Migratory Distribution of Fluvial Adult Bull Trout in Relation to Land and Water Use in Watersheds Within the Mid-Columbia and Snake River Basins

S. J. Starcevich[1], P.J. Howell[2], S. E. Jacobs[1], and P. M Sankovich[3]

[1]Oregon Department of Fish and Wildlife, ODFW Research Lab, 28655 Highway 34, Corvallis, Oregon, 97333, USA

[2]USDA Forest Service, Forestry and Range Sciences Laboratory, 1401Gekeler Lane, La Grande, Oregon, 97850, USA

[3]U.S. Fish and Wildlife Service, Columbia River Fisheries Program Office, La Grande Field Office, 3502 Highway 30, La Grande, Oregon, 97850, USA

ABSTRACT — Radio telemetry was used to investigate migratory patterns of 198 fluvial adult bull trout *Salvelinus confluentus* (mean, 449 mm FL) in relation to land and water use characteristics in the Imnaha, Grande Ronde, Walla Walla, Umatilla, and John Day river basins. Median migration distances of radio-tagged fluvial bull trout from the Imnaha (89 km) and Wenaha (56 km) and Lostine (41 km) rivers were relatively long. These study areas were characterized by low levels of water consumption, private landownership, and population density. Median migration distances were significantly shorter in the John Day (8 km) and Umatilla (22 km) rivers and Mill Creek (20 km), which were characterized by greater water and land use and no known barriers to movement. Bull trout from the Lostine and Wenaha rivers also returned to habitats in winter that were more extensive (73 and 86 km, respectively), and the spawning and wintering areas were spatially separated. In contrast, winter locations of bull trout in the John Day, Walla Walla, and Umatilla river were distributed over a relatively short mainstem reach (<25 km) adjacent to or overlapping the spawning distribution. These results suggest adult fluvial migration may be restricted in basins with substantial water and land use. Additional research on bull trout ecology in larger rivers and the effects of anthropogenic habitat degradation on the spatiotemporal distribution of critical resources will lead to a better understanding of how migrations patterns are established and the factors that limit distribution.

Introduction

Bull trout *Salvelinus confluentus*, and chars in general, are considered glacial relicts and have evolved several life history traits advantageous for persistence during glacial expansion and for recolonization of suitable habitat during glacial retreat (Power 2002). Among these traits are the physiological adaptation to cold water and the ability to move within freshwater systems to find resources (Northcote 1997; Power 2002). Adults spawn and juveniles rear within the coldest sections of the stream network, which are usually small, high-elevation headwater streams (Rieman and McIntyre 1993). During the fluvial subadult stage, when juveniles disperse from their early rearing habitat and their first spawning migration (Muhfeld and Marotz 2005), bull trout may spend 1 to 3 years rearing to adulthood in larger river habitats (Mogen and Kaeding 2005). These habitats provide greater space and food resources, which improve growth and reproductive potential (Gross 1987; Northcote 1997). Fluvial (e.g., Bjornn and Mallet 1964) and adfluvial (e.g., Fraley and Shepard 1989) bull trout can migrate over 250 km between their spawning grounds and these productive river and lake habitats.

Diversity in migratory behavior is important to the stability and persistence of bull trout populations (Rieman and McIntyre 1993). The extent and variation of fluvial migrations reflect how local populations have adapted to the spatiotemporal distribution of local habitats (Southwood 1977) and may provide information on how life history expression is affected by anthropogenic habitat alteration and degradation (Rieman and McIntyre 1995; Dunham and Rieman 1999). We used radio telemetry to study migration distance and diversity of fluvial adult bull trout in a range of habitat conditions in northeastern Oregon and southeastern Washington, a region for which there was little information on bull trout migrations. The study region included study areas with extensive human land and water use and those with substantially less human influence. Specifically, our objective was to quantify migration and seasonal distribution patterns of fluvial adult bull trout in relation to the wide range of human land and water use in our study areas.

Study Area

Bull trout were radio tagged in the Imnaha, Wenaha, Lostine, John Day, and Umatilla rivers and in Mill Creek (Figure 1). This region generally has a semiarid, continental climate and most precipitation falls as snow at higher elevations from November to May. In the Umatilla and Walla Walla river basins, the climate is modified by marine air from the Pacific Ocean, which brings rain in late fall and winter. The known bull trout spawning distribution was located in the forested headwaters of these watersheds in areas that are generally under federal management, most of which was in wilderness areas or other protective designations with little development (e.g., municipal watersheds) (USFWS 2002).

