purpose of Grand Coulee Dam is power production. It also serves to pump water into the United States Bureau of Reclamation’s Columbia Basin Project, to supply water for irrigating croplands. Additionally, Lake Roosevelt has a large storage capacity that supplies system flood control. As a result, the total water, elevation, depth, and flow regime fluctuates over the course of a year in predictable cycle. This cycle creates a hydrologic profile with two main drawdowns per year (Feb-May and Aug-Sept). The first, deeper drawdown is used to (1) produce hydroelectric power, (2) regulate down river flood control as a result of snowmelt, and (3) provide flows for juvenile

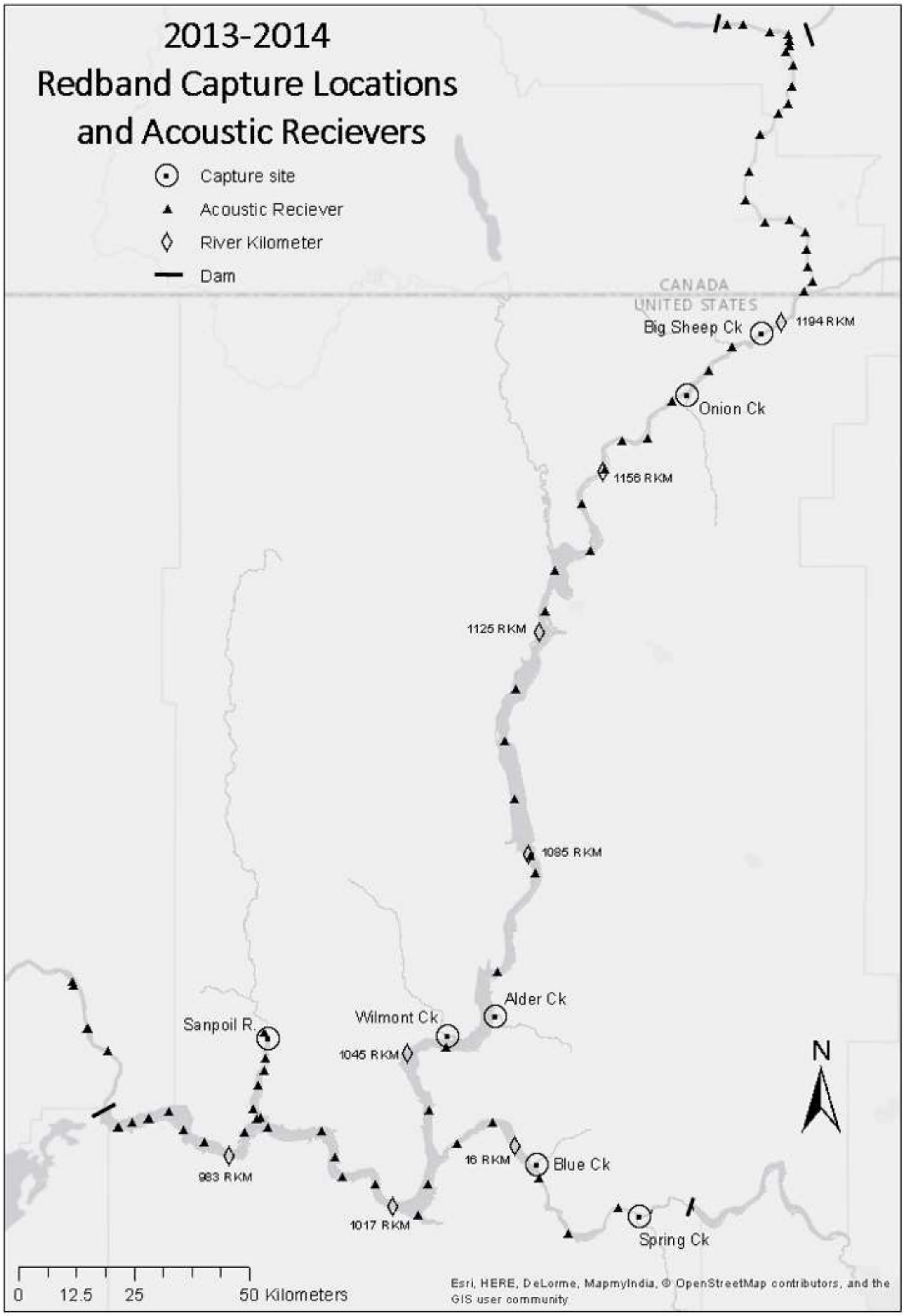

Figure 1. Map of Lake Roosevelt, Washington, marked with each capture sites (⦿) of Redband trout and all acoustic receivers (▲) used during this study. Hydropower dams in the study area are indicated (|) and river kilometer (RKM) are denoted by (◊).

salmon migration through the lower Columbia River to the ocean. The drawdown (1941-2014) had a max of 44 m and an average (±SD) of 16 ± 9 m (USBOR). The second, shallower drawdown is used to provide higher flows through the middle and lower Columbia for salmonid spawning.

Within this study area there is an array of 71 acoustic receivers (see Appendix A-1 for latitudinal and longitudinal coordinates and RKM of each receiver). Four recivers are located in Rufus Woods Reservoir (reservoir below Grand Coulee; Columbia River RKM 940.0 to RKM 949.9) and 37 in Lake Roosevelt from Columbia River RKM 953.6 (Grand Coulee Dam) to the international border (Columbia River RKM 1,192.0). In Canada, the receiver array extends from the international border to Columbia RKM 1,257.0 (below Hugh Keenlyside (Arrow Lakes) Dam British Columbia; n = 20). One receiver is located in the Kootenay River, B.C that enters the Columbia at Columbia River RKM 1,239.0 and Brilliant Dam is located 2 km upstream of this point. The array extends into 13 km of the Sanpoil (n = 4), which is 95 km long and flows south from the Okanogan Highlands, through the Colville Indian Reservation to merge with the Columbia at RKM 984.0 (Figure 1). Five receivers are in 44 km of the Spokane River that originates at the outlet of Lake Coeur d'Alene, Idaho and flows 180 km to its' confluence with the Columbia at Columbia River RKM 1,022.2 (Figure 1). With the reservoir at or near full pool (Elevation 1,280 – 1,290 feet above mean sea level (msl) the lower 13.0 km of the Sanpoil and 45.2 km of the Spokane rivers are inundated under the backwaters of Grand Coulee Dam, forming the Sanpoil River Arm of Lake Roosevelt and the Spokane River Arm of Lake Roosevelt respectively.

In 2013, fish were collected at the head of the Sanpoil Arm, in two tributaries of the Spokane River (Blue Creek, Spokane RKM 19.2 and Spring Creek, Spokane RKM 44.4), and two tributaries along the Columbia River mainstem at: Alder Creek (RKM 1,058.8); and Big Sheep Creek (RKM 1,186.1). In 2014, fish were sampled at the head of the Sanpoil River, in Blue and Spring creeks in the Spokane River, in the mainstem of Columbia River from Alder Creek, Wilmont Creek (RKM 1,055.0), Big Sheep Creek, and Onion Creek (RKM 1,180.0; Figure 1).

Fish Collection

Fish were collected from the Sanpoil River via boat electrofishing 12-13 km from the confluence with the Columbia (Figure 1). At Blue and Spring creeks in the Spokane River, fish were captured using stationary weir traps, dip netting, and backpack electrofishing. At Wilmont and Alder creeks, in the middle of the reservoir, fish were captured via stationary weir traps and backpack electrofishing. At Big Sheep and Onion creeks fish were captured using a rotary screw trap, stationary weir traps, and angling. Redband Trout were measured [total length (TL, mm), fork length (FL, mm)], weighed (g), and scanned for a Passively Integrated Transponder (PIT) tag. Fish were surgically implanted with acoustic transmitters and PIT tags (if they did not already have one). See below for details of these procedures.

Capture method, sex, sexual maturity, acoustic tag, and PIT tag numbers were recorded. A scale sample for aging and spawning history of fish was collected and a tissue sample from a spiny rayed fin was taken for genetic analysis and stored in 95% ethanol. These samples were given to the Spokane Tribe of Indians (STOI) for further analysis. Data from age, spawning history, and growth have not been analyzed and are not included in this report.

Surgical Tag Implantation

The transmitters were placed into fish that already engaged in spawning for the year (kelts) or were first time emigrants from their streams to Lake Roosevelt. Three different sized acoustic transmitters were purchased from Vemco® (Table 1 and 2). All three acoustic coded tag types used in this study transmitted a single 69 kHz identification code detectable by omnidirectional Vemco® VR-2 and VR-2W acoustic receivers. The smallest tags (V-7) were used for smaller fish (smolts) that were likely emigrants from the tributaries to Lake Roosevelt for the first time, while larger tags (V-9 and V-13) were used for kelts. Weight burden associated with the tags can influence the swimming behavior of the fish and to compensate for this, tag burden for this study was maintained at a strict maximum of 2% of the fish's total body weight in air (Winter 1983; Brown et al. 1999).

The acoustic transmitters were inserted into the coelomic cavity using an in-field laparotomy following the procedure set forth by Harms (2005) and Deter et al. (2010). In addition to acoustic tags, PIT tags were implanted in fish that did not have a PIT tag at time of capture. These tags consist of an integrated circuit chip, antenna coil, and capacitor in glass (Smyth and Nebel 2013) and are used to detect the fish as they enter tributaries or move below the dam through PIT tag arrays. Some of the spawning tributaries (Sanpoil River, Big Sheep Alder, Blue, and Spring creeks) that the fish were collected in and several dams in the Columbia mainstem (e.g., Rocky Reach, McNary, and Bonneville Dams) were equipped with PIT tag arrays that detect the presence of fish implanted with PIT tags. These tags were either inserted by a large gauge needle or surgically implanted into the body cavity in the same incision as the acoustic transmitter.

Table 1. Specifications of the transmitters used in 2013 Redband Trout tagging study in Lake Roosevelt Washington summarizing tag type, number (n), dimensions, nominal delay, frequency, power output, fish weight requirement and estimated tag life in days.

Tag type	*n*	Length (mm)	Diameter (mm)	Weight in air (g)	Weight in water (g)	Nominal Delay (sec)	Frequeny (kHz)	Power output (dB re 1uPa @1m)	Fish Weight requirement	Est. Tag Life (Days)
V7	12	20	7	1.6	0.75	60-180	69	136	> 32 g	336
V9	12	29	9	4.7	2.9	60-180	69	146	> 94 g	522
V13	12	36	13	11	6	60-180	69	147	> 220 g	1117

Table 2. Specifications of the transmitters used in 2014 Redband Trout tagging study in Lake Roosevelt Washington summarizing tag type, number (n), dimensions, nominal delay, frequency, power output, fish weight requirement and estimated tag life in days.

Tag type	*n*	Length (mm)	Diameter (mm)	Weight in air (g)	Weight in water (g)	Nominal Delay (sec)	Frequeny (kHz)	Power output (dB re 1uPa @1m)	Fish Weight requirement	Est. Tag Life (Days)
V7	15	20	7	1.6	0.75	60-180	69	136	> 32 g	376
V9	15	29	9	4.7	2.9	60-180	69	146	> 94 g	484
V13	15	36	13	11	6	60-180	69	147	> 220 g	1019

To surgically implant tags, the fish were brought to stage IV anesthesia (complete loss of muscle tone, equilibrium, spinal reflexes, and regular opercular movements; Summerfelt and Smith 1990; Stroud et al. 2014) using AQUI-S 20E© at a concentration of 28.5 mg of eugenol/L of water for takedown solution and the fish were held under with a maintenance solution that was half the concentration of the takedown solution (14.25 mg of eugenol/L of water; Stroud et al. 2014) during the surgical procedure. The fish were individually placed into a takedown solution mixed with water collected on site. The anesthetic bath ranged from 7 to 21 L of water depending on fish size. For fish tagged in the Sanpoil River in 2014, the Colville Confederated Tribes (CCT) used Low Volt Electroanesthesia (LVEA) to anesthetize fish for surgery.

Once stage IV anesthesia was reached, the fish was weighed (g) and total and fork lengths (mm) were measured. The fish was then positioned ventral side up on a V-shaped foam trough where a small tube was placed in the mouth of the fish which allowed maintenance solution to move freely over the gills. The surgical site between the pectoral and the pelvic fin was cleaned with betadine (Harms 2005; Stroud et al. 2014) and a single incision, just long enough to fit the respective size tag, was made with a sterile single-use steel scalpel. The incisions was deep enough to puncture the coelomic cavity, the tag was inserted, and the incision was closed with two to four interrupted surgeons' knots (Wagner 2000 and 2005; Deters et al. 2010). Once the last knot was tied, a pit tag was inserted into the pelvic girdle and a scales were collected from the dorsal side, above the lateral line, and behind the dorsal fin (Murphy and Willis 1996). The fish was placed individually into a large recovery tank filled with fresh water from the collection stream or gently held in slack water in the capture stream until fully recovered. All fish were returned to the stream they were originally captured from. Between surgeries all non-disposable equipment was cold sterilized with CIDEX OPA (CIVCO Medical Solutions, Kaloa, Iowa) bath for 15 minutes at room temperature and rinsed three times with distilled water. Time (sec) of induction (time to reach stage IV), surgery, and recovery was recorded. The average (± SD) time of induction to reach stage IV anesthesia was 224 sec (± 132). The average time (± SD) to perform a surgery and for the fish to recover from a surgery were 136 (± 111) and 545 (± 307) seconds respectively.

Acoustic Tracking

Following the tagging, fish were detected on an acoustic array (Figure 1) to determine the movements of Redband Trout in Lake Roosevelt. Acoustic tracking has been commonly used to determine long-term movements and migratory routes of fish (Heupel et al. 2006; Espinoza et al. 2011). In the past, managers of Lake Roosevelt have successfully tagged and tracked wild and hatchery origin Kokanee Salmon (*Oncorhynchus nerka*) and White Sturgeon (*Acipenser transmontanous*) using acoustic tracking (Howell and McLellan 2007; Stroud et al. 2011, 2012, and 2014; Seibert et al. 2015).

The tags used in this study transmitted a pulsed ultrasonic sound wave into the environment. Each tag is encoded with a unique transmitter number that is detected by stationary receiving units that are equipped with omnidirectional hydrophones (Figure 1 and 2). The tags are programed to transmit a sound wave at random between one and three minutes (Table 1 and 2). This design reduces the amount of ‘noise’ caused by sound wave collisions and by doing this, the chances of false detections or tag collisions are greatly reduced (discussed below).

Currently, 72 receivers are deployed within the study area, forming an array (Figure 1). Three different organizations manage the array. The EWU Fisheries Research Center is responsible for the southernmost section of the array (*n* = 34) which involved maintenance and downloading of four buoys below Grand Coulee dam, all the buoys in the Sanpoil and the Spokane, and all buoys in the Columbia River from Grand Coulee to Hunters, Washington. The receivers from Gifford to the Canadian border (*n* = 16) are maintained by the STOI and in Canada, B.C. Hydro maintains receivers (*n* = 22) in the Columbia River between the international border and Hugh Keenleyside Dam and in the Kootenay River between the confluence with the Columbia and Brilliant Dam.

The array consists of VEMCO© VR-2W and VR-2 submersible receivers. The receivers are attached to a white can buoy, anchored to a 300 lbs. (or more) weight with a permaflex cable (Figure 2). The receivers dangle 10 feet below the buoy into the water column on a cable separate of the anchor line (Figure 2). This design is commonly used and it allowed the receiving device to float free of the mooring line and limited the potential disruption of the acoustic signals that can be caused by the mooring equipment (Figure 2).

Each of the receiving units' records (24-hours a day, 365 days a year) and logs (long-term) data from tagged fish. These data include a unique serial number along with the time and date of detection. The data were downloaded from the receivers bimonthly for the receivers maintained by EWU and two to four times a year for the receivers maintained by STOI and B.C. Hydro. The receivers were able to communicate wirelessly, through a blue tooth device, to a computer with VEMCO© VUE software. This created

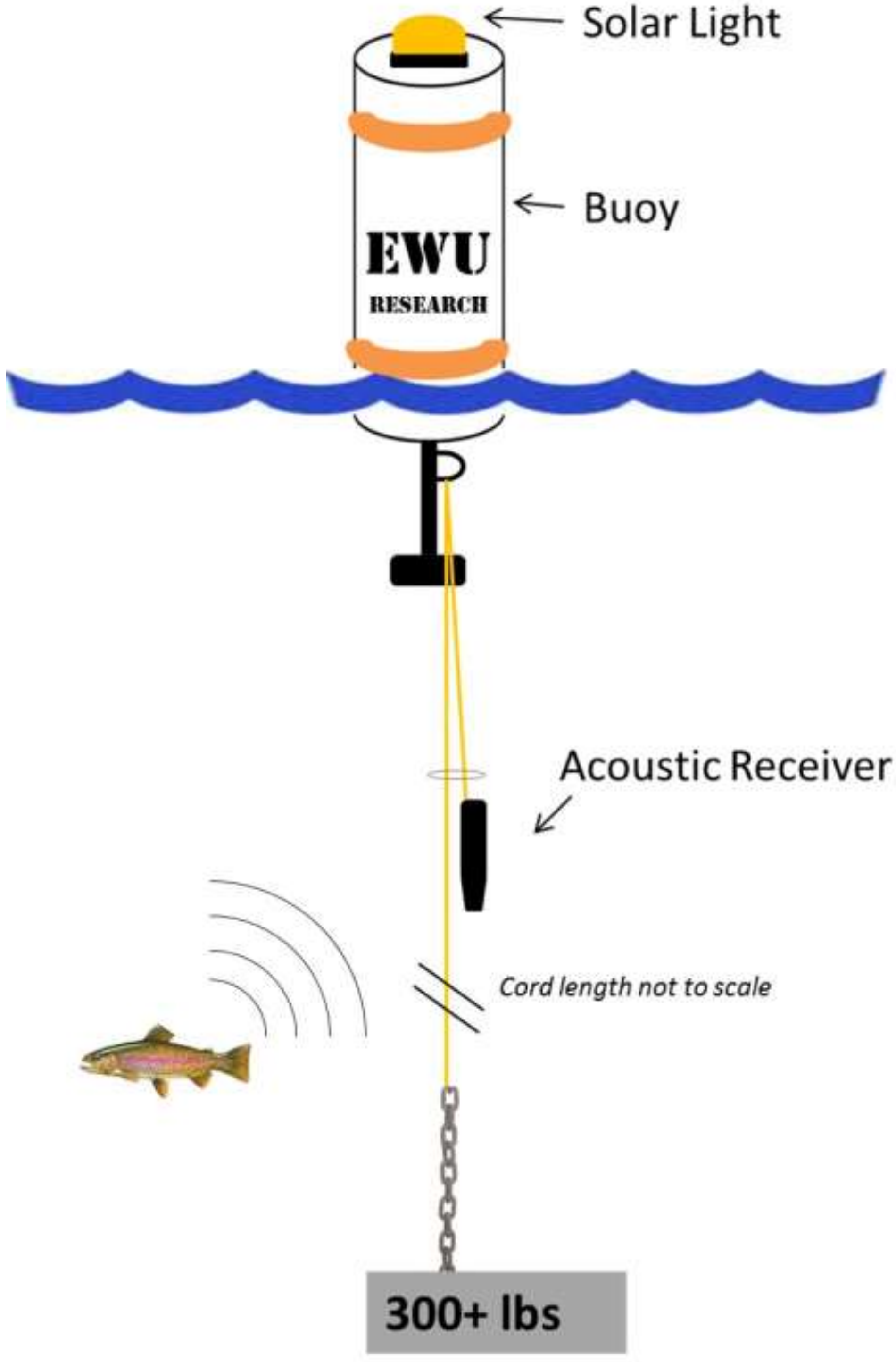

Figure 2. Commonly used buoy, receiver, and anchor design in Lake Roosevelt, Washington.

an interface that we retrieved data logged on the receiver for the entirety of the survey and all data were stored in a master database created in the Vue© program. Data were exported as a .csv Excel® file and were shared among agencies through a Dropbox® file or Hydra® website. All the data from this study were stored in raw form on an external hard drive and digital copies of the raw data were maintained separate of any analysis. Data were stored as a .csv and sorted and analyzed by Program R.

Detection Criteria

Signal collisions and false detections, though uncommon, occur and may cause an inaccurate representation of the data. VEMCO© suggests all data are subjected to two criteria and if they fail to meet these criteria then those data should be removed from the dataset.

Criteria one refers to false detections. A false detection occurs when a receiving unit misinterprets the environmental noise as a signal from a tagged fish. As a result, the receiver will detect and log a tag that is not there. Each tag comes with an “error detection code” that is a string of extra data sent with the unique ID coded tag transmissions. This extra data signals that the receiver has a genuine detection. If the extra data is not included in the transmission, the receiver will assign it as a false detection and will not log the code. Despite this, it is recommended that all logged transmissions must meet these criteria before acceptance (Pincock 2012). In order for the transmission to be verified, two or more detections had to be acquired from the same fish at the same receiver or within reasonable distance from the last detected receiver in a predetermined time (<9 minutes based on a 180 second nominal delay).

The second criterion for data refers to signal collisions. A signal collision is when two or more tags in the same area send a transmission at the same time. When the signals hit the receiver at the same time a disruption, scrambling, or mixing of signals occurs and has the potential to cause a receiver to log an invalid signal (Pincock 2012). The receiver may detect a signal similar to the type listed in criteria one, and as such, it will not be logged. If an invalid detection was found in the data, tag collisions were considered and the data were removed.

Range Testing

Many studies have suggested that the efficacy of deployed receivers be tested to determine their ability at detecting acoustic tags (Heupel et al. 2006; Espinoza et al. 2011). Environmental variables (i.e. water temperature, water velocity, weather, and ambient noise) can cause a disruption in the transmission of acoustic signals that result in the signal being blocked, missed, or scattered at different rates over time (Heupel et al. 2006). Each location is unique in channel width and depth and other environmental variables that make it difficult to predict where issues with detection in the array may be.

It is suggested by Vemco© that the receiving units are placed in such a manner that even in the worst possible environmental conditions (i.e. high water flow, turbulence) 50% of the signals transmitted by a test tag are recovered. Vemco© has determined a conservative maximum detection distance of 500 meters for each receiver unit after rigorous testing. Range testing of the receivers in Lake Roosevelt has been conducted since 2009 and most recently in the spring of 2014. These tests were performed on individual receivers and the test tags were deployed at a variety of distances and depths for ten minutes. The test tag had a nominal delay of five seconds and would generate 120 transmissions in ten minutes. Since each tag was deployed for ten minutes at a time we were able to determine a detection probability by dividing the total number of detected signals by the total number of signals generated from the test tag. These data were incorporated into the error parameters associated with the analysis of the movement data of the fish.

In addition to range testing in the field, which only gives you a small snapshot in time of the ability of the receiver to detect tags, trajectories of the fish were examined to determine the proportion of buoys missed by a single fish. For example, if a fish was traveling north and the fish was detected on receiver A and receiver C, but not receiver B, it is likely that the fish was not detected by receiver B when the fish should have been detected. “Trajectory detection testing” was performed on data collected in 2014 because this is the most recent array set up. With these data we generated a proportion for the number of missed detections out of the total number of detections for the entire array and for each receiver unit. These data were used to identify holes within the array and with these data and data from range testing, these holes can be addressed.

Utilization Distribution

The design of this study resulted in coarse locations and irregular time stamps that required us to analyze these data using a state-space modeling technique (Dynamic Brownian Bridge Movement Model; DBBMM) in R. This technique has been widely used for terrestrial animals (Johnsen et al. 2005; Horne et al. 2007) and allows us to interpolate where the animal is when it is not being detected. This methods develops a trajectory (path of animal movements through an area) for each animal for a given amount of time (Horne et al. 2007). Because this method assumes that continuous observation of the animal is impossible it uses discreet locations along a predicted trajectory. From these trajectories, the utilization distribution (the relative frequency of use in an area) is developed (Horne et al. 2007). The frequency of use in an area by an animal is estimated by treating each location along the trajectory as "approximately known" and using the properties of "conditional random walk" (Turchin 1998) to model expected movement paths between successive pairs of locations (Horne et al. 2007). The Brownian motion is extended in our analysis so that the movements are based on the beginning and ending locations of each pair and termed Brownian Bridge (Ross 1983; Horne et al. 2007). The mathematics associated with this technique can be seen in Horne et al. (2007). The DBBMM can be used when the movements of animals are extended over a period of time that result in unequal space-time observations and it is assumed that the error associated with these observations are normally distributed. Location error estimates in the model were determined from range testing of the receivers.

This study is unique because we have been able to adapt this technique for an aquatic organism. In the past, data similar to ours have been analyzed using kernel density analysis (Stroud et al. 2014; Stroud and Scholz 2014). However, kernel density is limited in that it is a technique that uses smoothing parameters on location data. Kernel density assumes observations are independent of one another and does not consider the time or behavior associated with the detections, whereas DBBMM does not assume independence and explicitly incorporates time between locations in the model (Horne et al. 2007; Horne and Garton 2006). DBBMM allows for ecologically relevant connectivity between points and while the smoothing parameter in kernel estimation may allow for "connectivity," there is no ecological relevance (Powell 2000).

DBBMM used individual fish locations to estimate the movements or trajectory of the fish using the "move" package developed by B. Kranstauber and M. Smolla in R. These trajectories include both spatial and temporal data and have been constrained to the river through an iterative process that was developed for this study. From these trajectories a map of the utilization distribution (UD) was constructed using the DBBMM. These distributions indicated the relative probability of an individual fish occupying an area within the reservoir. A UD was created for each fish and averaged to generate a UD for the tributary group. These averaged UD's were then compared to one another using the Mantel's test in the "vegan" package in R.

The Mantel's test is a correlation method in which dissimilarity/distance matrices are summarized as pairwise comparisons. This method is a correlation between entries of two matrices and since significance cannot be directly assessed Mantel's test is asymptotic where it uses permutations of *N* rows and columns of the matrix (Legendre and Legendre 1998). As a formal hypothesis test, it summarizes the strength of the correspondence between two matrices. The rows and columns of the matrices are subjected to random permutations and significance is determined from the proportion of these random permutations that lead to a higher correlation coefficient. The Mantel's test tests the null hypothesis that two matrices are unrelated (Dutilleul et al. 2000) and so, if the null hypothesis is "true" it makes sense that permuting the matrices should be equally as likely to lead to a larger or smaller coefficient. Because the null hypothesis is that the two matrices are different, significance values were reported as q or $1 - p$ and a q-value below the significance level of 0.05 indicated that the two matrices were different. A Mantel's test statistic (r) is similar to a correlation coefficient.

Because the Mantel's test compares two rasters the test can be biased by resolution of the rasters. To mitigate for this we compared two maps at thirteen different raster resolutions and plotted the test statistic and p-value against the resolution. The native resolution of 1875 was used because there was not a difference in p-value or test statistic when resolution was varied from 20,000 to 100. Mantel's tests were completed for each comparison of tributary groups as a whole, year to year, and by seasons resulting in a total of 58 comparisons. Seasons were identified as spring (March, April, and May), summer (June, July, and August), fall (September, October, and November), and winter (December, January, and February).

Homing

Homing was determined through the use of PIT tag data and acoustic receivers set near the home stream (i.e. the receiver nearest to the stream in which the fish had been tagged). As Redband Trout do not spawn every year (Scholz and McLellan 2010; McLellan et al. 2015), it is likely that not all fish will be detected returning to spawn and more likely that fish tagged with a v-9 or v-13 will be detected homing in the following years of the study. Each fish was implanted with a PIT tag and the Sanpoil River, Blue Creek, Alder Creek, and Big Sheep Creek have PIT tag arrays in the stream to detect and conclusively confirm that fish entered the stream. Return to other tagging streams was determined by movements detected near tagging streams during spawning season (February to June). The proportion of the fish that exhibited homing was determined by dividing the number that returned to their original tagging stream by the total number of fish that were implanted with acoustic transmitters in that stream for a given year. Because the last date of downloads for this report occurred in April and does not encompass the entire 2015 spawning season, only 2013 fish that returned in 2014 were analyzed.

Entrainment

Entrainment was detected by four buoys (3 in 2014) 10.5 km below Grand Coulee Dam. Despite this, it was still possible for a fish to entrain without detection because these buoys are subject to a high degree of interference from changes in flow and turbidity. However, only fish that were confirmed to have entrained (detected below the dam) were considered in this analysis. Since data will be collected through 2016, fish that were last detected on the two buoys (Spring Canyon 1 North and South) above the dam and were not detected anywhere else in the reservoir should be considered "possible" entrainers and included in future analysis. PIT tag arrays down stream of Grand Coulee Dam at Rocky Reach, McNary, and Bonneville Dams, can detect entrained fish as the move further downstream. These data were queried at PTAGIS.com.

Entrainment events were compared to reservoir operations by graphically displaying the reservoir operations (inflow, outflow, and elevation) as a function of time and plotting the entrainment events. The size class of the fish and proximity of tagging stream to the dam were also analyzed to determine if these variables influenced the fishes' likelihood of entrainment. Because of the low number of fish that entrained in the two years of this study, no statistical analysis was completed.

Results

Range Testing

Forty two receivers were trajectory detection tested. None of the receivers in B.C. were included in this analysis because there were not enough detections in B.C. to generate trajectories. The receivers in Rufus Woods were excluded because there was not enough receivers to generate a trajectory below the dam. Because this form of testing requires a detection before and a detection after a missed detection, terminal receivers (e.g. last receiver in the Sanpoil River) were also excluded from this analysis. The receivers in the north had the highest proportion of missed detections with the receiver near Flat Creek Eddy missing nearly 55% of the detections (Table 3). A comparison of the receivers maintained by the STOI and EWU using a Mann-Whitney rank sum test indicated that Receivers maintained by the STOI had a significantly higher rate of missed detections then receivers maintained by EWU (U = 108.5; $T_{15,27}$ = 416.5; p = 0.014).

Tagging

Fifty fish (17 females, 10 males, and 23 unknown sex; average total length: 408 ±148 mm) were tagged from April to May in 2013 in five tributaries and sixty fish (21 females, 26 males, and 13 unknown sex; average total length: 457 ±56 mm) were tagged in 2014 from March to May in seven tributaries. A summary of the information from both tagging seasons can be found in Table 4. Data were collected from April 2013 to April 2015 for a total of 24 months of data.

EWU tagged all of the fish in 2013 and 2014 except the fish in the Sanpoil River, which were tagged by the CCT. Thirty-seven out of the 50 fish tagged 2013 were detected and of the 13 fish not detected, four were less than 200 mm in total length. Eleven out of 50 fish tagged were less than 200 mm in TL (Table 4). Of the 37 fish, 14 were suspected to have expelled the tag or died as indicated by no movements for three or more months (Table 5). All fish movements until date of death or tag expulsion were included in analysis.

Table 3. Summary of detections from acoustically tagged Redband Trout on acoustic receiver array in Lake Roosevelt, WA. This includes total number of detections recorded, number of fish trajectories that each receiver is a part of and number of missed trajectories. % missed detections is number of missed on trajectory/total number of trajectories*100. Page 1 of 2.

Receiver	Total detections	Number of missed trajectories	Total number of trajectories	% missed
01 Spring Canyon	31123	4	34	11.76
02 Spring Canyon	27618	3	34	8.82
03 Spring Canyon	29648	1	34	2.94
04 Plum Point	31250	0	34	0
05 Plum Point	18795	1	34	2.94
06 Camel Rocks	8137	0	34	0
07 Camel Rocks	4993	1	34	2.94
08 Keller Ferry BL	3194	5	34	14.71
09 Keller Ferry	11693	9	41	21.95
10 Hanson Harbor	15529	8	28	28.57
11 Whitestone Creek	11563	5	28	17.86
12 Whitestone Rock	4973	4	28	14.29
13 Halverson Canyon	31400	2	28	7.14
14 Burbot Creek	3038	2	28	7.14
15 Hawk Creek	4558	2	28	7.14
16 Seven Bays	2547	2	15	13.33
17 Castle Rock	3891	2	15	13.33
18 Wilmont Cove	5301	3	15	20
19 Hunters	12400	5	15	33.33
Sanpoil Mouth Bouy A West	861	7	51	13.73
Sanpoil Mouth Bouy A East	1931	8	51	15.68
SP1 Sanpoil Mouth	2132	4	45	8.89
SP2 Sanpoil Middle	5639	6	45	13.33
SR1 Fort Spokane	809	4	27	14.81
SR2 McCoy's Marina	8968	3	27	11.11
SR3 Upper Spokane River	16129	0	29	0
SR4 Harker Canyon	543	2	29	6.90
Big Sheep Creek	19709	0	15	0
Bissell Island	21124	2	11	13.33
Chalk Grade	1622	5	11	45.45
China Bend	7851	5	11	45.45

Table 3 continued on next page

Table 3. Continued summary of detections from acoustically tagged Redband Trout on acoustic receiver array in Lake Roosevelt, WA. This includes total number of detections recorded, number of fish trajectories that each receiver is a part of and number of missed trajectories. % missed detections is number of missed on trajectory/total number of trajectories*100. Page 2 of 2.

Receiver	Total detections	Number of missed trajectories	Total number of trajectories	% missed
Flat Creek Eddy	12	6	11	54.54
French Rocks	7353	1	15	9.09
Gifford	2384	1	15	6.67
Kettle Falls Marina	698	2	15	13.33
Little Dalles Eddy	103	5	15	33.33
Milepost 110	66	6	15	40
Mission Point	1622	2	11	18.18
Nancy Creek	425	5	15	33.33
North Gorge	16	5	11	45.45
Northport	56	1	11	9.09
Snag Cove	32	2	11	18.18

Table 4. Tagged rainbow Trout and transmitter codes with associated capture tributary (AC = Alder Creek, BC = Blue Creek, BS = Big Sheep Creek, OC= Onion Creek, SC = Spring Creek, SR = Sanpoil River, WC= Wilmont Creek), total length (mm), total weight (g), sex (F = female, M = male, U = unknown) and sexual maturity status (SO = spawned out, R=ripe, IM = immature, M = mature and not spawned, U = unknown). Page 1 of 5.

Year-ID#	Date	Trib	Tag Size	Acoustic ID code	TL (mm)	Wt (g)	Sex	Maturity
13-01	4/26	BS	V13	A69-1601-28923	535	1184	F	SO
13-02	4/26	BC	V7	A69-1601-8782	170	41	U	IM
13-03	4/26	BC	V7	A69-1601-8780	163	31	U	IM
13-04	5/1	SC	V13	A69-1601-28932	540	1503	F	SO
†13-05	5/1	BC	V7	A69-1601-8778	164	36	U	IM
13-06	5/1	BC	V7	A69-1601-8777	180	46	U	IM
13-07	5/1	BC	V7	A69-1601-8787	180	41	U	IM
13-08	5/1	BC	V7	A69-1601-8788	171	43	U	IM
13-09	5/1	BC	V7	A69-1601-8779	160	29	U	IM
13-10	5/1	BC	V7	A69-1601-8781	156	32	U	IM
13-11	5/1	BC	V7	A69-1601-8786	155	33	U	IM
13-12	5/1	BC	V13	A69-1601-28931	490	903	F	SO
†13-13	5/2	BS	V13	A69-1601-28921	456	941	M	SO
13-14	5/2	BS	V13	A69-1601-28942	535	1459	F	SO
†13-15	5/7	BC	V13	A69-1601-28926	313	244	M	SO
13-16	5/8	SP	V9	A69-1601-10170	511	918	M	SO
13-17	5/8	SP	V9	A69-1601-10164	476	1013	U	IM
13-18	5/8	SP	V9	A69-1601-10169	512	1140	U	IM
13-19	5/9	AC	V13	A69-1601-28922	574	1710	F	SO
13-20	5/9	AC	V13	A69-1601-28925	493	976	F	SO
13-21	5/9	AC	V7	A69-1601-8784	189	60.5	U	IM
†13-22	5/11	AC	V13	A69-1601-28928	558	1294	F	SO
13-23	5/16	SC	V7	A69-1601-8783	184	55	U	IM
13-24	5/16	SC	V7	A69-1601-8785	162	39	U	IM

Table 4 continued on next page

Table 4. Continued tagged rainbow Trout and transmitter codes with associated capture tributary (AC = Alder Creek, BC = Blue Creek, BS = Big Sheep Creek, OC= Onion Creek, SC = Spring Creek, SR = Sanpoil River, WC= Wilmont Creek), total length (mm), total weight (g), sex (F = female, M = male, U = unknown) and sexual maturity status (SO = spawned out, R=ripe, IM = immature, M = mature and not spawned, U = unknown). Page 2 of 5.

Year-ID#	Date	Trib	Acoustic Tag	Acoustic ID code	TL (mm)	Wt (g)	Sex	Maturity
13-25	5/16	SC	V13	A69-1601-28927	546	1235	F	SO
†13-26	5/16	AC	V13	A69-1601-28929	446	693	M	SO
13-27	5/16	BC	V13	A69-1601-28930	295	212	M	SO
13-28	5/16	BC	V9	A69-1601-8800	472	1065	M	SO
†13-29	5/17	BS	V9	A69-1601-8789	616	1802	F	SO
13-30	5/17	BS	V9	A69-1601-8799	524	1273	F	SO
13-31	5/17	BS	V9	A69-1601-8794	496	1151	F	SO
13-32	5/17	BS	V9	A69-1601-8795	472	1014	M	SO
13-33	5/17	BS	V9	A69-1601-8790	518	1314	M	SO
13-34	5/17	BS	V9	A69-1601-8791	500	1198	F	SO
13-35	5/17	BS	V9	A69-1601-8796	549	1437	F	SO
†13-36	5/23	BS	V9	A69-1601-8798	319	323	U	IM
†13-37	5/23	BS	V9	A69-1601-8797	370	558	U	IM
†13-38	5/23	BS	V9	A69-1601-8793	421	780	U	IM
†13-39	5/23	BS	V9	A69-1601-8792	420	699	U	IM
†13-39	5/23	BS	V9	A69-1601-8792	420	699	U	IM
13-40	5/15	SP	V9	A69-1601-10160	422	817	U	M
†13-41	5/15	SP	V9	A69-1601-10161	521	1470	U	M
13-42	5/15	SP	V9	A69-1601-10162	412	641	U	M
†13-43	5/15	SP	V9	A69-1601-10163	550	1197	M	SO
13-44	5/15	SP	V9	A69-1601-10165	414	798	U	U
13-45	5/15	SP	V9	A69-1601-10166	420	655	F	SO
13-46	5/15	SP	V9	A69-1601-10167	531	1119	F	SO
†13-47	5/15	SP	V9	A69-1601-10168	518	1501	F	SO

Table 4 continued on next page.

Table 4. Continued tagged rainbow Trout and transmitter codes with associated capture tributary (AC = Alder Creek, BC = Blue Creek, BS = Big Sheep Creek, OC= Onion Creek, SC = Spring Creek, SR = Sanpoil River, WC= Wilmont Creek), total length (mm), total weight (g), sex (F = female, M = male, U = unknown) and sexual maturity status (SO = spawned out, R=ripe, IM = immature, M = mature and not spawned, U = unknown). Page 3 of 5.

Year-ID#	Date	Trib	Acoustic Tag	Acoustic ID code	TL (mm)	Wt (g)	Sex	Maturity
13-48	5/21	SP	V9	A69-1601-10171	528	1157	F	SO
13-49	5/22	SP	V9	A69-1601-10172	536	1058	M	SO
13-50	5/22	SP	V9	A69-1601-10173	490	891	U	SO
13-51	5/22	SP	V9	A69-1601-10174	469	1171	U	SO
14-01	3/17	SP	V13	A69-1601-25979	575	2160	F	R[b]
†14-02	3/17	SP	V13	A69-1601-25974	419	781	F	R
14-03	3/17	SP	V13	A69-1601-25984	391	539	M	R
14-04	3/17	SP	V13	A69-1601-25985	561	1668	M	R
14-05	3/17	SP	V9	A69-1601-14458	452	854	M	R[b]
14-06	4/9	AC	V13	A69-1601-25980	443	1000	M	R
14-07	4/9	AC	V13	A69-1601-25975	492	1550	M	R[b]
14-08	4/9	AC	V13	A69-1601-25976	357	650	M	R
14-09	4/9	AC	V9	A69-1601-14457	519	1650	F	R[b]
14-10	4/9	AC	V9	A69-1601-14456	495	1225	M	R[b]
14-11	4/9	AC	V9	A69-1601-14455	411	800	M	R
14-12	4/9	AC	V9	A69-1601-14454	547	1700	F	SO[b]
14-13	4/9	AC	V9	A69-1601-14453	437	900	M	R
14-14	4/16	OC	V13	A69-1601-25981	515	1207	F	SO
14-15	4/16	OC	V7	A69-1601-15682	268	177	M	SO
14-16	4/23	WC	V13	A69-1601-25986	536	1506	M	R[b]
14-17	4/23	WC	V13	A69-1601-25977	513	1223	F	R
†14-18	4/23	WC	V9	A69-1601-14452	380	553	M	R
14-19	4/23	WC	V13	A69-1601-25982	515	1093	F	R
14-20	4/23	WC	V9	A69-1601-14451	402	597	M	R[b]

Table 4 continued on next page

Table 4. Continued tagged rainbow Trout and transmitter codes with associated capture tributary (AC = Alder Creek, BC = Blue Creek, BS = Big Sheep Creek, OC= Onion Creek, SC = Spring Creek, SR = Sanpoil River, WC= Wilmont Creek), total length (mm), total weight (g), sex (F = female, M = male, U = unknown) and sexual maturity status (SO = spawned out, R=ripe, IM = immature, M = mature and not spawned, U = unknown). Page 4 of 5.

Year-ID#	Date	Trib	Acoustic Tag	Acoustic ID code	TL (mm)	Wt (g)	Sex	Maturity
14-21	5/1	OC	V7	A69-1601-15684	252	177	F	M
14-22	5/1	OC	V9	A69-1601-14450	377	505	M	SO[b]
14-23	5/2	BC	V13	A69-1601-25987	507	1135	F	SO[b]
14-24	5/2	BC	V7	A69-1601-15674	465	1156	M	SO[b]
14-25	5/2	BC	V7	A69-1601-15671	427	832	F	SO
14-26	5/2	BC	V9	A69-1601-14449	513	1243	M	SO [b]
14-27	5/2	AC	V9	A69-1601-14448	429	973	F	SO
14-28	5/7	BC	V9	A69-1601-14447	404	597	F	SO
14-29	5/7	BC	V7	A69-1601-15675	468	1053	M	SO[b]
14-30	5/7	AC	V7	A69-1601-15672	462	1254	M	R[b]
14-31	5/7	AC	V7	A69-1601-15673	357	439	M	R
†14-32	5/9	OC	V9	A69-1601-14446	493	1087	F	SO
14-33	5/14	SP	V7	A69-1601-15676	421	647	F	M
†14-34	5/21	BS	V13	A69-1601-25978	523	1254	F	SO
14-35	5/21	BS	V13	A69-1601-25983	524	1415	F	SO
†14-36	5/21	BS	V13	A69-1601-25988	550	1680	M	R
14-37	5/21	BS	V9	A69-1601-14444	530	1441	M	R
14-38	5/21	BS	V9	A69-1601-14445	494	983	F	SO
14-39	5/21	BS	V7	A69-1601-15679	525	1279	M	M [b]
14-40	5/21	BS	V7	A69-1601-15668	483	1095	F	SO
†14-41	5/21	BS	V7	A69-1601-15678	527	1186	M	SO
14-42	5/21	BS	V7	A69-1601-15671	464	983	M	SO
14-43	5/24	OC	V7	A69-1601-15669	471	911	M	SO
14-44	5/28	OC	V7	A69-1601-15670	464	1090	F	M [b]

Table 4 continued on next page

Table 4. Continued tagged rainbow Trout and transmitter codes with associated capture tributary (AC = Alder Creek, BC = Blue Creek, BS = Big Sheep Creek, OC= Onion Creek, SC = Spring Creek, SR = Sanpoil River, WC= Wilmont Creek), total length (mm), total weight (g), sex (F = female, M = male, U = unknown) and sexual maturity status (SO = spawned out, R=ripe, IM = immature, M = mature and not spawned, U = unknown). Page 5 of 5.

Year-ID#	Date	Trib	Acoustic Tag	Acoustic ID code	TL (mm)	Wt (g)	Sex	Maturity
14-45	5/28	OC	V7	A69-1601-15677	462	984	M	SO
14-46	5/30	OC	V13	A69-1601-25974	510	1128	F	SO
14-47	4/18	SR	V9	A69-1601-15253	552	1716	U	-
†14-48	4/18	SR	V9	A69-1601-15254	426	874	U	-
†14-49	4/18	SR	V9	A69-1601-15255	406	720	F	IM[a]
14-50	4/18	SR	V9	A69-1601-15256	435	934	U	-
14-51	4/18	SR	V9	A69-1601-15257	423	989	U	-
†14-52	4/18	SR	V9	A69-1601-15258	437	869	U	-
14-53	4/18	SR	V9	A69-1601-15259	376	632	U	-
†14-54	4/18	SR	V9	A69-1601-15260	493	1197	U	- [b]
14-55	4/18	SR	V9	A69-1601-15261	380	746	U	-
14-56	4/18	SR	V9	A69-1601-15262	386	622	U	-
14-57	4/18	SR	V9	A69-1601-15263	415	780	U	-
14-58	4/18	SR	V9	A69-1601-15264	430	795	U	- [b]
14-59	4/18	SR	V9	A69-1601-15265	412	799	U	-
14-60	4/18	SR	V9	A69-1601-15267	477	1128	U	-
14-61	4/23	SR	V9	A69-1601-15266	535	1288	F	SO

[a] Fish angled on 10/20/2014, sex determined F (angler noted full of eggs)
† Indicates mortality
[b] Had not been detected on array

Table 5. Summary of Redband Trout tagging origin, number, tagging year, acoustic code, and day of death/expelled tag, as well as comments regarding angling of redbands in Lake Roosevelt, Washington. * indicates fish was angled, ** indicates tag from angled fish was replanted.

Fish (Origin_#_Tagging Year)	Acoustic Tag Code	Day of death/expelled tag
Sanpoil_4_13	10161	3/31/2014
Sanpoil_7_13	10163	7/29/2013
Sanpoil_10_13	10168	1/15/2014
BigSheep_6_13	28921	5/21/2013
Blue_11_13	28926	5/10/2013
Alder_4_13	28928	6/5/2013
Alder_5_13	28929	5/16/2014
Blue_12_13	28930	5/19/2013
Blue3_13	8778	5/23/2013
BigSheep_8_13	8789	5/31/2013
BigSheep1_13	8798	5/19/2013
BigSheep3_13	8792	5/25/2013
BigSheep_11_13	8793	5/24/2013
BigSheep2_13	8797	5/24/2013
Onion_4_14	14446	5/19/2014
Sanpoil_2_14	15254	4/18/2015
Sanpoil_6_14	15258	4/18/2014
Sanpoil_8_14	15260	4/18/2014
BigSheep_8_14	15678	10/10/2014
Blue_5_14	25978	5/28/2014
BigSheep_3_14	25988	6/15/2014
**Spring_2_14	25974	5/18/2014
*Wilmont_3_14	14452	8/1/2014
*Sanpoil_3_14	15255	10/20/2014

Table 6. Summary of Columbia River Redband Trout length of detections based on transmitter life and size. Page 1 of 4.

Tributary and Year	Acoustic ID Code	Tag Size	Transmitter Life (days)	# of days detected	Date tagged	Date of last detection	Homed?	Date Entrained
Sanpoil 2013	A69-1601-10160	v-9	522	314	5/15/2013	3/25/2014	Yes	
	A69-1601-10161	v-9	522	438	5/15/2013	7/27/2014		7/26/2013
	A69-1601-10162	v-9	522	532	5/15/2013	10/29/2014		
	A69-1601-10163	v-9	522	462	5/15/2013	8/20/2014	Yes	
	A69-1601-10165	v-9	522	12	5/15/2013	5/27/2013		5/27/2013
	A69-1601-10166	v-9	522	531	5/15/2013	10/28/2014		5/13/2014
	A69-1601-10167	v-9	522	506	5/15/2013	10/3/2014		
	A69-1601-10168	v-9	522	413	5/15/2013	7/2/2014	Yes	
	A69-1601-10169	v-9	522	18	5/8/2013	5/26/2013		
	A69-1601-10170	v-9	522	64	5/8/2013	7/11/2013		
	A69-1601-10171	v-9	522	73	5/21/2013	8/2/2013	Yes	
	A69-1601-10172	v-9	522	6	5/22/2013	5/28/2013		
	A69-1601-10173	v-9	522	520	5/22/2013	10/24/2014	Yes	
	A69-1601-10174	v-9	522	109	5/22/2013	9/8/2013		
Sanpoil 2014	A69-1601-15253	v-9	484	355	4/18/2014	4/8/2015		
	A69-1601-15254	v-9	484	104	4/18/2014	1/4/2014		
	A69-1601-15255	v-9	484	290	4/18/2014	10/21/2014		
	A69-1601-15256	v-9	484	355	4/18/2014	4/8/2015		
	A69-1601-15257	v-9	484	288	4/18/2014	1/31/2015		
	A69-1601-15258	v-9	484	271	4/18/2014	1/14/2015		
	A69-1601-15259	v-9	484	336	4/18/2014	3/20/2015		

Table 6 continued on next page

Table 6. Continued summary of Columbia River Redband Trout length of detections based on transmitter life and size. Page 2 of 4.