The floodplain habitat below the spawning reaches in the John Day (basin area, 20,980 km^2) and Umatilla (6,580 km^2) rivers and Mill Creek (Walla Walla basin area, 4,450 km^2) has been altered by over a century of human activities (USFWS 2002) that have resulted in the extensive loss of riparian vegetation, channel complexity, in-stream large wood, and large pools (Wissmar et al. 1994). In the Umatilla and Walla Walla river basins, seasonal dewatering of large river sections was common historically and has been reported as recently as 2000 (USFWS 2002). In Mill Creek, Bennington Diversion Dam (river kilometer [RK] 18) was originally built in 1942 with no fish passage facilities and was retrofitted with a fish ladder in 1982. Through the city of Walla Walla, Mill Creek

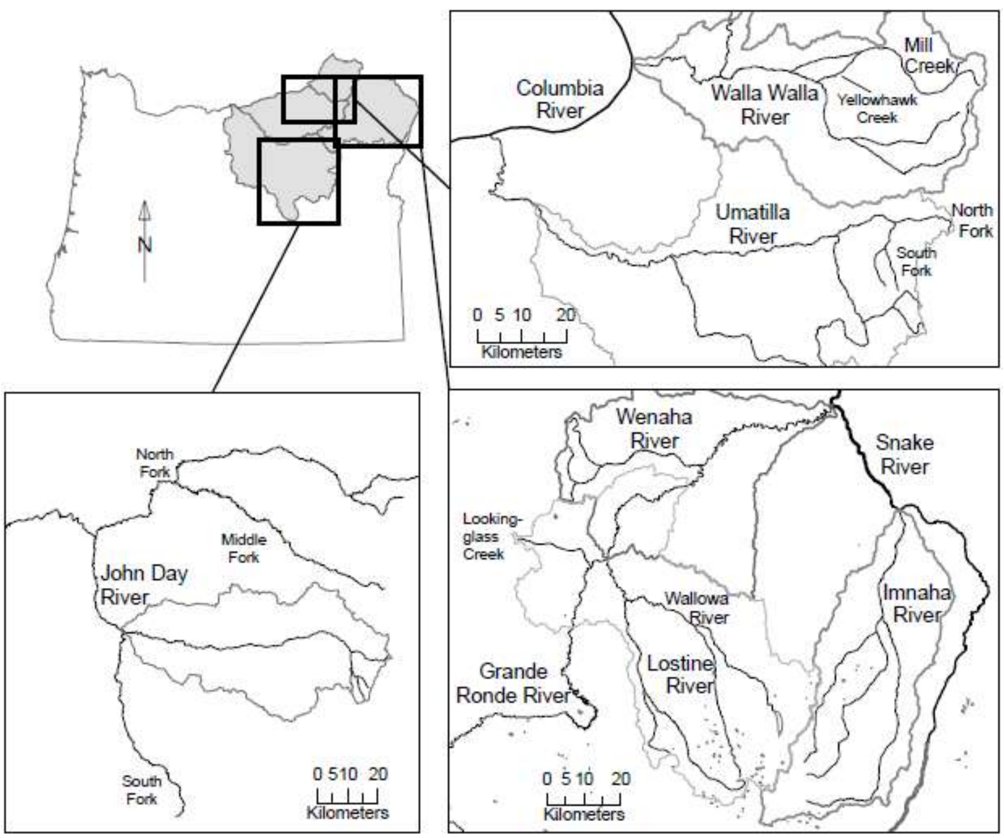

Figure 1. The study region in the Columbia and Snake river basins and individual study areas (outlined in gray).

is a concrete canal with channel-spanning weirs.During summer most of the river is diverted into Yellowhawk Creek, which is a modified irrigation diversion that provides an additional connection to the Walla Walla River. Unscreened diversions on Yellowhawk Creek may obstruct upstream fish passage and entrain fish moving downstream (USFWS 2002)

Similarly, migratory reaches downstream of spawning habitat in the Lostine River (basin area, 240 km^2)and portions of the Wallowa River (RK 20 upriver to Wallowa Lake) have reduced habitat quality because of irrigation diversions, other agricultural practices, residential development, and stream channelization (Howell et al. 2010; USFWS 2002). In contrast, the lower reaches of the Imnaha, Grande Ronde, and Snake rivers potentially used by migratory bull trout have relatively low human population density and high summer base flows (respective means, 21 and 504 cms).

Methods

Fish Capture

Bull trout were caught in the Imnaha River by angling between RK 98 and 107. Fish were captured in the Wenaha River by angling near RK 5, 14, and 20. In the Lostine River, bull trout were caught in an upstream picket weir trap near the mouth (RK 1) and by angling between RK 17 and 39. In the John Day River basin, fish were caught by angling and in weir traps in Call Creek (RK 0.5), Deardorff Creek (RK 5), Roberts Creek (RK 1), and two location on the mainstem (RK 437 and 450). Bull trout were captured by angling between RK 140 on the upper Umatilla River and RK 2 on the North Fork Umatilla River. In Mill Creek, bull trout were caught by angling in the pools adjacent to the municipal intake dam (RK 41) or in a trap affixed to the upstream end of its fish ladder.

Radio Transmitters and Tagging

We used radio transmitters that ranged in battery life from 8 to 24 months (Lotek NTC-6-2, and Advanced Telemetry Systems models 2-357, 2-375, and 10-28) and emitted a pulsed signal at frequencies from 150 to 152 MHz. Transmitter weight did not exceed 3% of the host fish weight. Bull trout were anesthetized prior to and during surgery with 50 mg/L tricaine methanesulfonate buffered with equal amounts of sodium bicarbonate. The transmitters were implanted into the peritoneal cavity using the methods described by Winter (1996). The transmitter antenna was passed through the body wall using a technique similar to that described by Ross and Kleiner (1982). Surgery lasted less than six minutes. The fish recovered from anesthesia in a covered and aerated bath for at least 15 min before being released in slow, deep water near the capture site. Fish were not tagged when water temperatures exceeded 15°C.

Radio Tracking

Radio-tagged fish were tracked from the ground and air using a Lotek receiver (SRX 400). We used a handheld two-element antenna when tracking on foot and a five-element Yagi antenna when tracking by vehicle. Aerial tracking was conducted from a Cessna 180 with two-element antennas affixed to each wing. When tracking by vehicle or foot, we estimated the transmitter location in the river by triangulating on the strongest signal (White and Garrot 1990). We estimated aerial tracking error by comparing aerial location estimates with the actual location of transmitters we placed in the river. The interval between tracking observations differed among watersheds depending on remoteness, private land accessibility, and flight availability.

Quantification of Migration and Distribution

We quantified migration distance as the distance in river length between the farthest upstream location during the spawning period and winter modal location. Winter modal location represented where a fish was observed most often during winter. We plotted on maps these two locations for each fish to show seasonal distribution patterns. The spawning period, based on previous spawning surveys in these basins, was defined as 15 August to 15 November.

Water and land use index

We used median water consumption in summer as an index to evaluate the relationship between human land and water use and median migration distance, because it represented water consumption as well as irrigated agricultural acreage and the degree of urbanization in the large river habitats in each study area. It was indeed significantly positively correlated with two measures of general human land use: private landownership (Pearson product correlation coefficient [r] = 0.89; P=0.017) and, after square root transformation, population density (r = 0.84; P=0.036).

Water use was characterized in our study areas using the online Water Availability Reporting System [WARS] provided by the Oregon Water Resources Department website. We used the estimated reduction in the median monthly natural streamflow (i.e., a flow that is exceeded 50% of the time for a particular month) caused by consumption of surface water at several WARS stations during July through September (see Cooper [2002] for a detailed description of this calculation). We selected the WARS station nearest the downstream end of each study area. These stations were located at the mouth of the Imnaha, Grande Ronde, and Wallowa rivers; and at RK 342 of the John Day River, RK 66 of the Umatilla River, and RK 77 of the Walla Walla River.

Private landownership percentage and population density were estimated using a geographical information system [GIS] and coverages for private and public (i.e., federal and state) landownership and population density (2000 census) in 5^{th} field hydrologic units adjacent to the potential migratory habitat of each population. This was defined as 100 river km from the lower limit of the observed spawning distribution. We selected the 100 km measurement for all study areas because it represented the longest migrations observed in this study and facilitated stndard comparisons among basins.

Data Analysis

To determine if there were significant differences ($P<0.05$) among the basins in migration distance, we used the Kruskal-Wallis test on ranks (Sokal and Rohlf 1995) as the Kolmogorov-Smirnov test (with Lilliefor's correction) indicated the data were not normally distributed. We compared individual basins using Dunn's method (Dunn 1964) for multiple comparisons of ranked data and unequal sample sizes. Pearson product-moment correlation (Sokal and Rohlf 1995) was used to evaluate the relationship between the water and land use index and median migration range.