Tributary and Year	Acoustic ID Code	Tag Size	Transmitter Life (days)	# of days detected	Date tagged	Date of last detection	Homed?	Date Entrained
Sanpoil 2014	A69-1601-15261	v-9	484	282	4/18/2014	1/25/2015		
	A69-1601-15262	v-9	484	119	4/18/2014	8/15/2014		
	A69-1601-15263	v-9	484	326	4/18/2014	3/10/2015		
	A69-1601-15265	v-9	484	342	4/18/2014	3/26/2015		
	A69-1601-15266	v-9	484	314	4/23/2014	3/3/2015		
	A69-1601-15267	v-9	484	23	4/18/2014	5/11/2014		
Spring 2013	A69-1601-28927	v-13	1117	371	5/16/2013	5/19/2014		
Spring 2014	A69-1601-15676	v-7	376	6	5/14/2014	5/19/2014		
	A69-1601-25974	v-13	1019	84	3/17/2014	6/9/2014		
	A69-1601-25984	v-13	1019	12	3/17/2014	3/29/2014		
	A69-1601-25985	v-13	1019	94	3/17/2014	6/19/2014		
Blue 2013	A69-1601-28926	v-13	1117	46	5/7/2013	6/22/2013		
	A69-1601-28930	v-13	1117	29	5/16/2013	6/14/2013		
	A69-1601-28931	v-13	1117	26	5/1/2013	5/27/2013		
	A69-1601-8777	v-9	522	345	5/1/2013	4/11/2014		
	A69-1601-8778	v-9	522	111	5/1/2013	8/20/2013		
	A69-1601-8779	v-9	522	22	5/1/2013	5/23/2013		
	A69-1601-8780	v-9	522	23	4/26/2013	5/19/2013		
	A69-1601-8781	v-9	522	110	5/1/2013	8/19/2013		
	A69-1601-8787	v-9	522	121	5/1/2013	8/30/2013		
	A69-1601-8788	v-9	522	18	5/1/2013	5/19/2013		
	A69-1601-8800	v-9	522	158	5/16/2013	10/21/2013		

Table 6 continued on next page

Table 6. Continued summary of Columbia River Redband Trout length of detections based on transmitter life and size. Page 3 of 4.

Tributary and Year	Acoustic ID Code	Tag Size	Transmitter Life (days)	# of days detected	Date tagged	Date of last detection	Homed?	Date Entrained
Blue 2014	A69-1601-14447	v-9	484	300	5/7/2014	3/3/2015		
	A69-1601-15671	v-7	376	71	5/2/2014	7/12/2014		
Alder 2013	A69-1601-28922	v-13	1117	7	5/9/2013	5/16/2013		
	A69-1601-28925	v-13	1117	16	5/9/2013	5/25/2013	Yes	
	A69-1601-28928	v-13	1117	611	5/11/2013	1/12/2015		
	A69-1601-28929	v-13	1117	384	5/16/2013	6/4/2014		5/16/2014
	A69-1601-8784	v-9	522	104	5/9/2013	8/21/2013		
Alder 2014	A69-1601-14448	v-9	484	10	5/2/2014	5/12/2014		
	A69-1601-14453	v-9	484	23	4/9/2014	5/2/2014		
	A69-1601-14455	v-9	484	356	4/9/2014	3/31/2015		
	A69-1601-15673	v-7	376	18	5/7/2014	5/25/2014		
	A69-1601-25976	v-13	1019	330	4/9/2014	3/5/2015		
	A69-1601-25980	v-13	1019	205	4/9/2014	10/31/2014		
Wilmont 2014	A69-1601-14452	v-9	484	114	4/23/2014	8/15/2014		
	A69-1601-25977	v-13	1019	5	4/23/2014	4/28/2014		
	A69-1601-25982	v-13	1019	37	4/23/2014	5/30/2014		6/3/2014
Big Sheep 2013	A69-1601-28921	v-13	1117	319	5/2/2013	3/17/2014		
	A69-1601-28923	v-13	1117	47	4/26/2013	6/12/2013		
	A69-1601-8789	v-9	522	44	5/17/2013	6/30/2013		
	A69-1601-8790	v-9	522	530	5/17/2013	10/29/2014		
	A69-1601-8792	v-9	522	476	5/23/2013	9/11/2014	Yes	
	A69-1601-8793	v-9	522	472	5/23/2013	9/7/2014	Yes	
	A69-1601-8795	v-9	522	15	5/17/2013	6/7/2013		

Table 6 continued on next page

Table 6. Continued summary of Columbia River Redband Trout length of detections based on transmitter life and size. Page 4 of 4.

Tributary and Year	Acoustic ID Code	Transmitter Size	Transmitter Life (days)	# of days detected	Date tagged	Date of last detection	Homed?	Date Entrained
Big Sheep 2013	A69-1601-8796	v-9	522	355	5/15/2013	5/5/2014	Yes	
	A69-1601-8797	v-9	522	18	5/23/2013	6/10/2013		
	A69-1601-8798	v-9	522	17	5/23/2013	6/9/2013		
	A69-1601-8799	v-9	522	13	5/17/2013	5/30/2013		
Big Sheep 2014	A69-1601-14444	v-9	484	72	5/21/2014	8/1/2014		
	A69-1601-15671	v-7	376	52	5/21/2014	7/12/2014		
	A69-1601-15678	v-7	376	202	5/21/2014	12/9/2014		
	A69-1601-25978	v-13	1019	4	5/21/2014	5/25/2014		
	A69-1601-25983	v-13	1019	238	5/21/2014	1/14/2015		1/13/2015
	A69-1601-25988	v-13	1019	83	5/21/2014	8/12/2014		
Onion 2014	A69-1601-14446	v-9	484	214	5/9/2014	12/9/2014		
	A69-1601-15669	v-7	376	63	5/24/2014	7/26/2014		
	A69-1601-15677	v-7	376	9	5/28/2014	6/6/2014		
	A69-1601-25974	v-13	1019	10	5/30/2014	6/9/2014		
	A69-1601-25981	v-13	1019	154	4/16/2014	9/17/2014		8/5/2014

Sixty fish were tagged in 2014. Twenty-two fish have yet to be detected on the array. Most of the fish that were not detected were greater than 400 mm TL (average =461 mm, SD = 80 mm; Table 4). Three fish were harvested by anglers and seven others are suspected to have died or expelled their tags (Table 5). The number of days the each fish was detected, if the homed, and if the fish entrained can be found summarized in Table 6.

Sanpoil River

Fifteen Redband Trout were tagged in May 2013 in the Sanpoil River. The fish ranged in total length from 414 to 550 mm and included four post-spawn females, three post-spawn males and eight immature fish (Table 4). All Sanpoil River fish were tagged with v-9 Vemco© acoustic tags and half duplex PIT tags. One fish, an immature, was never detected. Of the remaining 14, two fish (immature) were detected on the acoustic receivers in Rufus Woods Reservoir in May and July. Because these fish were tagged with half duplex PIT tags it is unlikely that these fish will be detected on any of the downstream PIT tag arrays as they can only detect full duplex PIT tags.

Fifteen Redband Trout were tagged in April 2014 in the Sanpoil River. The fish ranged in total length from 376 to 552 mm and included one post spawn female, one immature female, and 13 immature, undetermined sex fish (Table 4). All Sanpoil River fish were tagged with v-9 Vemco© acoustic tags and half duplex PIT tags. One fish, a sexually immature fish was caught by an angler on October 20th near Whitestone Rock at Columbia River RKM 994.4 and was reported to be full of eggs by the angler (Table 5). Two fish, both immature, were never detected.

Spring Creek

Four Redband Trout were tagged in May 2013 in Spring Creek with the assistance of the Spokane Tribe of Indians (STOI). The size ranged from 162 to 546 mm and included two post spawn females and two immature fish. (Table 4). These fish were tagged with v-7 and v-13 Vemco© acoustic tags and full duplex PIT tags. Only one (post spawn female) out of the four fish tagged has been detected.

Five Redband Trout, two ripe females and three ripe males, were tagged on March 17, 2014 with help from the STOI. The size ranged from 391 to 575 mm (Table 4). Spring Creek experienced a flood in the spring of 2014 and deposited sediments at the mouth which prevented emigration and immigration into and out of the creek. Water from the creek still flows subsurface through these sediments into the Spokane River. Because of this, fish were netted from pools in the stream, tagged, and released in the mainstem of the Spokane River near the former mouth of Spring Creek. These fish were tagged with v-9 and v-13 Vemco© acoustic tags and full duplex PIT tags. One fish, a ripe female, was angled near Plum Point at Columbia River RKM 975 on May 15, 2014 (Table 5) and the tag was returned and implanted in an Onion Creek fish. Three (two ripe males and a ripe female) out of five fish were detected by the receiver array.

Blue Creek

Thirteen Redband Trout were tagged in Blue Creek from April to May in 2013 with assistance from the STOI. Fish were tagged with v-7, v-9, and v-13 Vemco© acoustic tags and full duplex PIT tags. Size ranged from 155 to 490 mm and included four post spawn fish (1 female, 3 males) and nine immature, sex undetermined fish (Table 4). Two immature fish tagged were not detected on the array. One fish (#8781) tagged in Blue Creek in 2013 was detected on the Canadian array from 9/4/2013 to 3/20/14 at Rock Island at Columbia River RKM 1,242.0. This fish was detected moving up as far as Hugh Keenlyside Dam at RKM 1,257.0.

Six Redband Trout were tagged in Blue Creek in May 2014 with help from the STOI. Size ranged from 404 to 513 mm and included three post-spawn males and three post-spawn females that were tagged with v-7, v-9, and v-13 Vemco© acoustic tags and full duplex PIT tags (Table 4). Two fish were detected on the array.

Alder Creek

Five Redband Trout were tagged in Alder Creek in May 2013 with assistance from STOI. Total length ranged from 189 to 574 mm and included four post spawn (one male, three females) and one immature tagged with v-7 and v-13 Vemco© acoustic tag and full duplex PIT tags (Table 4). All five were detected on the array. Eleven Redband Trout were tagged in Alder Creek in April and May 2014 with help from STOI. Total length ranged from 357 to 547 mm and included two post spawn females, eight ripe males, and one ripe female tagged with v-7, v-9, and v-13 Vemco© acoustic tags and full duplex PIT tags. (Table 4). Six fish (five ripe males and one post spawn female) were detected by the acoustic receiver array.

Wilmont Creek

Five fish were tagged in April 2014 in Wilmont Creek with help from CCT. Total length ranged from 380 to 536 mm and included two ripe females and three ripe males tagged with v-9 and v-13 Vemco© acoustic tags and full duplex PIT tags (Table 4). One fish, a male, was caught by an angler near Plum Point at RKM 975.0 on August 1, 2014.

Three fish (two ripe females and one ripe male) were detected on the acoustic receiver array (Table 5).

Big Sheep Creek

Fourteen Redband Trout were tagged in Big Sheep Creek in April and May 2013 with the help of the Washington Department of Fish and Wildlife (WDFW). Total length ranged from 319 to 616 mm and included seven post spawn females, three post spawn males, and four immature fish tagged with v-9 and v-13 Vemco© acoustic tags and full duplex PIT tags (Table 4). Seven fish (four post spawned females, one post spawned male, and two undetermined sex) were detected on the array.

Nine Redband Trout were tagged in Big Sheep Creek in May 2014 assistance from WDFW and Justin and Dean Hotchkiss (local anglers). Total length ranged from 464 to 550 mm and included four post spawn females, two post spawn males, and three ripe males were tagged with v-7, v-9, and v-13 Vemco© acoustic tags and full duplex PIT tags (Table 4). Seven fish (two post spawn males, three post spawn females, and two ripe males) were detected on the array. Fish #25978 was detected in Canada from 6/25/2014 to 7/2/2014. This fish was detected at RKM 1251.0 north of the international border before returning downstream.

Onion Creek

Nine Redband Trout were tagged in Onion Creek in April and May with help from WDFW. Total length ranged from 252 to 515 mm and included three post spawn females, four post spawn males, and two mature fish were tagged with v-7, v-9 and v-13 Vemco© acoustic tags and full duplex PIT tags (Table 4). Four fish (two post spawn females, one mature female, and one post spawn male) were detected on the acoustic receiver array.

Utilization Distribution

The utilization distributions (UD) in Figure 3, 4, 5, and 6 give, with 95% confidence, the areas of the reservoir where the group of fish frequently used. Individual UDs were developed and averaged to generate overall UDs. The warmer colors (red) indicate areas of relatively high use and the cooler colors (green) are areas of relatively low use, normalized between 0 and 1. The overall UDs represent the entire detection histories of the fish.

Sanpoil River

Sanpoil river fish utilized the lower portion of the reservoir more frequently than the northern portion of the reservoir with areas of high use near the Sanpoil River and Grand Coulee Dam (Figure 3a and 3b). The fish did not utilize any areas above Rice, WA at RKM 1,114.0.

Spokane River (Spring/Blue Creek)

Fish tagged in the Spokane River were observed to utilize nearly the entire reservoir in 2013 (Figure 4a). These fish were detected as far north as Kettle Falls, WA at RKM 1,141.0 and as far down stream as Grand Coulee at RKM 960.0 (Figure 4a). In 2014, fish tagged in the Spokane River utilized the lower portion of the reservoir from Grand Coulee to Hunters at RKM 1,064.0 (Figure 4b).

Alder/Wilmont Creek

Redbands tagged in Alder Creek in 2013 utilized the southern portion of the reservoir (Figure 5a) and fish tagged in Alder and Wilmont Creek 2014 used the entire reservoir (Figure 5b).

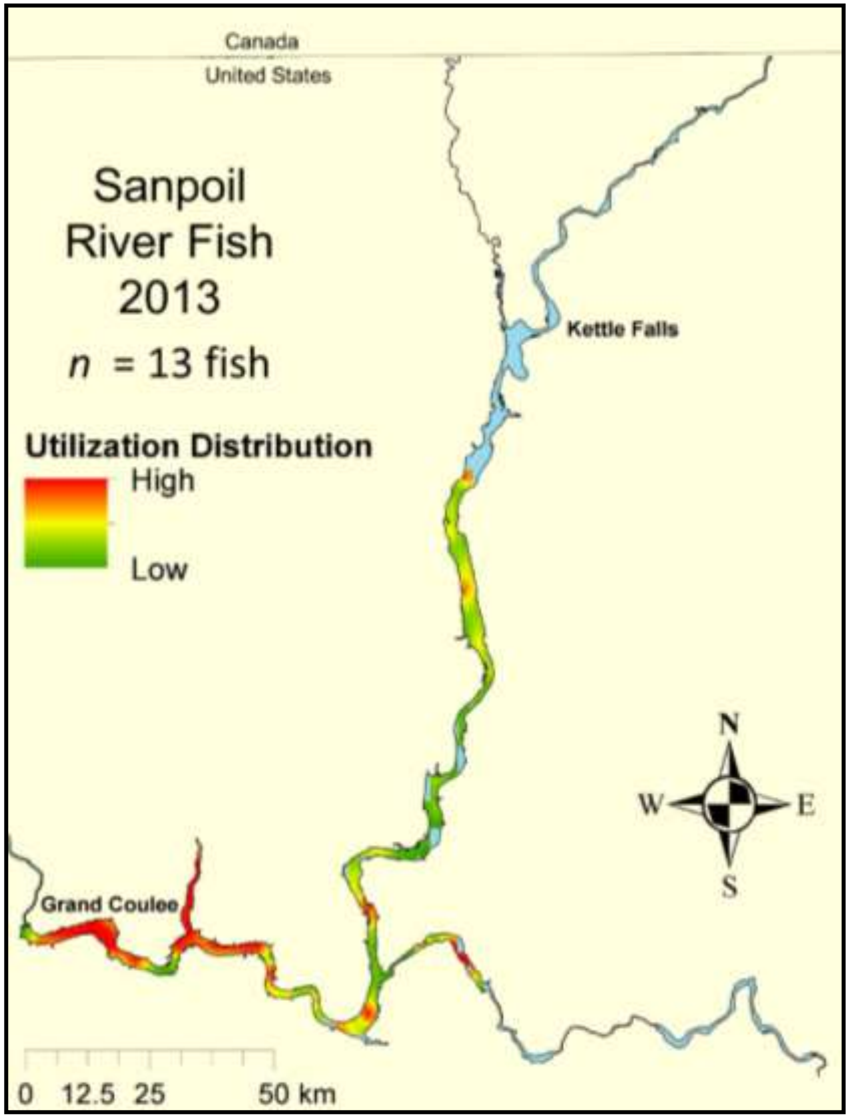

Figure 3a. Utilization distribution of Redband trout tagged in the Sanpoil River in 2013 and entire tracking history in Lake Roosevelt.

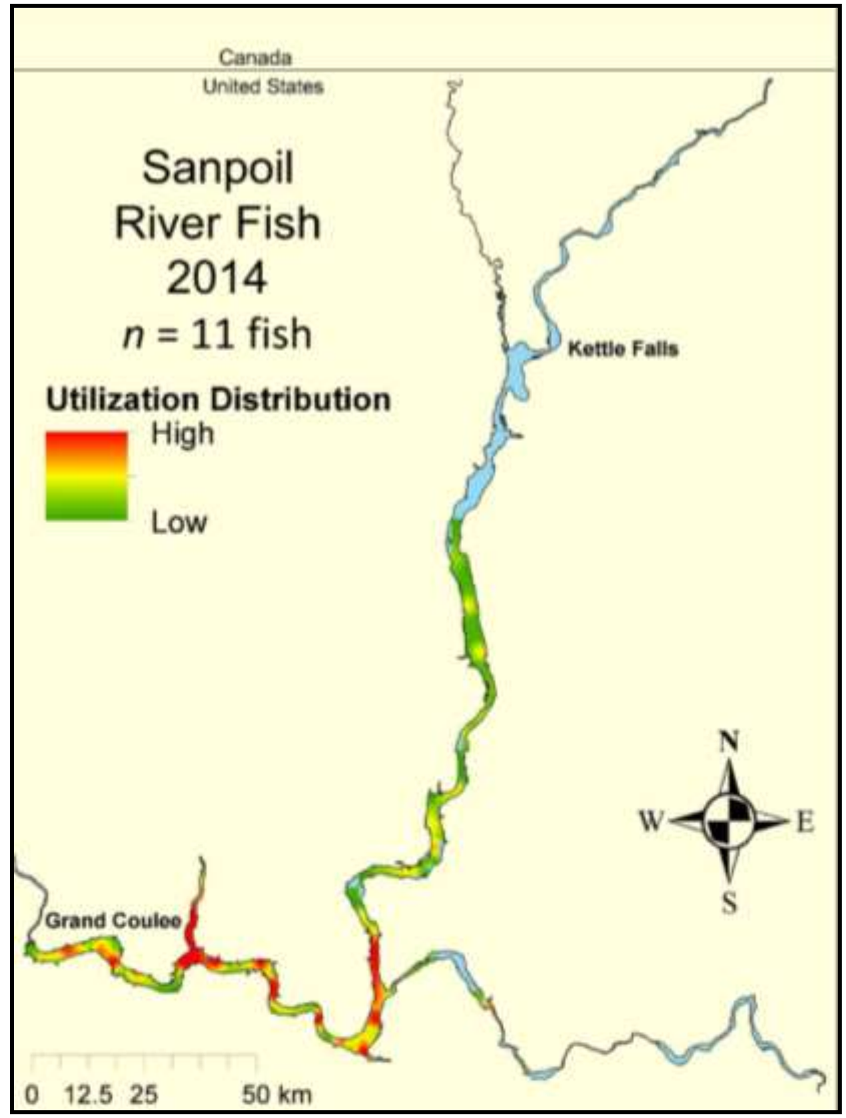

Figure 3b.Utilization distribution of Redband trout tagged in the Sanpoil River in 2014 and entire tracking history in Lake Roosevelt.

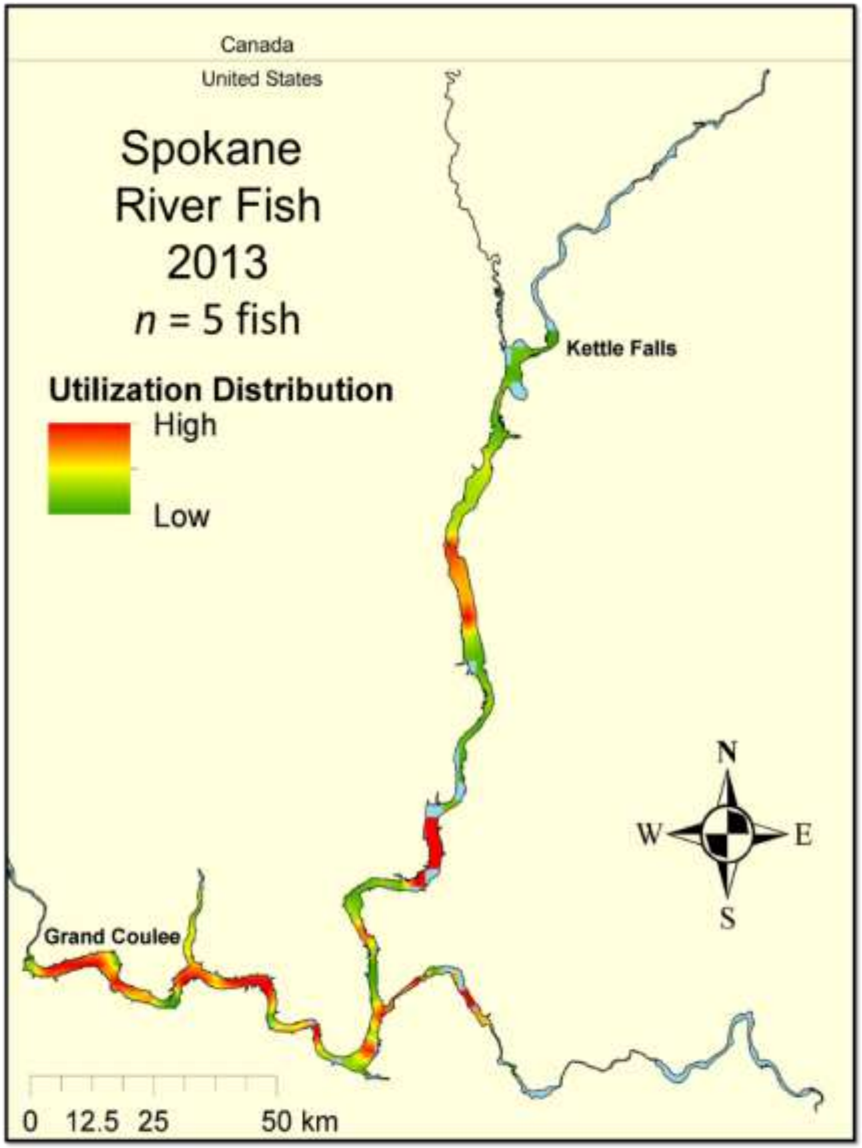

Figure 4a. Utilization distribution of Redband trout tagged in the Spokane River in 2013 and entire tracking history in Lake Roosevelt.

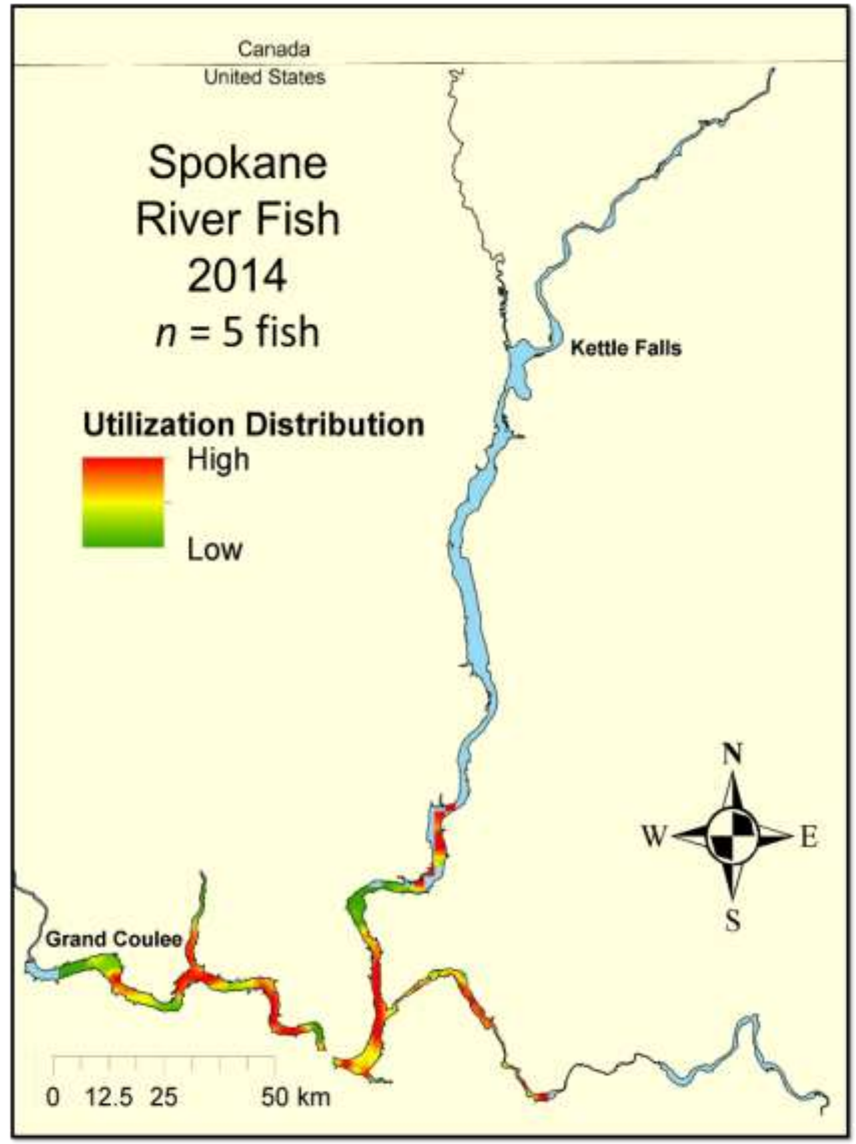

Figure 4b. Utilization distribution of Redband trout tagged in the Spokane River in 2013 and entire tracking history in Lake Roosevelt.

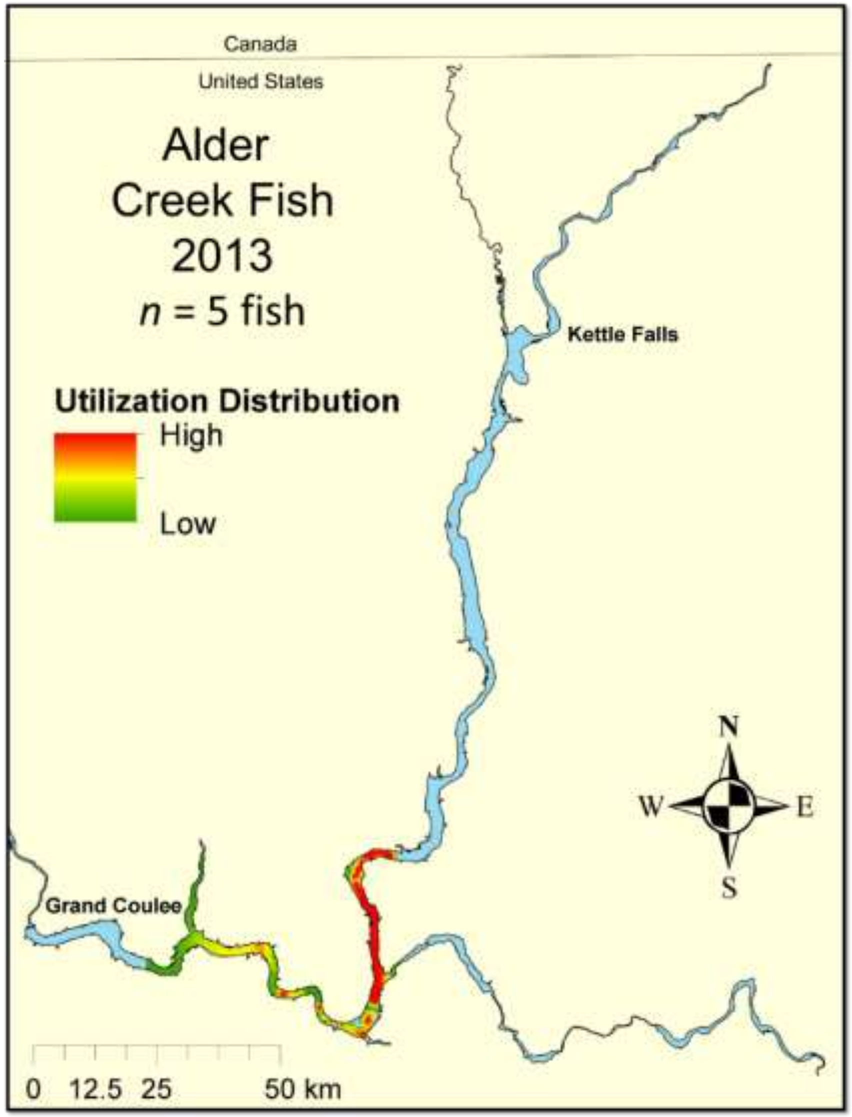

Figure 5a. Utilization distribution of Redband trout tagged in Alder Creek in 2013 and entire tracking history in Lake Roosevelt.

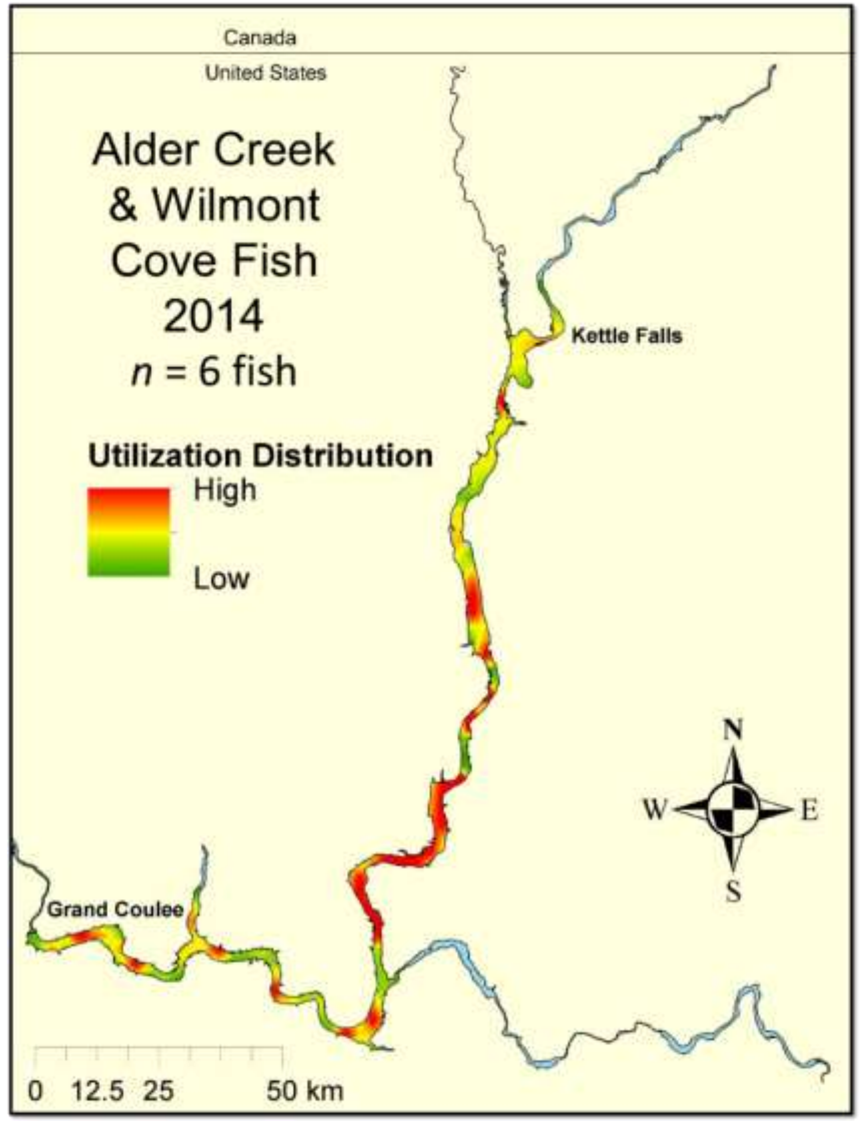

Figure 5b. Utilization distribution of Redband trout tagged in Alder and Wilmont Creek in 2014 and entire tracking history in Lake Roosevelt.

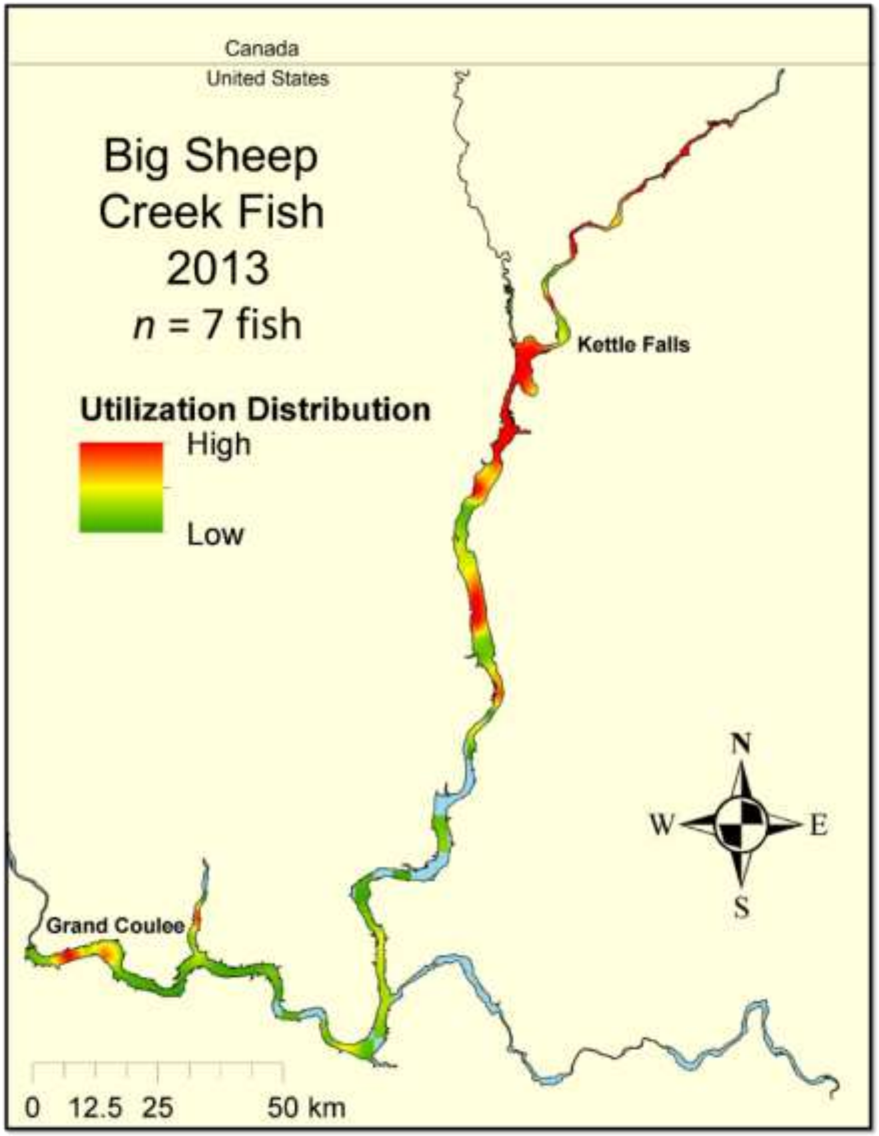

Figure 6a. Utilization distribution of Redband trout tagged Big Sheep Creek in 2013 and entire tracking history in Lake Roosevelt.

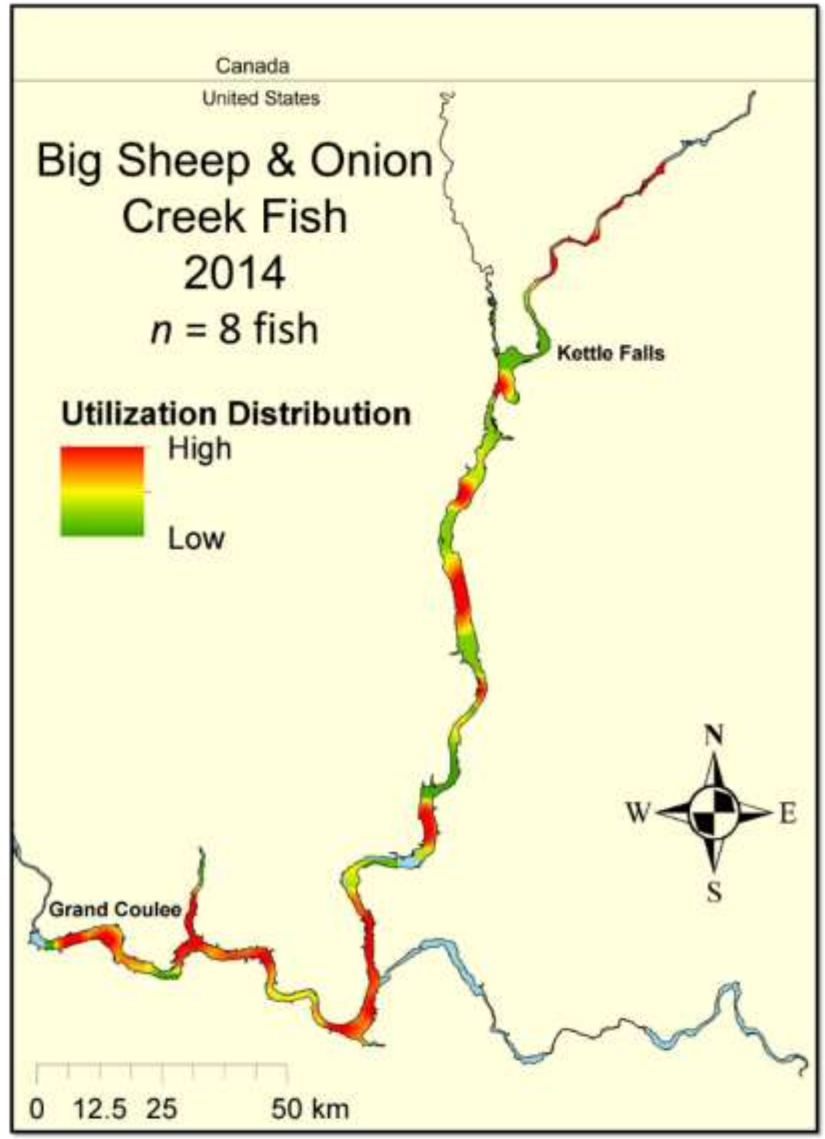

Figure 6b. Utilization distribution of Redband trout tagged Big Sheep Creek and Onion Creek in 2014 and entire tracking history in Lake Roosevelt.

Big Sheep/Onion Creek

Fish tagged in Big Sheep and Onion creeks were observed to use the entire reservoir (Figure 6a and 6b). Fish from the 2013 tagging season utilized areas north of Hunter's (RKM 1,064.0) most frequently (Figure 6a) while, fish tagged in 2014 were observed to have areas of high use throughout the entire reservoir (Figure 6b).

Utilization Distribution Comparisons & Differences

Fifty four comparisons were tested for significant overlap in their space utilization using the Mantel's test and Spearman's correlation (Table 7). The comparisons compared overall spatial distributions and comparisons were also made between years to determine year to year variability (Table 7). Seasonal comparisons can be found in Appendix B. Year to year variation was not significant for any of the groups (Table 7). The Sanpoil River fish UD's compared to the Big Sheep Creek UD's in 2013 (r = 0.045, q = 0.020; Table 7) and those from Big Sheep/Onion in 2014 (r = 0.064, q = 0.019; Table 7) were significantly different. All other UD comparisons were not significantly different.

Homing

Five fish tagged in 2013 (33%) from the Sanpoil River were suspected to have homed back to their natal stream. Table 8 summarizes the fish numbers and their suspected times of returns. Fish #10163 and #10168 were suspected to have died or expelled the tag from their lack of movement for 3 or more months, however, there was a period of time (~2 months) during the spawning season where these fish were not detected indicating a possible spawning event during that time. Fish number #10171 does not have a detection history after 8/2/2013, so it is likely that this fish expelled its tag or the tag stopped working. No fish tagged in 2013 returned to Spring Creek or Blue Creek

Table 7. Utilization distribution (UD) pairwise comparisons for year, total UD's, and by season for Redband Trout tagged in different tributaries of Lake Roosevelt in 2013 and 2014. UD's compared with a Mantel's test using a Spearman's correlation method. Mantel's test statistic "*r*" and *q* (1-*p*) are shown in the table.

UD1	UD2	Mantel statistic *r*	*q*-value
2013 and 2014 Comparisons			
Sanpoil	Sanpoil	0.951	0.999
Spokane	Spokane	1.000	0.999
Alder	Alder/Wilmont	0.836	0.999
Big Sheep	Big Sheep/Onion	0.990	0.999
2013 Overall Comparisons			
Sanpoil	Alder	0.789	0.999
Sanpoil	Spokane	0.789	0.998
Sanpoil	Big Sheep	0.045	0.020
Spokane	Alder	1.000	0.999
Spokane	Big Sheep	0.622	0.999
Alder	Big Sheep	0.632	0.999
2014 Overall Comparisons			
Sanpoil	Alder/Wilmont	0.973	0.999
Sanpoil	Spokane	0.910	0.999
Sanpoil	Big Sheep/Onion	0.064	0.019
Spokane	Alder/Wilmont	0.836	0.999
Spokane	Big Sheep/Onion	0.617	0.998
Alder/Wilmont	Big Sheep/Onion	0.584	0.998

Table 8. Summary table of possible spawning events from Redband Trout tagged in 2013 that includes if the Redband Trout tagged in Lake Roosevelt tributaries returned to tagging tributary (homing), if it was detected in stream by a PIT tag reader, when the fish was likely in the tributary, and comments about its movements.

Tagging Stream	Acoustic Code	Homed?	1st PIT Detection	2nd PIT Detection	Last acoustic detection	First acoustic detection
Sanpoil	10160	Yes	-	-	3/25/14	?
Sanpoil	10163	Yes	-	-	4/1/14	6/7/14
Sanpoil	10168	Yes	-	-	3/5/14	5/20/14
Sanpoil	10171	Yes	4/29/14	-	-	-
Sanpoil	10173	Yes	5/1/14	-	4/14/14	6/1/14
Big Sheep	8793	Yes	-	-	4/3/14	6/27/14
Big Sheep	8796	Yes	-	-	5/5/14	?
Big Sheep	8792	Yes	-	-	5/8/14	6/25/14
Alder	28925	Yes	3/28/13	4/29/14	-	-

Table 9. Summary of the fish size, tagging origin and date, and *date of first detection below Grand Coulee Dam, for the entrainment events of Redband Trout Tagged in 2013 and 2014 and tracked until April 2015.

Tag Number	Tagging Origin	Date Tagged	Date Entrained*	TL (mm)
A69-1601-10161	Sanpoil R.	5/15/2013	7/26/2013	521
A69-1601-10165	Sanpoil R.	5/15/2013	5/27/2013	414
A69-1601-10166	Sanpoil R.	5/15/2013	5/13/2014	420
A69-1601-28929	Alder Ck.	5/16/2013	5/16/2014	446
A69-1601-25981	Onion Ck.	4/16/2014	8/5/2014	515
A69-1601-25982	Wilmont Ck.	4/23/2014	6/3/2014	515
A69-1601-25983	Big Sheep Ck.	5/21/2014	1/13/2015	524

in 2014. Of the five fish tagged in Alder Creek, one fish (20%) was detected on PIT tag arrays during the spawning season (Table 8). However, this fish likely expelled its tag on 5/25/2013, because there is no detection history for this fish after 5/25/2013, just 16 days after it was tagged.

Of the 14 fish tagged in Big Sheep Creek, three (24%) were detected through the spawning season (Table 8). One fish (#8796) showed a lot of movement traveling down to Grand Coulee Dam, up the Sanpoil River, and returned to Big Sheep Creek on 5/5/2014. One fish (#8793) was detected near Big Sheep in April and was not detected until the end of June near Big Sheep Creek. The last fish was detected at Big Sheep Creek on 5/8/2014 and was not detected again until 6/25/201 near Big Sheep Creek.

Entrainment

A total of seven fish were confirmed to have entrained. Table 9 shows the date of entrainment, tagging stream, and size class of the fish that entrained. Three of the seven fish (~ 43%) tagged in the Sanpoil entrained. Two of the seven fish (~ 29%) that entrained were from Big Sheep/Onion area and two of the fish that entrained were tagged in the Alder/Wilmont area. All of these fish were larger than 400 mm in total length (Table 4 and 6). Due to the small number of entrainment events it would be inappropriate to conduct statistical analysis on these data. However, it is worth noting that reservoir operations (inflow, outflow, and elevation) were graphed and entrainment events were plotted (Figure 7).

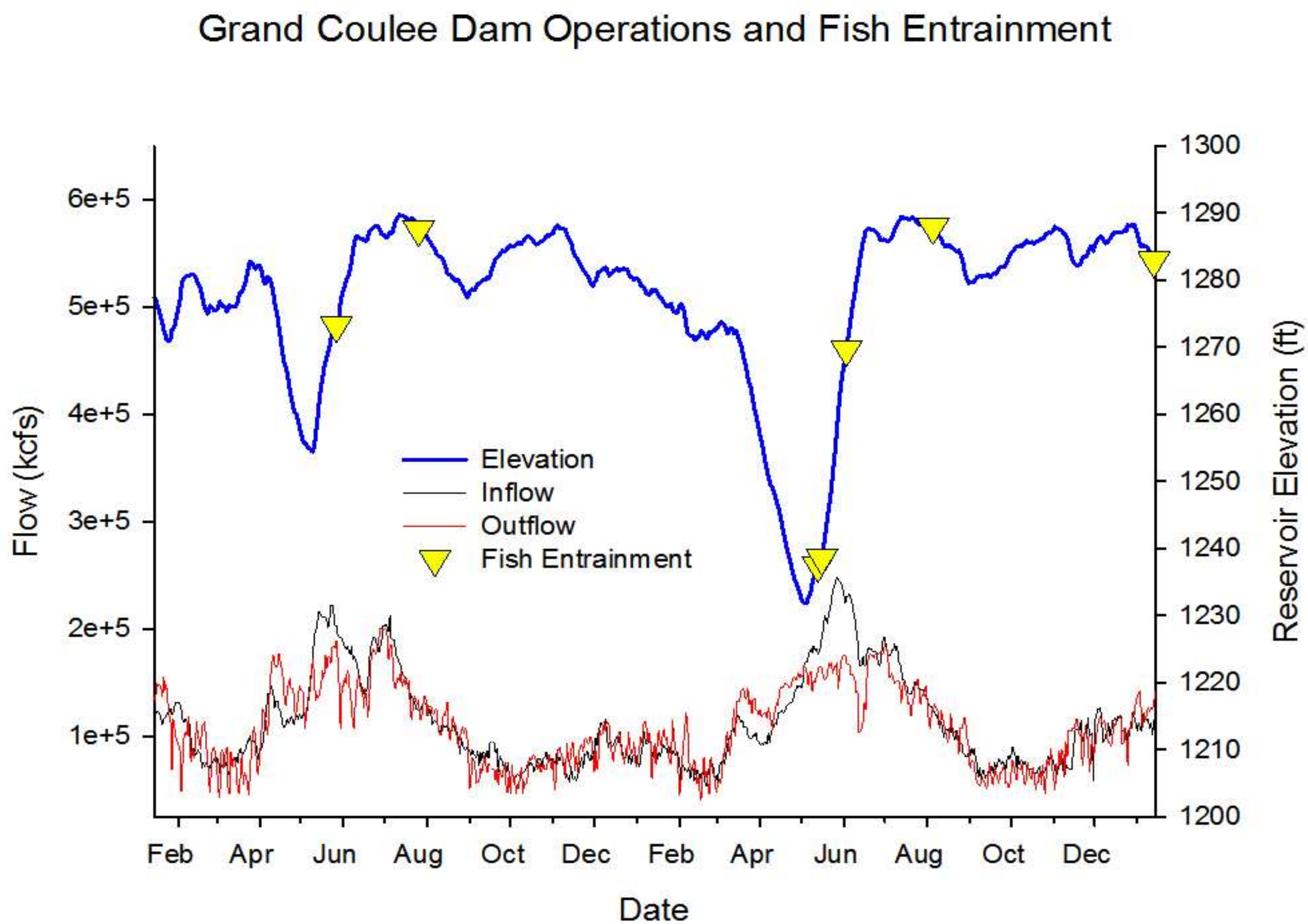

Figure 7. Entrainment events (yellow triangles) of acoustically tagged Redband trout in Lake Roosevelt plotted against date and reservoir operations (elevation, inflow, and outflow).

Discussion

Range Testing

Based on the high proportion of missed detections it appears that the ability of the northern portion (above Hunter's) of the array is not as effective at detecting fish as the southern portion (p = 0.014; Table 3). This may be because this area is faster flowing and coupled with the nominal delay of the tags (Table 1 and 2) it is possible that the fish can move past a receiver without being detected. This area is typically shallower and more turbid, which can influence the ability of the receivers to detect and decode tags (Pincock 2012).