RESULTS

Radio Tagging and Tracking

We radio tagged 198 adult bull trout in 6 basins (Table 1). Fish fork length (FL) averaged 449 mm and ranged from 260 to 675 mm. Ninety-three percent of the fish were tagged between March and early September and 7% were tagged in October and November. Overall, 51% were tracked through spawning and at least one winter (Table 1). The time between observations ranged from 7 d in the Imnaha River and Mill Creek; 11 to 22 d in the Lostine, John Day, and Umatilla rivers; to 25 d in the Wenaha River. The longer interval in the Wenaha River was caused by the relative inaccessibility of the watershed and the difficulty in obtaining tracking flights. The mean tracking error from comparing aerial location estimates (N=15) to known transmitter locations in Mill Creek was 1.7 km (range, 0.2 to 3.1 km). The error associated with tracking by vehicle or on foot was not determined but presumably was much less than aerial tracking error.

Table 1. Study period, number of bull trout tagged, fork length (FL) mean and range, and the number (and percentages) of fish tracked through at least spawning and the first winter.

Study area	Year	N	Mean FL (mm)	Range FL (mm)	≥1^{st} winter *N* (%)
John Day River	1998-1999	23	405	285-560	17 (74)
Lostine River	2001, 2004	41	468	360-600	14 (34)
Wenaha River	1997-1999	51	461	260-645	40 (78)
Mill Creek	1997-1999	46	441	282-630	20 (43)
Umatilla River	2002	15	410	351-513	7 (47)
Imnaha River	2001	22	470	379-675	3 (15)
Totals		198			101 (51)

Migration Distance in Relation to Water and Land Use

We found a significant negative correlation (r = -0.89; P=0.019) between median migration distance and the water and land use index. The median migration distances were relatively high in the Imnaha (median, 89; range, 89-116), Wenaha (median, 56 km; range, 11-100), and Lostine (median 41 km; range, 6-77) rivers. These basins had relatively low levels of water and land use (Table 2). Shorter median migration distances were observed in the John Day River basin (median, 8 km; range, 1-46), Mill Creek (median, 20 km; range, 6-31) and Umatilla River basin (median, 22 km; range, 9-33). These basins showed greater levels of water and land use.

Table 2. Characteristics of human influence in each study area.

Study area	Median water consumption in summer (%)	Private land (%)	Population density (Pop./km2)
Imnaha River	17	29	0.1
Wenaha River	27	44	0.1
Lostine River	34	53	1.1
John Day River	81	55	1.7
Umatilla River	84	72	5.8
Mill Creek	95	86	20.0

There were significant differences (df = 5, P<0.001) in median migration distance among fish from different study areas (Figure 2). Specifically, the median migration distances of fish from the Imnaha, Wenaha, and Lostine rivers were not significantly different from each other (P>0.05). Bull trout from the Imnaha and Wenaha river basins showed significantly longer median migration distances (P<0.05) than the other basins, while the Lostine River fish were significantly different only from those in the John Day River basin. There were no significant differences (P>0.05) in median migration range among bull trout from the John Day and Umatilla river basins and Mill Creek.

During the spawning period, adults were distributed in the upper watershed of each basin (Figure 3 and 4). Winter distribution of adults from the Lostine and Wenaha rivers were extensive (73 and 86

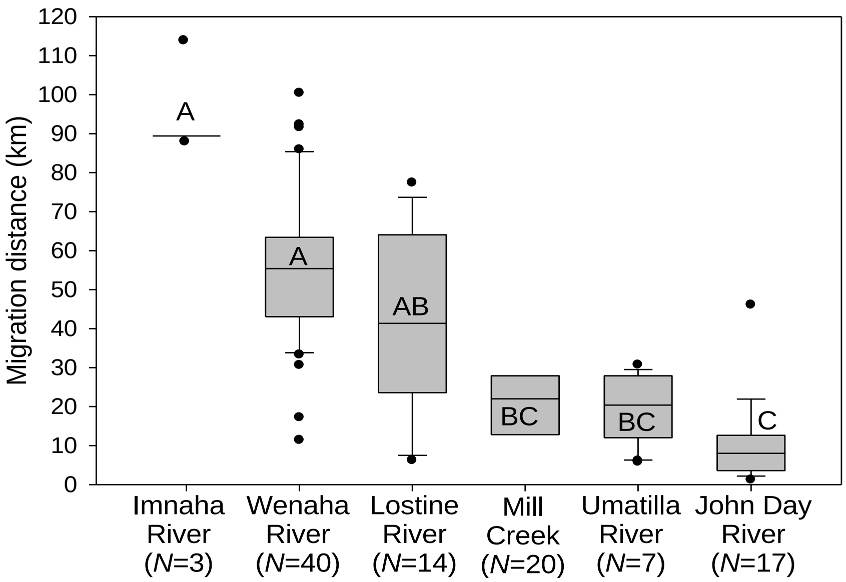

Figure 2. Box plots of annual range with median (solid line), two middle quartiles (box), 5th and 95th percentiles (whiskers), and outliers (black dots) for tagged bull trout in each study area. Letters denote significant differences (P<0.05) among study areas.*Seasonal distribution*

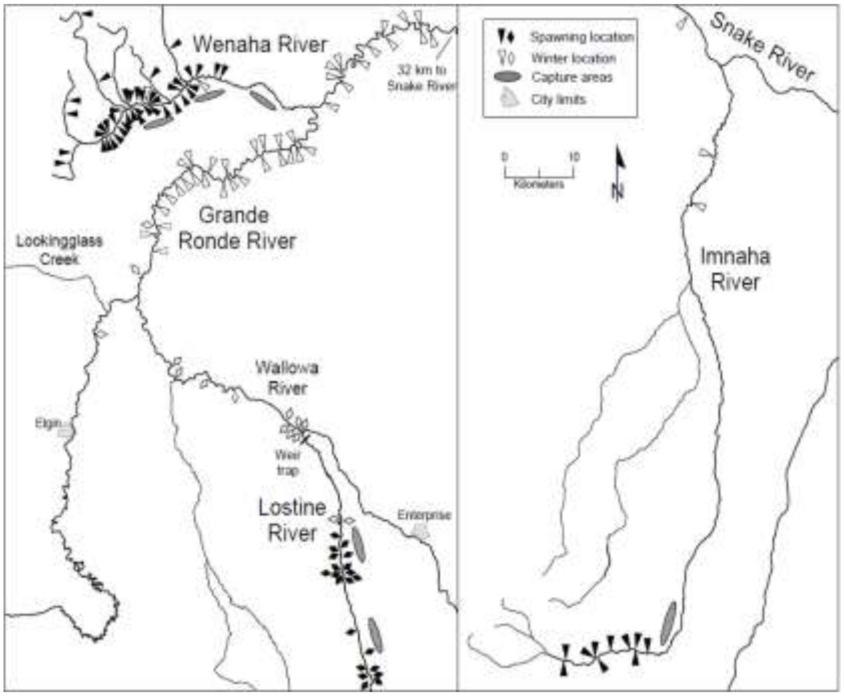

Figure 3. Migratory distribution of bull trout in the study areas of the Wenaha, Lostine, and Imnaha rivers.

km, respectively) and included larger river habitats. In contrast, winter distributions were more restricted for bull trout from Mill Creek (21 km), Umatilla River (24 km), and the John Day River (49 km). In the John Day River, 93% of bull trout were distributed in winter in the upper 13 km.

Discussion

The migratory distribution of fluvial adult bull trout among the six river basins was generally related to differences in water and land use characteristics of the basins. Bull trout in the Grande Ronde and Imnaha rivers migrated significantly greater distances between the spawning and overwintering areas (medians, 41-89 km; maxima, 77-116 km) than in the other basins (medians, 8-22 km; maxima, 31-46 km), which were more highly impacted by water and land use practices. In the interior Columbia River basin, bull trout occurrence and population strength were similarly inversely related to road density and intensity of development (Rieman et al. 1997; Lee et al. 1997).

The migratory behavior of fish from the Imnaha and Grande Ronde rivers was similar to that reported in other watersheds with no passage barriers and relatively little human influence. For example, in the Salmon River basin, Idaho, bull trout migrated between 35 and 106 km in the South Fork basin (Schill et al. 1994; Hogen and Scarnecchia 2006); and in the Middle Fork basin, Bjornn and Mallet (1964) recorded seasonal movements up to 307 km. In the complex and woody Morice River, tributary of the Skeena River, British Columbia, migrations of radio-tagged bull trout extended over 75 km (Bahr and Shrimpton 2004). In the Athabasca River, Alberta, McLeod and Clayton (1997) recorded adult annual ranges between 59 and 110 km.

In contrast, the migration distances we observed in Mill Creek and the John Day and Umatilla river basins are uniquely short when compared to the published literature on large-bodied (>300 mm FL) fluvial bull trout. In most other instances, the reduction or loss of diversity in migratory behavior has been associated with dam construction, nonnative species or habitat degradation (e.g., Fitch 1997, Swanberg 1997, Jakober et al. 1998, Brenkman et al. 2001, Nelson et al. 2002). The rarity, or lack, of long distance migration among tagged bull trout in three of our study areas suggests that fluvial life history expression has been curtailed; however, there is little information in these study areas about the spatiotemporal distribution of resources critical to bull trout life history expression and the effect of human activities on them.