Another possibility may be because Sturgeon that are acoustically tagged in that area have been shown to remain in the same location for long periods of time (Howell and McLellan 2007) and this increases the likelihood of tag collisions. It is possible that the tag collisions may influence the detection rate of Redbands as tags from Sturgeon will ping and collide with tags from redband resulting in no tags being logged (Parametrix 2005). Another possibility is the frequency of downloads for this part of the reservoir. The STOI downloads between two and four times a year and it is possible that some of the receivers are down for longer periods of time than expected. To mitigate for this, we recommend downloading at minimum four times a year.

Lastly, reduced detection rates in this part of the reservoir could be the result of geomorphology of the river. The river tends to be shallower and narrower, which could result in reflection of signals that cause scrambling or mixing of signals similar to what occurs with tag collisions (Parametrix 2005). When this occurs, the code is not logged.

To mitigate for this, each receiver should be range tested and geomorphology should be evaluated to determine if this may influence detection rates.

Detection Histories

Fifteen of the 51 (29%) fish tagged in 2013 had a detection history that continued into 2014. However, 12 of the tags were v-7 which had a tag life of around 336 days (Table 1), so it makes sense that these fish would not be detected into 2014 and only 39 fish would be detected into 2014. Thirty-eight percent (15/39) of the fish that should have been detected in 2014 were detected in 2014. Most detection histories (93%) ended between June and August of 2013 for the 2013 tagged fish, well in advance of the tag expiration date (Appendix B). Creel surveys indicate that wild rainbow trout were harvested all year long with peak fishing between April and May and the third highest peak was in August in 2012 (McLellan et al. 2015). It is possible that the small number of fish detected in 2014 from the 2013 tagging season were the result of mortality, possibly due to angling pressure. Angling pressure has been shown to be a strong factor contributing to mortality of wild Redband Trout and according to McLellan et al. (2015) 69% of the anglers surveyed in 2012 were targeting Rainbow/Redband Trout. Of the 1,194 fish observed by creel clerks in Lake Roosevelt in 2012, 150 were wild Redband Trout, 616 hatchery origin Rainbow Trout, 35 were undetermined origin, and the remainder were other species. Reservoir wide harvest trends suggest the majority of all wild Redband Trout harvest occurs in the lower third portion of the reservoir (between Grand Coulee Dam and Keller, including the Sanpoil River Arm of Lake Roosevelt) and anglers in this region are primarily targeting trout (~73%; McLellan et al. 2015; STOI unpublished data). It is possible that mortality could also be attributed to natural causes as well e.g. bald eagles are known to target Redband/Rainbow Trout in Lake Roosevelt and carry them to the nest to feed their young (Scholz 2014).

Utilization Distributions

The UDs were not significantly different from year (2013) to year (2014) for each group of fish, but were the most similar for the Sanpoil River fish (Figure 3a and 3b). Despite determining that there was no significant difference between the years for all sections (Table 6) we chose not to group the two years together for the comparisons. Each group of fish was exposed to differences in flow, climate, or other environmental variables, that can influence movements and effect our ability or lack thereof to detect differences. The differences between the UDs could also be attributed to random noise. Even though Alder and Wilmont creek were in close geographic proximity and there was not a significant difference between the years (r = 0.836, q = 0.999), the behavior of the fish was opposite between the two streams; fish tagged in Wilmont Creek utilized downstream habitat and Alder Creek fish tended to utilized upstream habitat. However, this was with a sample size of two fish at Wilmont Creek and four fish at Alder Creek which may have reduced the power to detect a difference. Overall, we chose to analyze the data for each year separately. Future analysis of these data should compare movements based on tagging stream, not only geographic area of the reservoir.

The major differences in UD occurred between the Sanpoil River and Big Sheep/Onion in both 2013 (r = 0.045, q = 0.020; Table 6) and 2014 (r = 0.064, q = 0.019; Table 6). This is in agreement with work done by Small et al. (2014) that found fish tagged in the Sanpoil River were genetically distinct from fish tagged in Big Sheep Creek (F_{st} = 0.0230, p = 0.000). According to Small et al. (2014) fish tagged in the Sanpoil were genetically similar to fish from the Wilmont/Alder area (F_{st} = 0.0103, p = 0.0099) and the Spokane River (Spring F_{st} = 0.0210, p = 0.002; Blue F_{st} = 0.0210, p = 0.002) at an alpha at 0.001. Only two fish were detected in Canada and because of this, these data were not incorporated into the UD or DBBMM. The use of Canadian waters by Redband Trout tagged in the United States does not appear to be frequent. Generally there was significant overlap in the UD's of the fish spatially. Overall, the biggest differences in UDs were observed between the most geographically distant groups (Sanpoil and Big Sheep/Onion) and this was in agreement with the genetic findings by Small et al. (2014).

Fish UDs were broken down by season, however, these data were representative of variable (n = 1 to 13) and small sample sizes with 40% of the 48 groups having fewer than four fish, which may not fully represent the movements of fish throughout the year. A summary of these movements can be found in Appendix C. It is also worth noting that the Mantel's test we used for the comparisons had some strong biases, especially when dealing with spatial autocorrelations (Guillot and Rousset 2013) and future analysis of these data should evaluate more robust techniques for comparing spatial rasters that could detect differences more effectively.

Homing

Of the nine fish that exhibit evidence of homing, two were previously considered possible mortalities (#10163 and #10168). The movements of these fish prior to spawning season were such that they illustrated no change in location for the entire time they were detected. Fish #10163 was consistently detected on Sanpoil receivers near Sanpoil Campground (most northern receiver in the Sanpoil River) every month until 4/1/2014 and was not detected again on the same receiver until 6/7/2014. This period of non-detection suggests that this fish resided in the northern part of the Sanpoil River Arm of Lake Roosevelt and migrated into the Sanpoil River to spawn. The same is true of fish #10168, which was detected on the northern most receiver of the Sanpoil River until 3/5/2014 and was not detected again until 5/20/2014. Presumably, this fish also migrated into the Sanpoil River to spawn. Sanpoil river fish have been shown to exhibit multiple life history strategies in the Sanpoil River through radio tracking of 125 Rainbow Trout (Brown et al. 2013). Thirty-six fish were classified as fluvial-adfluvial based on overwintering in the Sanpoil Arm of Lake Roosevelt (Brown et al. 2013). Our data from these two fish (#10163 and #10168) suggest a life history strategy of fluvial-adfluvial because these fish likely overwintered in the Sanpoil Arm of Lake Roosevelt and (McLellan et al. 2015; Brown et al. 2013).

Of the other two fish thought to have homed back to the Sanpoil River (#10160 and #10173), #10160 tagged on 5/15/2013 showed extensive movements throughout the lower reservoir and was last detected on the northern most Sanpoil River receiver on 3/25/2014, indicating a possibility that the fish returned to spawn. However, this fish was not detected again. It is possible that this fish died in the tributary or expelled the tag during this spawning season. Fish #10173 tagged on 5/22/2013 also showed extensive movements throughout the reservoir and was detected on the northern most Sanpoil River receiver on 4/14/2014 and was not detected again until 6/1/2014 on the same receiver, suggesting that this fish likely returned to the Sanpoil River, spawned, and then re-entered Lake Roosevelt as kelt in 2014. This fish continued to exhibit extensive movements in the lower and middle reservoir until 10/24/2014, when the tag was no longer detected and possibly stopped working because it was near the end of the tag life

(Appendix B). This fish was tagged with a v-9 (estimated life of 522 days; Table 2) on 5/22/2013 and the last detection of this fish was 520 days later.

The only other fish from 2013 that showed potential homing behavior were three fish tagged in Big Sheep Creek. One fish, #8792, was not detected on the array until 4/22/2014 (over a year after tagging). This fish was only detected on the receiver closest to Big Sheep Creek. It showed potential spawning as it was not detected between 5/8/2014 and 6/25/2014 and this fish may be a resident of Big Sheep Creek that did not utilize the reservoir since it was not detected anywhere else in the array. When fish #8792 was tagged it was recorded as immature, so it is possible that this fish resided in the stream to feed throughout the year and it is possible that this is not a spawning event.

Fish #8793 is similar to fish #8792 in that this fish was not detected on the array until 3/16/2014, almost a year until after it was initially tagged and stayed near Big Sheep Creek. It too was recorded as immature. Both fish were only detected on the receiver closest to Big Sheep Creek. Most likely these fish were residents or were not ready to migrate at the time of tagging. Benthic and pelagic macroinvertebrates are limited in the upper reservoir (Voeller 1993) and it is possible that these fish remained near Big Sheep Creek as the creek provided a source for food.

The last fish from Big Sheep, #8796, was detected throughout the reservoir as far down as Grand Coulee Dam. The fish moved up the entire Sanpoil Arm of Lake Roosevelt and the fish began migrating back to Big Sheep around the beginning of April and was detected at the mouth of Big Sheep on 5/5/2014. This fish was not detected again suggesting the tag stopped working (Appendix B), was expelled, or the fish died in the tributary. Only nine fish exhibited homing in 2014 from the 2013 tagging season, which is likely the result of mortalities (angling/predation), entrainment, or tag failure or loss. The low number of fish that spawned in 2013 may also be the result of an iteroparous life history.

Entrainment

Seven Redbands entrained from May 2013 to January 2015 (Table 8). Only one entrainment event was observed during the first two-week post tagging. It is worth noting that the fish was tagged in the Sanpoil River and displayed periods of obvious upstream movement (10-28 km upstream in a 24-hr period) after tagging and prior to entrainment indicating active behavior at this time so it is unlikely that this was a passive event. Approximately 10% of the fish tagged in the Sanpoil River entrained. This is the closest tagging tributary to the dam. Around 6% of the fish tagged in Alder Creek, 20% from Wilmont, 11% from Onion, and 4% from Big Sheep Creek entrained. Proximity to the dam does not appear to influence a fishes likelihood to entrain, however, only seven fish entrained, so it is likely that this is not a large enough sample size to conclude anything significant. It is important to note that no fish tagged in the Spokane River entrained, which is interesting because of its proximity to the dam which is closer relative to the other two tagging locations (Alder/Wilmont and Big Sheep/Onion).

All of the fish that entrained to date were large adults (> 400mm TL; Table 8). This is contradictory to a hypothesis that large adult fish that have resided in Lake Roosevelt for a number of years would be less likely to entrain. McLellan et al. (2015) observed 2.2% of the fish tagged in the Sanpoil River entrained and were detected in the lower Columbia River had a mean TL of 152 mm. A query of the PTAGIS database indicated that none of the Redband Trout implanted with transmitters in 2013 and 2014 were detected below Grand Coulee and Chief Joseph dams. It appears that the fish from the study by McLellan et al. (2015) were most likely exhibiting an anadromous life history strategy, while the fish that entrained in this study were likely kelts that did not willing migrate downstream. All of the fish that entrained in the present study were detected in Rufus Woods reservoir for at least a month, with most being detected for much longer (two or more months). It is possible that these fish have expended a large amount of energy during spawning (Kiessling et al. 1995) so much so that the lack of energy reserves makes it difficult for the fish to maintain its position within the reservoir. However, because of the movements and dates of entrainment, this seems unlikely as ~71% of the entrainment events occurred more than two months post tagging/post spawning season suggesting that the fish were not exhausted from spawning (Table 8).

A study by LeClaire (1998) demonstrated that entrainment through Grand Coulee Dam peaks between May and June each year and during this time, water retention time in Lake Roosevelt falls to its annual low as the reservoir reaches its minimum elevation in preparation for winter runoff in March and April and then refills in May. This creates large fluctuations in flow conditions. These fluctuations have been suggested as the main contributing factor influencing entrainment of hatchery Rainbow Trout (McLellan et al. 2008), wild Rainbow Trout (Stroud et al. 2014) and acoustic tagged hatchery Kokanee (Parsons 2014). The data from our study suggest that fish may entrain in close association with refill events and peaks in outflow (Figure 14). LeCaire (1998 and 1999) estimated entrainment of fishes out of Lake Roosevelt through hydroacoustic surveys. He set gill nets in the forebay of Grand Coulee Dam to estimate relative abundance of species that could have entrained. Between 1996 and 1997, 1,112,777 total fish entrained and the gill nets set in the forebay revealed that the relative abundance of Rainbow/Redband Trout was 14.9% indicating that as many as 165,804 fish Rainbow/Redband Trout could potentially have entrained through or over Grand Coulee Dam.

Of the seven entrainment events of wild Rainbow Trout in our study, six seem to be in close association with peaks in inflow and during the refill portion of the hydrograph (Figure 8). Fluctuations in reservoir operations tend to occur around known spawning timing for wild Rainbow Trout and this may be subjecting already weakened kelts to highly unstable flows resulting in an increased probability of entrainment.

One fish entrained from Big Sheep Creek entrained in January, which seems out of place relative to the other entrainment events, which occurred between May and September. This fish was last detected near Hawk Creek (Columbia River RKM 1,020.3) on 9/16/2014 and was not detected again until January 2015 when the fish was below the dam. It is possible that the transmitter was nearing the end of its life and that may have caused the fish to remain undetected for a period of time (Appendix B). It is likely that this fish entrained earlier than its' first detection below the dam.

It is possible that some fish entrained without being detected. A study by Stroud et al. (2015) revealed that the proportion of missed detections was between 7% and 83% with the average around 33%, when a test tag with the same nominal delay as the tags in the study was floated by receivers in Rufus Woods. This detection efficiency in Rufus Woods Reservoir reflects data from 2013. Currently, there are four receivers in Rufus Woods Reservoir and of those four, three have yet to be range tested. Future studies should evaluate the efficiency of the buoys below Grand Coulee Dam. Since it is possible for fish to entrain without detection, future studies should consider manually tracking for fish whose last detections were at the last receivers above the Grand Coulee Dam.

It is important to point out that these “entrainment event” dates are actually the date the fish was first detected on a receiver below the dam. The actual date of entrainment could have occurred at any time, especially when considering the 10.5 km of river from the dam to the first receiver. It is possible that entrainment can occur at almost any time throughout the year. The small sample size of the two-year study gives a poor estimation of total population entrainment and a more robust assessment of entrainment is needed to clearly answer this question.

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Appendix A. Table of location (latitude/longitude and Columbia River RKM) and agency of receivers within the upper Columbia and its receivers from Columbia River RKM 940 to Columbia River RKM 1,256. SP = Sanpoil River RKM and SR = Spokane River RKM. Page 1 of 4.

Number	Name	Latitude	Longitude	Columbia River RKM	Agency
1	RW1 Buckley Bar	48.065	-119.015	944.6	EWU
2	Rufus Woods Nespelem Confluence East	48.120	-119.042	940.0	EWU
3	Rufus Woods Nespelem Confluence west	48.126	-119.046	940.0	EWU
4	Rufus Woods South	48.065	-119.015	944.8	EWU
5	RW2 Buckly Bar South	48.065	-119.016	947.8	EWU
6	Rufus Woods	48.036	-118.975	949.5	EWU
7	01 Spring Canyon north	47.938	-118.956	962.4	EWU
8	01 Spring Canyon south	47.937	-118.955	962.4	EWU
9	02 Spring Canyon	47.944	-118.928	965.6	EWU
10	03 Spring Canyon	47.949	-118.896	968.0	EWU
11	04 Plum Point	47.958	-118.857	971.2	EWU
12	05 Plum Point	47.934	-118.829	975.3	EWU
13	06 Camel Rocks	47.919	-118.787	979.3	EWU
14	07 Camel Rocks	47.992	-118.683	984.9	EWU
65	Sanpoil Arm Buoy B	48.012	-118.672	SP 8.7	EWU
66	Sanpoil Mouth Bouy A East	47.951	-118.679	991.3	EWU
67	Sanpoil Mouth Bouy A West	47.948	-118.686	991.0	EWU
68	SP1 Sanpoil Mouth	47.961	-118.692	SP 1.6	EWU
69	SP2 Sanpoil Middle	47.992	-118.683	SP 6.9	EWU
70	SP3 Sanpoil Campground	48.027	-118.669	SP 10.9	EWU
15	08 Keller Ferry BL	47.931	-118.709	989.7	EWU
16	09 Keller Ferry	47.938	-118.665	992.2	EWU

Appendix A continued on next page

Appendix A. Continued table of location (latitude/longitude and Columbia River RKM) and agency of receivers within the upper Columbia and its receivers from Columbia River RKM 940 to Columbia River RKM 1,256. SP = Sanpoil River RKM and SR = Spokane River RKM. Page 2 of 4.

Number	Name	Latitude	Longitude	Columbia River RKM	Agency
17	10 Hanson Harbor	47.933	-118.561	995.4	EWU
18	11 Whitestone Creek	47.933	-118.561	999.4	EWU
19	12 Whitestone Rock	47.900	-118.533	1003.4	EWU
20	13 Halverson Canyon	47.875	-118.519	1007.4	EWU
21	14 Burbot Creek	47.864	-118.455	1013.1	EWU
22	15 Hawk Creek	47.825	-118.372	1020.3	EWU
71	SR1 Fort Spokane	47.918	-118.295	SR 4.8	EWU
72	SR2 McCoy's Marina	47.944	-118.227	SR 11.1	EWU
73	SR3 Upper Spokane River	47.872	-118.136	SR 22.5	EWU
74	SP4 Harker Canyon	47.801	-118.079	SR 32.2	EWU
75	SP5 Tribal boat launch	47.834	-117.983	SR 41.8	EWU
23	16 Seven Bays	47.864	-118.353	1025.2	EWU
24	17 Castle Rock	47.960	-118.350	1035.6	EWU
25	18 Wilmont Cove	48.041	-118.317	1053.0	EWU
26	19 Hunters	48.139	-118.217	1070.0	EWU
27	Bissell Island	48.264	-118.143	1083.0	STOI
28	Gifford	48.287	-118.154	1084.3	STOI
29	Mission Point	48.360	-118.183	1091.9	STOI
30	Barnaby Light	48.416	-118.197	1103.4	STOI
31	Chalk Grade	48.435	-118.202	1105.6	STOI
32	French Rocks	48.500	-118.182	1112.9	STOI
33	Kettle Falls Marina	48.599	-118.125	1128.2	STOI

Appendix A continued on next page

Appendix A. Continued table of location (latitude/longitude and Columbia River RKM) and agency of receivers within the upper Columbia and its receivers from Columbia River RKM 940 to Columbia River RKM 1,256. Page 3 of 4.

Number	Name	Latitude	Longitude	Columbia River RKM	Agency
34	Milepost 110	48.677	-118.037	1133.6	STOI
35	Nancy Creek	48.652	-118.107	1135.4	STOI
36	Snag Cove	48.736	-118.054	1149.1	STOI
37	North Gorge	48.780	-118.008	1155.3	STOI
38	Flat Creek Eddy	48.816	-117.974	1161.8	STOI
39	China Bend	48.819	-117.924	1169.9	STOI
40	Little Dalles Eddy	48.866	-117.878	1172.4	STOI
41	Northport	48.905	-117.805	1179.6	STOI
42	Big Sheep Creek	48.935	-117.762	1185.9	STOI
43	WanetaEddy & Temp Logger	49.005	-117.620	1201.0	B.C. Hydro
44	Sp Sht Boatt Launch	49.018	-117.604	1203.2	B.C. Hydro
45	U.S. of Trimac Eddy LB	49.036	-117.614	1205.5	B.C. Hydro
46	Trail Apt RB	49.058	-117.616	127.7	B.C. Hydro
47	Beaver Lodge	49.080	-117.619	1209.7	B.C. Hydro
48	Rock Island LB	49.095	-117.650	1213.5	B.C. Hydro
49	Old Trail Bridge	49.098	-117.707	1217.5	B.C. Hydro
50	Rivervale & Temp Logger	49.120	-117.735	1221.2	B.C. Hydro
51	Fishing Bay	49.093	-117.698	1223.6	B.C. Hydro
52	Across from Birch Bank	49.156	-117.727	1226.3	B.C. Hydro
53	Gene RB & Temp Logger	49.202	-117.705	1231.0	B.C. Hydro
54	Sandbar Eddy RB	49.229	-117.670	1235.2	B.C. Hydro
55	U/S of Blueberry Creek	49.242	-117.651	1237.1	B.C. Hydro
56	Water Loo Eddy	49.263	-117.643	1240.1	B.C. Hydro

Appendix A continued on next page

Appendix A. Continued table of location (latitude/longitude and Columbia River RKM) and agency of receivers within the upper Columbia and its receivers from Columbia River RKM 940 to Columbia River RKM 1,256. Page 4 of 4.

Number	Name	Latitude	Longitude	Columbia River RKM	Agency
57	Kinn Eddy & Temp Logger	49.290	-117.643	1243.6	B.C. Hydro
58	Selkirk College Point LB	49.307	-117.656	1264.3	B.C. Hydro
59	Koot; Eddy &Temp Logger	49.315	-117.650	1246.5	B.C. Hydro
60	Tin Cup Rapids	49.321	-117.649	1247.2	B.C. Hydro
61	Waldie's Island	49.328	-117.652	1248.0	B.C. Hydro
62	Sturgeon Island	49.331	-117.687	1250.5	B.C. Hydro
63	Balfour Bay	49.341	-117.740	1254.5	B.C. Hydro
64	HLK	49.341	-117.770	1256.9	B.C. Hydro

Appendix B. Seasonal Movement of Redband Trout tagged in different tributaries of Lake Roosevelt.

Seasonal Comparisons

Fish UDs were broken down by season. Seasons were identified as spring (March, April, and May), summer (June, July, and August), fall (September, October, and November), and winter (December, January, and February). Comparisons were not made for the fish in the winter of 2013 because there were not enough detections from for the fish tagged in the Spokane River, Wilmont/Alder, or Big Sheep/Onion areas to develop UDs.

During the spring, the UDs did not have a high overlap because the UDs of the fish were near their tagging stream (Appendix C-1). This may be because these fish were returning to the area to spawn. Since it is possible that these fish exhibit natal homing, it makes sense that during the spring/spawning season the UDs would be geographically distinct and near their tagging stream. During the fall, fish tended to utilize similar areas in the lower portion of the reservoir. This may be because reservoir operations are in the drawdown phase, resulting in more biomass being pushed further downstream and increasing the food availability (Voeller 1993).

During the summer, fish from all groups and both years, with the exception the Big Sheep/Onion area, utilized the lower portion of the reservoir more frequently than other parts of the reservoir (Appendix C-1). This may be because there is a more abundant food supply in the lower portion of the lake and deeper, likely cooler water for the fish to reside in. Although Lake Roosevelt does not become thermally stratified, like a typical natural lake in the Pacific Northwest, the temperature in the lower depths of the lake during the summer are usually a few degrees cooler than the surface water. In 2008, mean annual temperature across 14 sampling locations in Lake Roosevelt was around 14.1 ± 5.8ºC and highest in August (19.8 ± 2.5 ºC) and lowest in January (2.6 ± 0.5 ºC; Lee et al. 2006). The temperature profiles were isothermal to weakly stratified by meeting the stratification criterion of a change in 1º C per meter change in depth at two locations, but were typically short-lived (Lee et al. 2006). The weak stratification may be just enough to provide the optimal temperature for Rainbow Trout (optimal temperature range is between 12º and 18º C in both lake and riverine environments; McCauley et al. 1997; May 1973; Hess 1974; Raleigh et al. 1984).

Reservoir operations have the potential to influence habitat and food availability. In 1993 zooplankton densities were highest in the lower end of the reservoir and Voeller (1993) found that the drawdown in the spring causes water to move, bringing with it invertebrates and increasing downstream densities and biomass. Zooplankton densities experienced two peaks throughout the year and both occurred in the lower reservoir. The weak stratification of temperature coupled with an abundant food supply may be sufficient to allow for good growth of Redband Trout in the lower reservoir despite the suboptimal temperature regime elsewhere in the reservoir.

Seasonal comparisons of UDs were representative of variable (n = 1 to 13) and small sample sizes with 40% of the 48 groups having fewer than four fish, which may not fully represent the movements of fish throughout the year. Seasonally, the UDs of fish from different areas of the reservoir were unique in the fall and spring, but were similar in the summer months.

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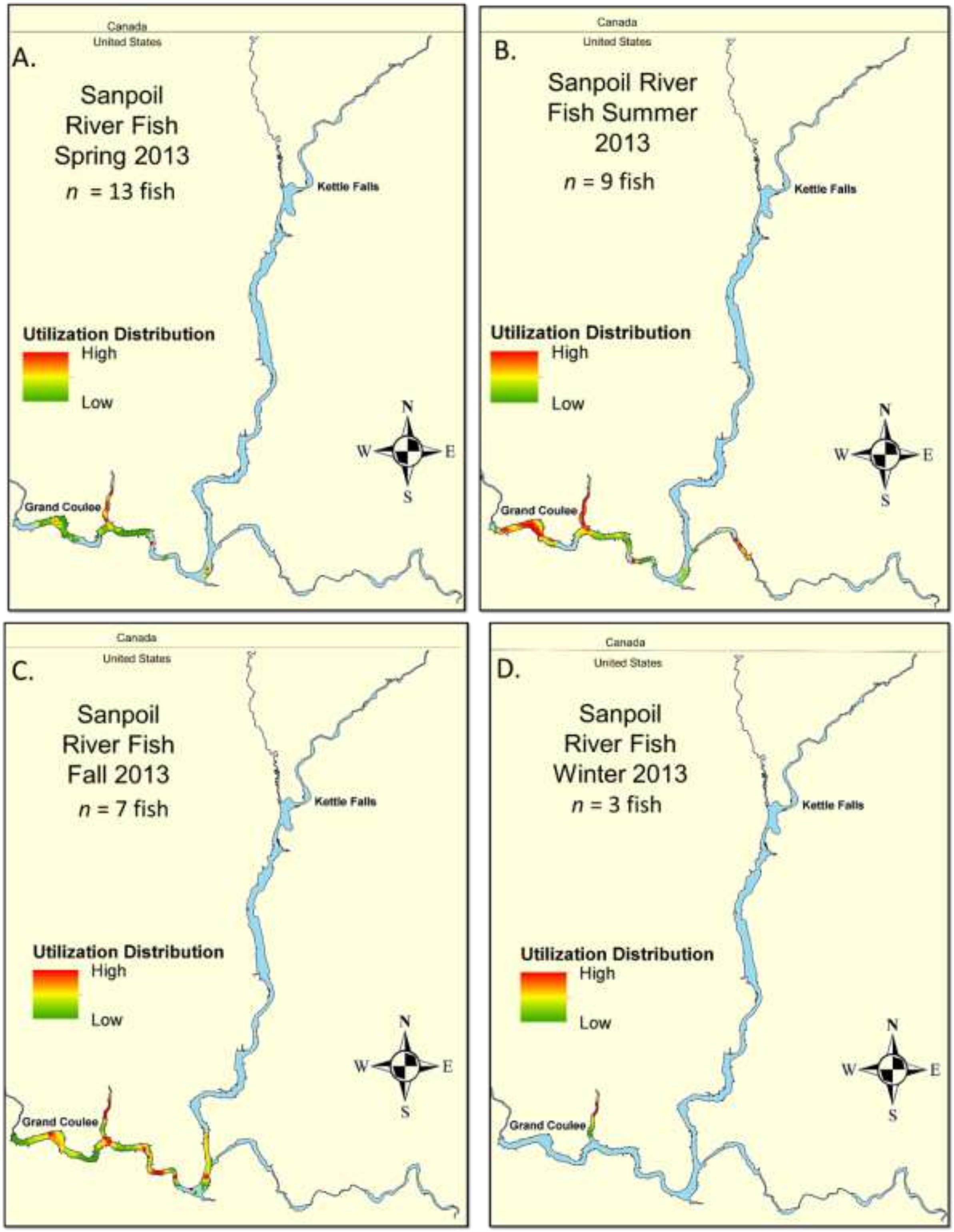
Appendix B-1. Utilization distribution (UD) pairwise comparisons by season for Redband Trout tagged in different tributaries of Lake Roosevelt in 2013 and 2014. UD's compared with a Mantel's test using a Spearman's correlation method. Mantel's test statistic "*r*" and *q* (1-*p*) are shown in the table. Page 1 of 2.

UD1	UD2	Mantel statistic *r*	*q*-value
		Spring 2013	
Sanpoil	Alder	0.984	0.999
Sanpoil	Spokane	0.998	0.999
Sanpoil	Big Sheep/Onion	0.169	0.015
Spokane	Alder	0.979	0.999
Spokane	Big Sheep	0.160	0.022
Alder	Big Sheep	0.185	0.033
		Spring 2014	
Sanpoil	Alder/Wilmont	0.909	0.999
Sanpoil	Spokane	0.361	0.902
Sanpoil	Big Sheep/Onion	0.053	0.035
Spokane	Alder/Wilmont	0.180	0.022
Spokane	Big Sheep/Onion	0.429	0.991
Alder/Wilmont	Big Sheep/Onion	0.894	0.999
		Summer 2013	
Sanpoil	Alder	0.9114	0.999
Sanpoil	Spokane	0.8566	0.999
Sanpoil	Big Sheep	0.108	0.007
Spokane	Alder	0.787	0.999
Spokane	Big Sheep	0.416	0.997
Alder	Big Sheep	0.1473	0.005
		Summer 2014	
Sanpoil	Alder/Wilmont	0.996	0.999
Sanpoil	Spokane	0.607	0.988
Sanpoil	Big Sheep/Onion	0.446	0.899
Spokane	Alder/Wilmont	0.604	0.988
Spokane	Big Sheep/Onion	0.434	0.888
Alder/Wilmont	Big Sheep/Onion	0.419	0.899
		Fall 2013	
Sanpoil	Alder	0.911	0.999
Sanpoil	Spokane	0.4477	0.999
Sanpoil	Big Sheep	0.228	0.019
Spokane	Alder	0.359	0.889
Spokane	Big Sheep	-0.0624	0.027
Alder	Big Sheep	0.147	0.025
		Fall 2014	
Sanpoil	Alder/Wilmont	0.926	0.999
Sanpoil	Spokane	0.972	0.999

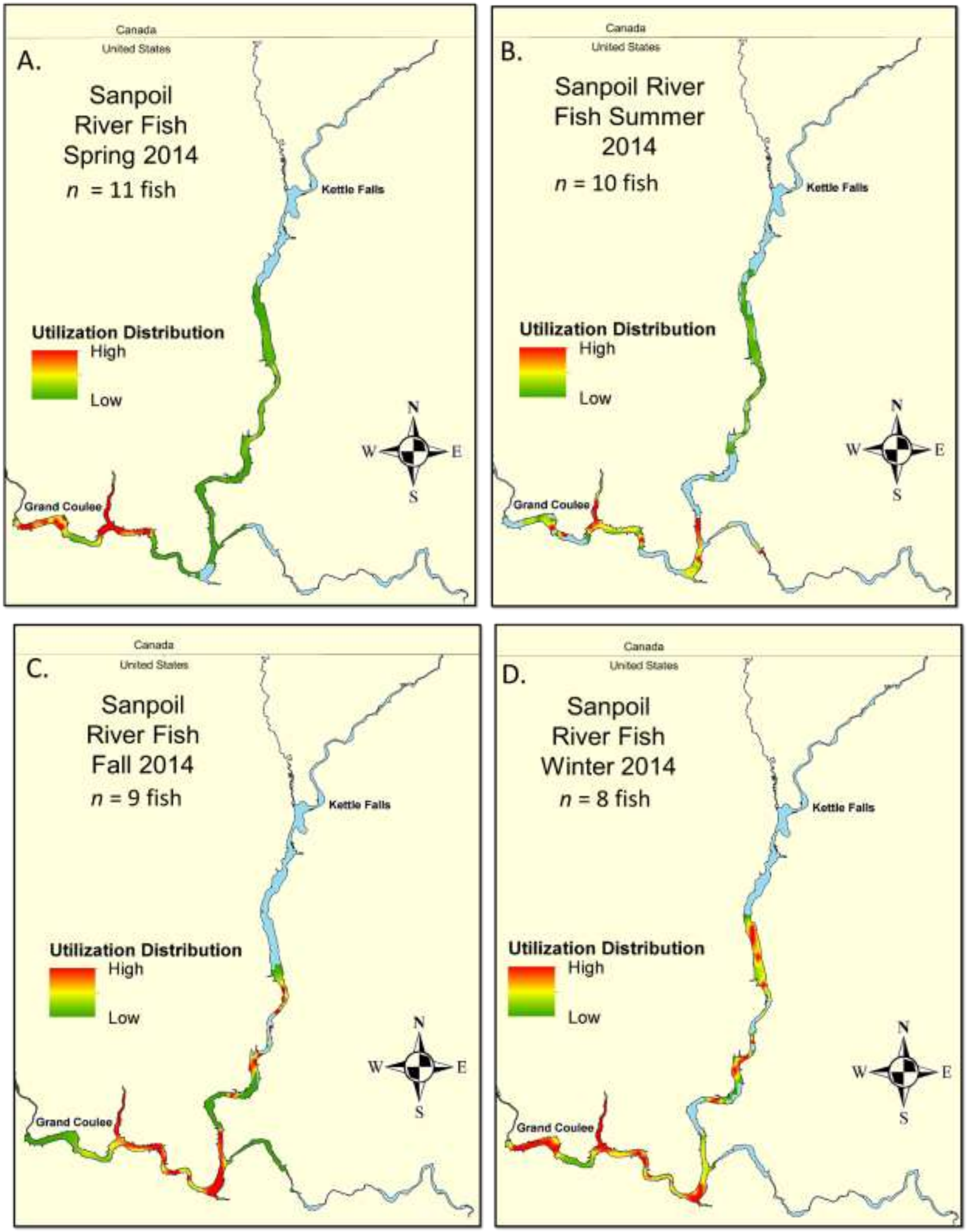
Appendix C-1 continued on next page

Appendix B-1. Continued utilization distribution (UD) pairwise comparisons by season for Redband Trout tagged in different tributaries of Lake Roosevelt in 2013 and 2014. UD's compared with a Mantel's test using a Spearman's correlation method. Mantel's test statistic "*r*" and *q* (1-*p*) are shown in the table. Page 2 of 2

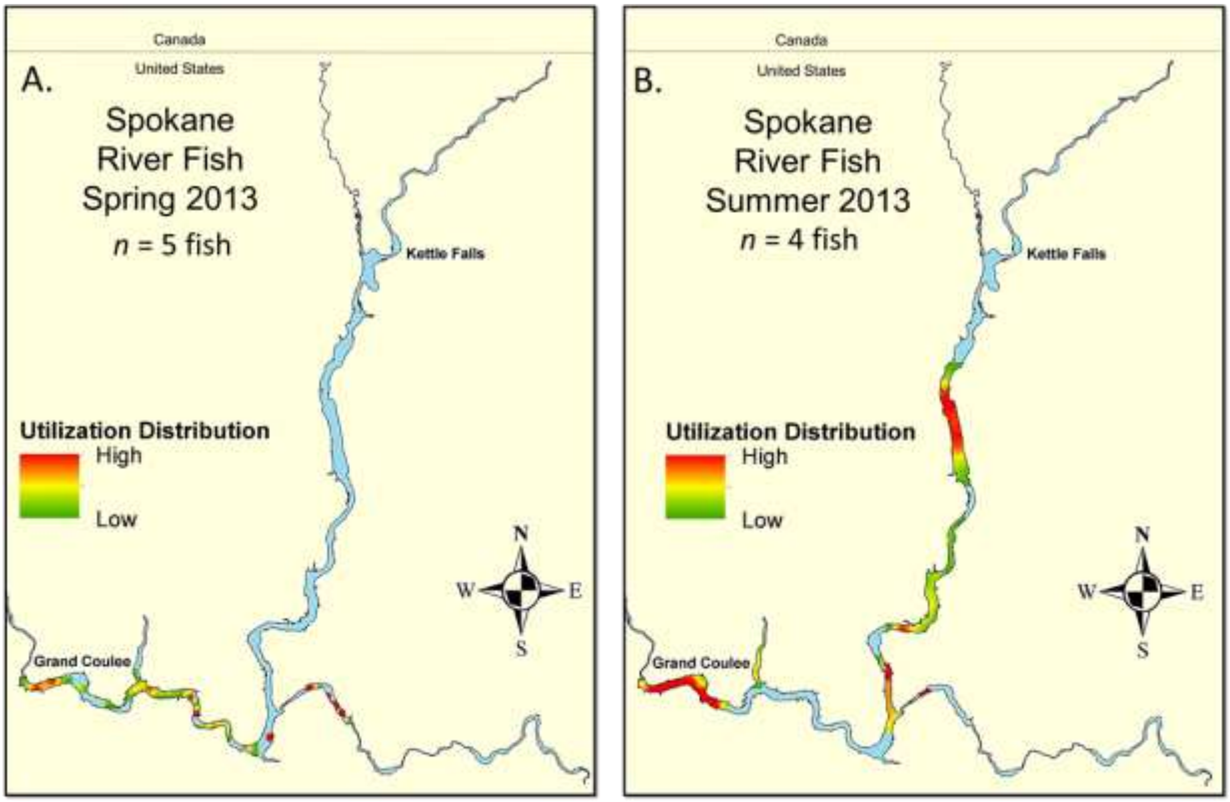
UD1	UD2	Mantel statistic r	q-value
Fall 2014			
Sanpoil	Big Sheep/Onion	0.862	0.999
Spokane	Alder/Wilmont	0.878	0.999
Spokane	Big Sheep/Onion	0.840	0.999
Alder/Wilmont	Big Sheep/Onion	0.897	0.999
Winter 2013			
Sanpoil	Alder	Not enough detections	
Sanpoil	Spokane	Not enough detections	
Sanpoil	Big Sheep	Not enough detections	
Spokane	Alder	Not enough detections	
Spokane	Big Sheep	Not enough detections	
Alder	Big Sheep	Not enough detections	
Winter 2014			
Sanpoil	Alder/Wilmont	0.897	0.999
Sanpoil	Spokane	0.950	0.999
Sanpoil	Big Sheep/Onion	0.962	0.999
Spokane	Alder/Wilmont	0.789	0.998
Spokane	Big Sheep/Onion	0.990	0.999
Alder/Wilmont	Big Sheep/Onion	0.822	0.999

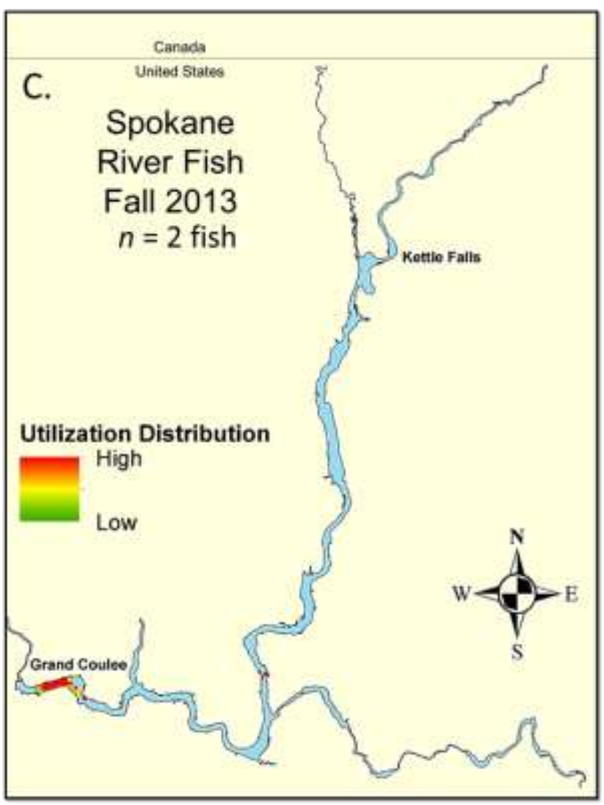


Appendix B-2. Seasonal utilization distribution of Redband trout tagged in the Sanpoil River in 2013 (A = spring, B = summer, C = fall, D = winter).

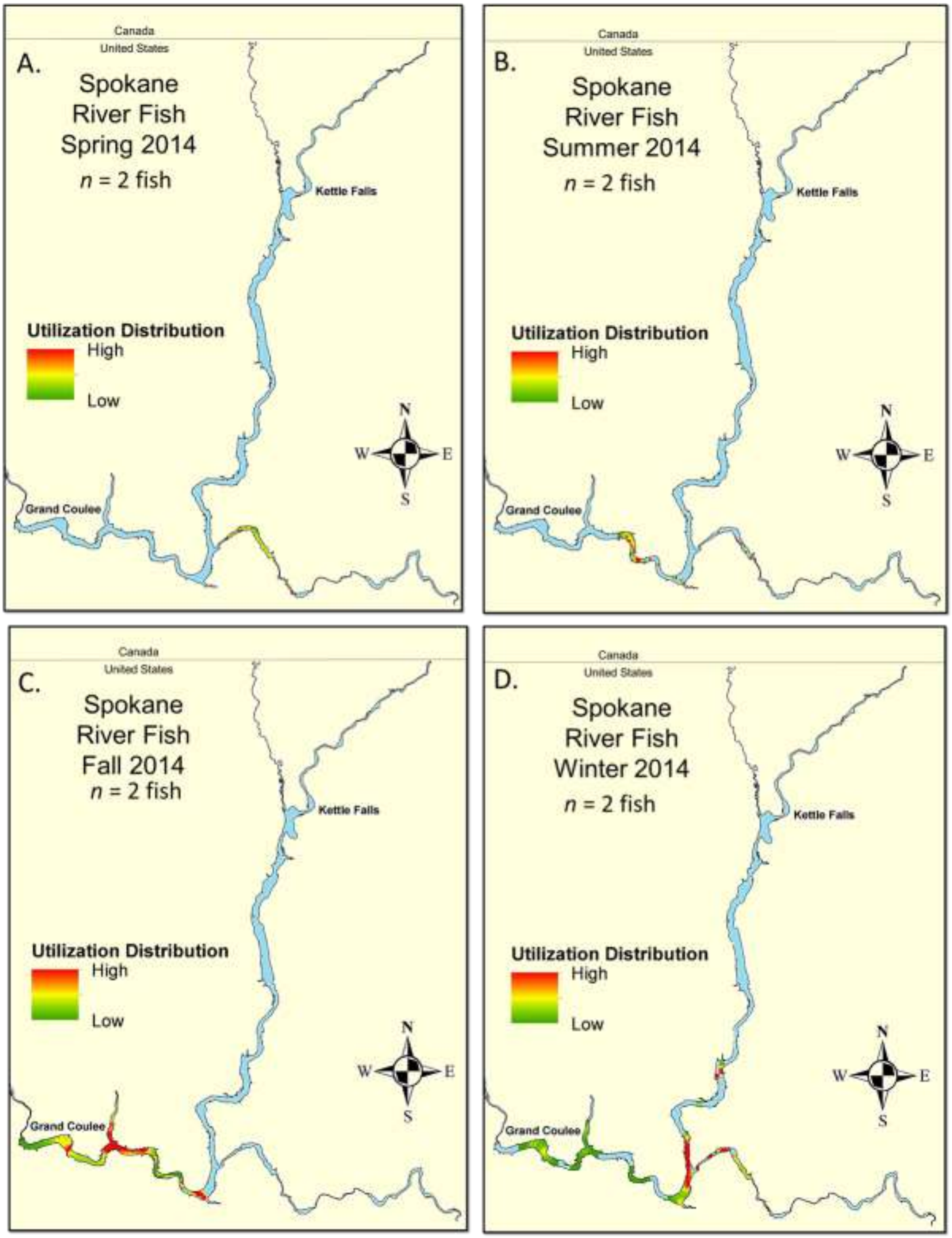


Appendix B-3. Seasonal utilization distribution of Redband trout tagged in the Sanpoil River in 2014 (A = spring, B = summer, C = fall, D = winter).

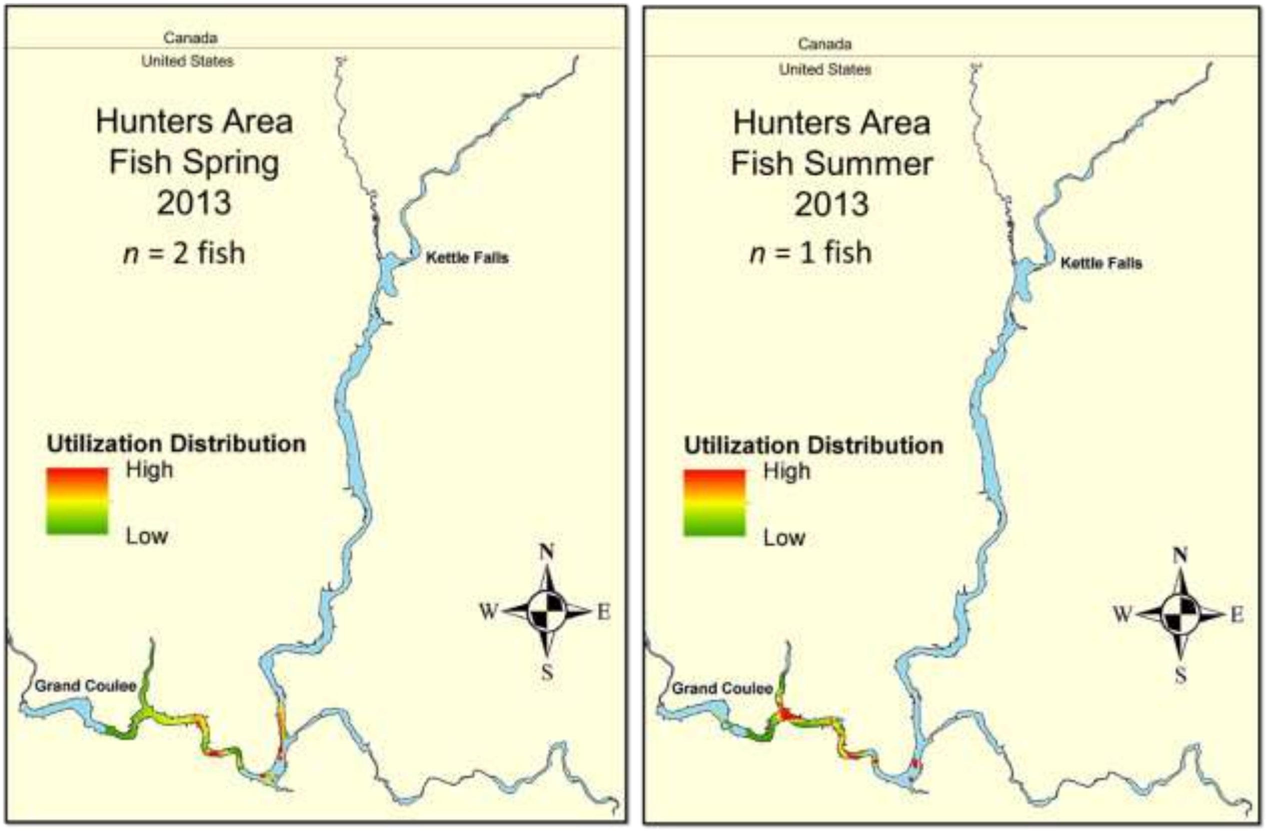


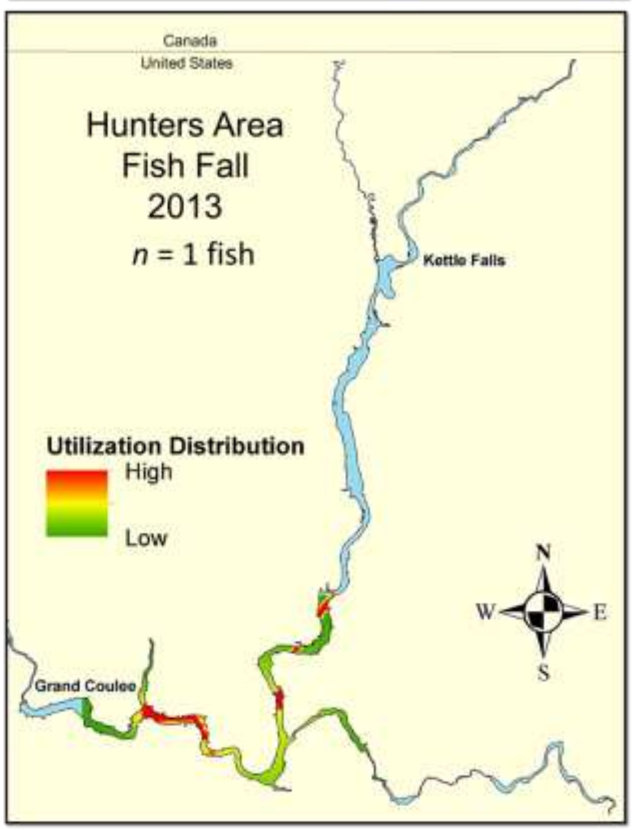


Appendix B-4. Seasonal utilization distribution of Redband trout tagged in the Spokane River (Spring and Blue creeks) in 2013 (A = spring, B = summer, and C = fall). Winter is not shown because not enough data was collected to generate a utilization distribution.