The distributions of wintering locations also contrasted sharply between the study areas. Most bull trout from the Wenaha and Lostine rivers returned to larger rivers in winter and were spread over long distances (73-86 km) and generally had some spatial separation between spawning and wintering areas, similar to the patterns observed for fluvial bull trout in the upper Salmon River basin (e.g., Schill et al. 1994; Hogen and Scarnecchia 2006; Watry and Scarnecchia 2008). These two study areas also contained diverse migration patterns. Two large-bodied bull trout from each study area displayed short migrations (6-17 km) and resided year-round within the known spawning distribution and most of the

Wenaha River migrants (66%) displayed a unique fluvial migration pattern. This pattern consisted of a post-spawning migration downstream out of the Wenaha River and then upstream to wintering areas in the Grande Ronde River as far as 49 km from the Wenaha River confluence. This postspawning migration pattern differed from the downstream-only patterns previously reported for adult fluvial bull trout (e.g., Bjornn and Mallet 1964; Jakober et al. 1998; Bahr and Shrimpton 2004; Hogen and Scarnecchia 2006) and was similar to those observed in adfluvial populations (e.g., Herman 1997, Hogen and Scarnecchia 2006, DuPont et al. 2007, Watry and Scarnecchia 2008). As DuPont et al. (2007) noted for adfluvial bull trout populations, the complex pattern we observed expands our view of what may have been historically occupied habitats for fluvial bull trout populations.

In contrast, winter locations of fluvial bull trout from Mill Creek and the Umatilla River were distributed over a relatively short main stem reach (<25 km). In the John Day River basin, 93% of the fish were distributed over a 13 km main stem reach in winter. Although fish in these basins generally alternated between headwater stream habitat during the spawning period and larger main stem habitats in winter, there was little or no spatial separation between wintering and spawning areas. Small numbers of subadult bull trout have been reported downstream of the adult winter distributions we observed in other studies in the John Day River near

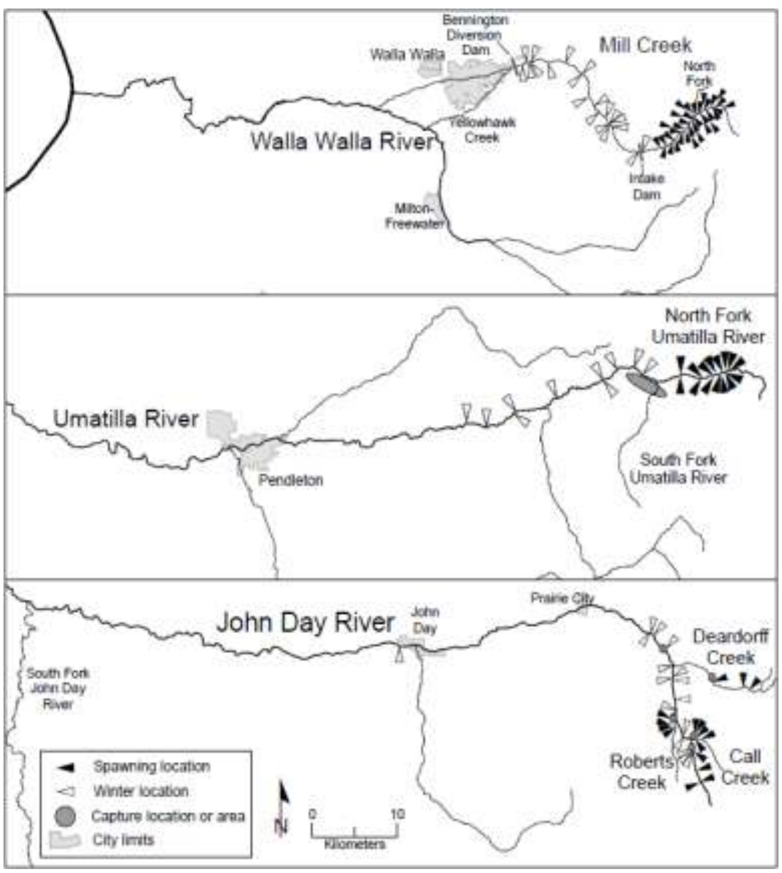

Figure 4. Migratory distribution of bull trout in the study areas of Mill Creek and the Umatilla and John Day rivers.

the South Fork John Day River confluence (Wilson et al. 2008), from Bennington Dam on Mill Creek to the lower Walla Walla River (Anglin et al. 2009), and in the lower Umatilla River (RK 5) (P. Bronson, Confederated Tribes of the Umatilla Indian Reservation, personal communication, 2008). These studies show that in these study areas the distribution of subadult bull trout may be more extensive than that of the adults in our study; however, there is no information on subadult survival in these habitats.