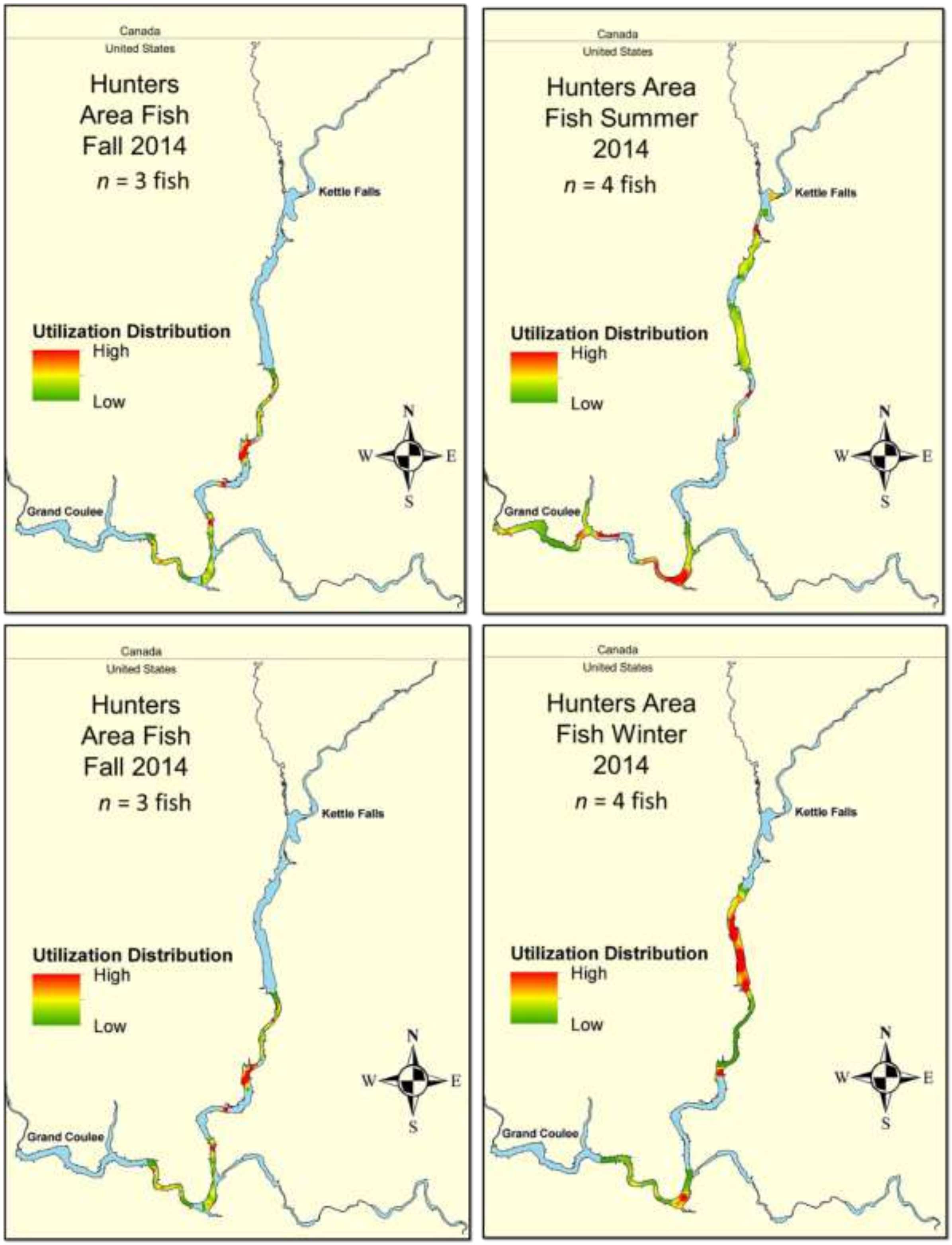


Appendix B-5. Seasonal utilization distribution of Redband trout tagged in the Spokane River (Spring and Blue creeks) in 2014 (A = spring, B = summer, C = fall, D = winter).

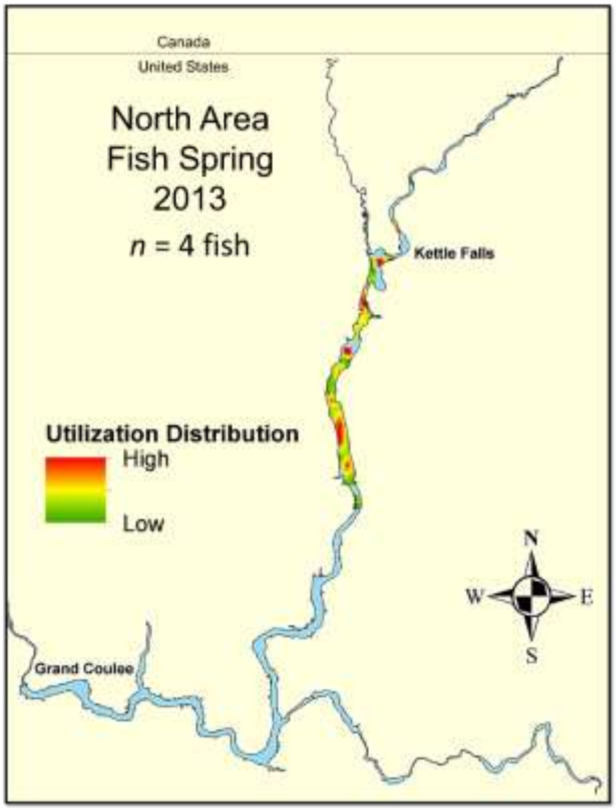


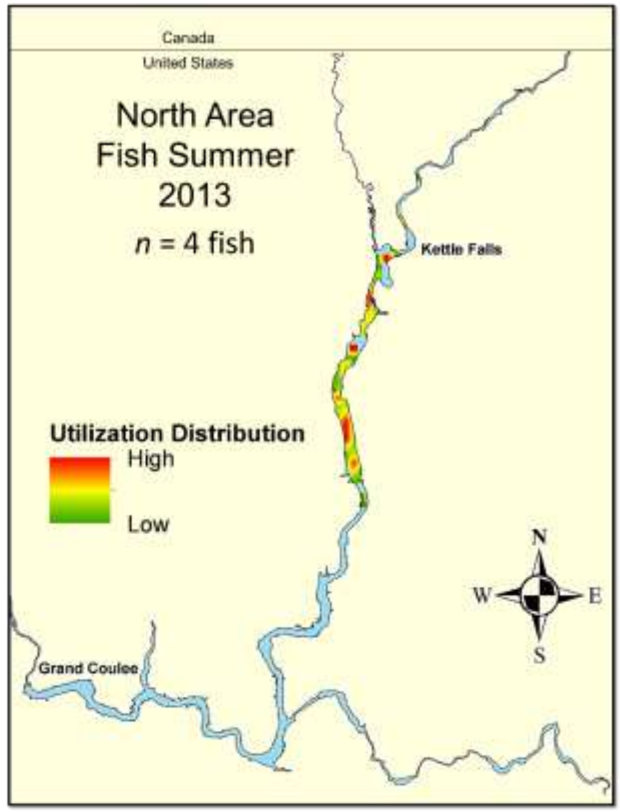


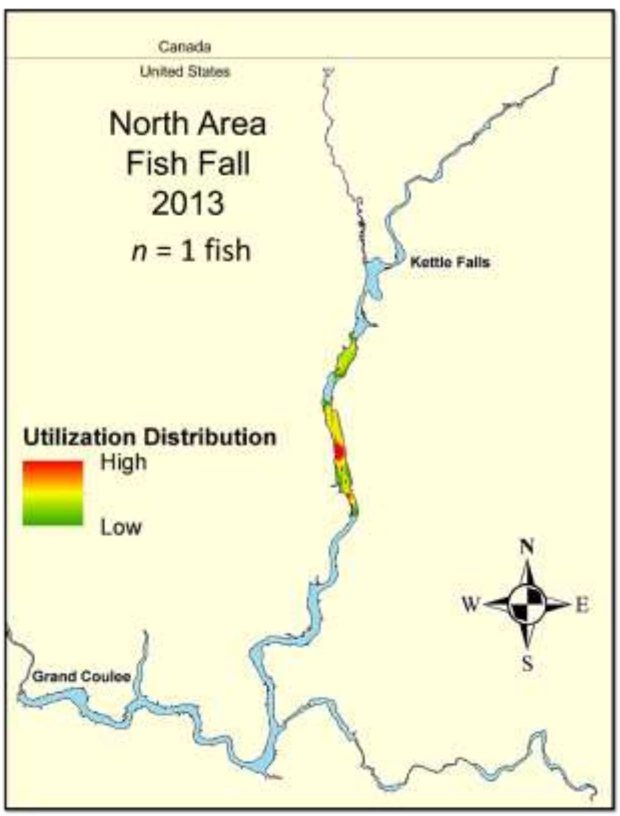
Appendix C-6. Seasonal utilization distribution of Redband trout tagged in Alder Creek in 2013 (A = spring, B = summer, and C = fall). Winter is not shown because not enough data was collected to generate a utilization distribution.



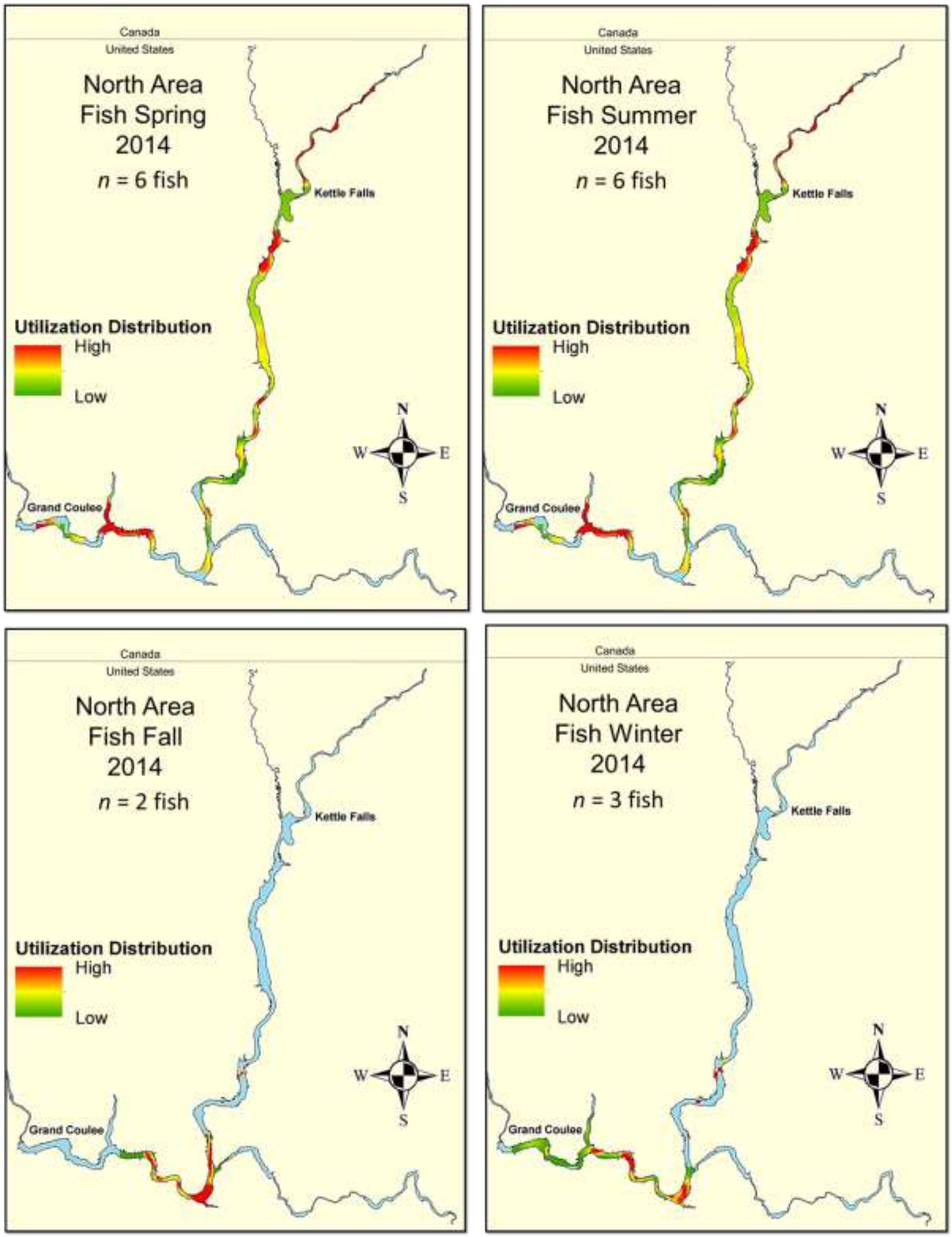
Appendix B-7. Seasonal utilization distribution of Redband trout tagged in Wilmont/Alder creek area in 2014 (A = spring, B = summer, C = fall, D = winter).





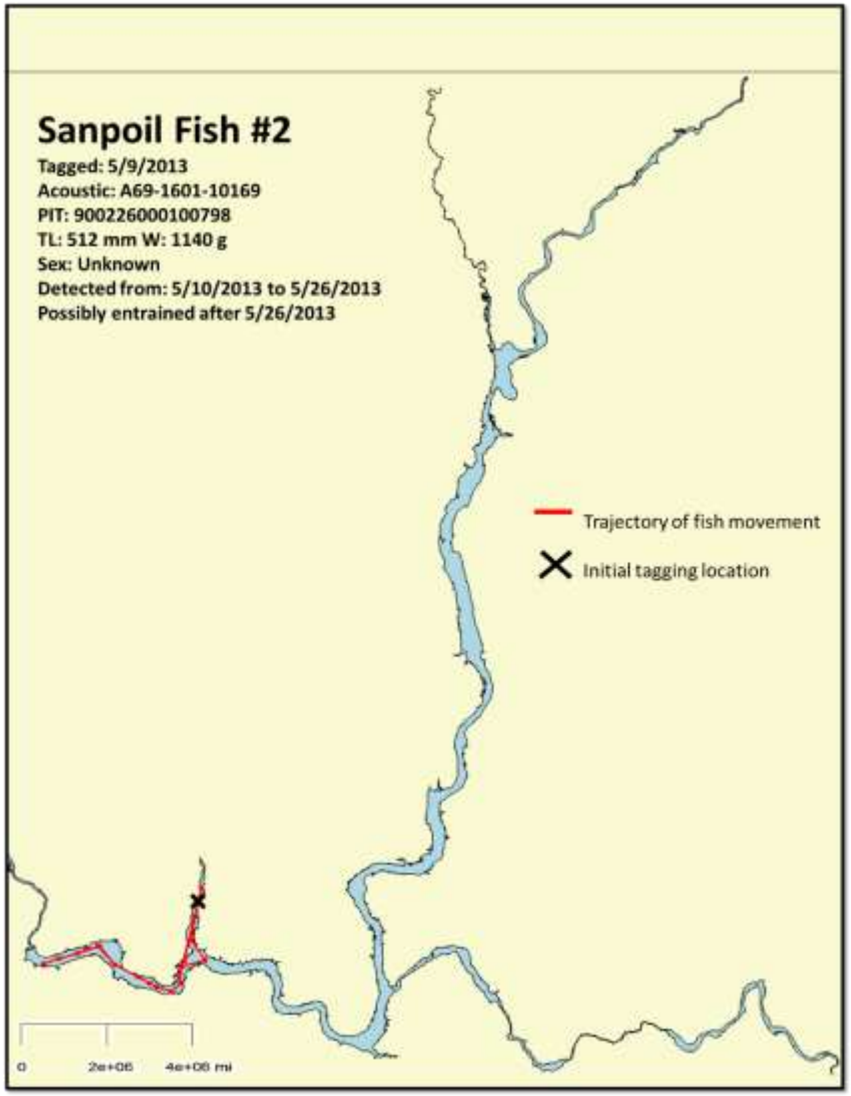


Appendix B-8. Seasonal utilization distribution of Redband trout tagged in Big Sheep Creek in 2013 (A = spring, B = summer, and C = fall). Winter is not shown because not enough data was collected to generate a utilization distribution.



Appendix B-9. Seasonal utilization distribution of Redband trout tagged in Big Sheep/Onion creek area in 2014 (A = spring, B = summer, C = fall, D = winter).

Appendix C. 2013 trajectories and utilization distribution of Redband Trout tagged in the Sanpoil River.



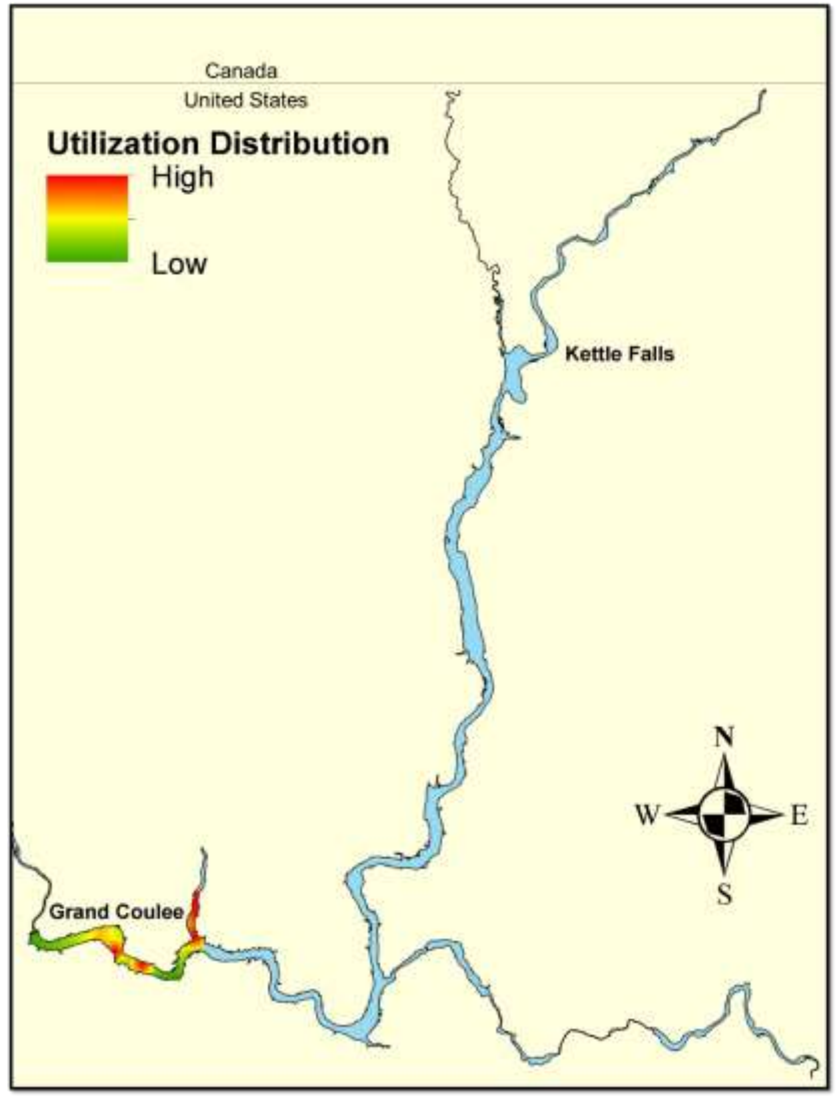
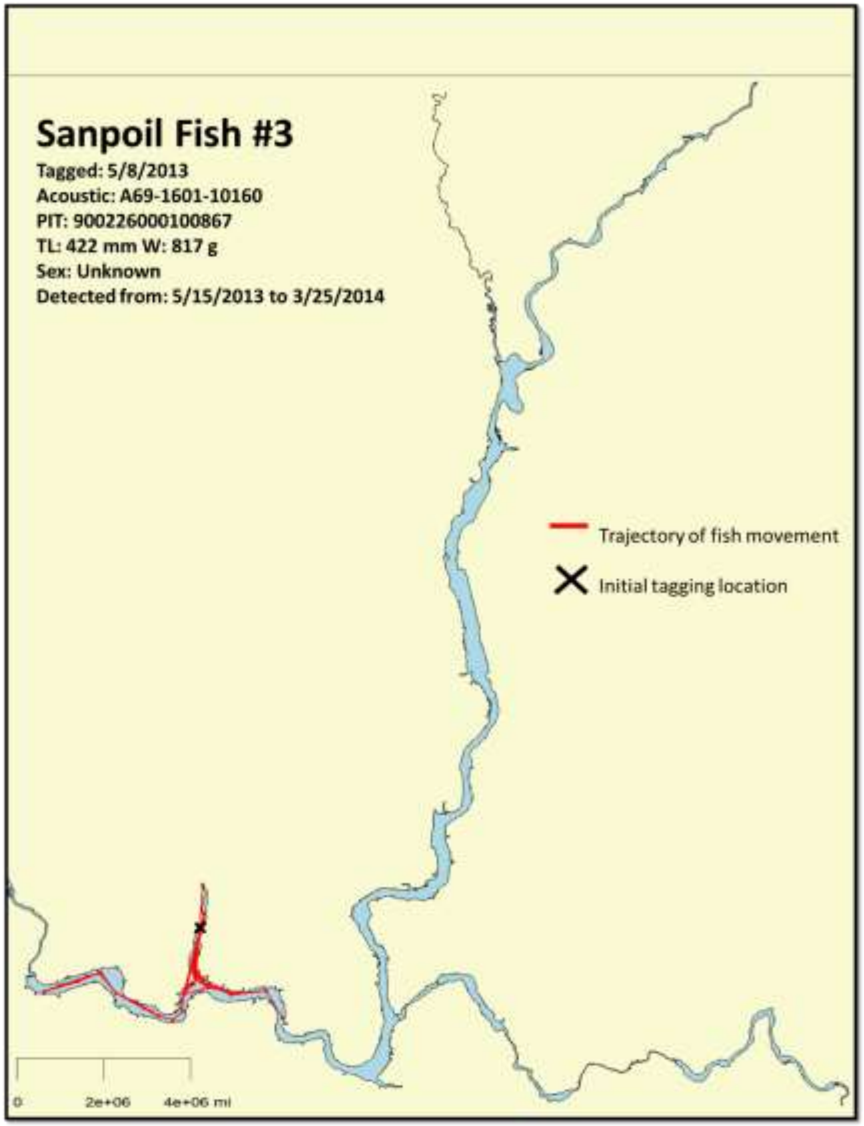


Figure C- 1. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #2 tagged in the Sanpoil River in 2013.



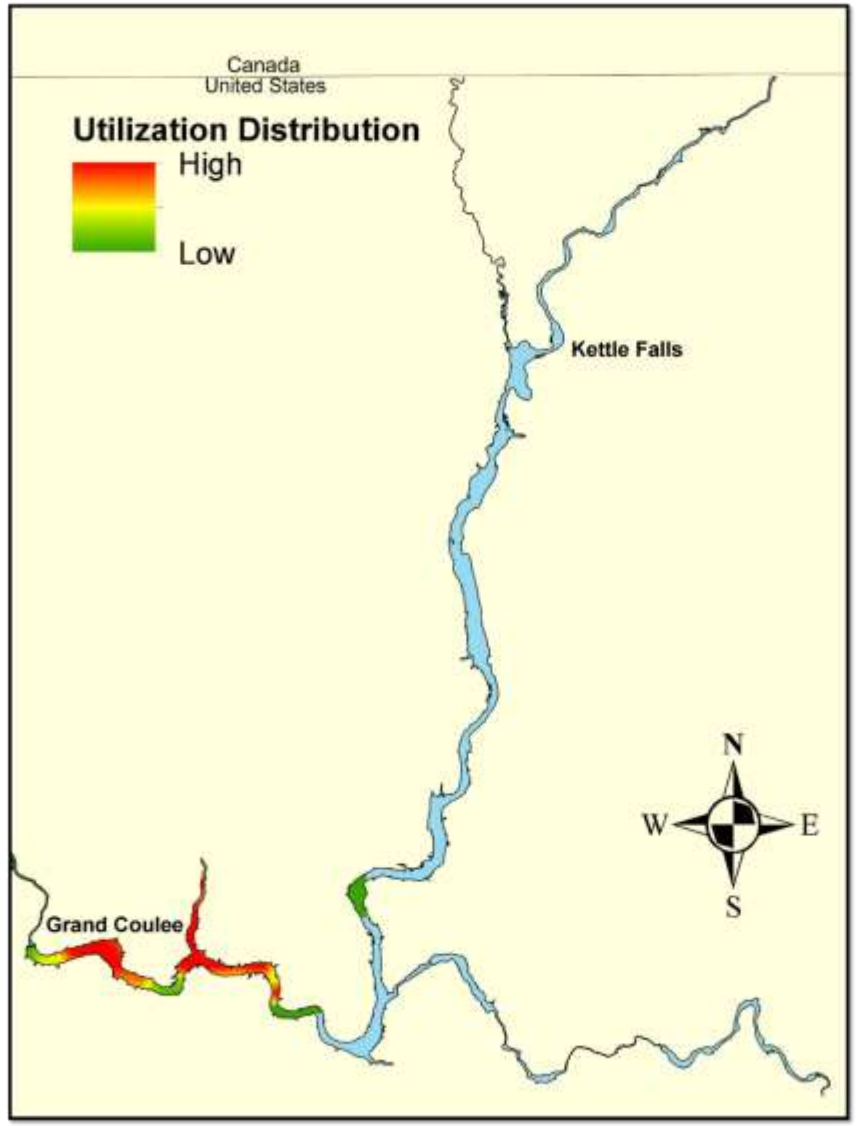


Figure C- 2. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #3 tagged in the Sanpoil River in 2013.

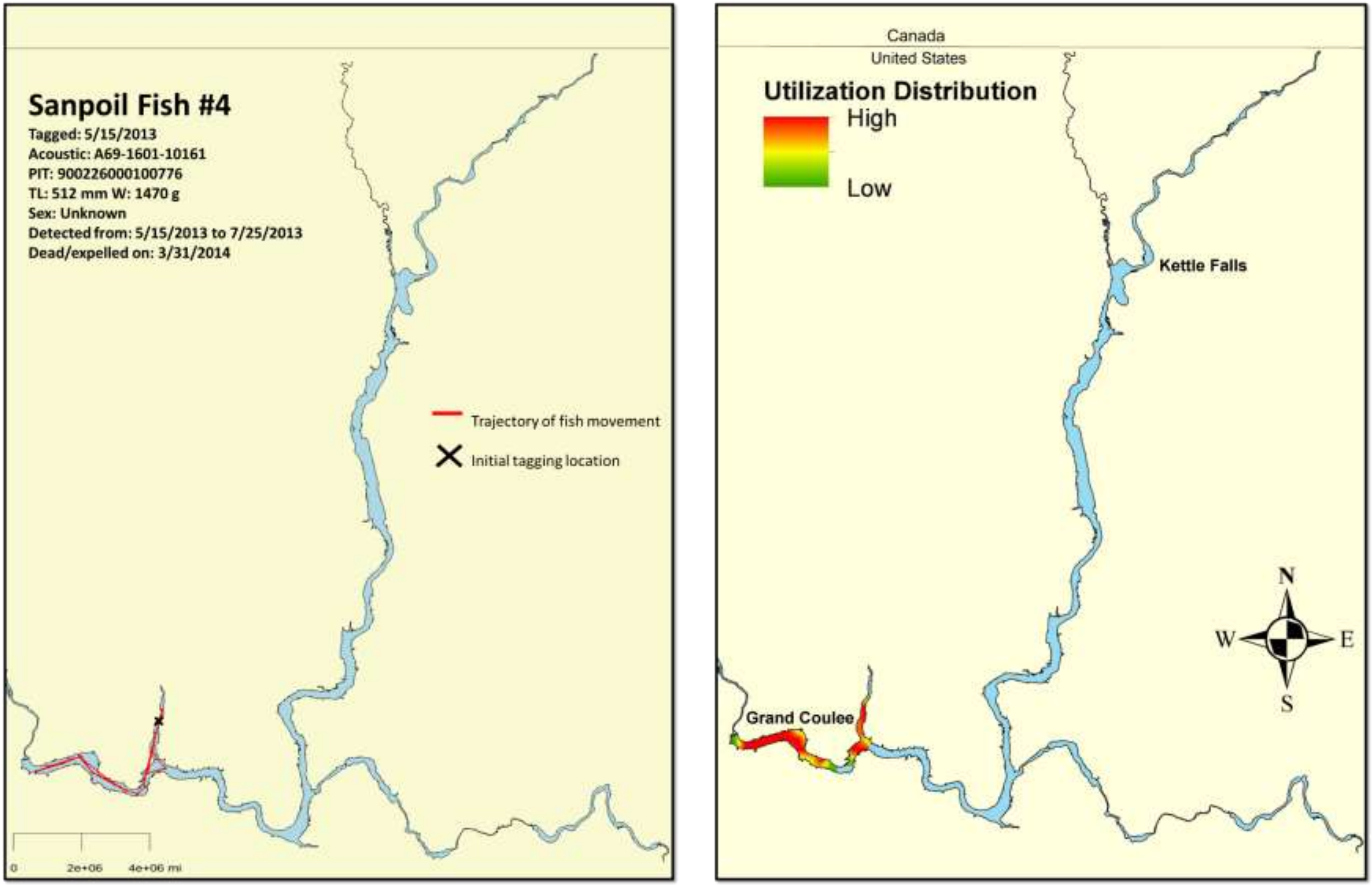


Figure C- 3. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #4 tagged in the Sanpoil River in 2013.

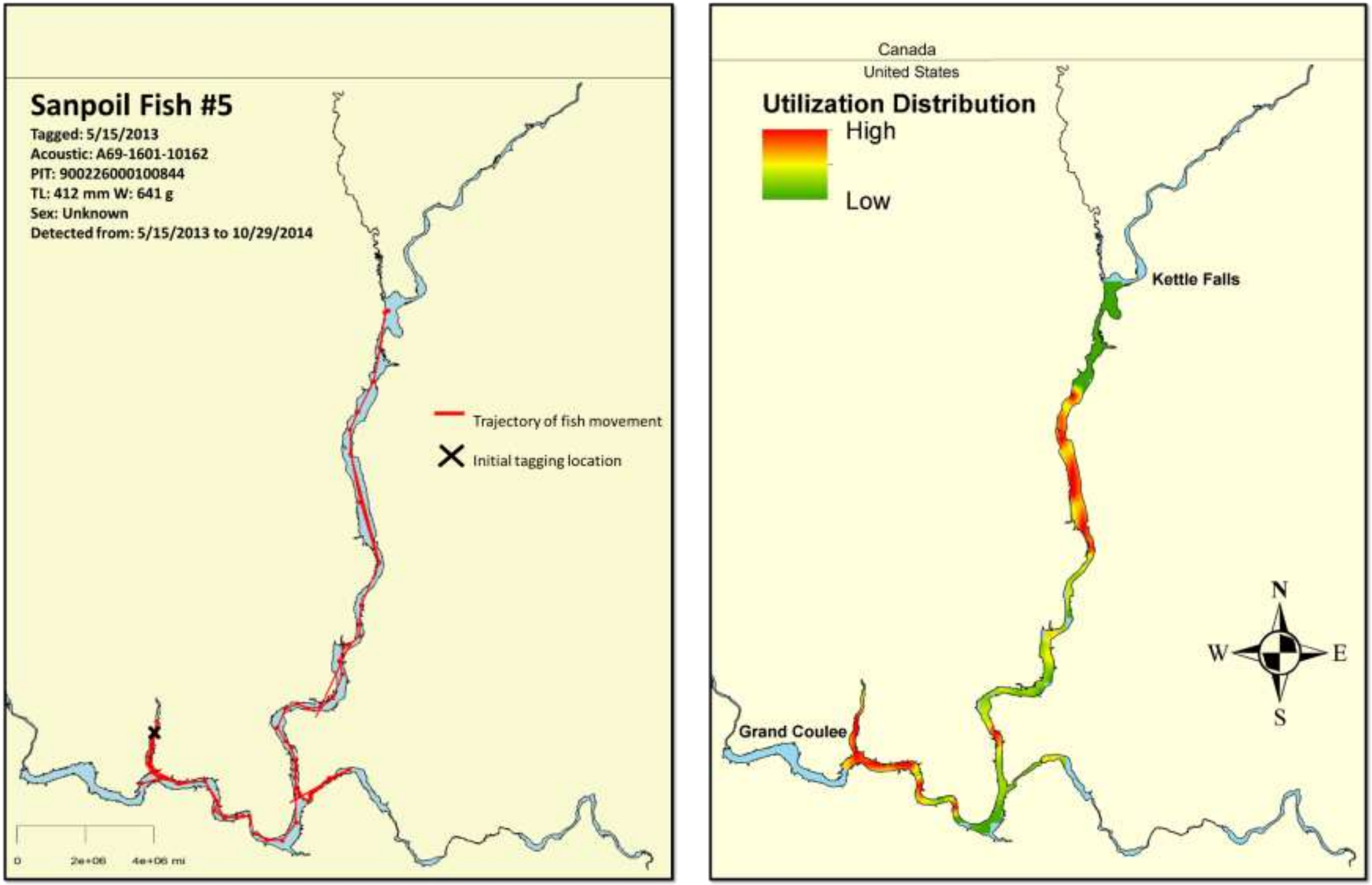


Figure C- 4. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #5 tagged in the Sanpoil River in 2013.

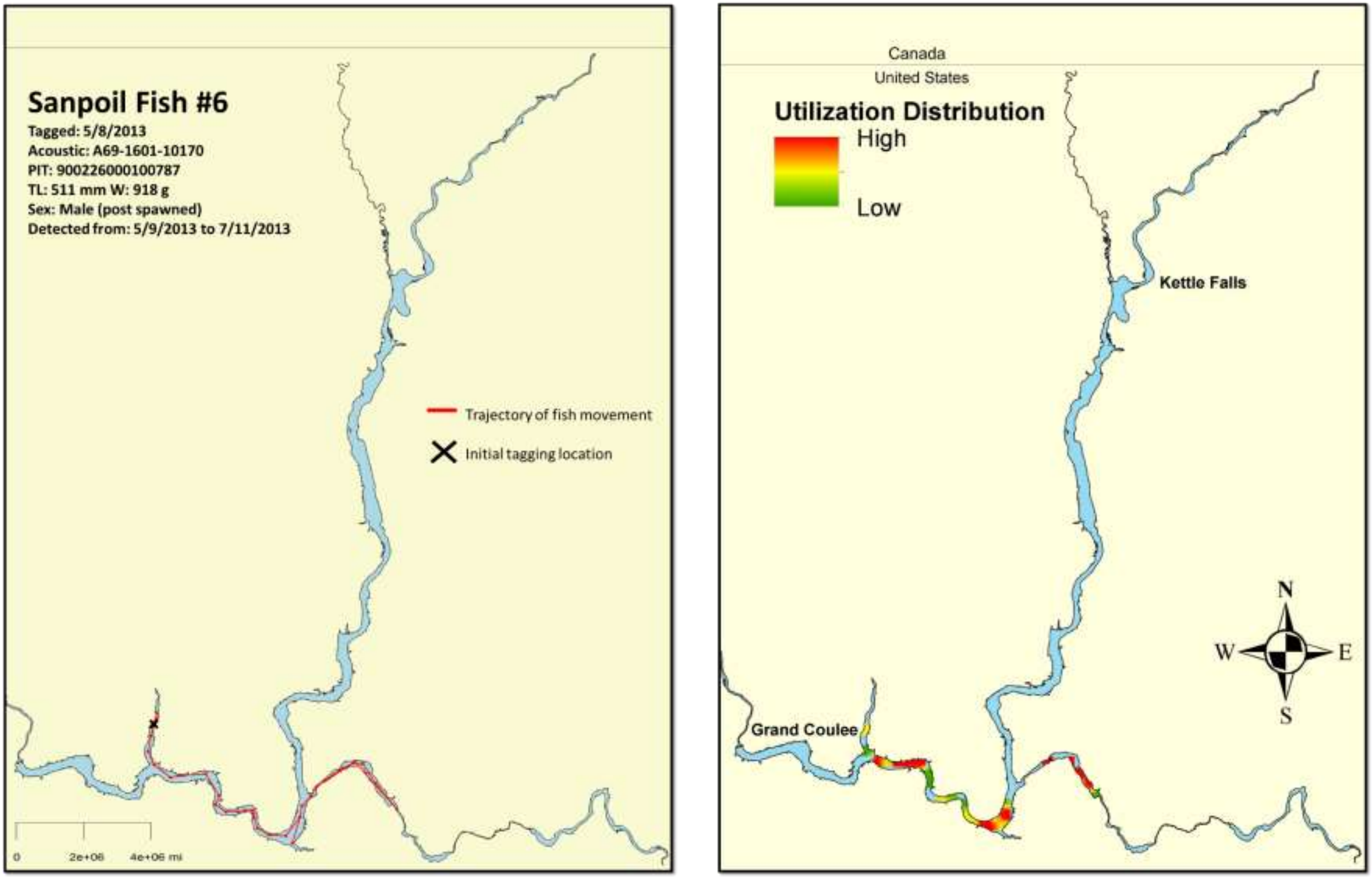


Figure C- 5. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #6 tagged in the Sanpoil River in 2013.

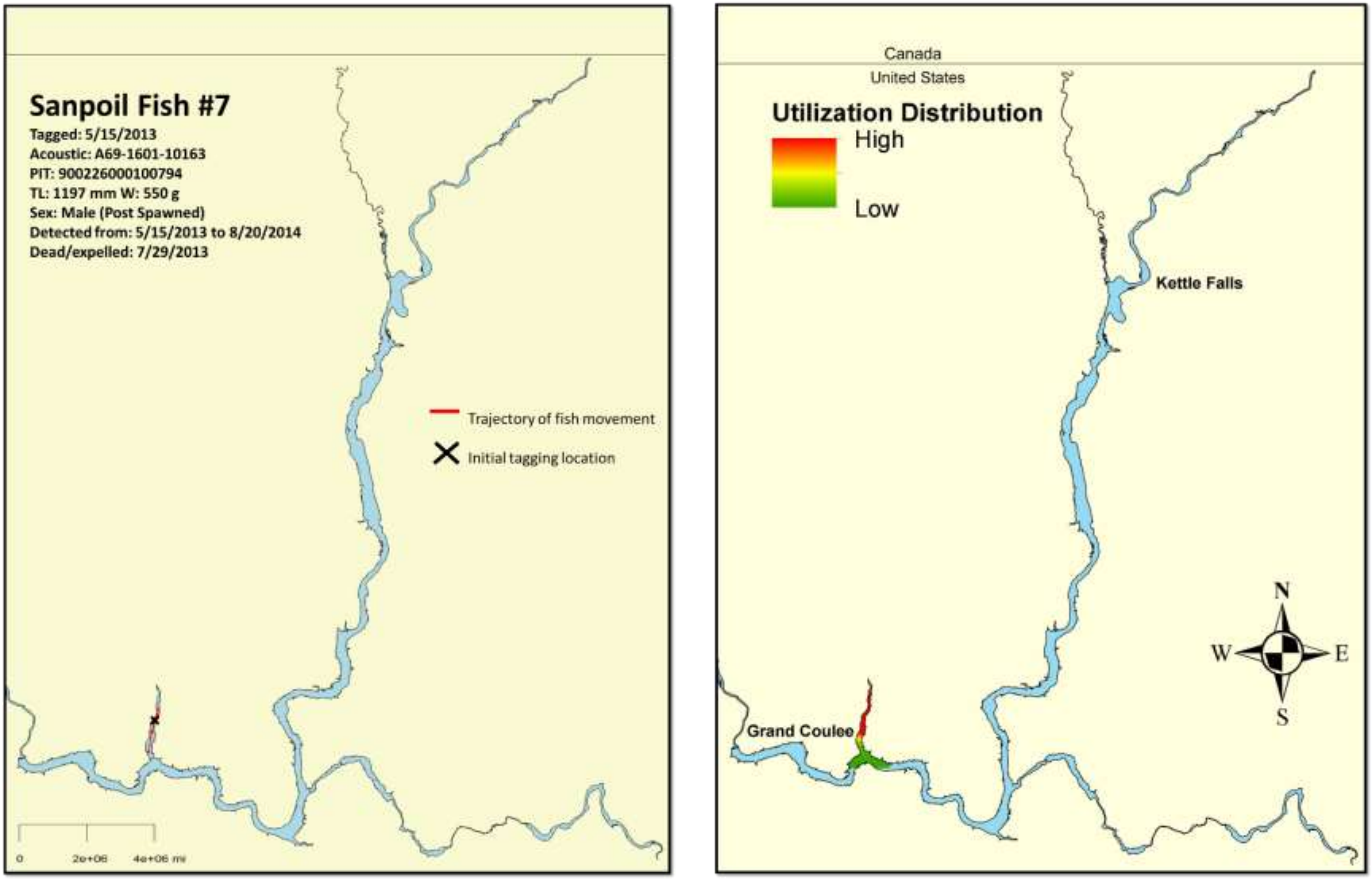


Figure C- 6. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #7 tagged in the Sanpoil River in 2013.

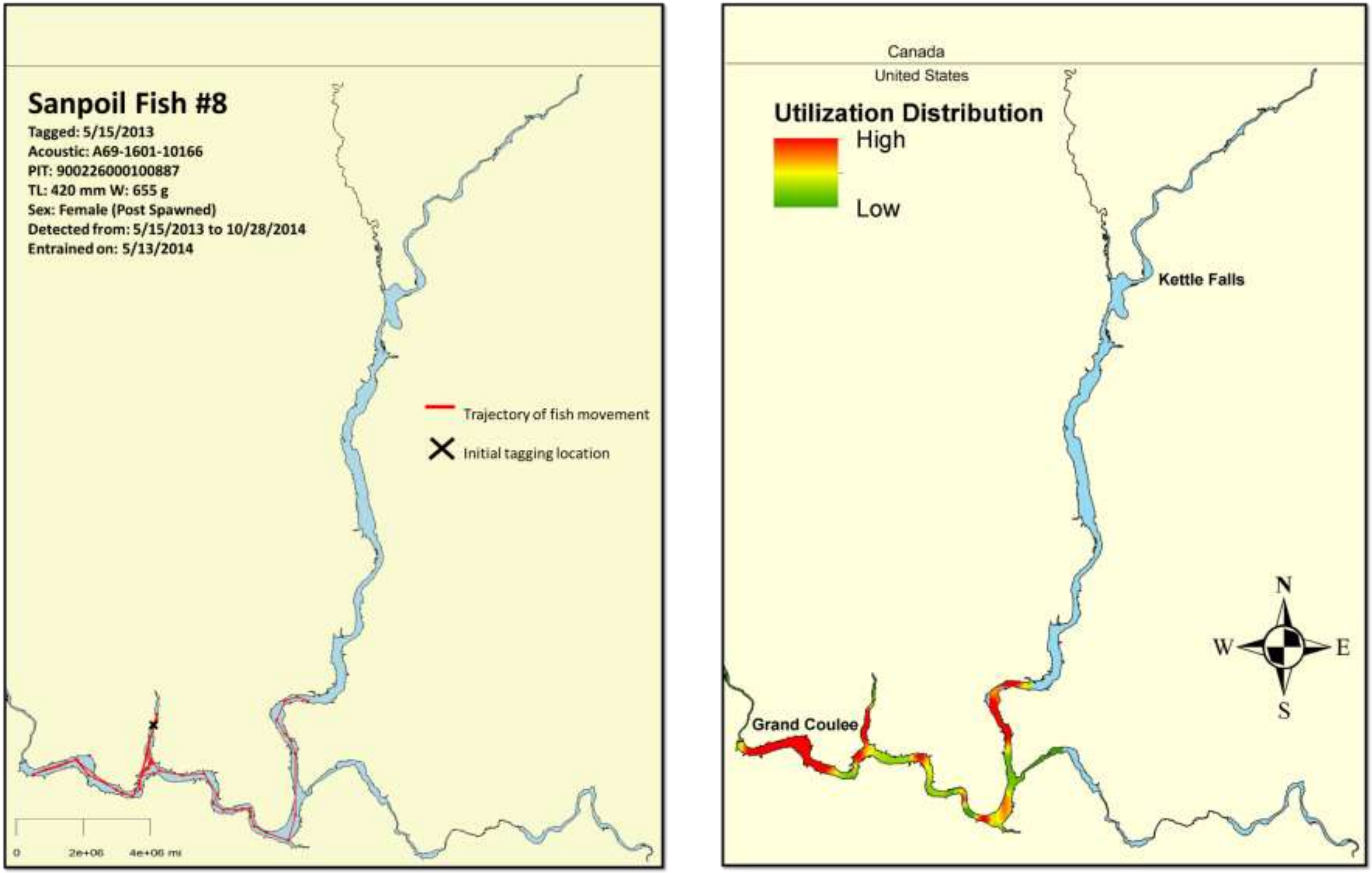


Figure C- 7. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #8 tagged in the Sanpoil River in 2013.

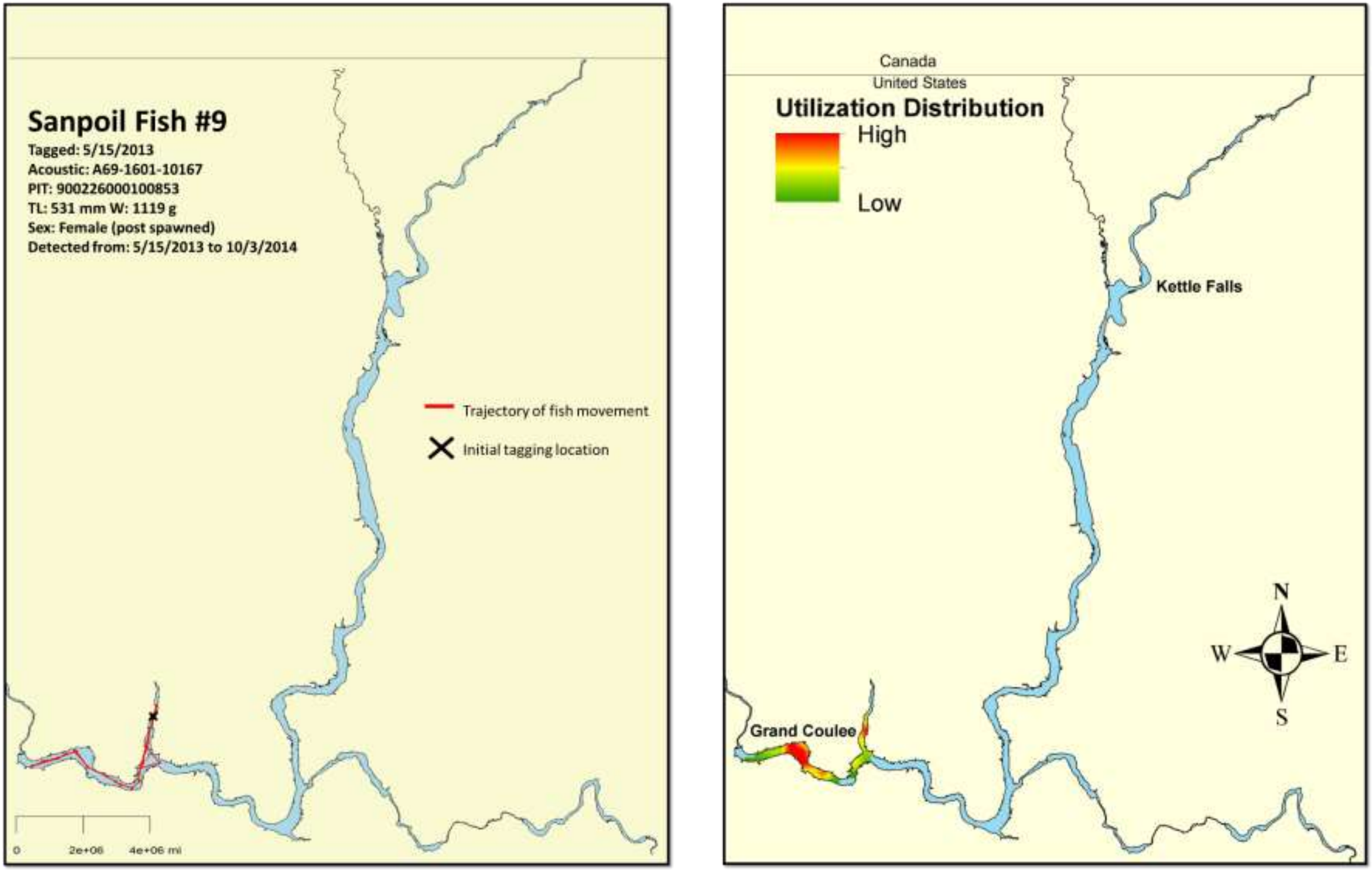
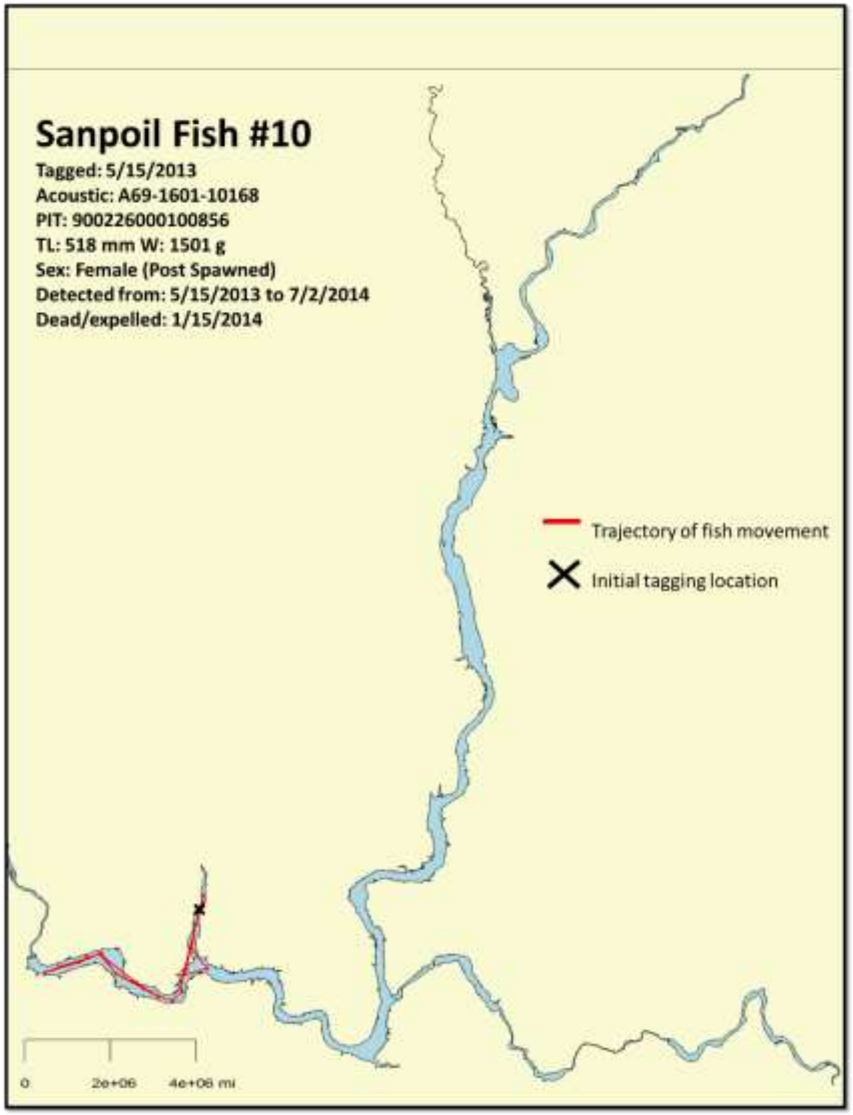


Figure C- 8. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #9 tagged in the Sanpoil River in 2013.



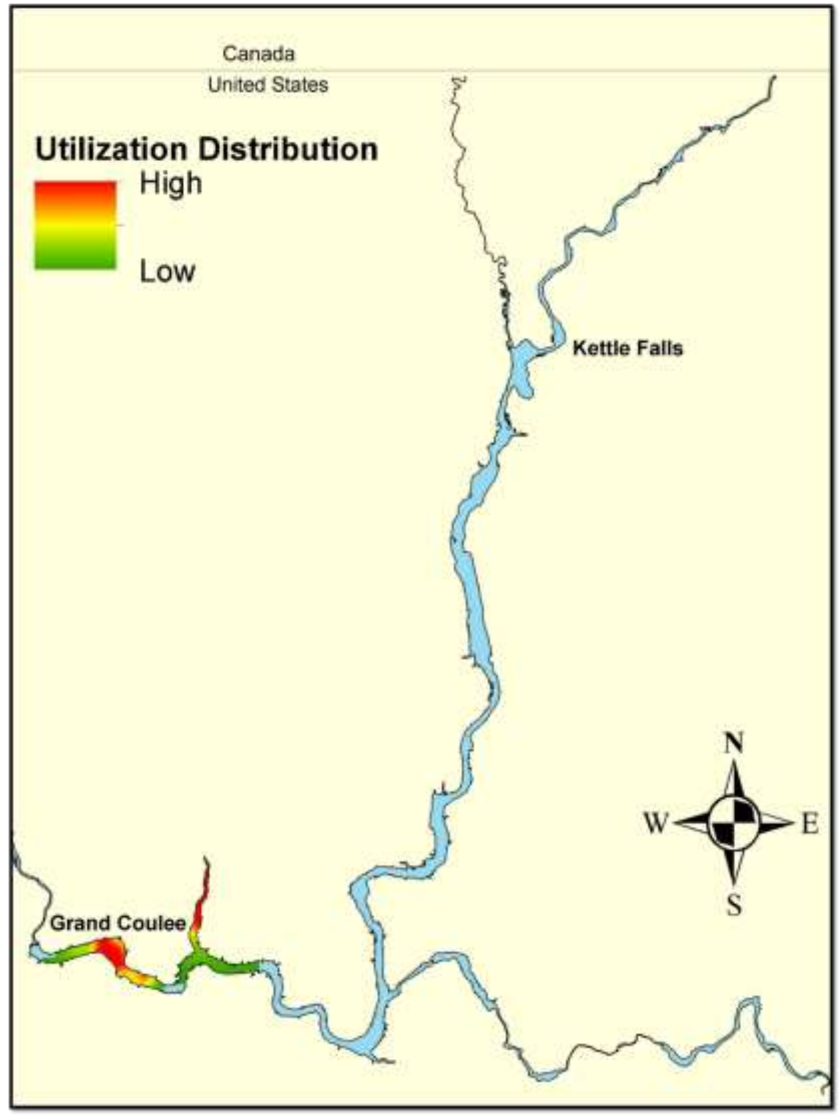


Figure C- 9. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #10 tagged in the Sanpoil River in 2013.

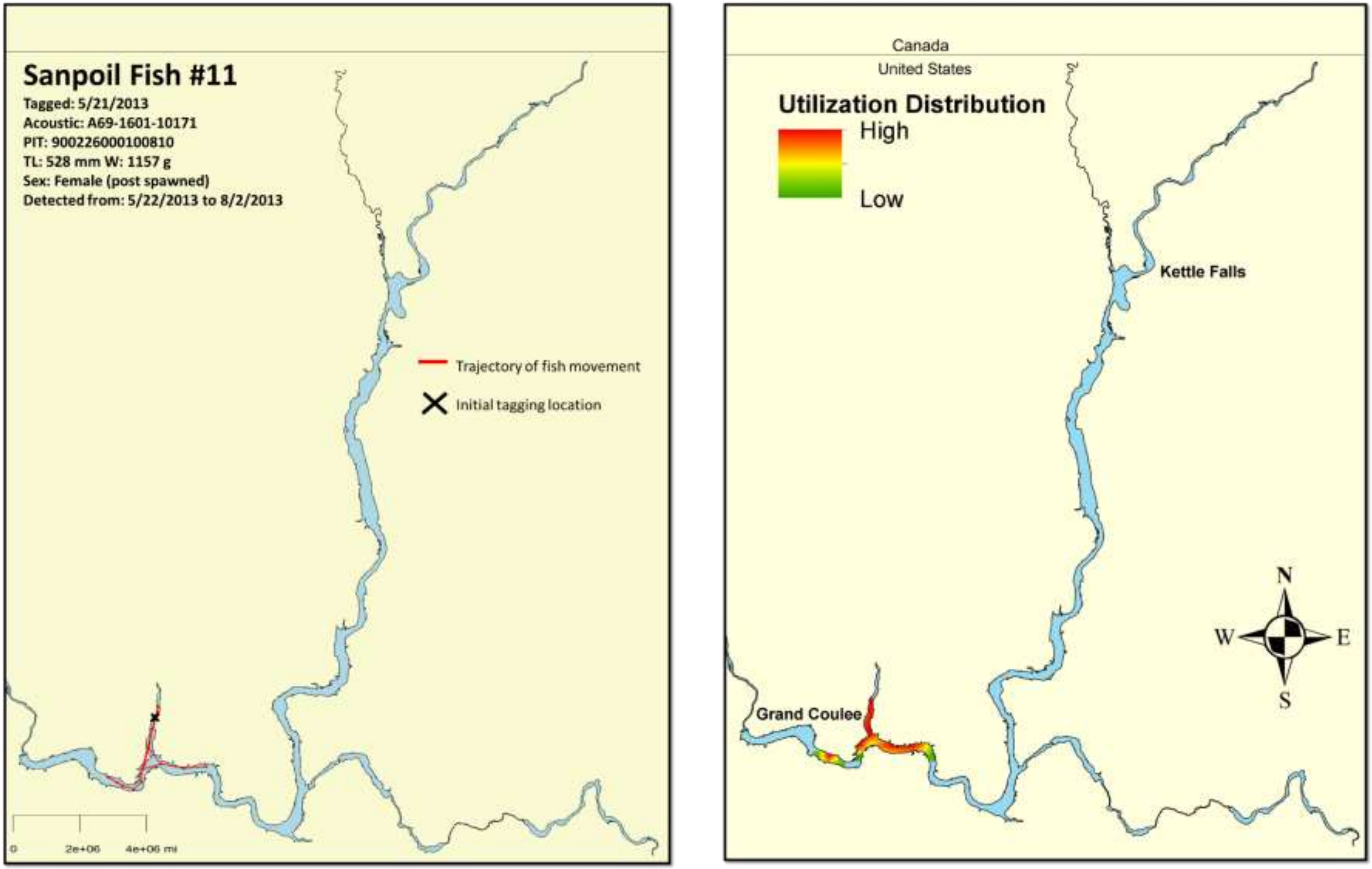


Figure C- 10. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #11 tagged in the Sanpoil River in 2013.

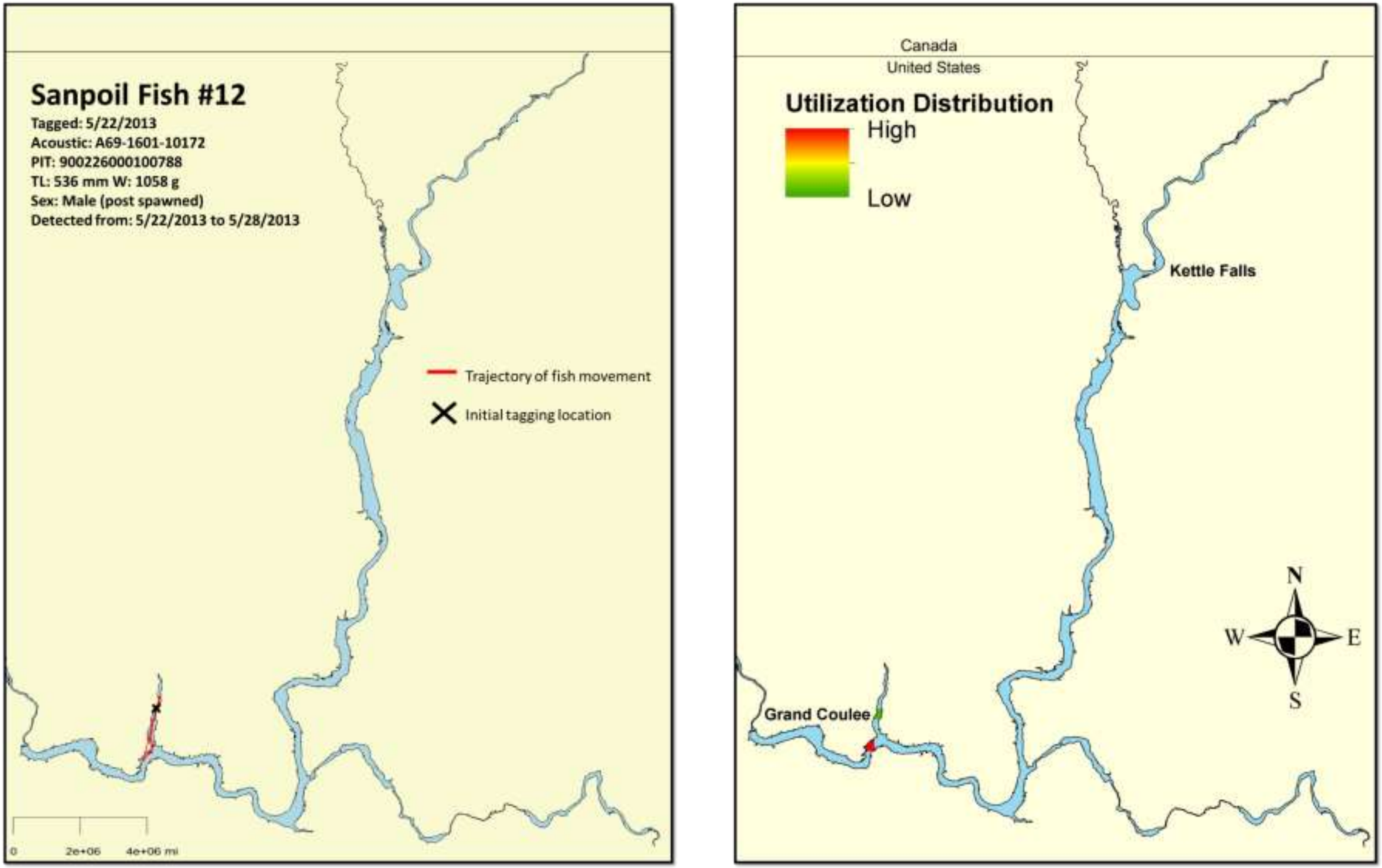


Figure C- 11. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #12 tagged in the Sanpoil River in 2013.

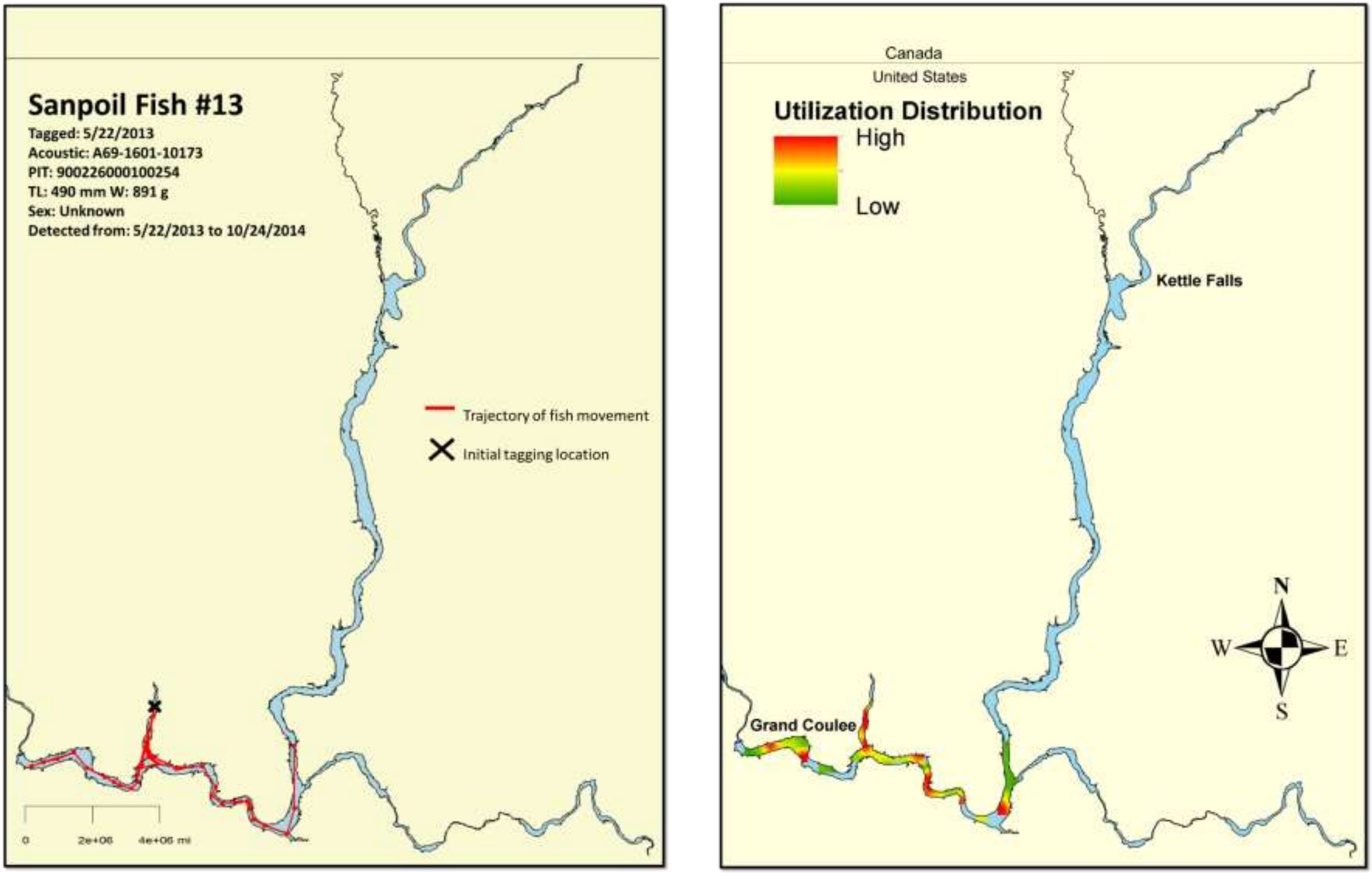


Figure C- 12. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #13 tagged in the Sanpoil River in 2013.

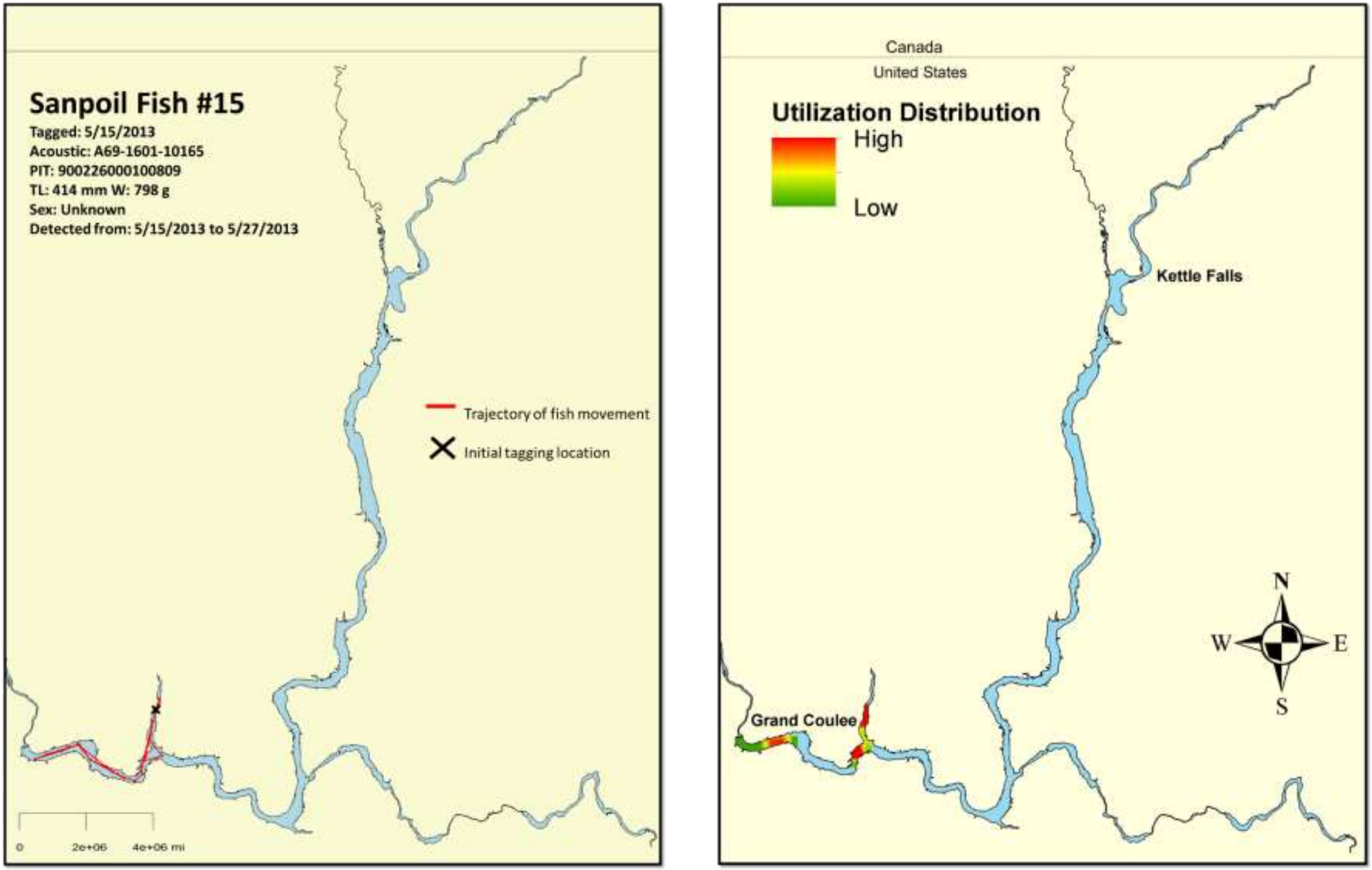


Figure C- 13. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #15 tagged in the Sanpoil River in 2013.

Appendix D. 2013 trajectories and utilization distribution of Redband Trout tagged in Alder Creek.

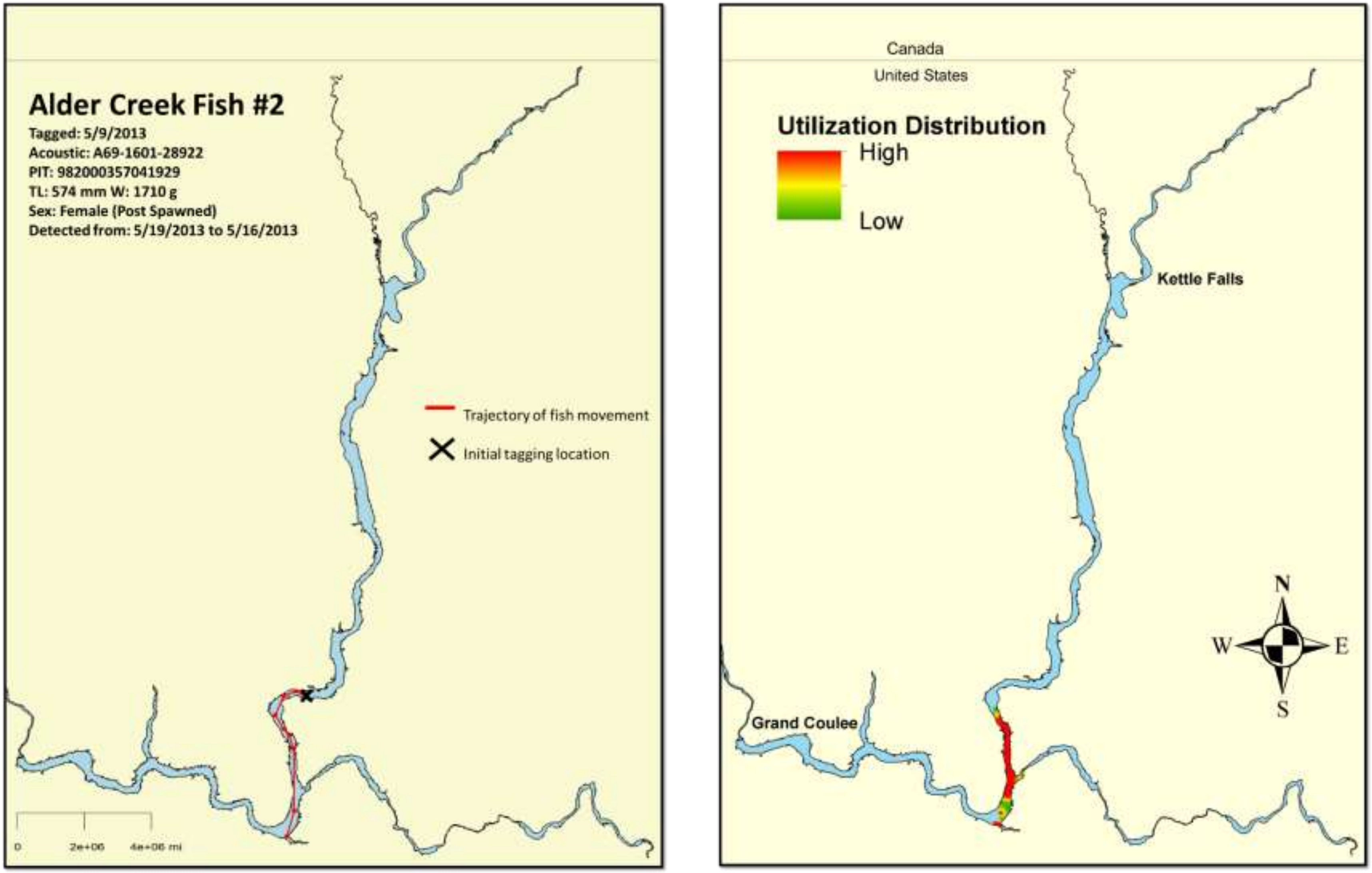


Figure D- 1. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #2 tagged in Alder Creek in 2013.

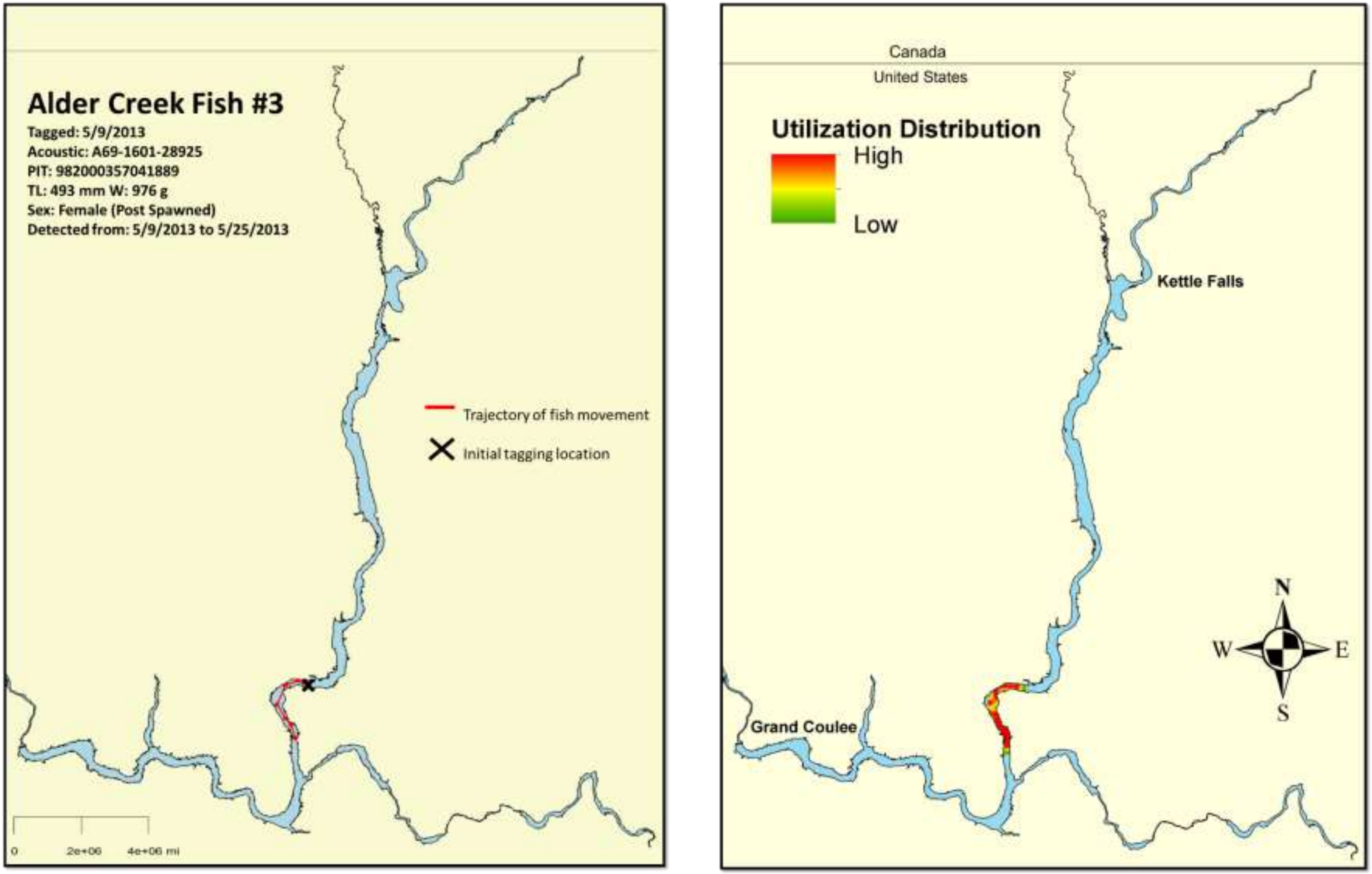


Figure D- 2. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #3 tagged in Alder Creek in 2013.

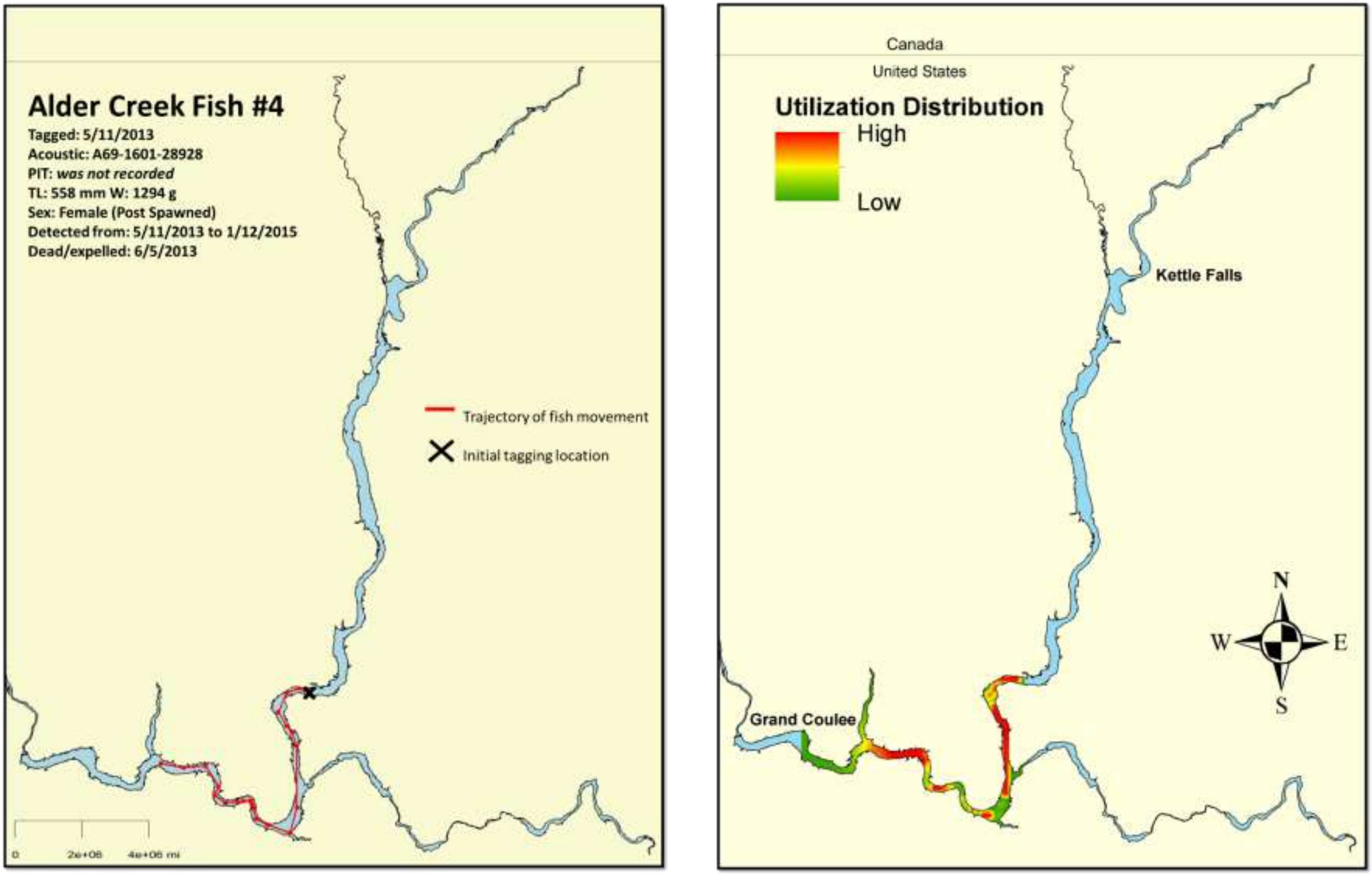


Figure D- 3. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #4 tagged in Alder Creek in 2013.

Appendix E. 2013 trajectories and utilization distribution of Redband Trout tagged in the Spokane River.

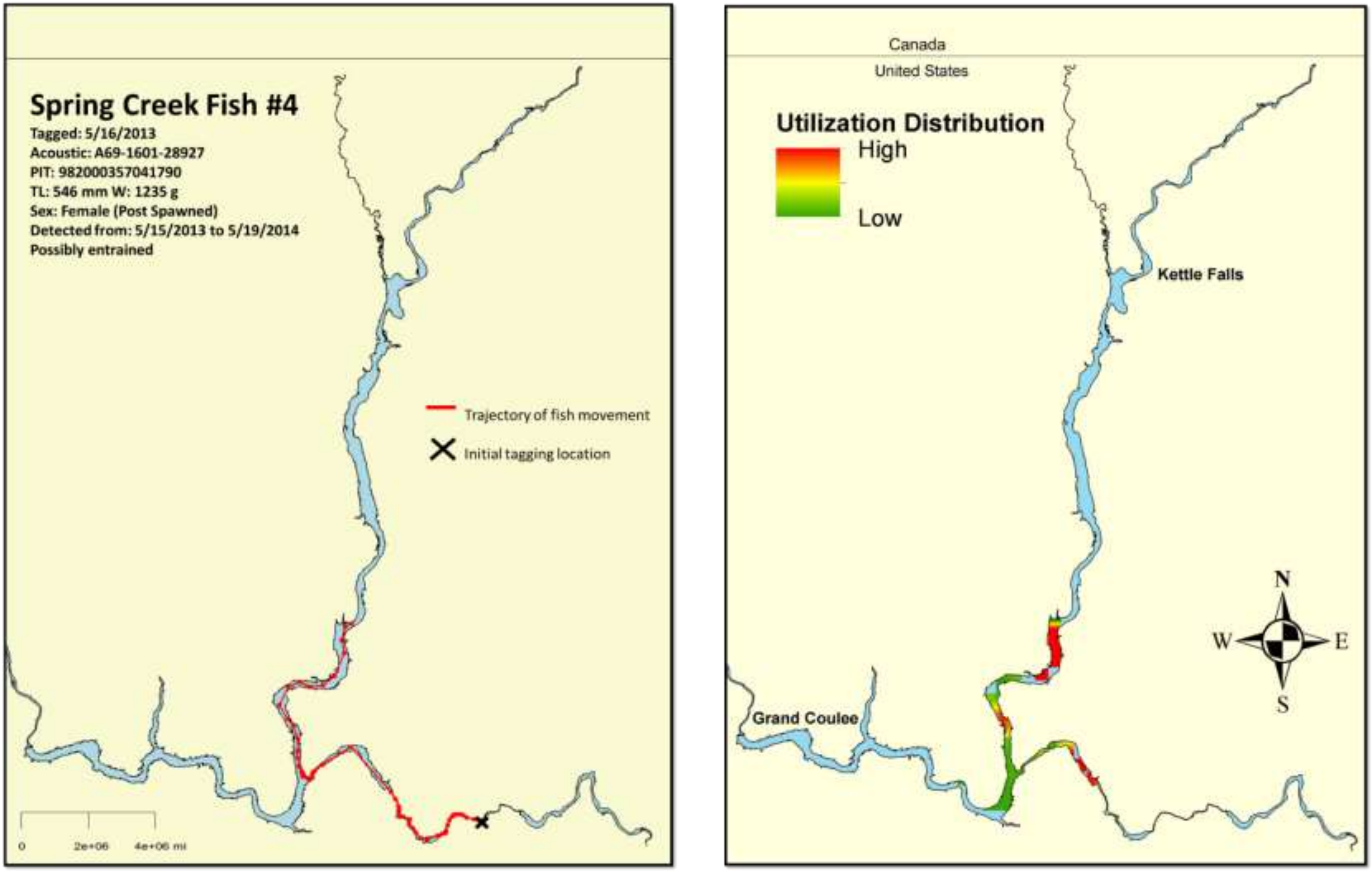


Figure E- 1. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #4 tagged in Spring Creek in 2013.

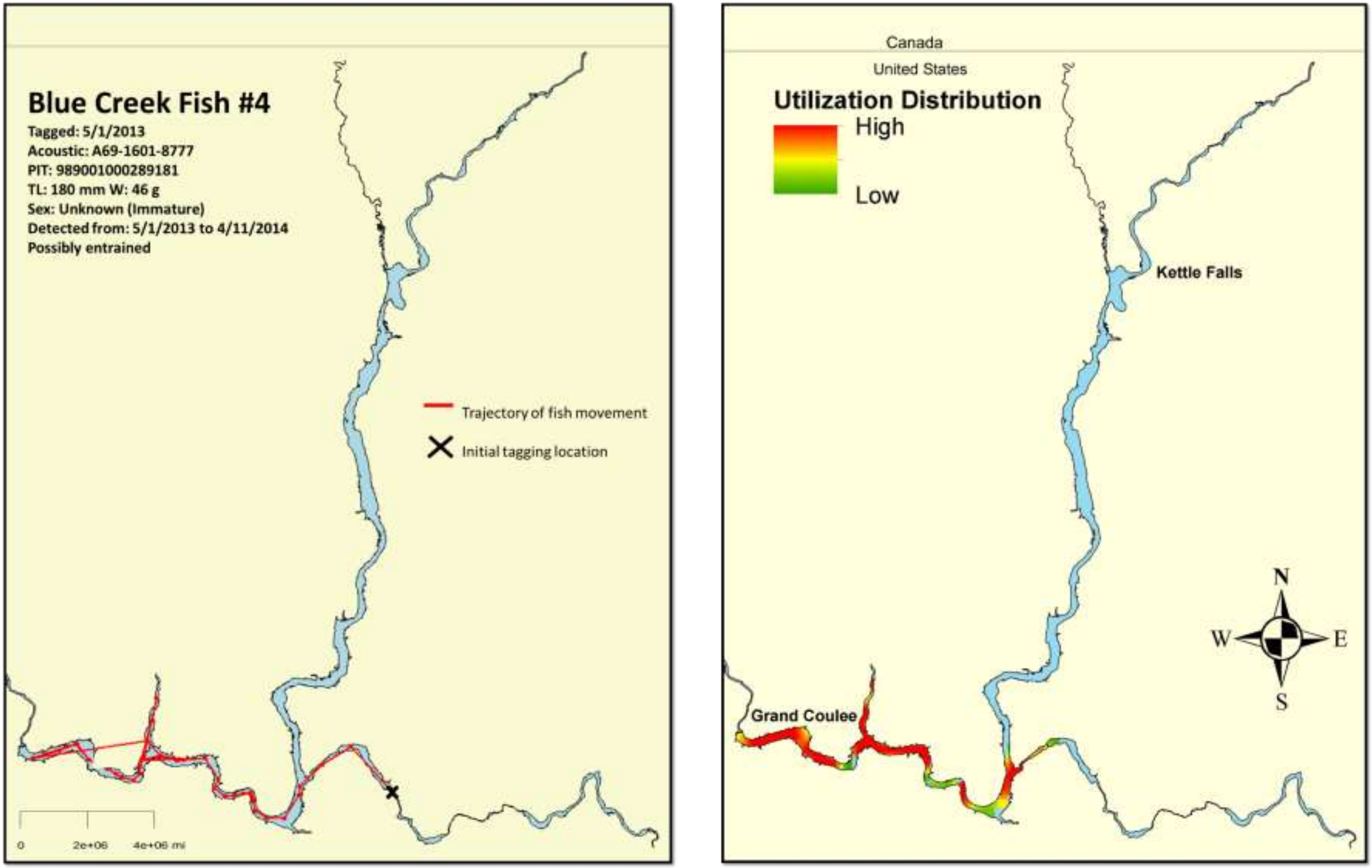


Figure E- 2. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #4 tagged in Blue Creek in 2013.

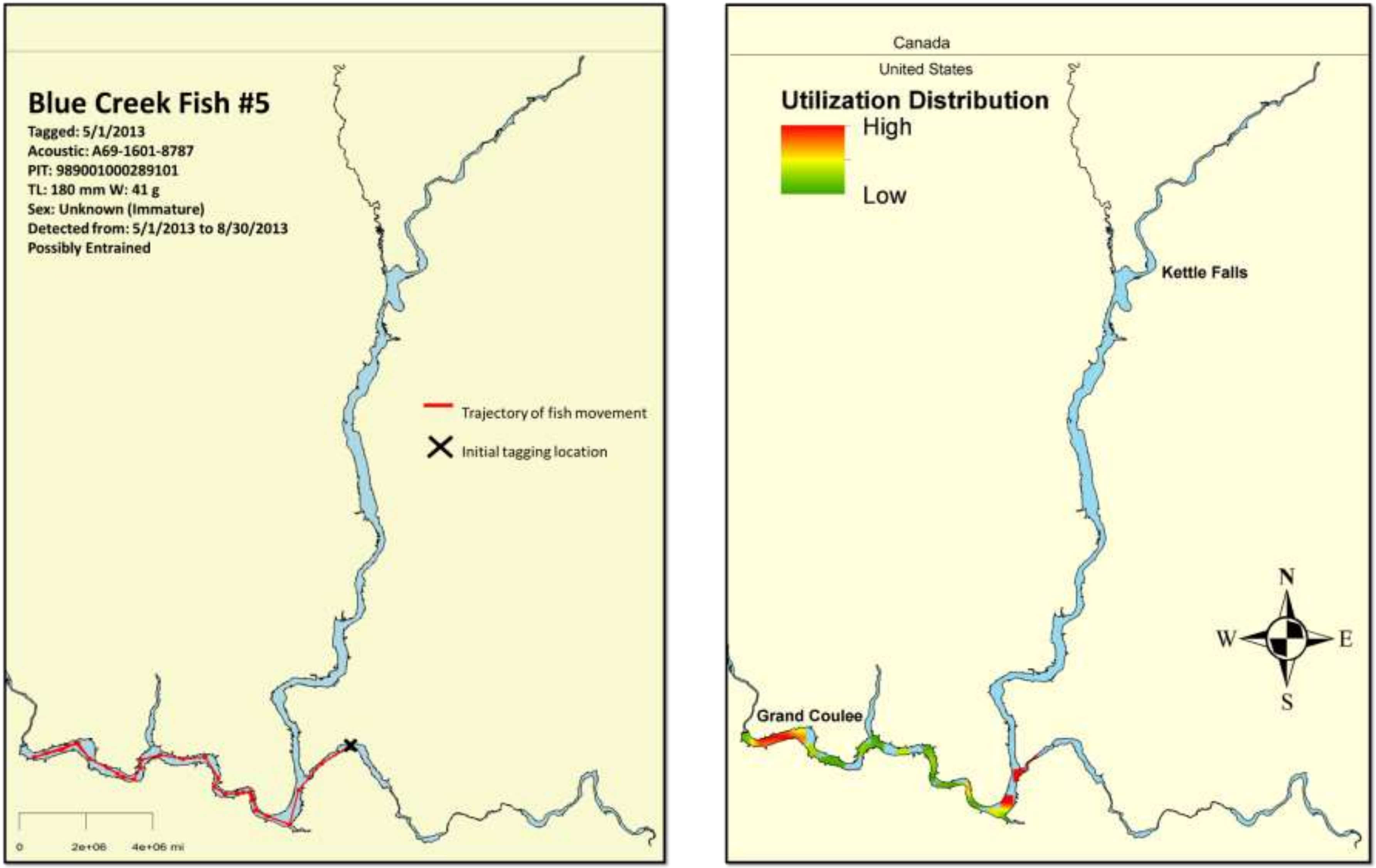


Figure E- 3. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #5 tagged in Blue Creek in 2013.

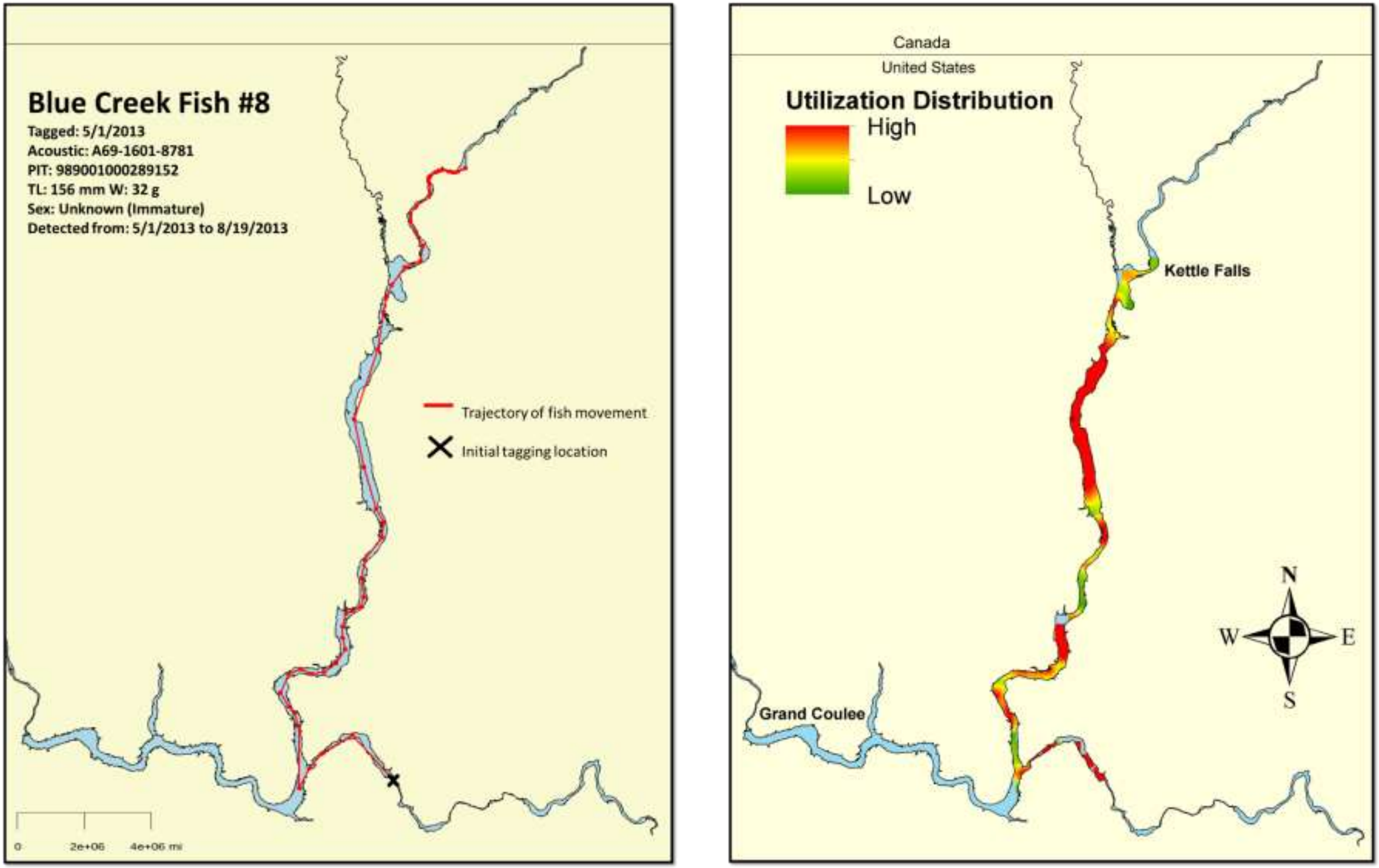


Figure E- 4. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #8 tagged in Blue Creek in 2013.

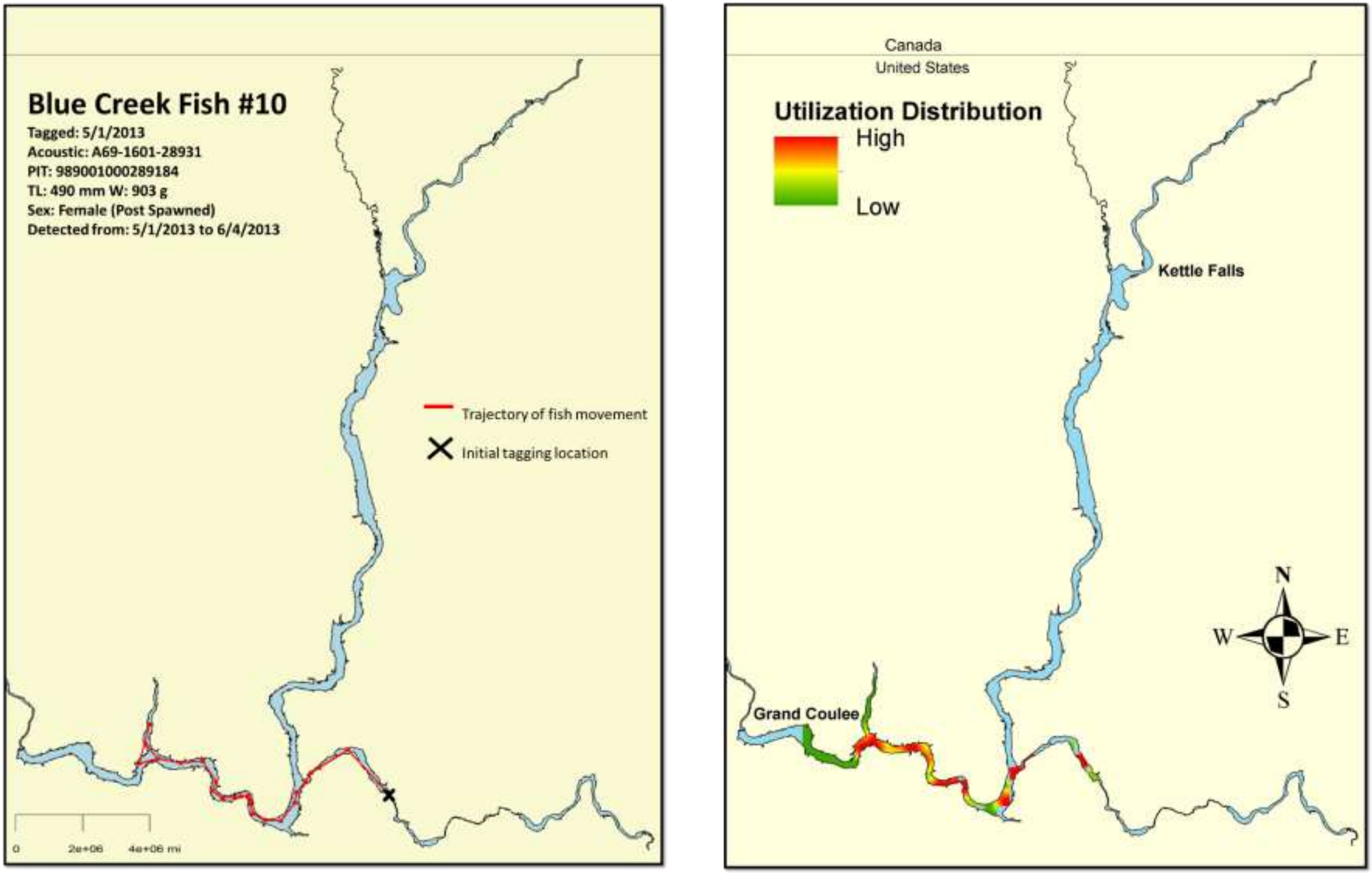


Figure E- 5. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #10 tagged in Blue Creek in 2013.