Additional research on juvenile and adult bull trout habitat selection in larger rivers and the effects of anthropogenic habitat degradation on the spatio-temporal distribution of critical resources will lead to a better understanding of the factors that limit migratory distribution.

Acknowledgements

We thank Dave Buchanan and Al Hemmingsen for their role in planning and conducting this research. We thank Larry Boe, Jason Shappart, Blane Bellerud, Ian Tattam, Lisa and Dave Gaudette, and Chris Abbes for field assistance; Glen Mendel (Washington Department of Fish and Wildlife) Tim Bailey and Tim Unterwegner (ODFW), and Dave Crabtree (U.S.D.A. Forest Service [USFS]) for their assistance and cooperation; and the Oregon State Police for piloting the plane during tracking flights. This research was funded by the Bonneville Power Administration and the USFS.

References

Anglin, D. R., D. Gallion, M. Barrows, R. Koch, and C. Newlon. 2009. Monitoring the Use of the Mainstem Columbia River by Bull Trout from the Walla Walla Basin. 2009 Annual Report to the U.S. Army Corps of Engineers, Walla Walla District. Project BT-W-05-6.

Bahr, M. A., and J. M. Shrimpton. 2004. Spatial and quantitative patterns of movement in large bull trout (*Salvelinus confluentus*) from a watershed in north-western British Columbia, Canada, are due to habitat selection and not differences in life history. Ecology of Freshwater Fish 13:294-304.

Bjornn, T. C., and J. Mallet. 1964. Movements of planted and wild trout in an Idaho river system. Transactions of the American Fisheries Society 93:70-76.

Brenkman, S. J., G. L. Larson, and B. E. Gresswell. 2001. Spawning migration of lacustrine-adfluvial bull trout in a natural area. Transactions of the American Fisheries Society 130:981-987.

Cooper, R. M. 2002. Determining surface water availability in Oregon. State of Oregon Water Resources Department, Open File Report SW 02-002.

Dunham, J. B., and B. E. Rieman. 1999. Metapopulation structure of bull trout: influences of physical, biotic, and geometrical landscape characteristics. Ecological Applications 9:642-655.

Dunn, O. J. 1964. Multiple contrasts using rank sum tests. Technometrics 6:241-252.

DuPont, J. M., R. S. Brown, and D. R. Geist. 2007. Unique allacustrine migration patterns of a bull trout population in the Pend Oreille River Drainage, Idaho. North American Journal of Fisheries Management 27:1268-1275.

Fitch, L. 1997. Bull trout in southwestern Alberta: notes on historical and current distribution. Pages 427- 434 *in* W. C. Mackay, M. K. Brewin, and M. Monita, editors. Friends of the Bull Trout conference proceedings, Bull Trout Task Force (Alberta), Trout Unlimited Canada, Calgary.

Fraley, J. J., and B. B. Shepard. 1989. Life history, ecology, and population status of migratory bull trout (*Salvelinus confluentus*) in the Flathead Lake and river system, Montana. Northwest Science 63:133- 143.

Gross, M. R. 1987. Evolution of diadromy in fishes. Pages 14-25 *in* M. J. Dadswell and five coeditors. Common strategies of anadromous and catadromous fishes. American Fisheries Society, Symposium 1, Bethesda, Maryland.

Herman, S. J. 1997. The unique bull trout spawning population of Pinto Lake, Alberta. Pages 217-226 in W. C. Mackay, M. K. Brewin, and M. Monita, editors. Friends of the Bull Trout conference proceedings. Bull Trout Task Force (Alberta), Trout Unlimited Canada, Calgary.

Hogen, D. M., and D. L. Scarnecchia. 2006. Distinct fluvial and adfluvial migration patterns of a relict charr, *Salvelinus confluentus*, stock in a mountainous watershed, Idaho, USA. Ecology of Freshwater Fishes 15:376-387.

Jakober, M. J., T. E. McMahon, R. F. Thurow, and C. G. Clancy. 1998. Role of stream ice on fall and winter movements and habitat use by bull trout and cutthroat trout in Montana headwater streams. Transactions of the American Fisheries Society 127:223-235.