Appendix F. 2013 trajectories and utilization distribution of Redband Trout tagged in Big Sheep Creek.

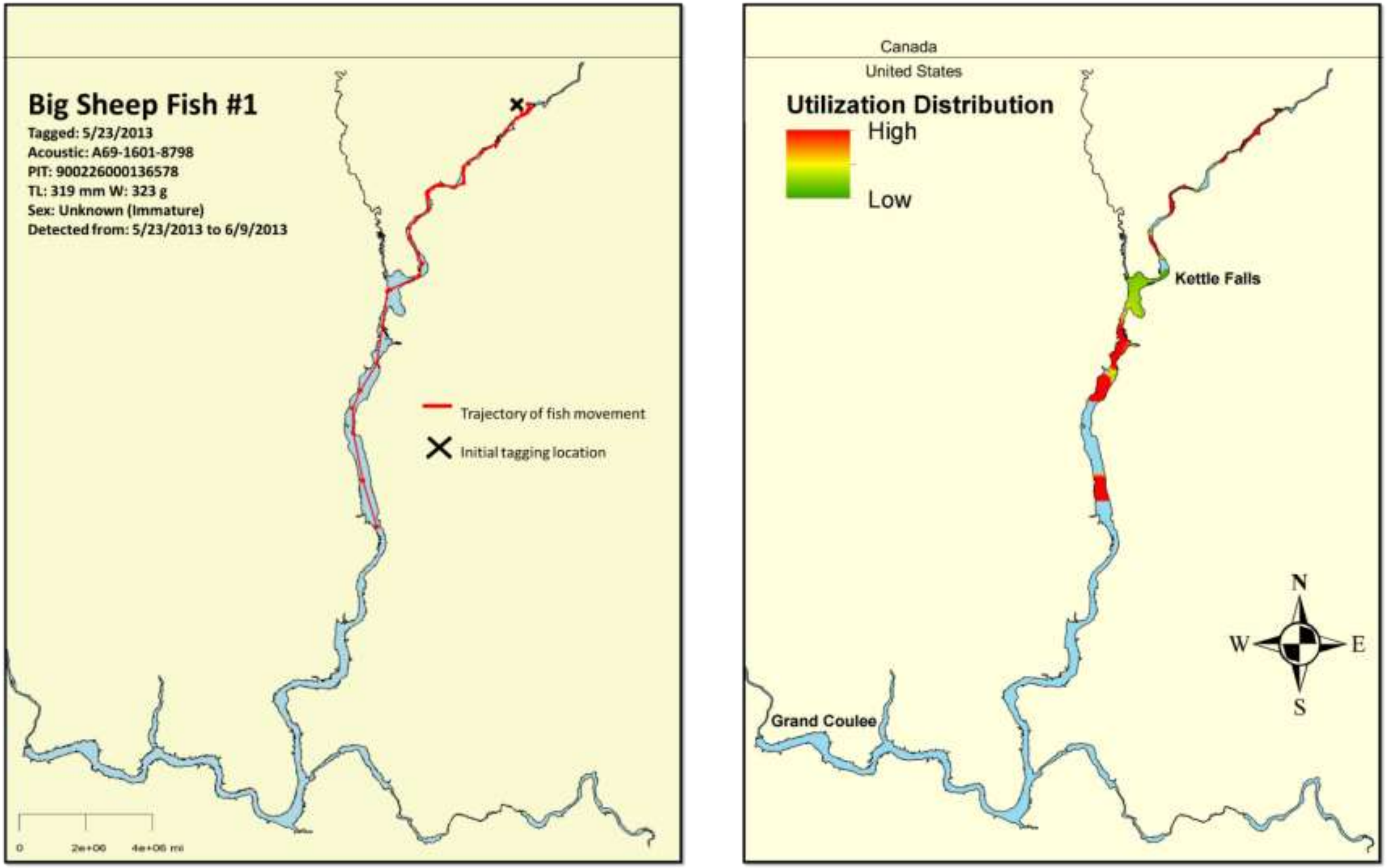


Figure F- 1. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #1 tagged in Big Sheep Creek in 2013.

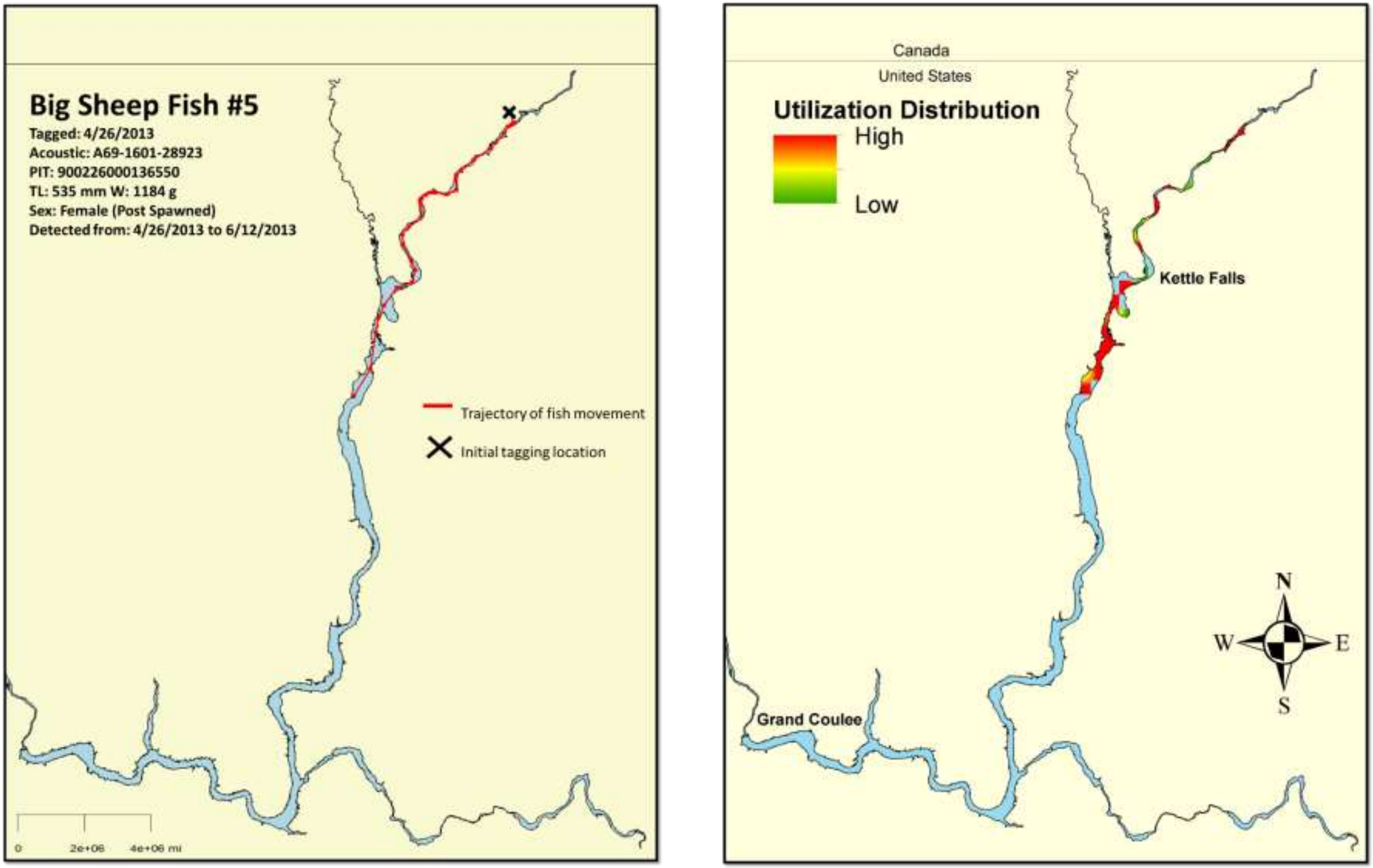


Figure F- 2. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #5 tagged in Big Sheep Creek in 2013.

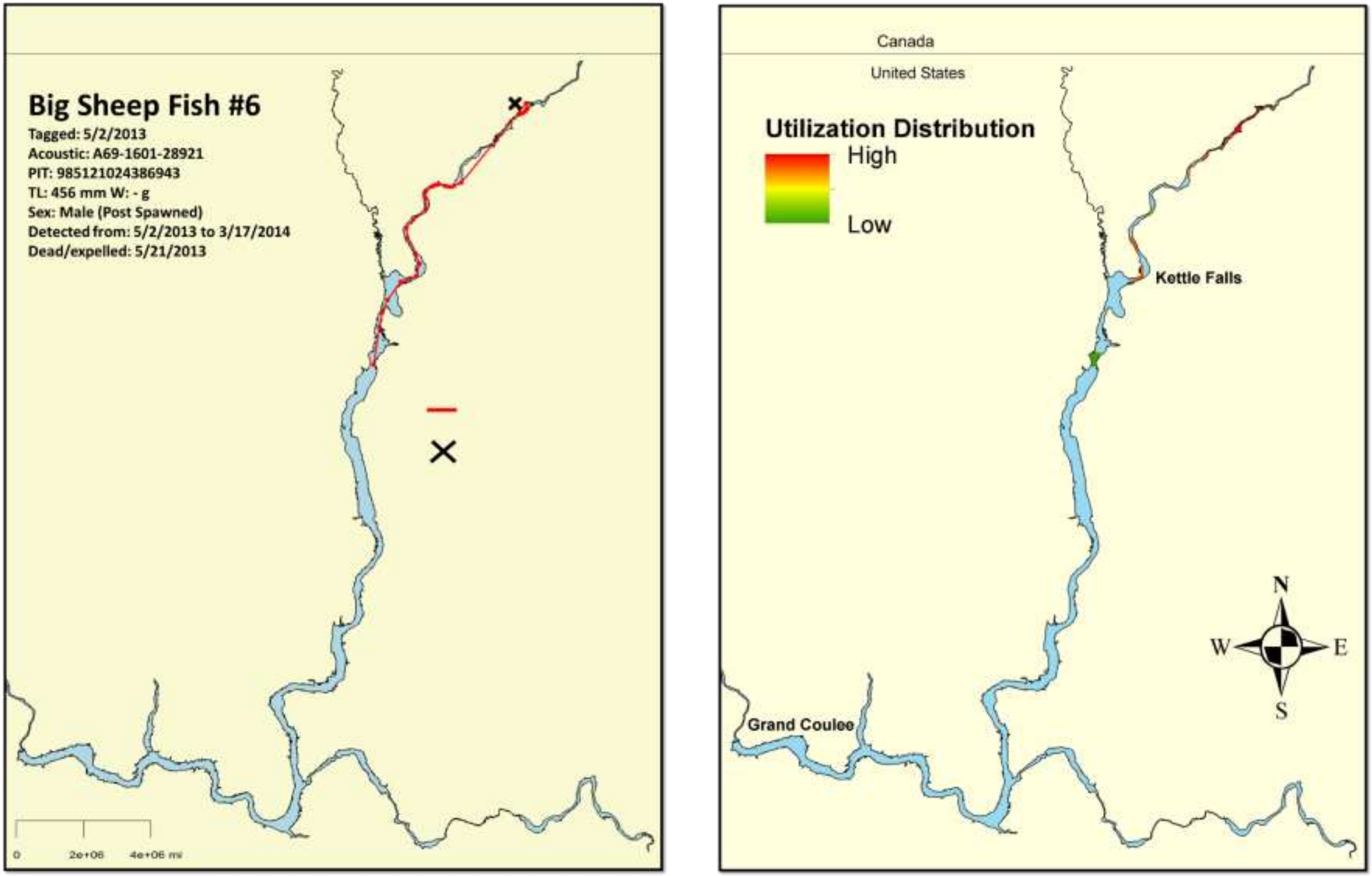
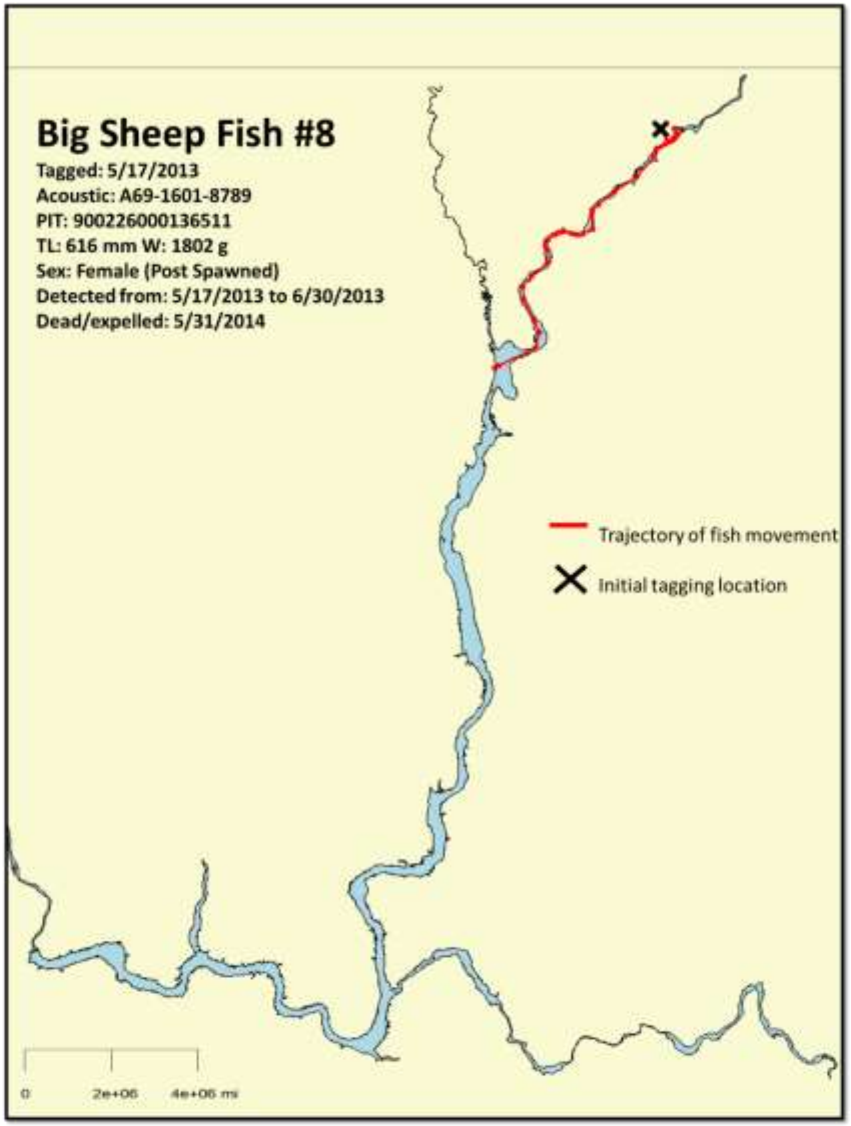


Figure F- 3. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #6 tagged in Big Sheep Creek in 2013.



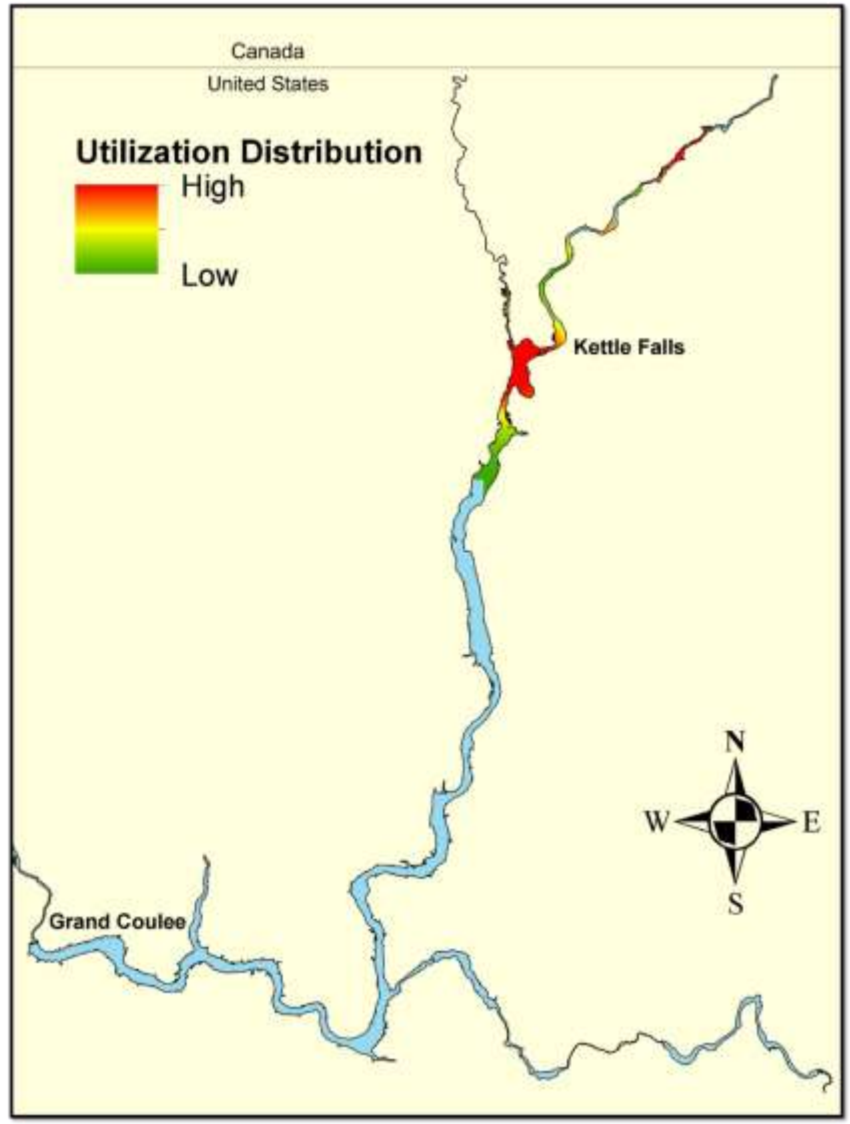


Figure F- 4. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #8 tagged in Big Sheep Creek in 2013.

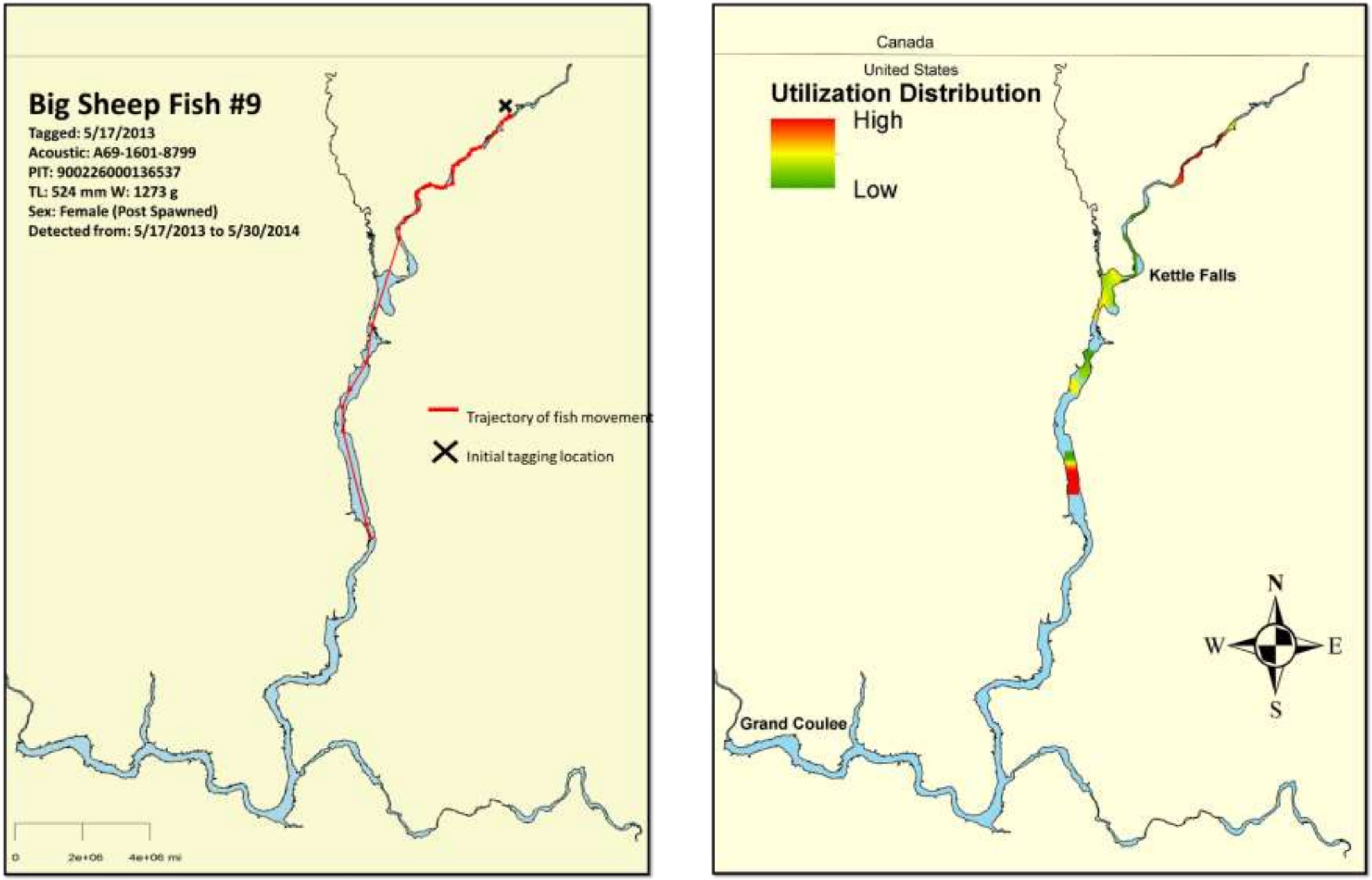


Figure F- 5. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #9 tagged in Big Sheep Creek in 2013.

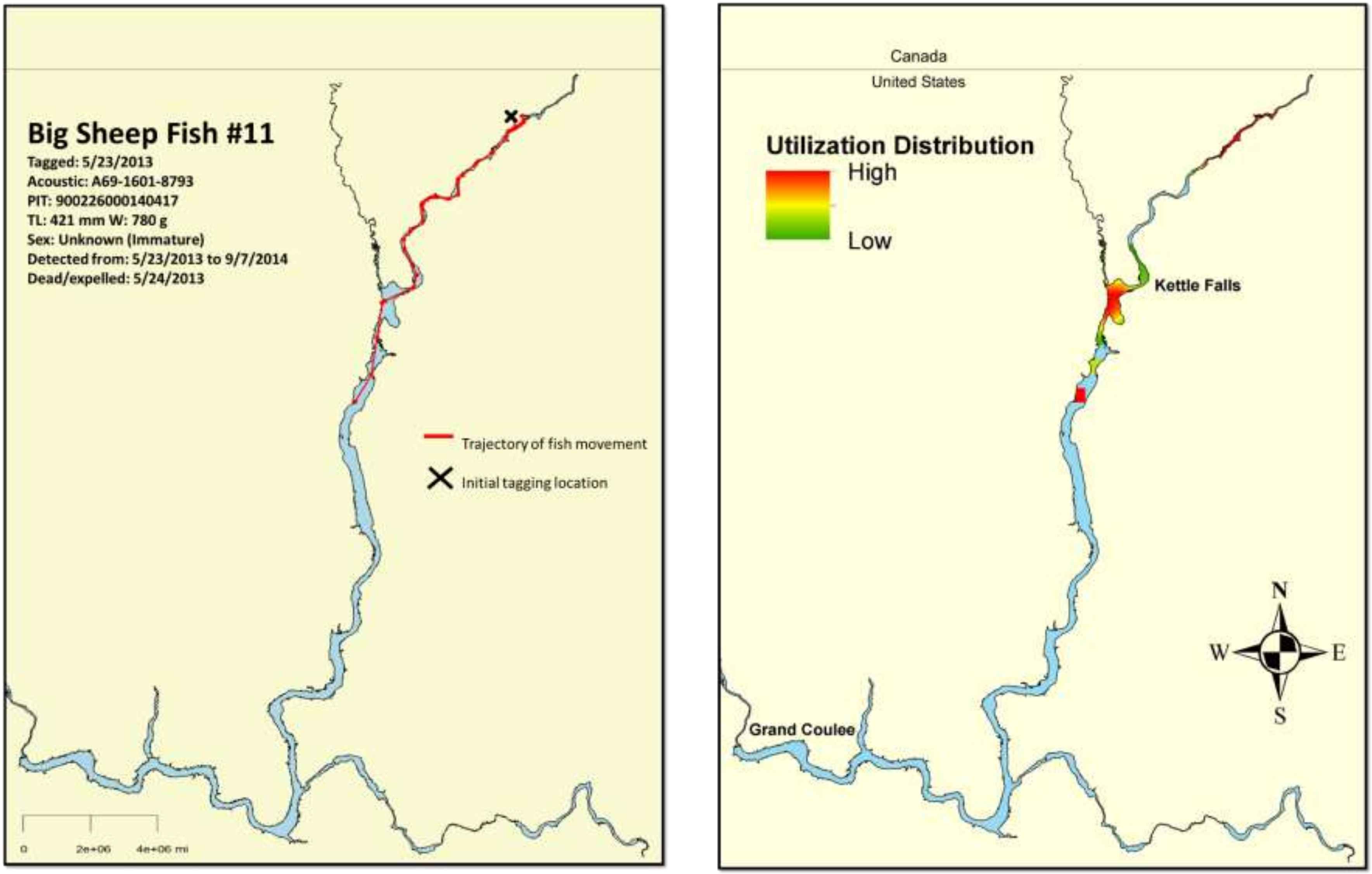


Figure F- 6. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #11 tagged in Big Sheep Creek in 2013.

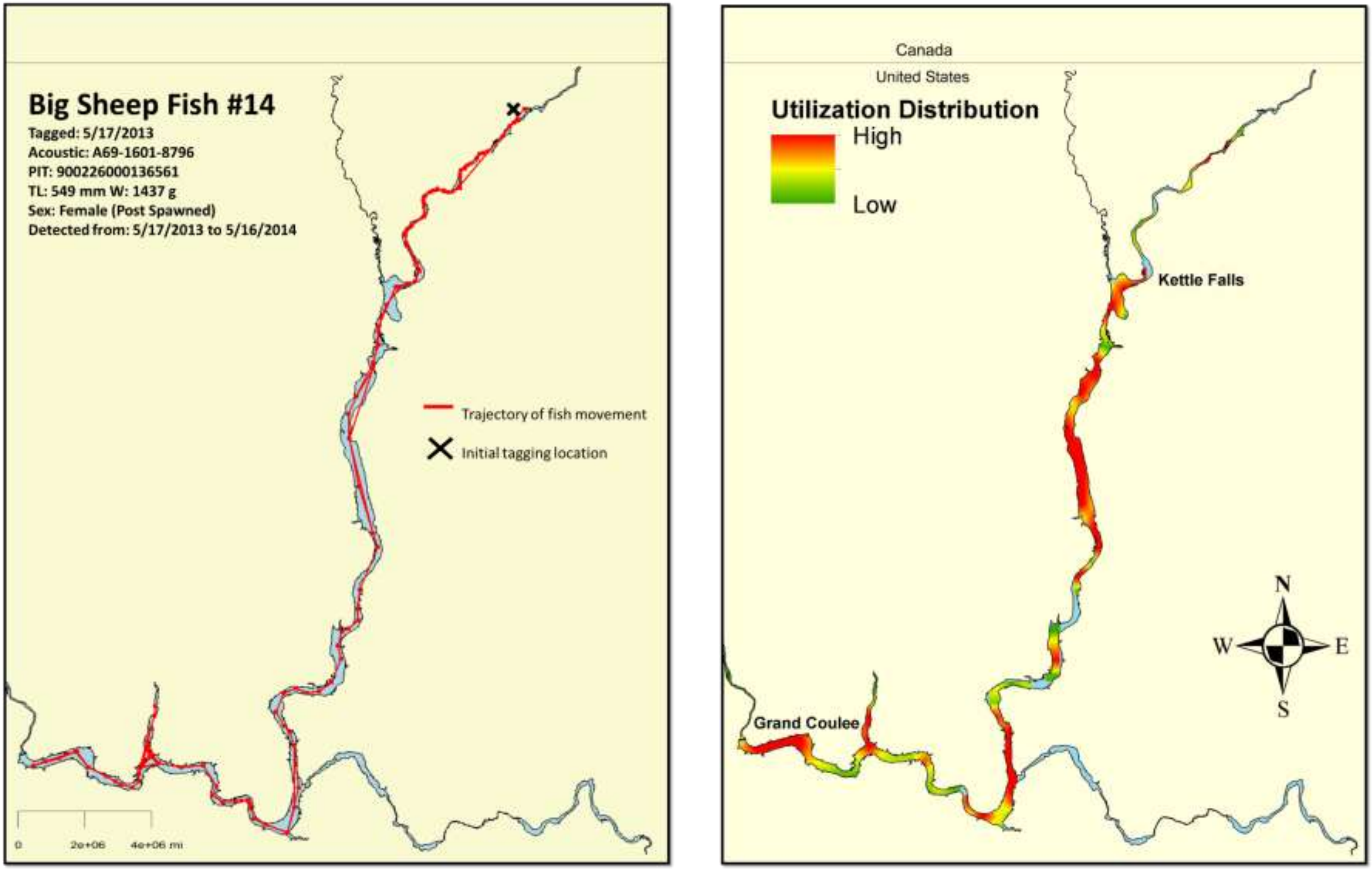
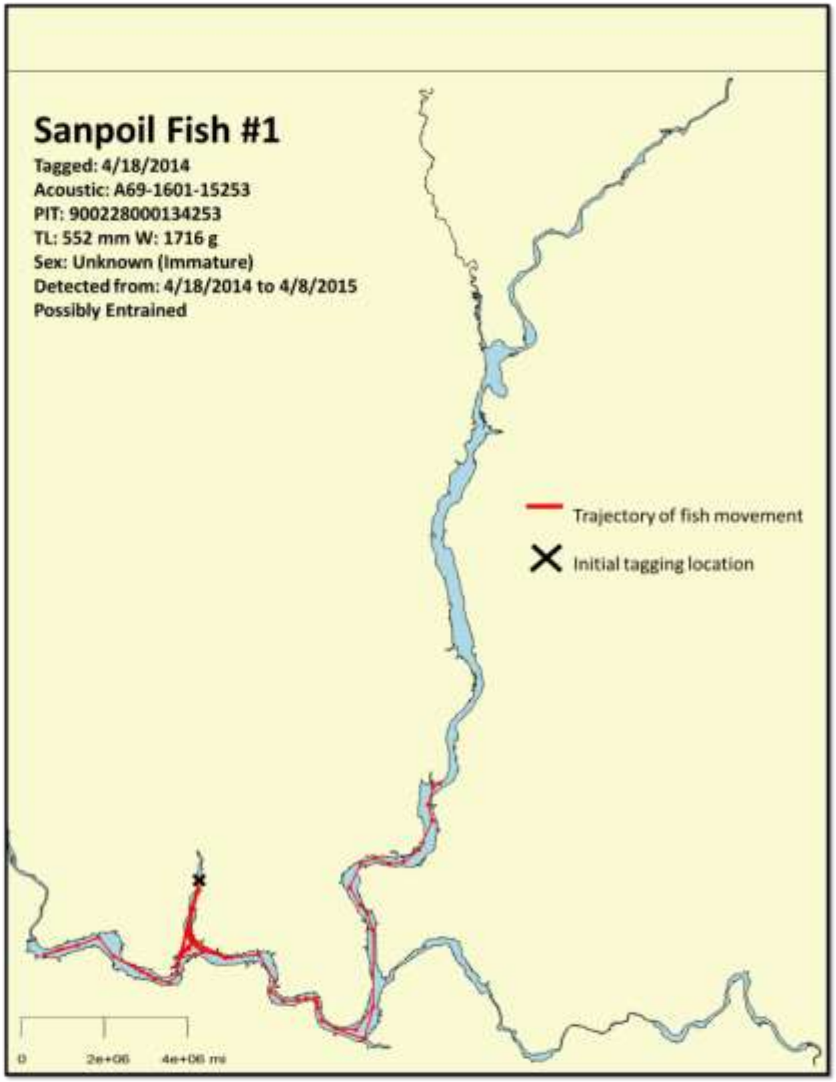


Figure F- 7. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #14 tagged in Big Sheep Creek in 2013.

Appendix G. 2014 trajectories and utilization distribution of Redband Trout tagged in the Sanpoil River.



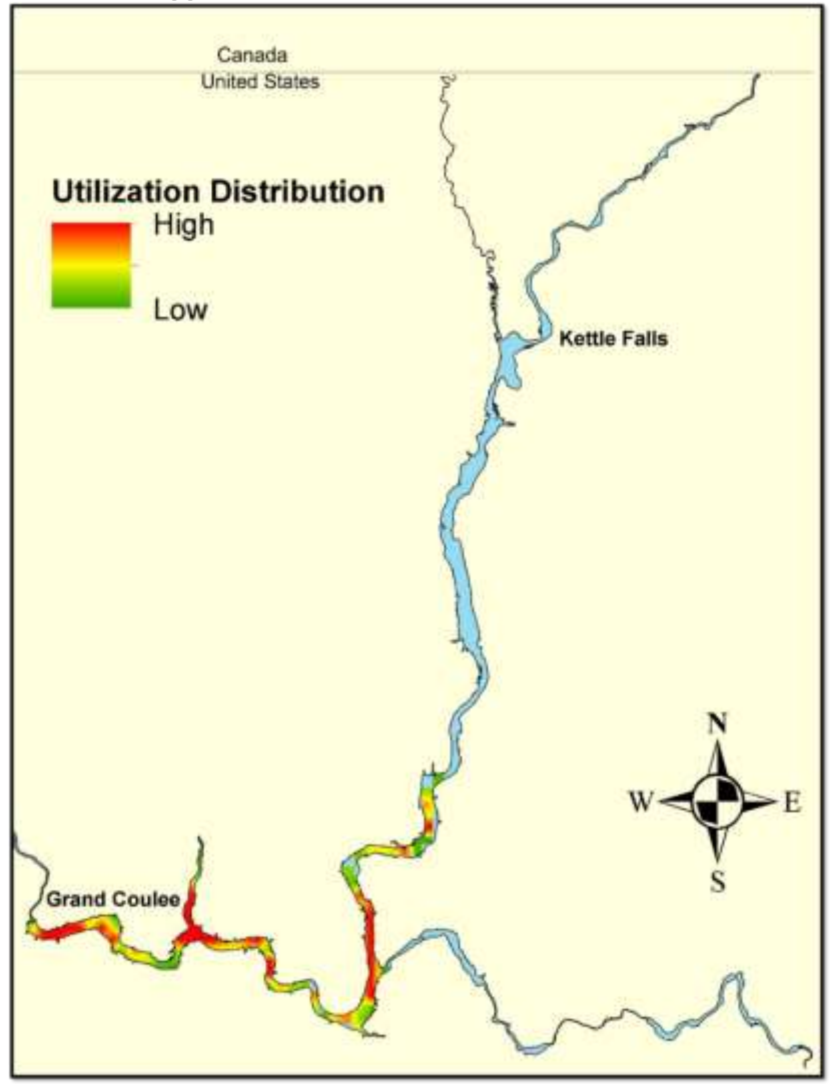


Figure G- 1. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #1 tagged in the Sanpoil River in 2014.

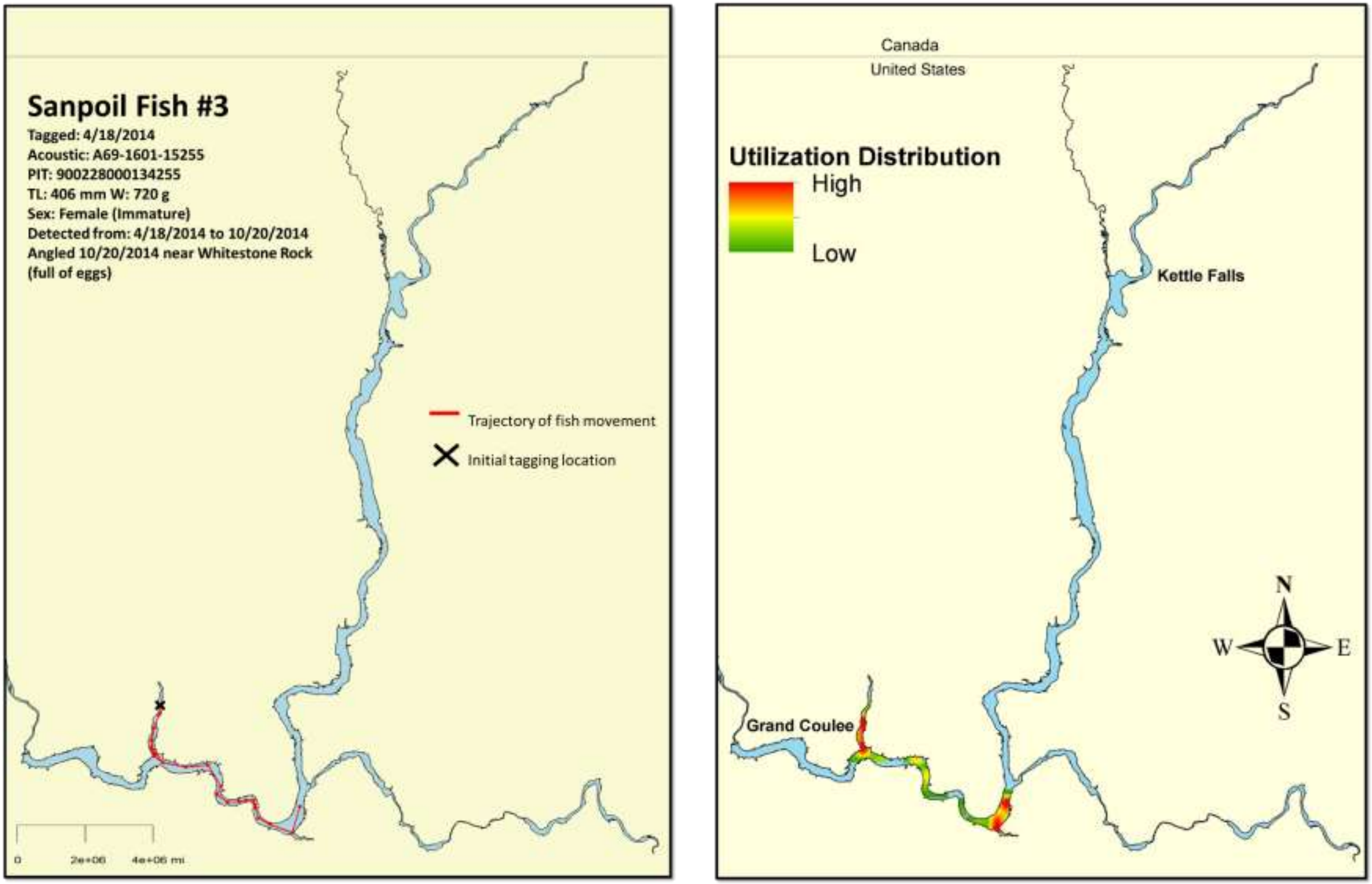


Figure G- 2. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #3 tagged in the Sanpoil River in 2014.

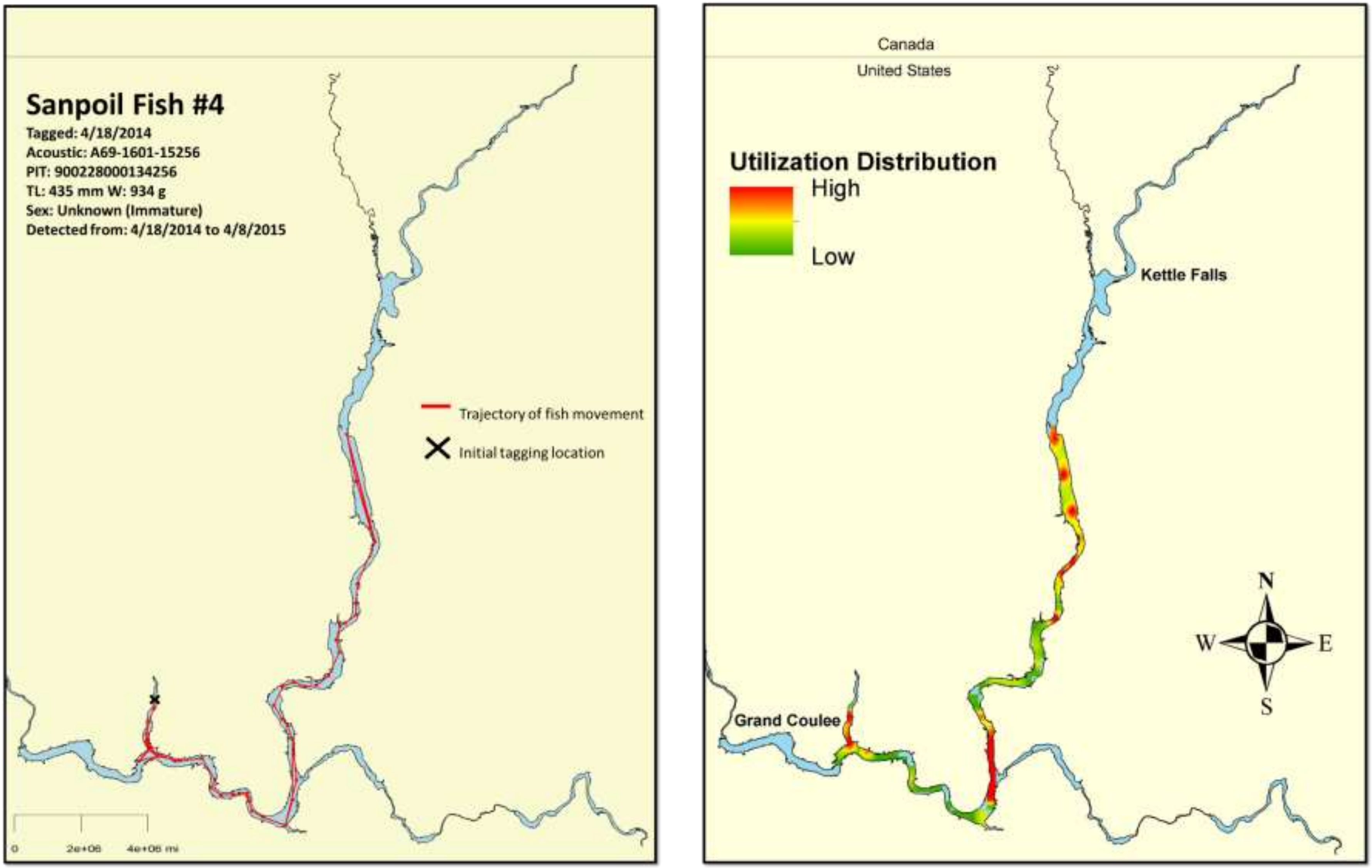


Figure G- 3. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #4 tagged in the Sanpoil River in 2014.

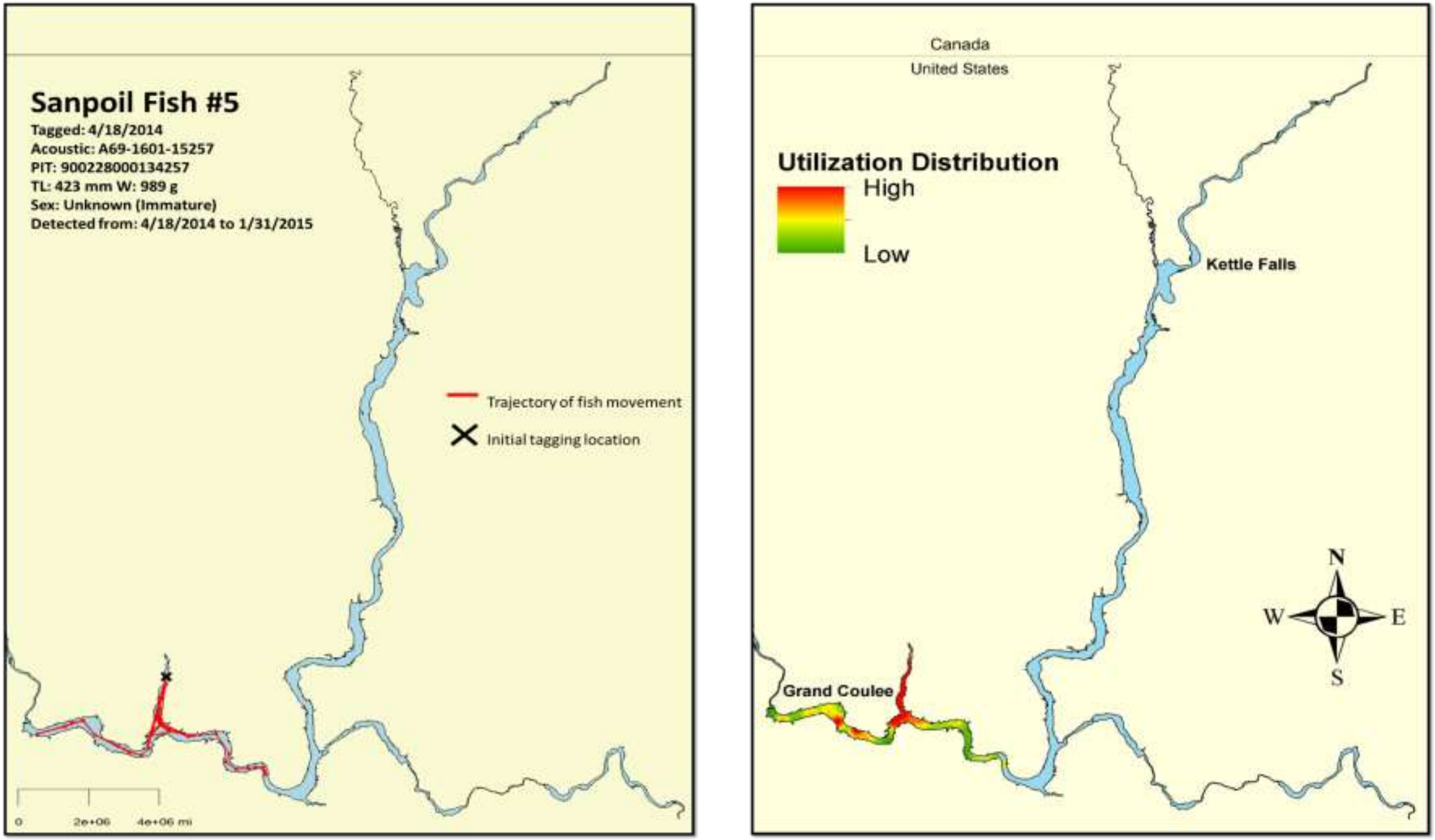


Figure G- 4. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #5 tagged in the Sanpoil River in 2014.

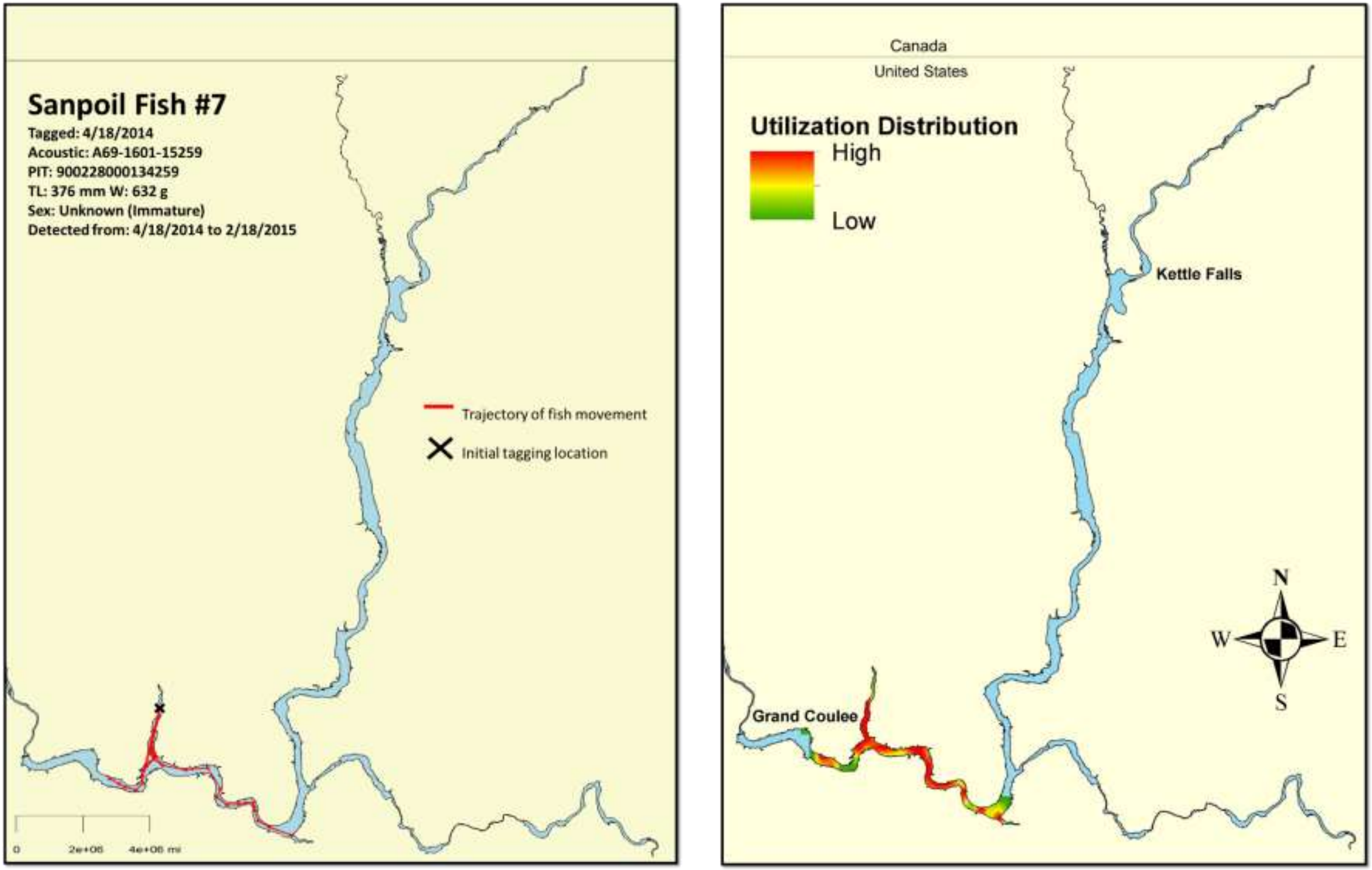


Figure G- 5. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #7 tagged in the Sanpoil River in 2014.

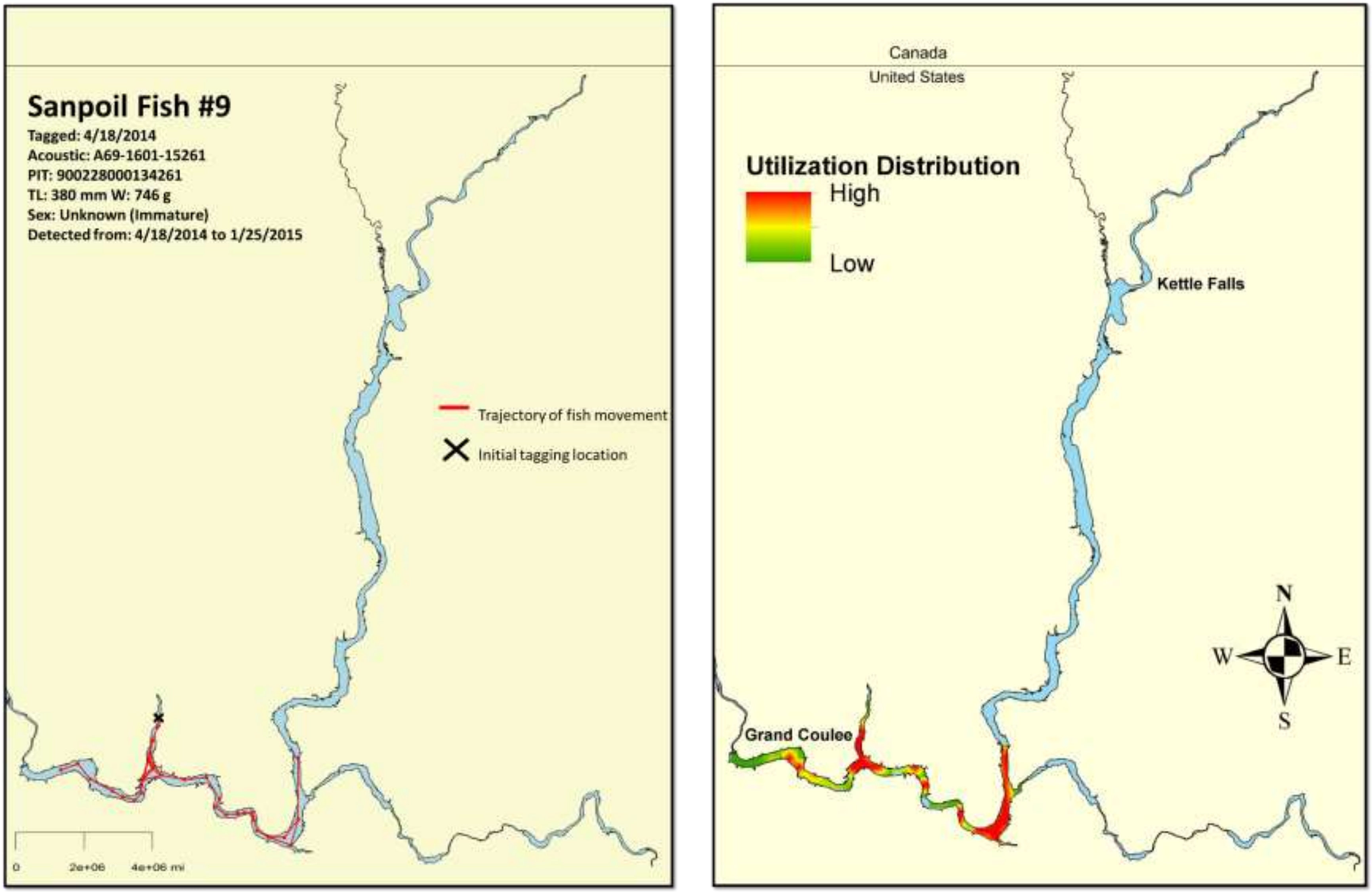
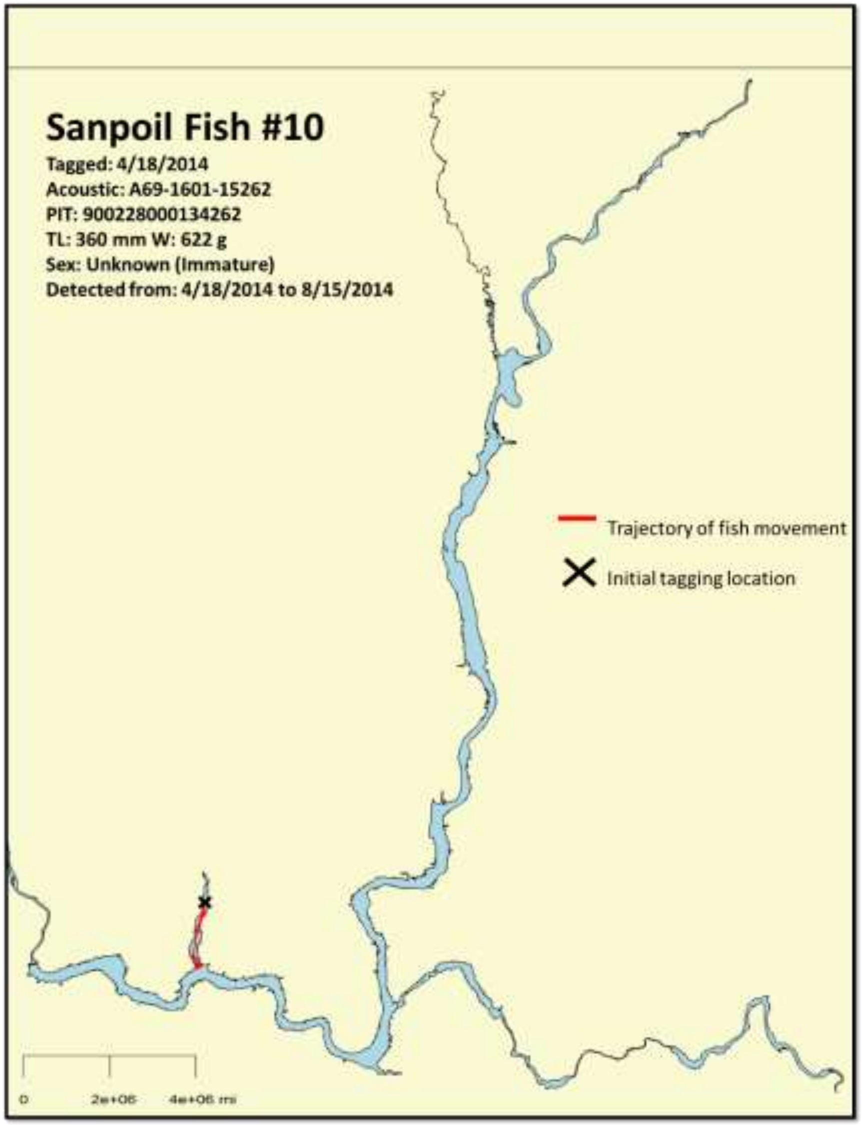


Figure G- 9. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #9 tagged in the Sanpoil River in 2014.



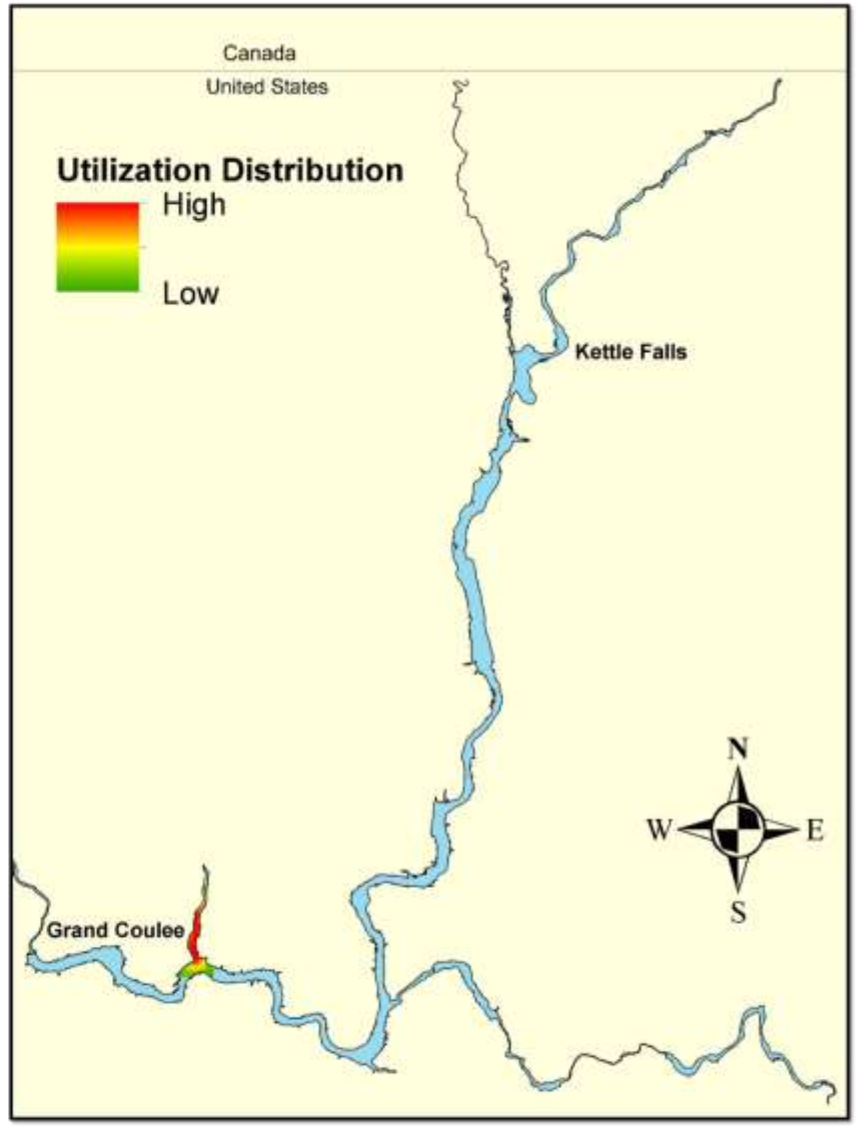


Figure G- 10. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #10 tagged in the Sanpoil River in 2014.

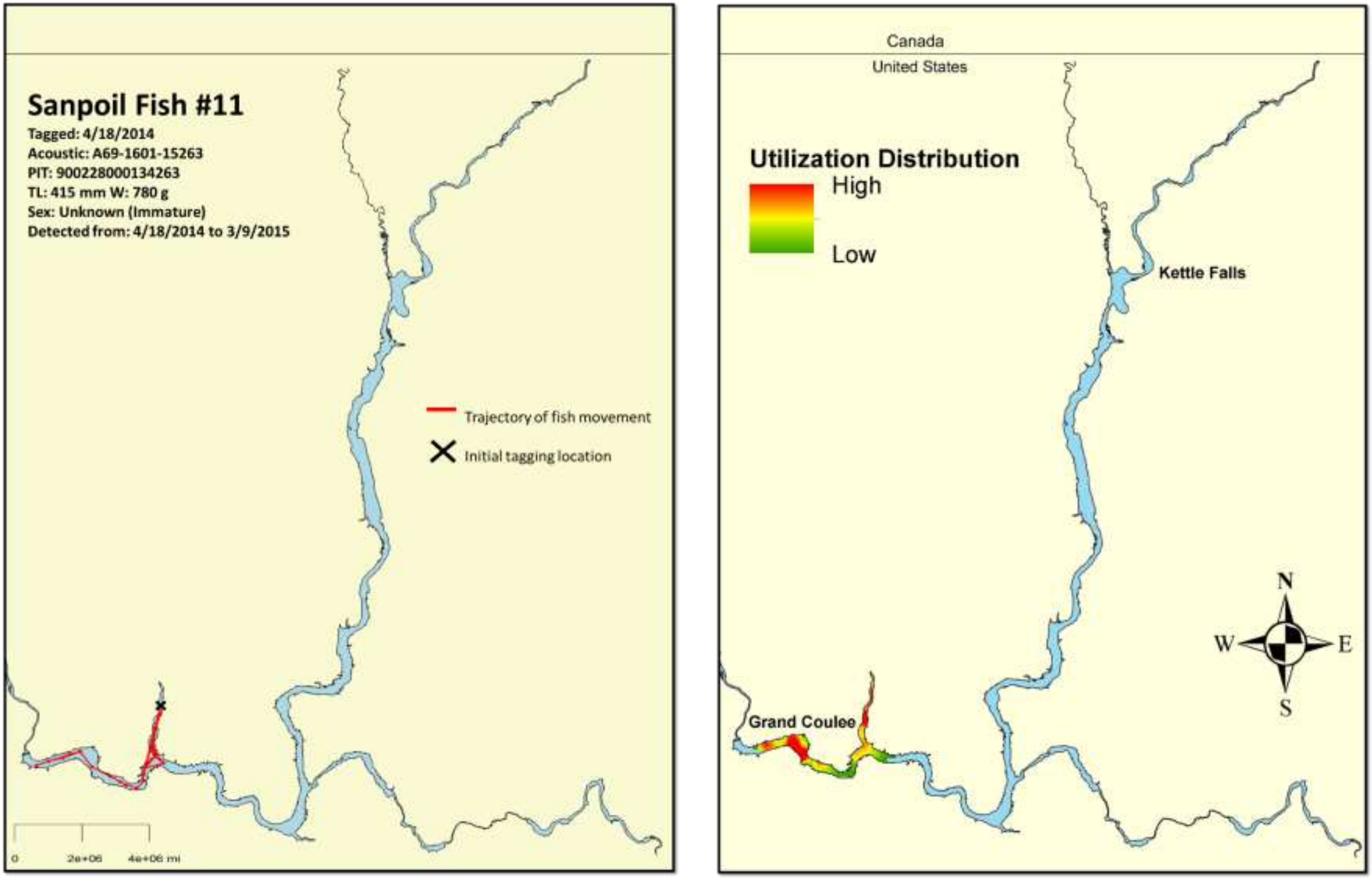


Figure G- 11. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #11 tagged in the Sanpoil River in 2014.

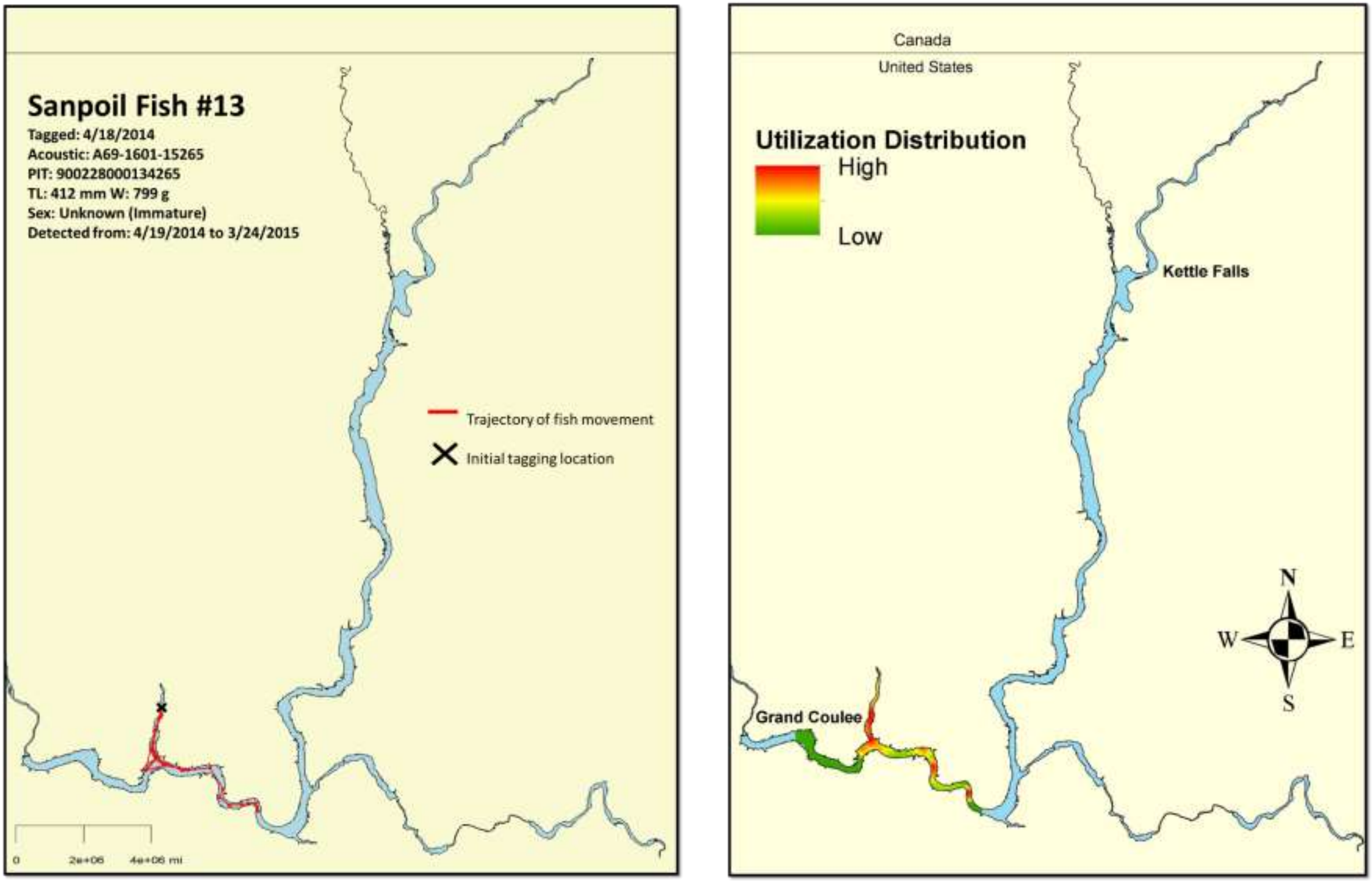


Figure G- 12. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #13 tagged in the Sanpoil River in 2014.

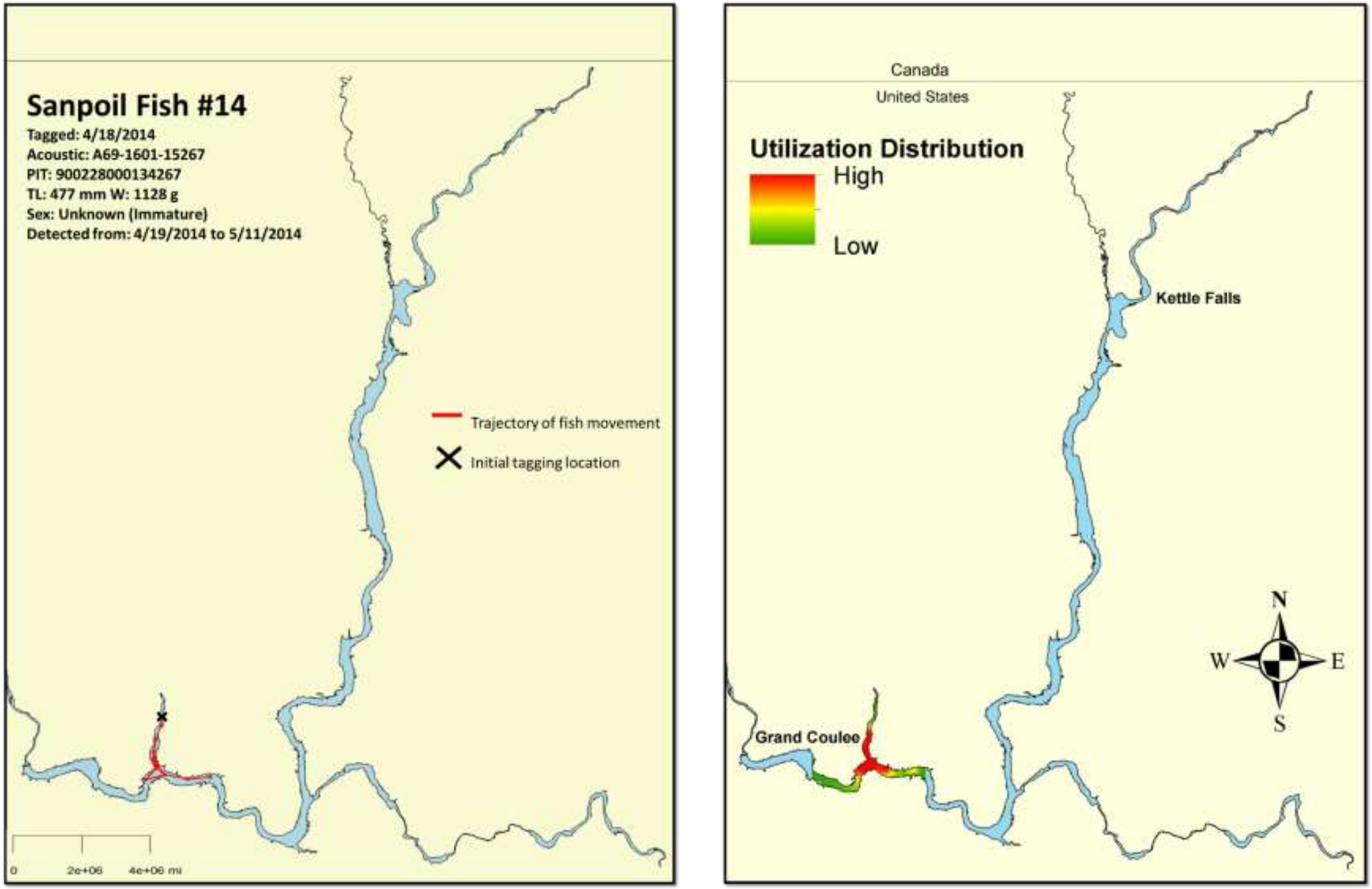


Figure G- 13. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #14 tagged in the Sanpoil River in 2014.

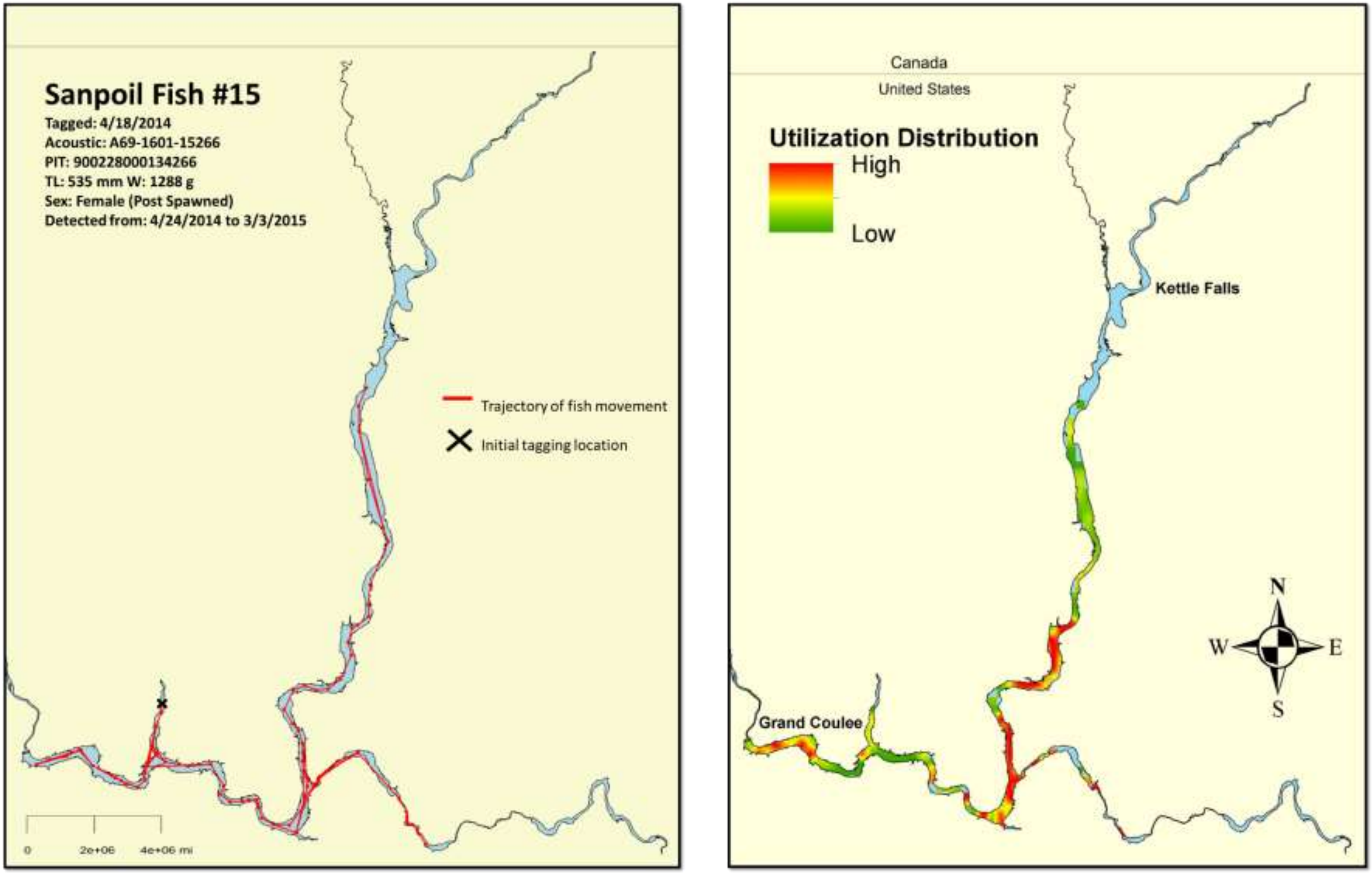
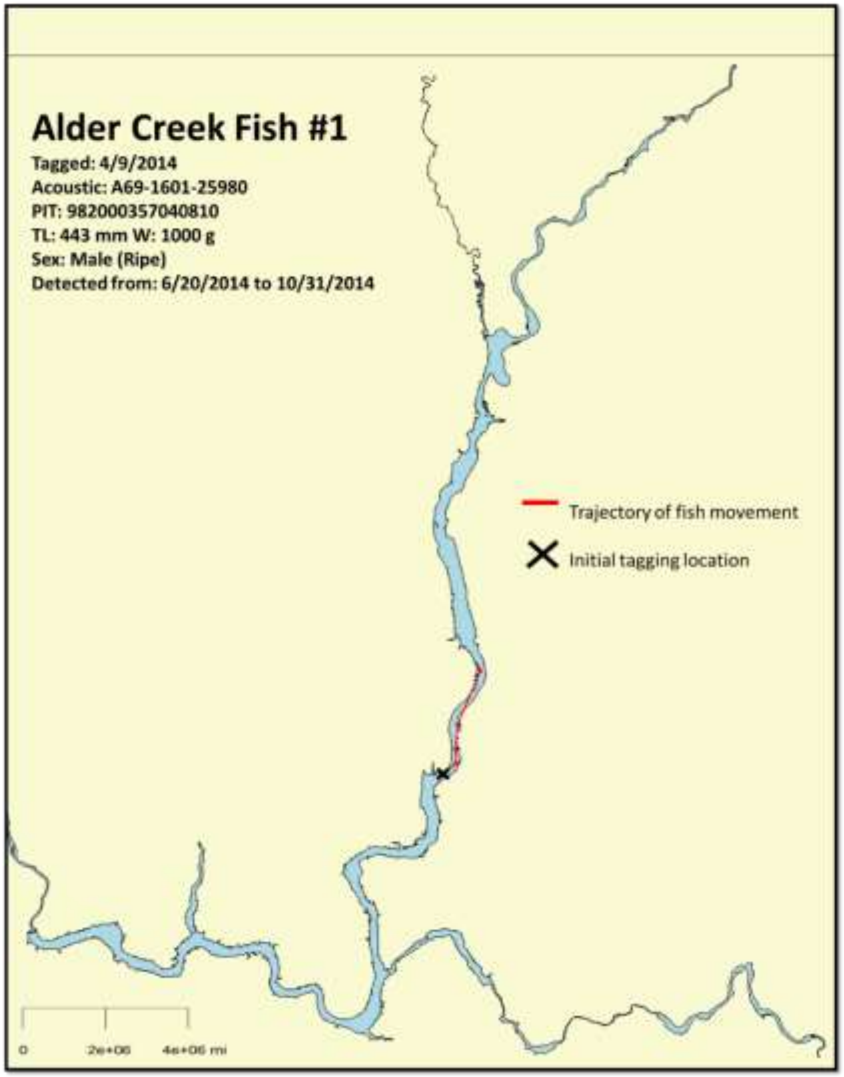


Figure G- 14. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #15 tagged in the Sanpoil River in 2014.

Appendix H. 2014 trajectories and utilization distribution of Redband Trout tagged near Wilmont/Alder Creek.



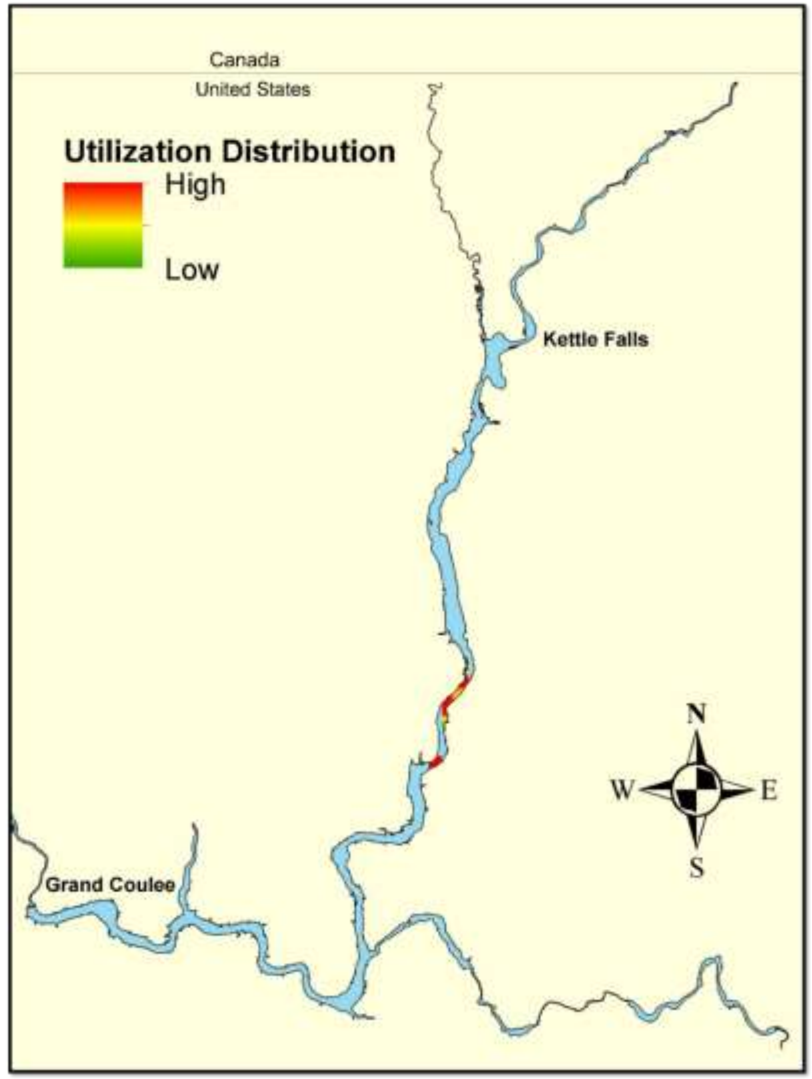


Figure H- 1. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #1 tagged in Alder Creek in 2014

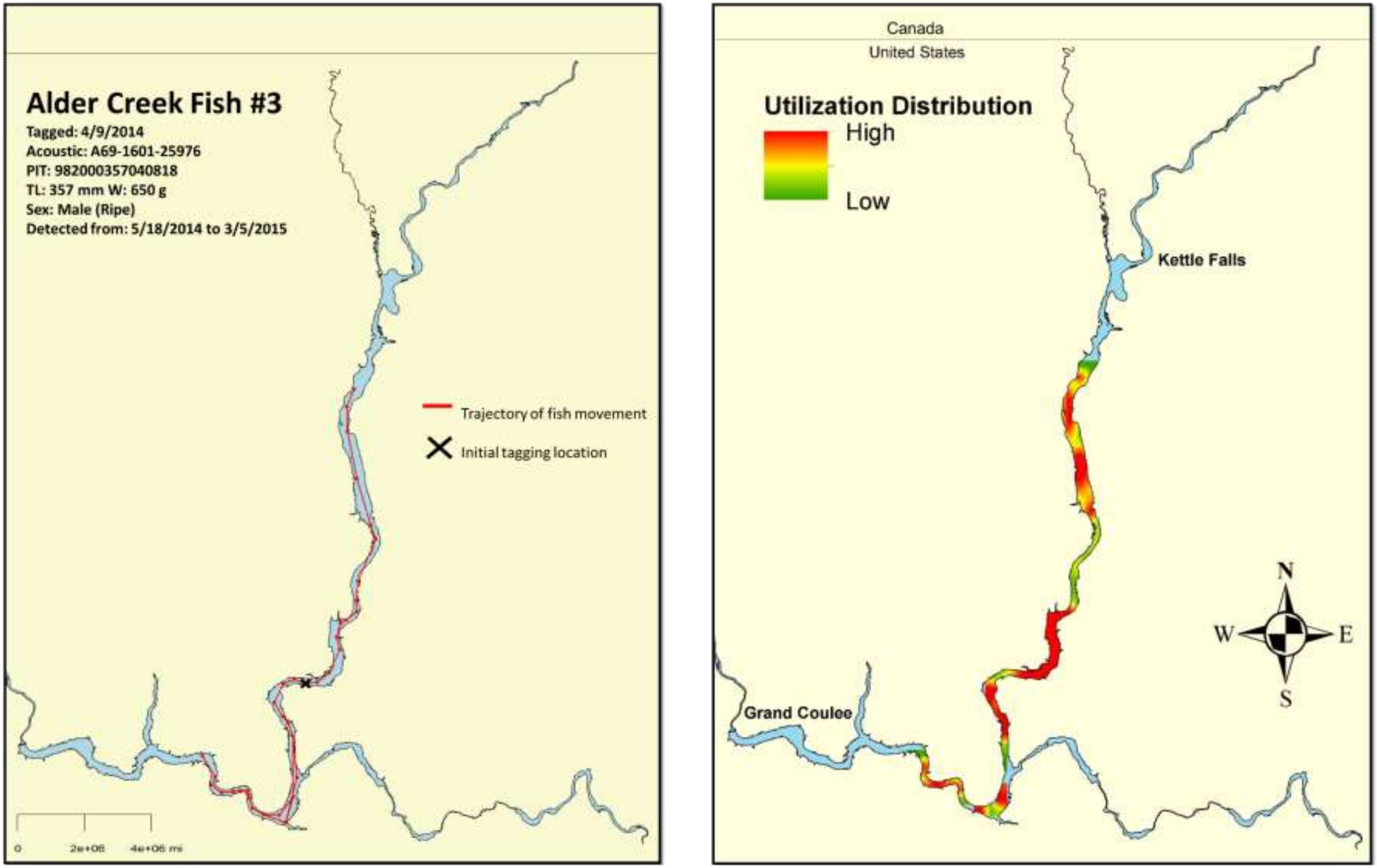


Figure H- 2. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #3 tagged in Alder Creek in 2014.

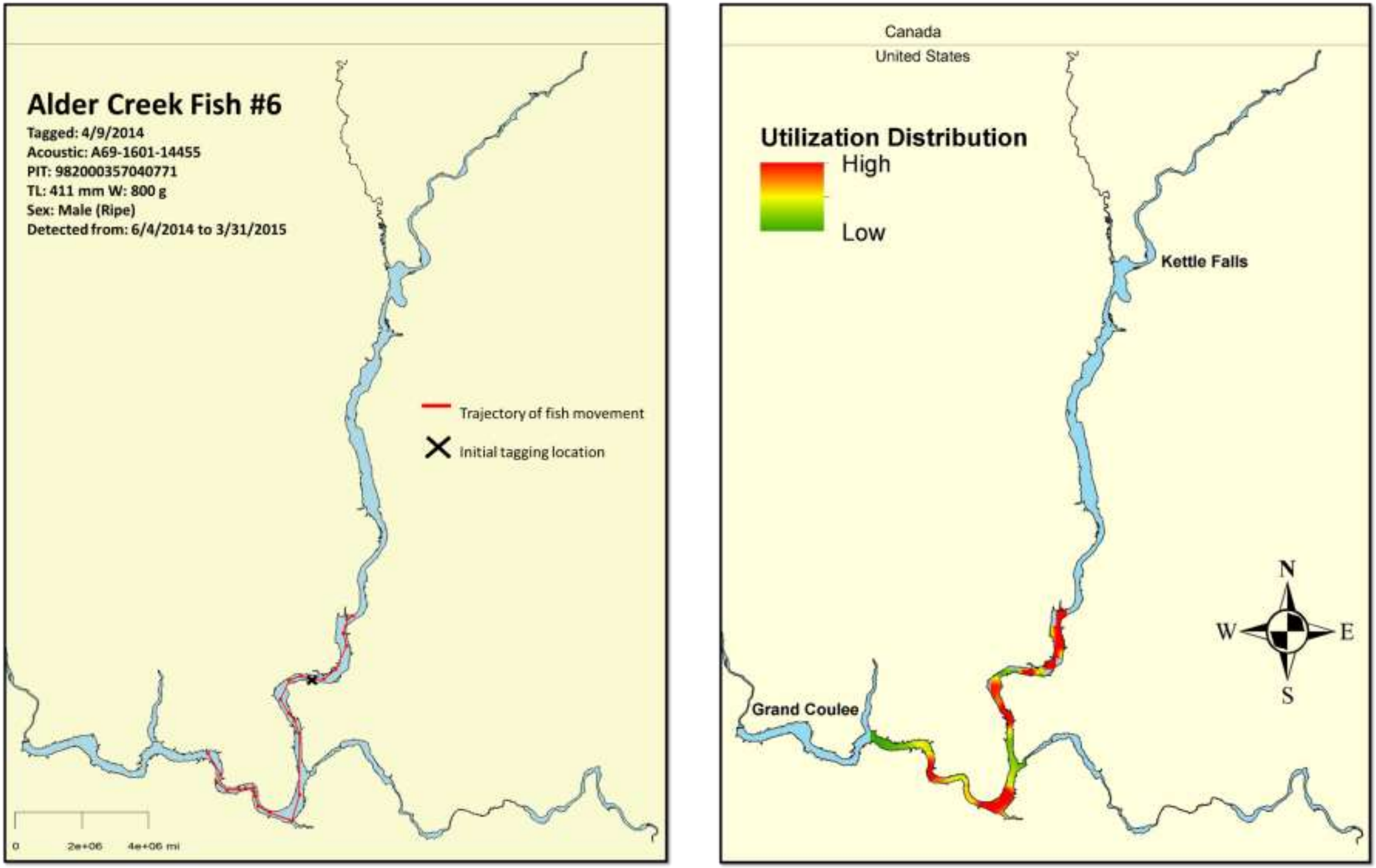


Figure H- 3. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #6 tagged in Alder Creek in 2014.

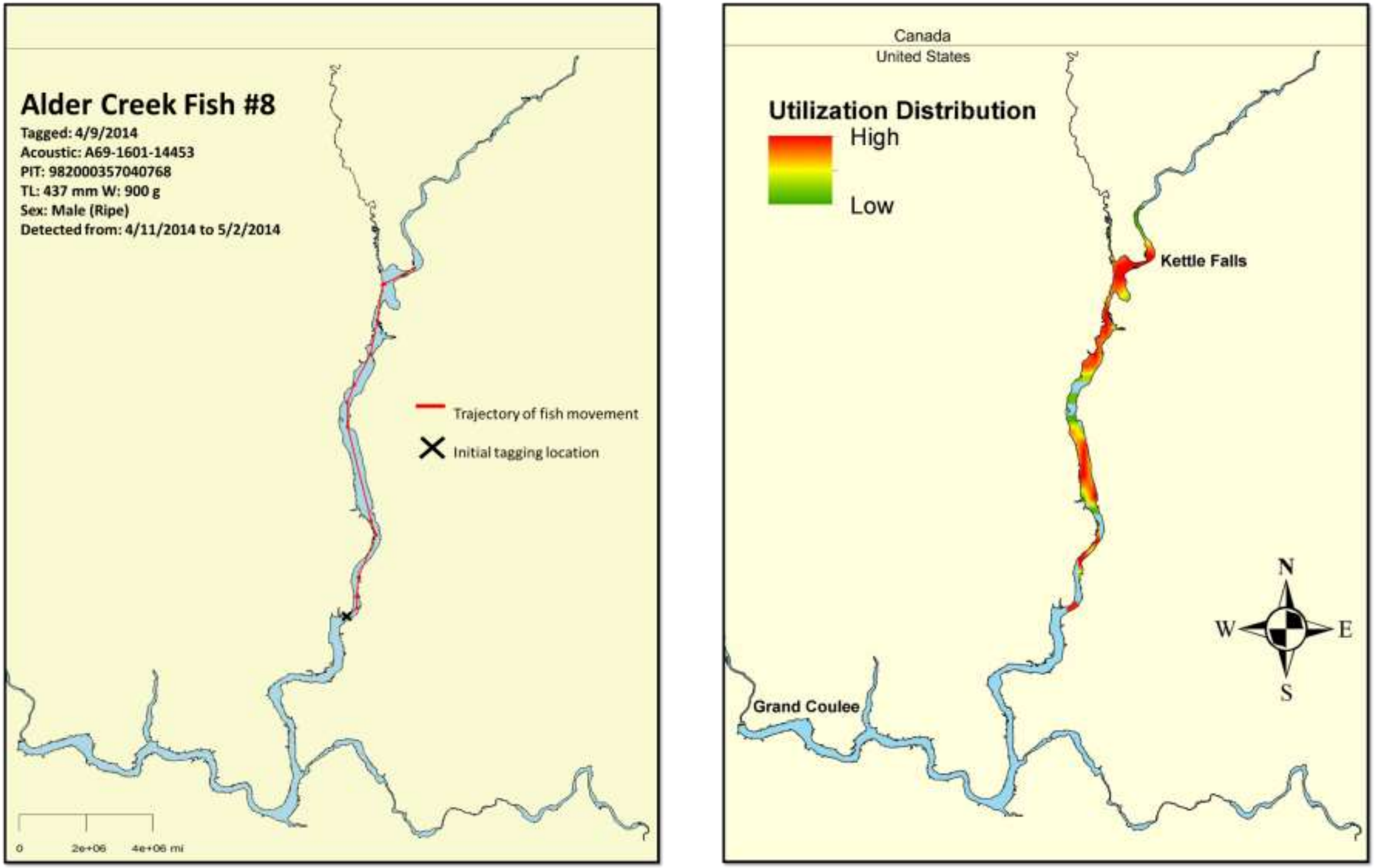


Figure H- 4. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #8 tagged in Alder Creek in 2014.

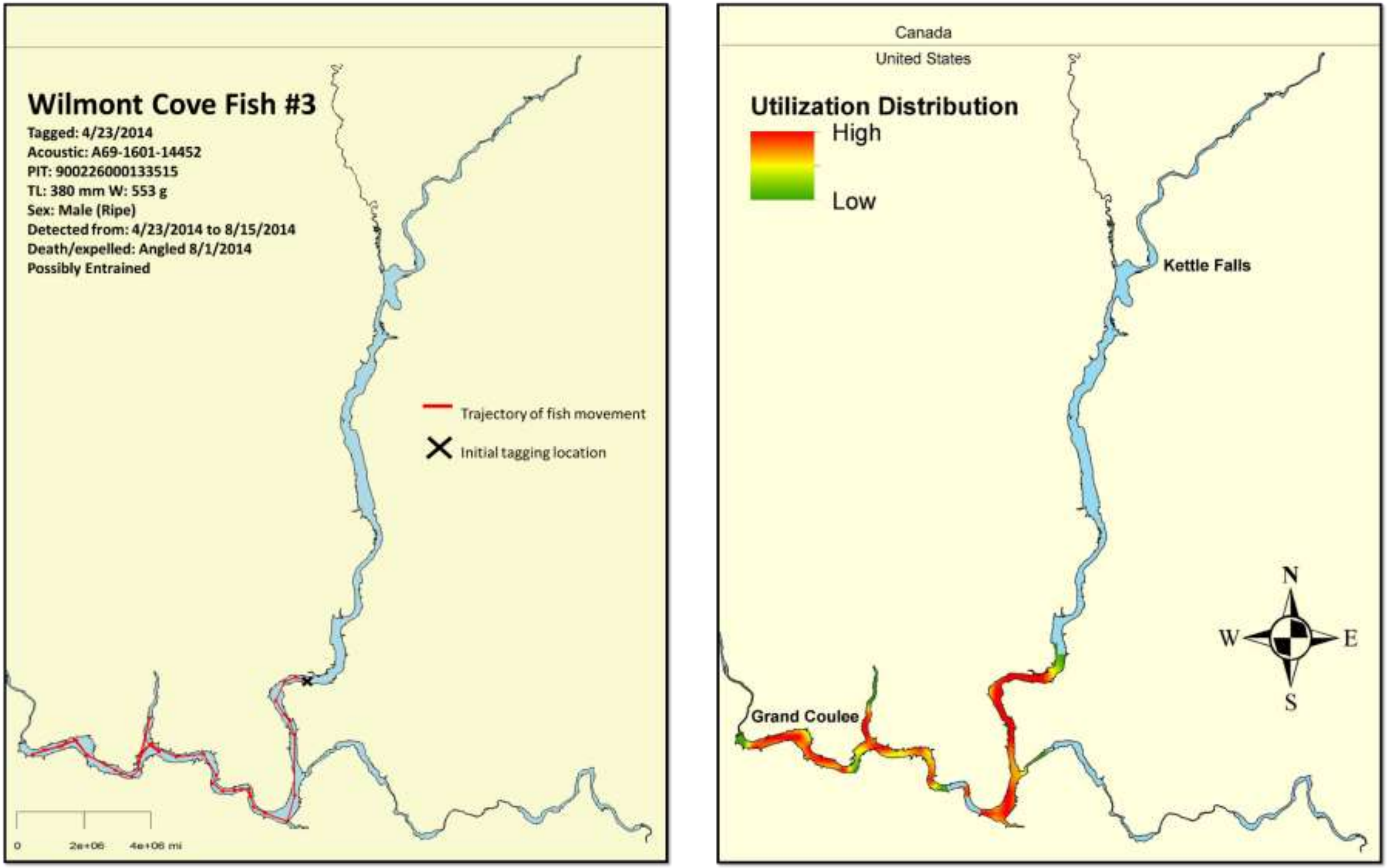


Figure H- 5. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #3 tagged in Wilmont Creek in 2014.