Lee, D. C., J. Sedell, B. E. Rieman, R. F. Thurow, J. E. Williams, and others. 1997. Broadscale assessment of aquatic species and habitats. In: Quigly, T. M., and S. J. Arbelbide, eds. An assessment of ecosystem components in the interior Columbia River Basin and portions of the Klamath and Great Basins. Gen. Technical Report PNW-GTR-405. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon.

McLeod, C. L., and T. B. Clayton. 1997. Use of radio telemetry to monitor movements and obtain critical habitat data for a fluvial bull trout population in the Athabasca River, Alberta. Pages 413-420 *in* W. C. Mackay, M. K. Brewin, and M. Monita, editors. Friends of the bull trout conference proceedings. Trout Unlimited Canada, Bull Trout Task Force (Alberta), Calgary.

Mogen, J. T., and L. R. Kaeding. 2005. Identification and characterization of migratory and nonmigratory bull trout populations in the St. Mary River drainage, Montana. Transactions of the American Fisheries Society 134:841-852.

Muhlfeld, C. C., and B. Marotz. 2005. Seasonal movement and habitat use by subadult bull trout in the upper Flathead River System, Montana. North American Journal of Fisheries Management 25:797-810.

Nelson, M. L., T. E. McMahon, and R. F. Thurow. 2002. Decline of the migratory form in bull charr, *Salvelinus confluentus*, and implications for conservation. Environmental Biology of Fishes 64:321- 332.

Northcote, T. G. 1997. Potamodromy in Salmonidae: living and moving in the fast lane. North American Journal of Fisheries Management 17:1029-1045.

Power, G. 2002. Charrs, glaciations, and seasonal ice. Environmental Biology of Fishes 64:17-35.

Rieman, B. E., and J. D. McIntyre. 1993. Demographic and habitat requirements for conservation of bull trout. U.S. Forest Service, Intermountain Research Station, General Technical Report INT-302, Ogden, Utah.

Rieman, B. E., and J. D. McIntyre. 1995. Occurrence of bull trout in naturally fragmented habitat patches of varied size. Transactions of the American Fisheries Society 124:285-296.

Ross, M. J., and C. F. Kleiner. 1982. Shielded-needle technique for surgically implanting radio-frequency transmitters in fish. Progressive Fish-Culturist 44:41-43.

Schill, D., R. Thurow, and P. Kline. 1994. Seasonal movement and spawning mortality of fluvial bull trout in Rapid River, Idaho. Boise, ID: Idaho Department of Fish and Game. Project: F-73-R-15, Job 2.

Sokal, R. R. and F. J. Rohlf. 1995. Biometry: the principles and practice of statistics in biological research. 3rd edition. W. H. Freeman and Co.: New York.

Southwood, T. R. E. 1977. Habitat, the templet for ecological strategies? Journal of Animal Ecology 30:1-8.

Swanberg, T. 1997. Movements of and habitat use by fluvial bull trout in the Blackfoot River, Montana. Transactions of the American Fisheries Society 126:735-746.

USFWS (U.S. Fish and Wildlife Service). 2002. Bull Trout (*Salvelinus confluentus*) Draft Recovery Plan, Portland, Oregon.

Watry, C. B., and D. L. Scarnecchia. 2008. Adfluvial and fluvial life history variations and migratory patterns of a relict charr, Salvelinus confluentus, stock in west-central Idaho, USA. Ecology of Freshwater Fishes 17:231-243.

White, G. C. and R. M. Garrot. 1990. Analysis of wildlife radio-tracking data. Academic Press, New York.

Wilson, W. H, T.L. Schultz, J. R. Ruzycki, R. W. Carmichael, J. Haire, J. Schricker. 2008 Escapement and Productivity of Spring Chinook and Summer Steelhead in the John Day River Basin", 2006-2007 Technical Report, project no. 199801600, 98 electronic pages (BPA Report DOE/BP-00036462-1).

Winter, J. D. 1996. Advances in underwater biotelemetry. In: Murphy, B. R., and D. W. Willis, eds. Fisheries techniques, 2nd edn. Bethesda, MD: American Fisheries Society, pp. 555-590.

Wissmar, R. C., J. E. Smith, B. A. McIntosh, H. W. Li, G. H. Reeves, and J. R. Sedell. 1994. A history of resource use and disturbance in riverine basins of eastern Oregon and Washington (early 1800s-1990s). Northwest Science 68:1-35.