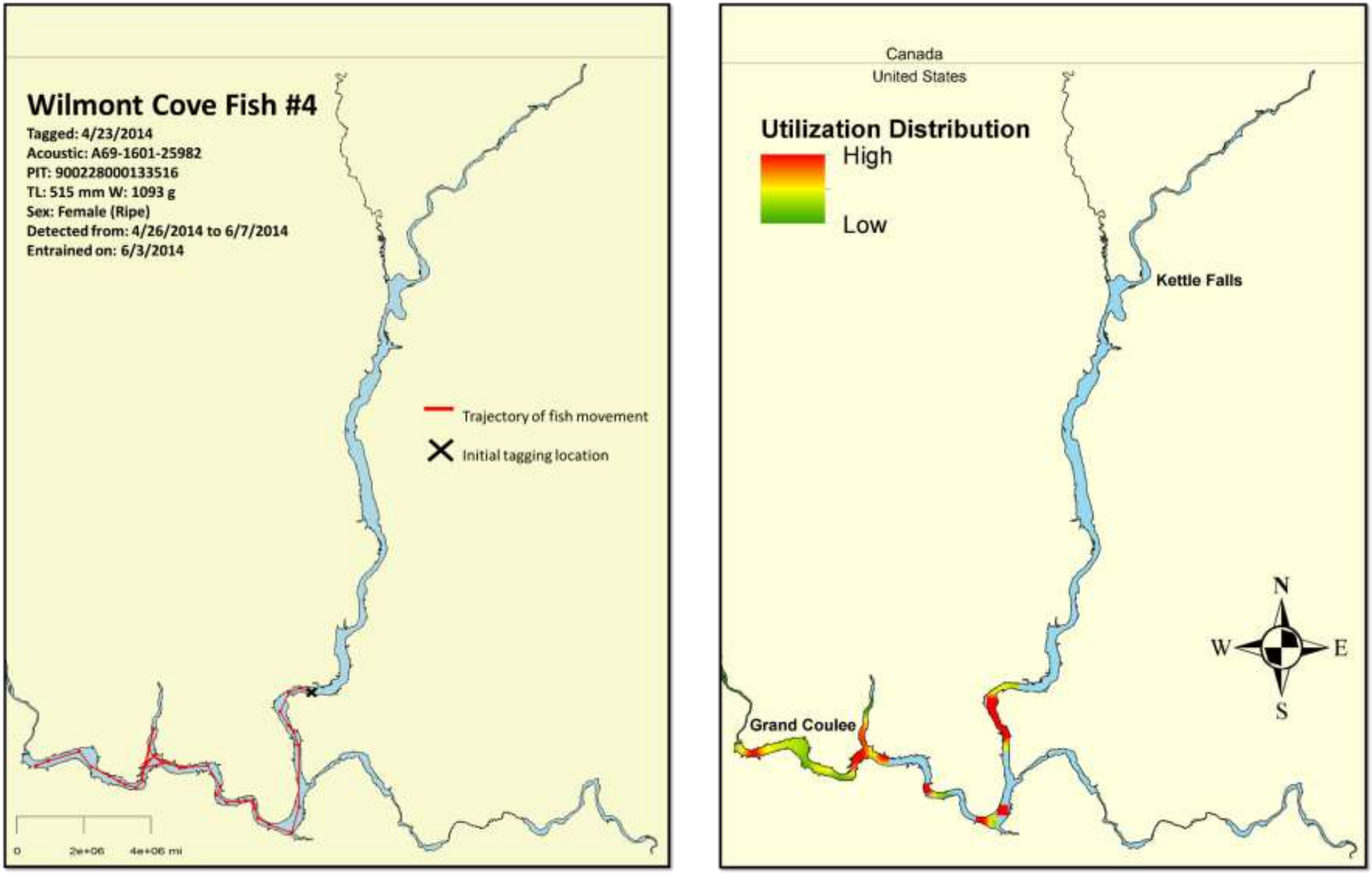
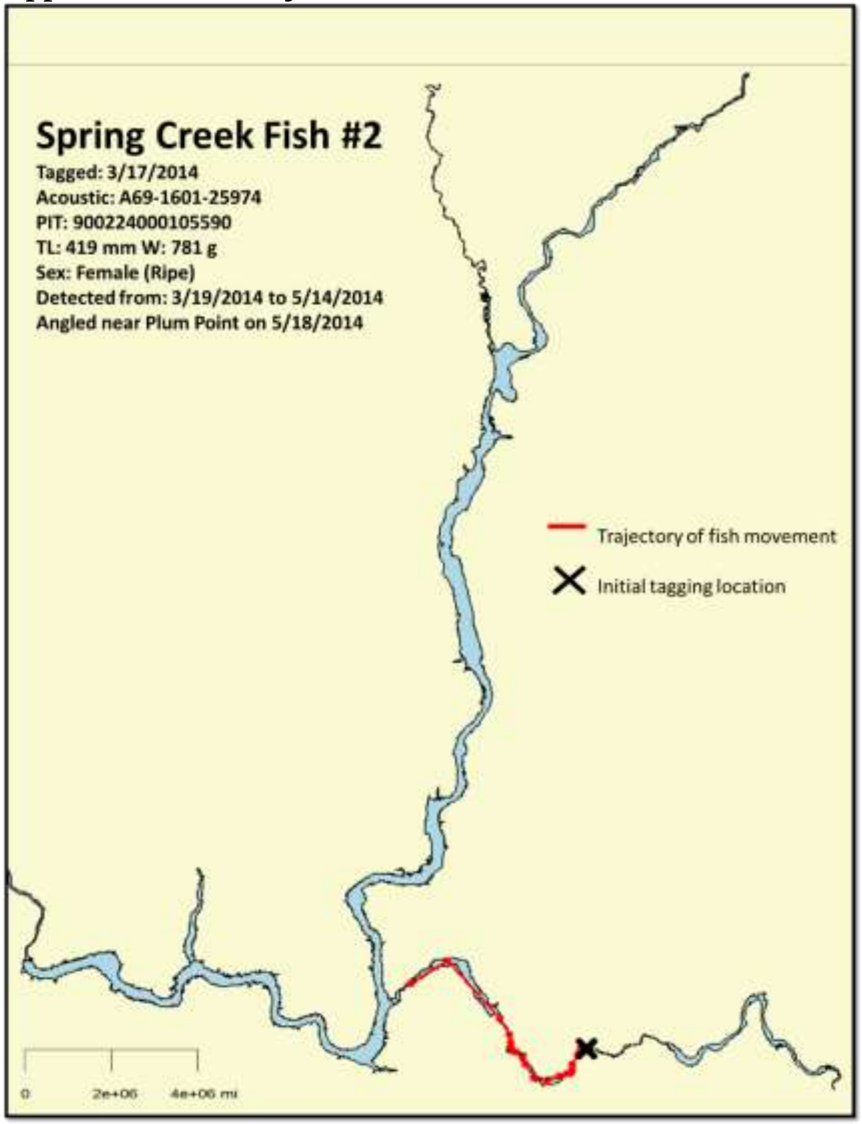


Figure H- 6. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #4 tagged in Wilmont Creek in 2014.

Appendix I. 2014 trajectories and utilization distribution of Redband Trout tagged in the Spokane River.



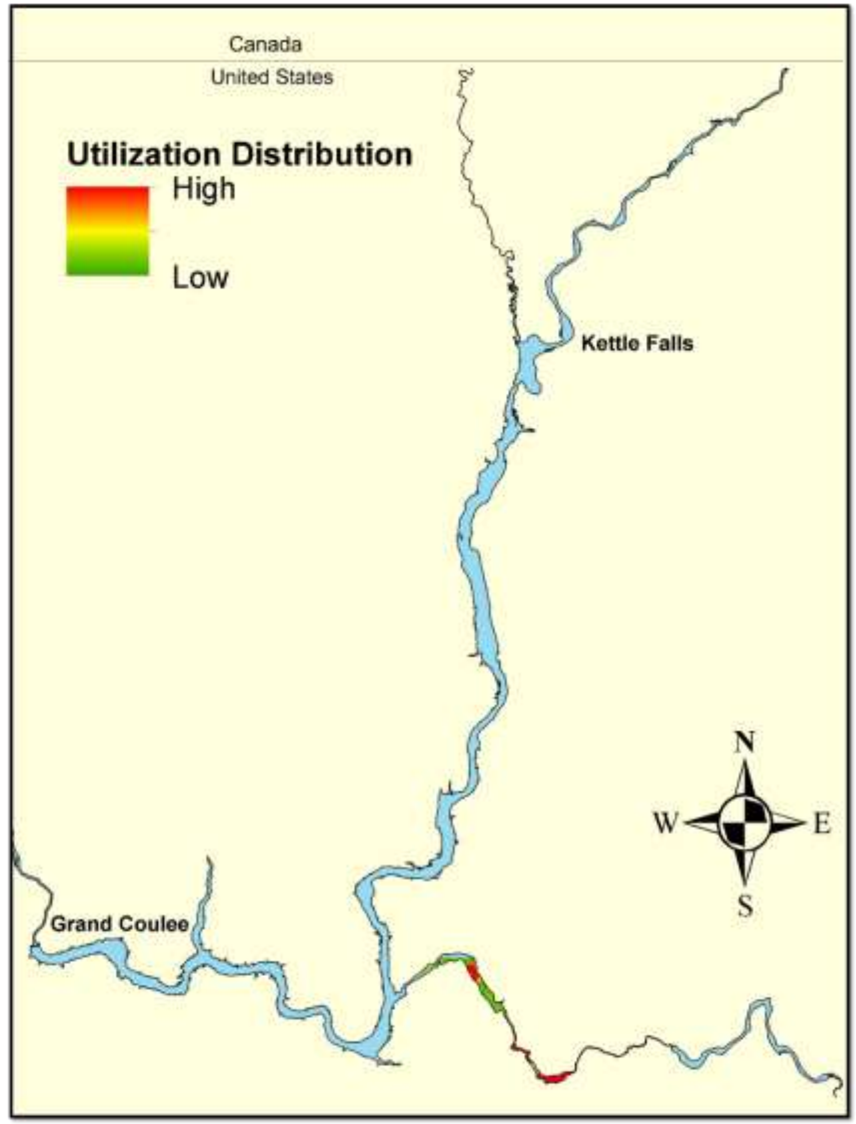


Figure I- 1. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #2 tagged in Spring Creek in 2014.

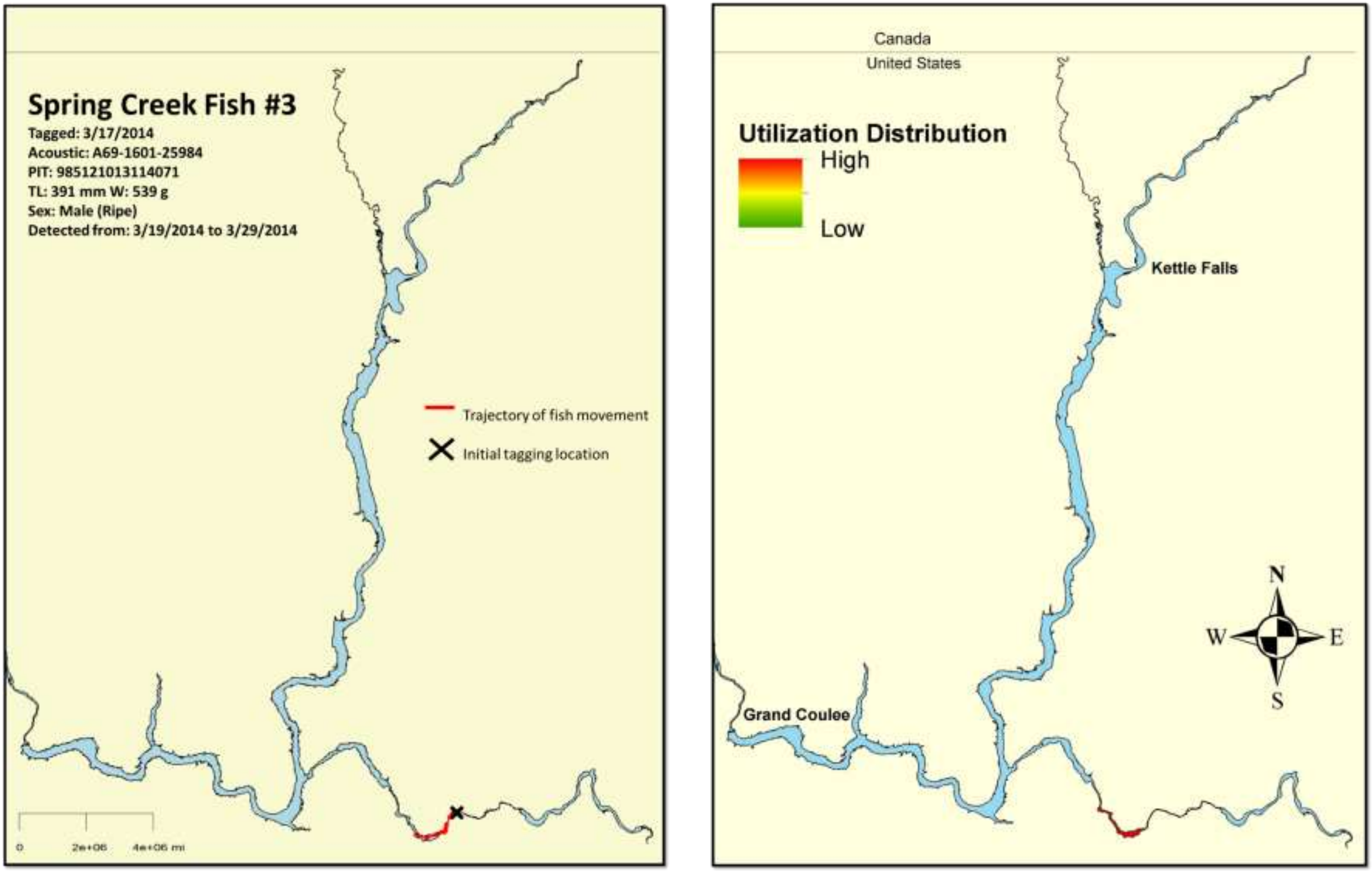


Figure I- 2. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #3 tagged in Spring Creek in 2014.

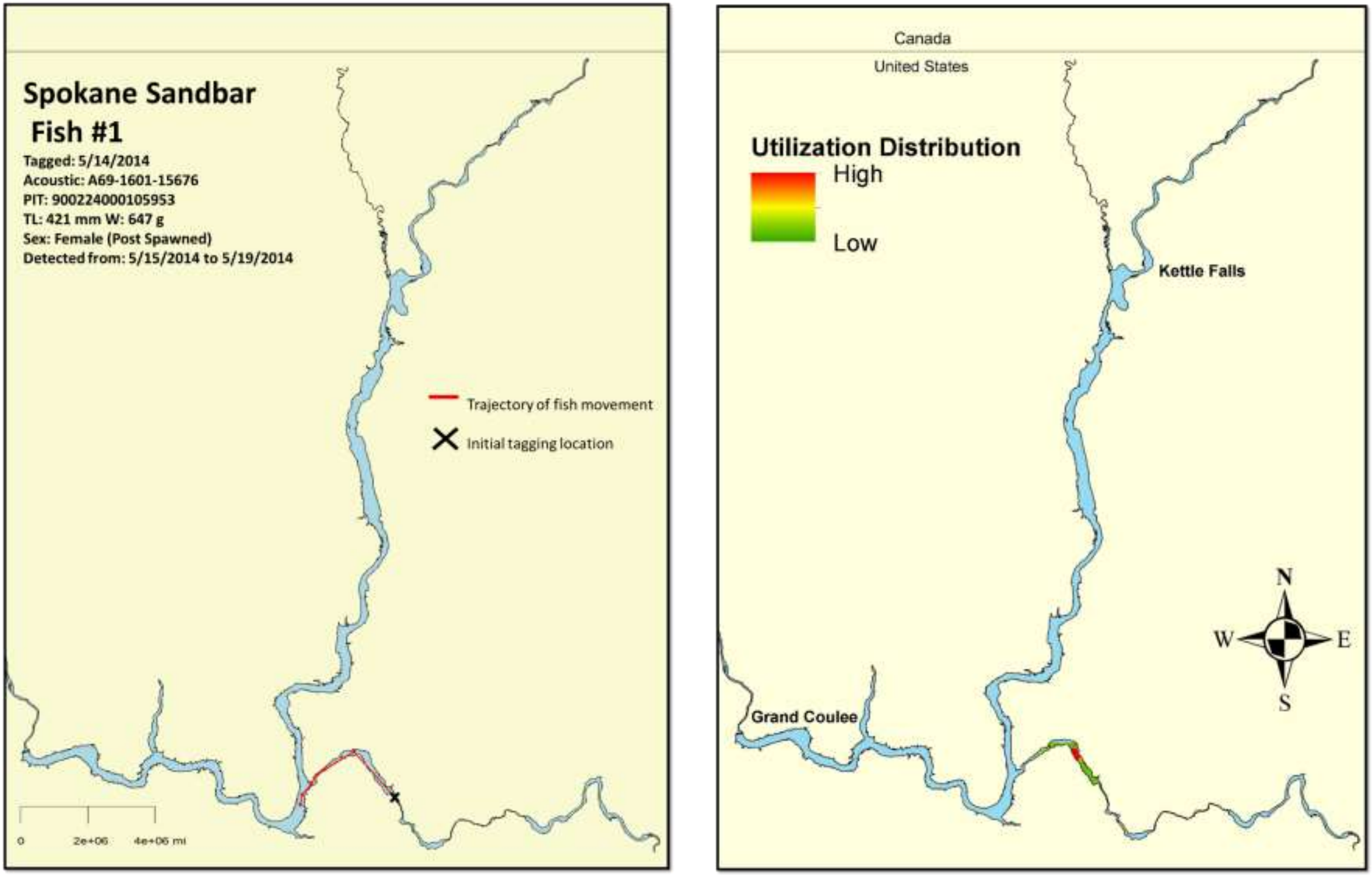


Figure I- 3. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #1 tagged in the Spokane River on the sandbar on the Spokane Tribe Indian Reservation.

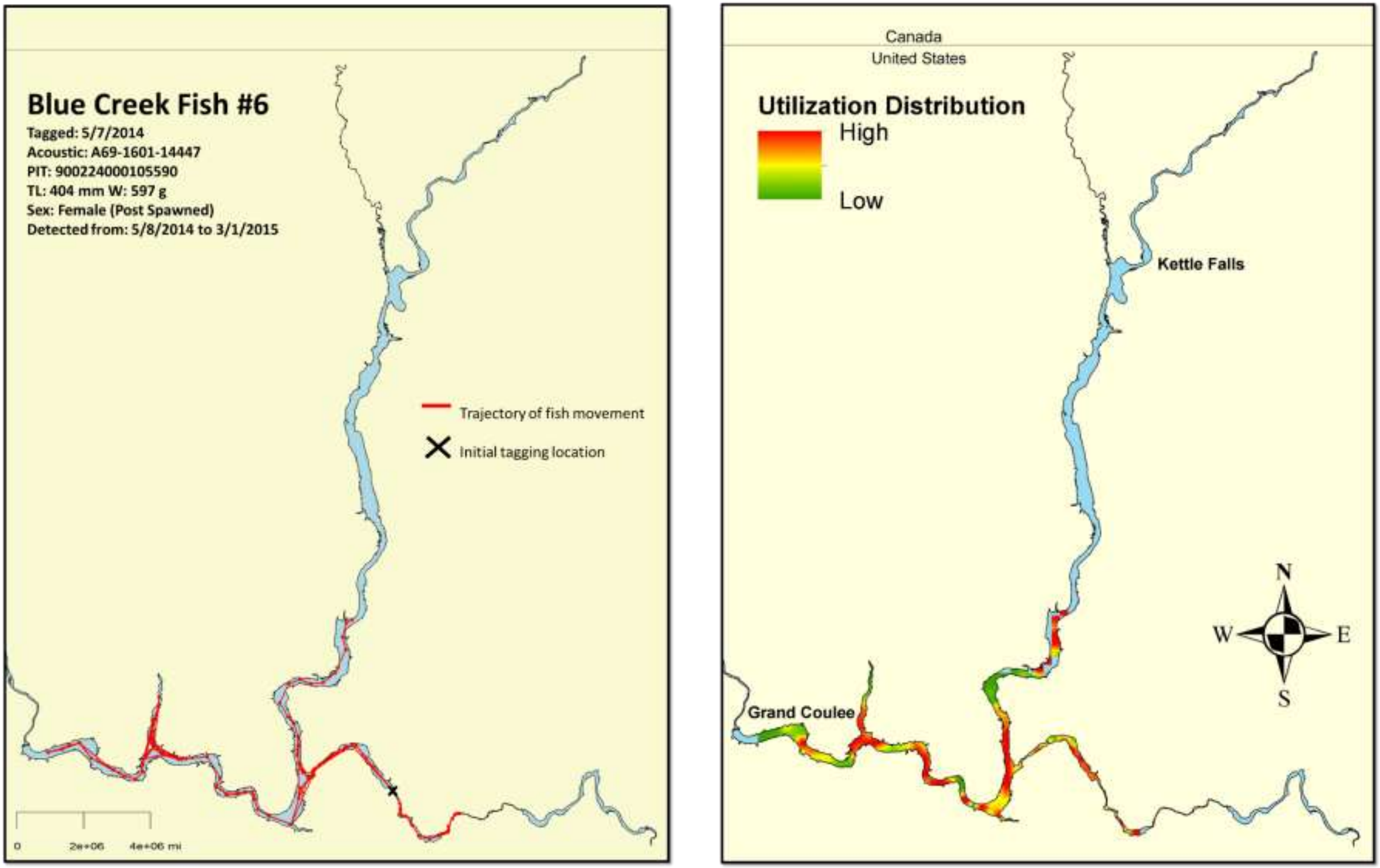


Figure I- 5. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #6 tagged in Blue Creek in 2014.

Appendix J. 2014 trajectories and utilization distribution of Redband Trout tagged in Big Sheep/Onion Creek.

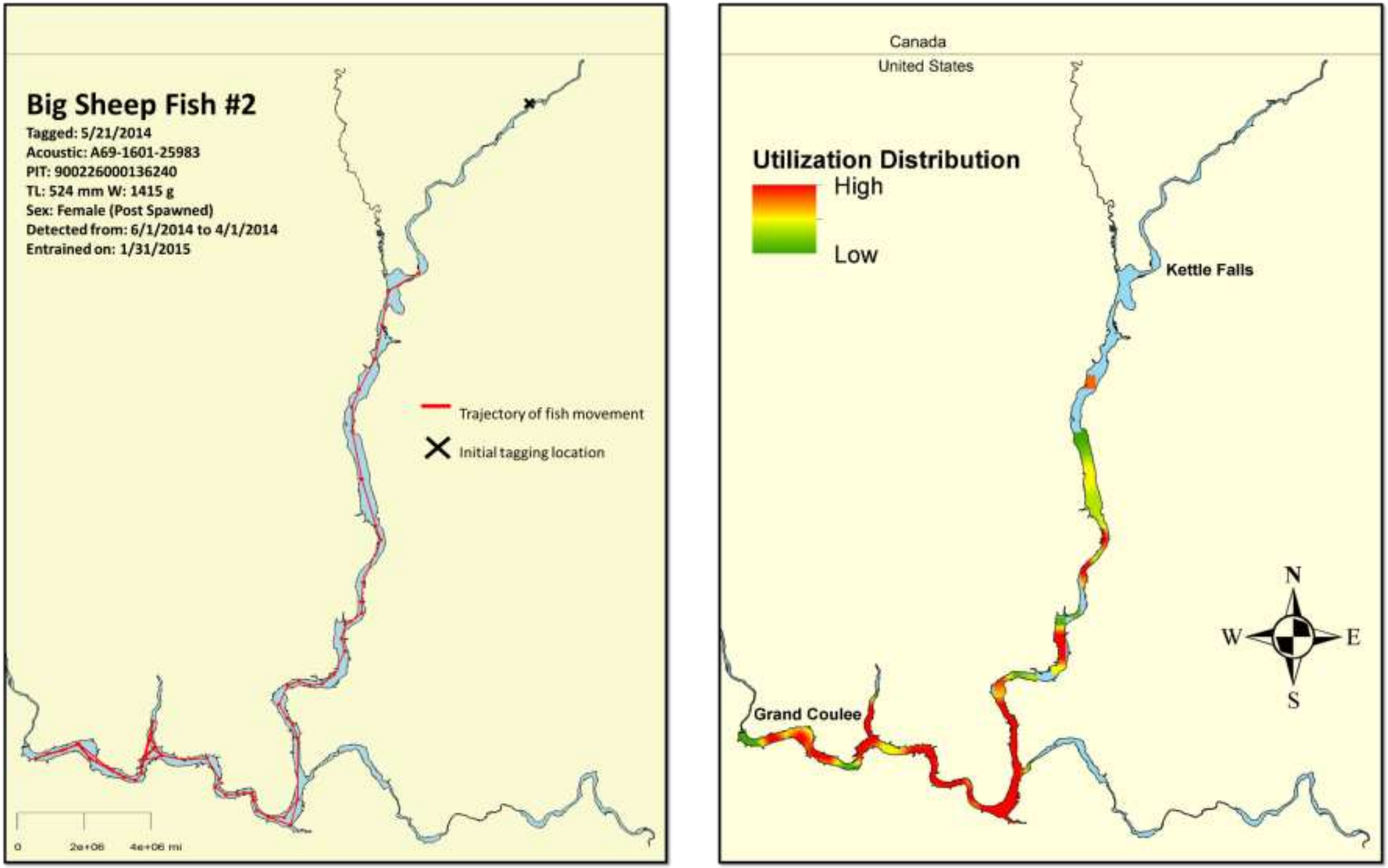


Figure J- 1. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #2 tagged in Big Sheep Creek in 2014.

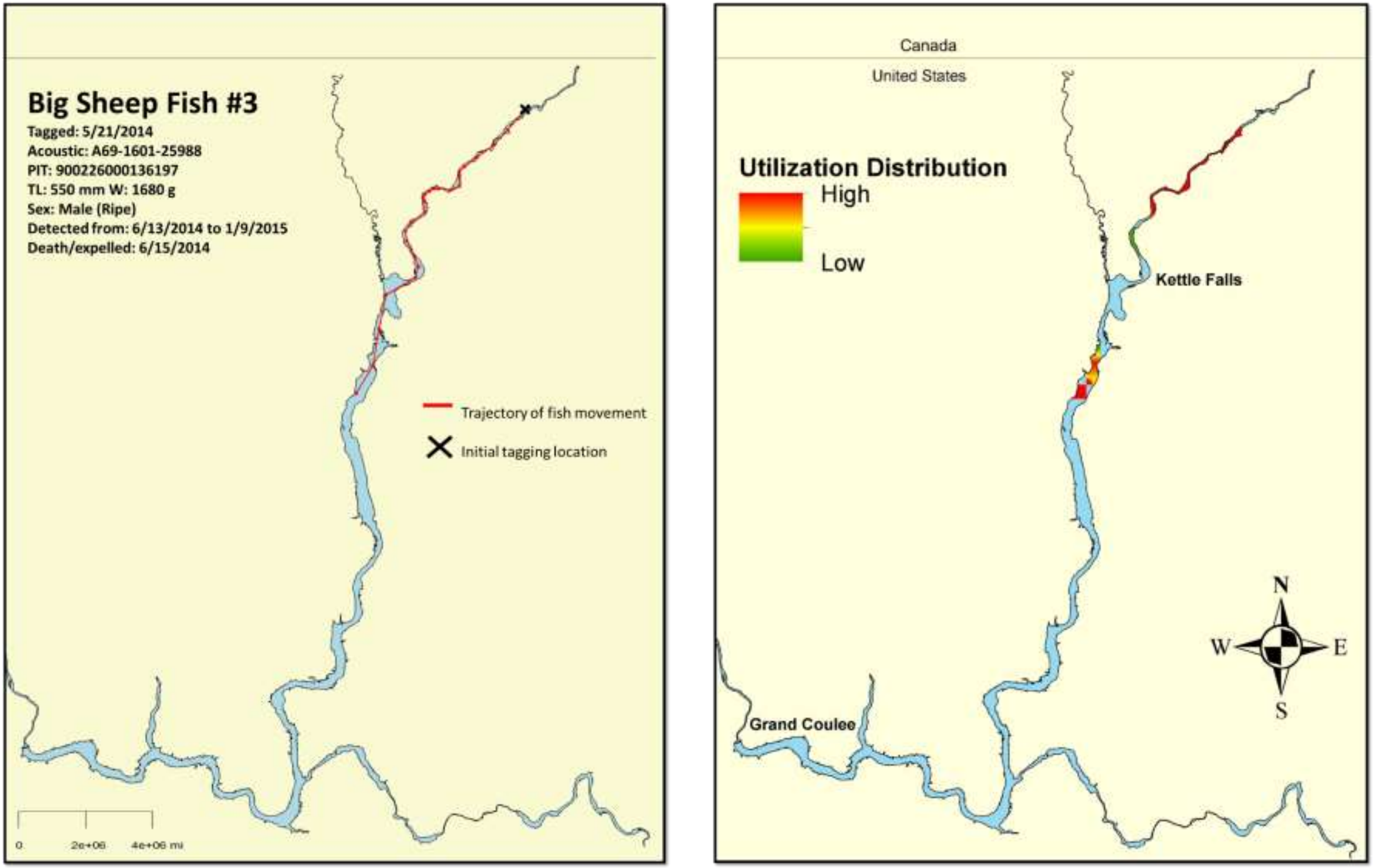


Figure J- 2. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #3 tagged in Big Sheep Creek in 2014.

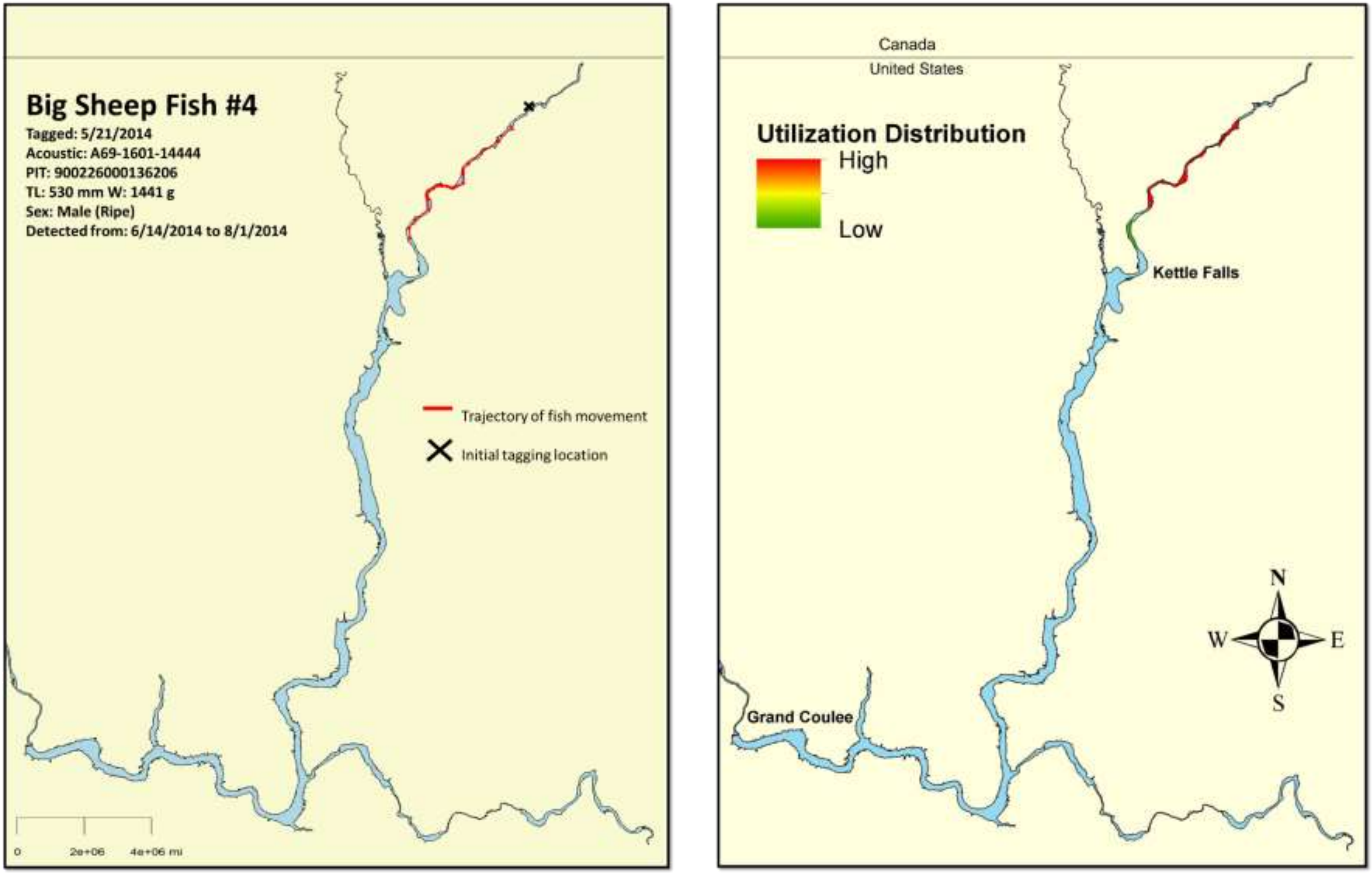


Figure J- 3. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #4 tagged in Big Sheep Creek in 2014.

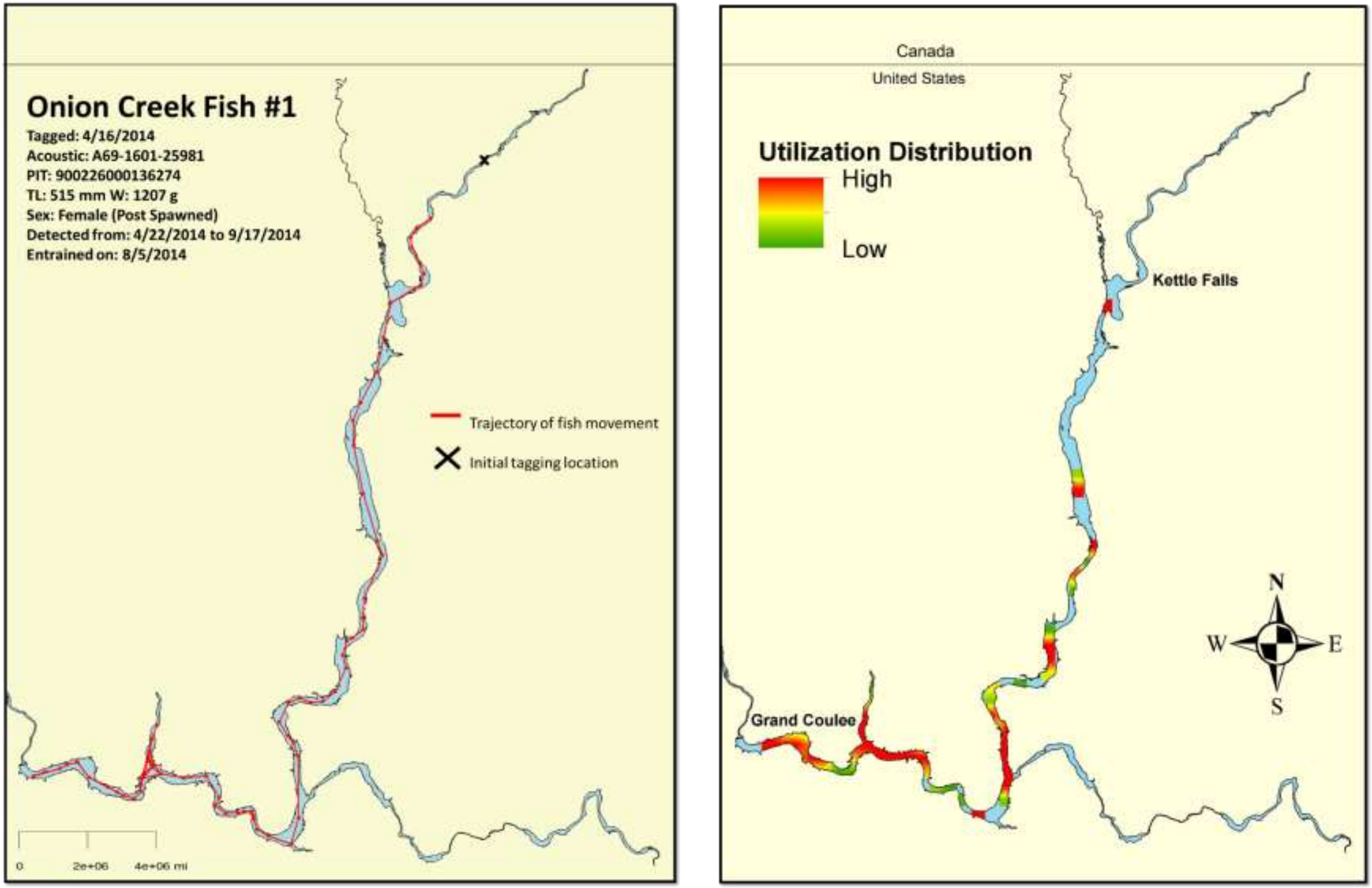


Figure J- 4. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #1 tagged in Onion Creek in 2014.

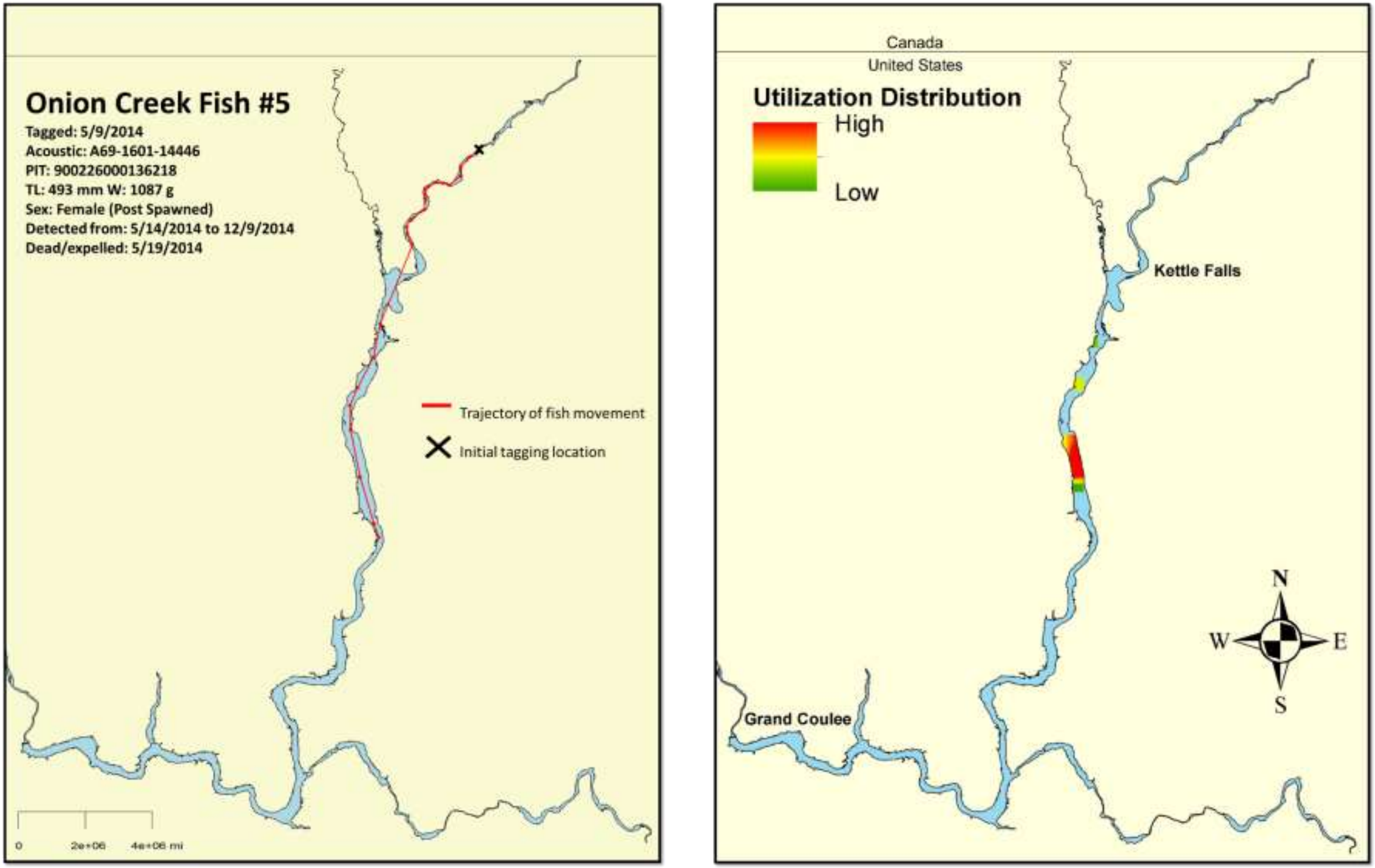


Figure J- 5. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #5 tagged in Onion Creek in 2014.

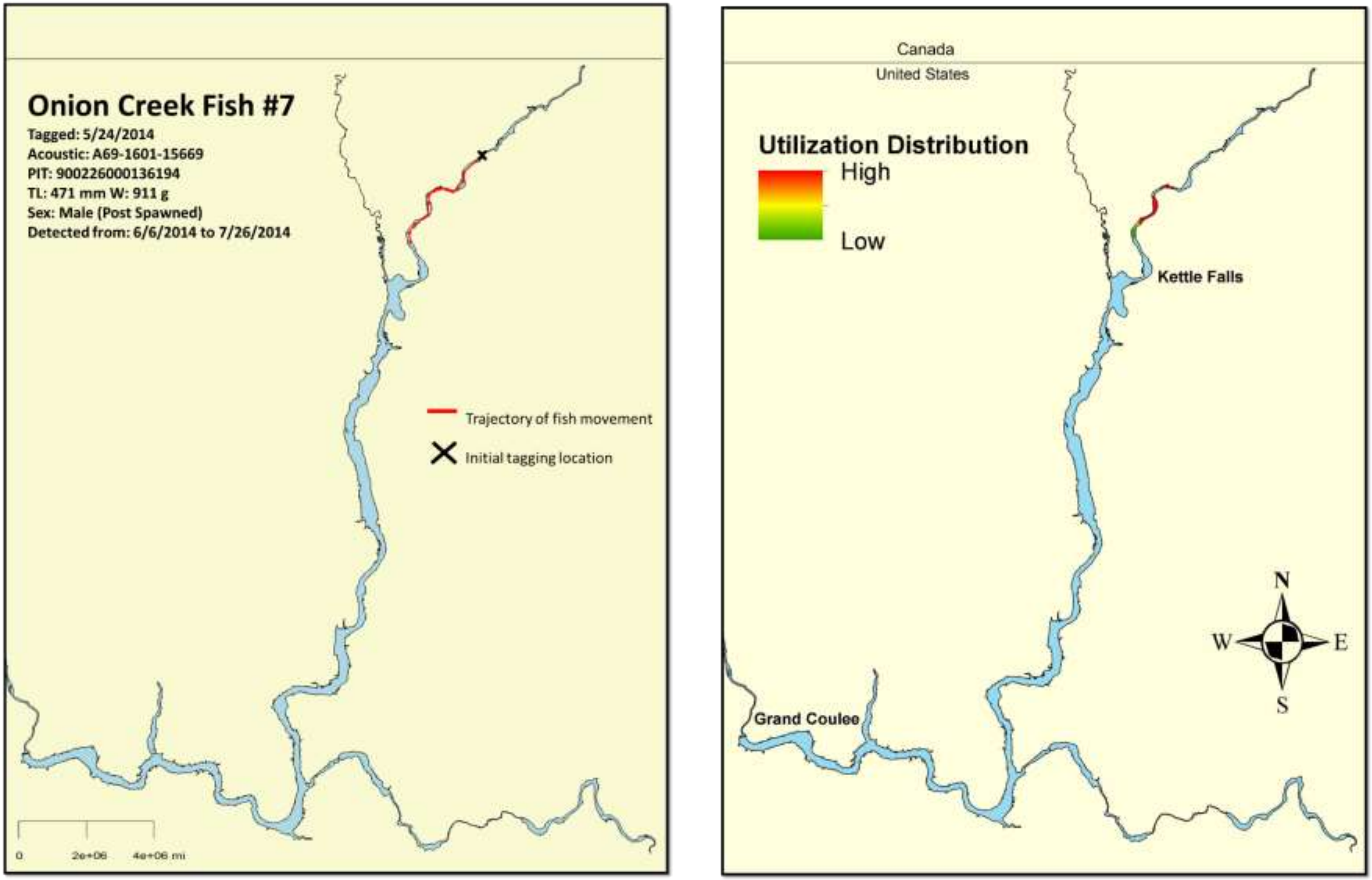


Figure J- 6. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #7 tagged in Onion Creek in 2014.

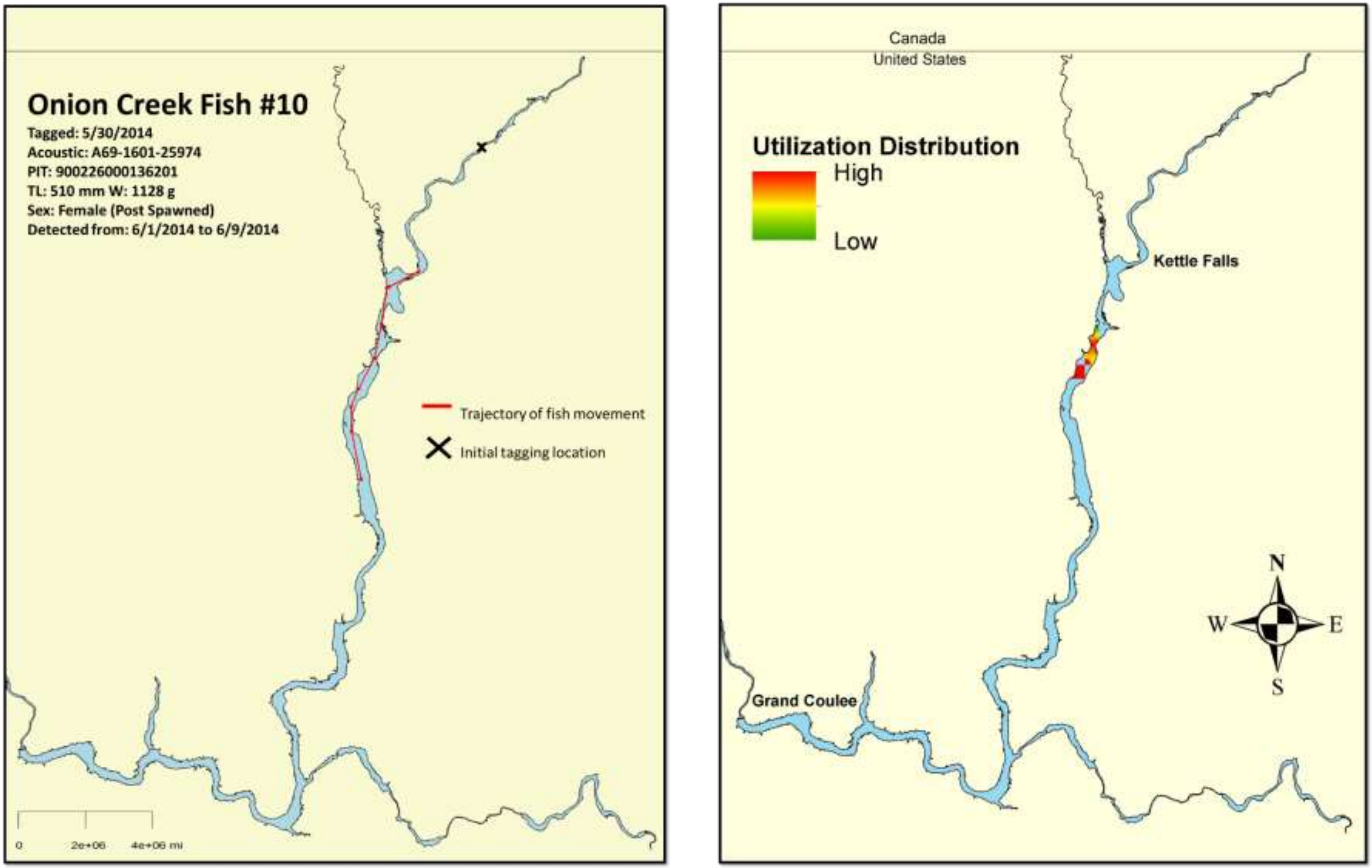


Figure J- 7. Trajectory of fish movements (left) and utilization distribution (right) of Redband trout #10 tagged in Onion Creek in 2014.

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