AN ABSTRACT OF THE THESIS OF

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Abstract approved: Redacted for Privacy

Barbara A. Shields

Redacted for Privacy

Robert E. Olson

Redband trout (*Oncorhynchus mykiss gairdneri*) are found over a wide range of environmental conditions and are known for their variability in life history traits among watersheds or even within streams. Life history traits and population structure of these trout can be influenced by a variety of anthropogenic changes including habitat degradation and habitat fragmentation. In 1964, the construction of Round Butte Dam created a large reservoir (Lake Billy Chinook) at the junctions of the Crooked, Deschutes, and Metolius Rivers. It is unknown what effect the creation of Lake Billy Chinook had on the native population structure of redband trout in this area because no baseline data were collected before the construction of the dam. The fate of a population of summer run of steelhead trapped above the dam also remains unknown. This study focused on determining if Lake Billy

Chinook presented a barrier to interactions among populations in the middle Deschutes, lower Metolius, and lower Crooked Rivers by examining movement of tagged redband trout within the system. The sub-populations of trout from the three major tributaries of Lake Billy Chinook were also examined to determine if they could be separated and identified based on biological characters including life history characters, morphometric characters, and parasite faunal assemblages. The large number of redband trout observed moving into arms other than where they were originally tagged suggests that the reservoir does not act as a barrier to ecological interactions among the sub-populations of redband trout in this system. Despite some mixing observed among locations, three sub-populations of redband trout were identified in this system. Redband trout captured in the Deschutes and Crooked Rivers were similar in morphology and in all life history characters examined. However, these populations could be separated based on parasite assemblages, indicating some ecological separation. Redband trout captured upstream in the Metolius River were morphologically unique from other populations and can be identified most readily using simple morphological measurements. Some differences in morphology, growth, movement patterns, fecundity and disease and parasites suggest the possible continued existence of a native, landlocked population of steelhead above Round Butte Dam.

Life History Variation and Movement among Three Populations of Redband Trout (*Oncorhynchus mykiss gairdneri*) in the Middle Deschutes Basin, Oregon

by

Kristy L. Groves

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APPROVED:

Redacted for Privacy

Co-Major Professor, representing Fisheries Science

Redacted for Privacy

Co-Major Professor, representing Fisheries Science

Redacted for Privacy

Chair of Department of Fisheries and Wildlife

Redacted for Privacy

Dean of Graduate School

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I have also had a great deal of assistance from students here at Oregon State University, many of whom were always willing to volunteer their time to help with collecting data. In particular, I would like to thank both Drew Mosher and Alex Gonyaw who both worked at one time or another for me during the coarse of this study. Drew had to put up with me 8 hours a day, 5-6 days a week and not only helped a great deal with data collection, but also helped to make the field season enjoyable for all. The ever-reliable Alex was always willing to do what ever was asked of him and did it well, with generally no complaints. I also want to thank Greg Schuerger, the 'self proclaimed' greatest angler to walk the banks of the Metolius River. I must admit that when no one else could catch any fish up there, Greg always came back with a few. Without his help I wouldn't have gotten enough samples from that river.

My journey into fisheries may not have even happed had I not met my current mentor Dr. Barbara Shields back in Michigan. With her assistance and unwavering belief in me, she has made this all possible. Thank you.

Lastly, we must never forget the valuable role friends play in our lives. So I also want to thank all of those people I have met and befriended along my journey. They have made leaving my family and friends behind, while in pursuit of my dreams, bearable.

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This thesis is dedicated to all those I had to leave behind

to pursue my dreams….

Life History Variation and Movement among Three Populations of Redband Trout (*Oncorhynchus mykiss gairdneri*) in the Upper Deschutes Basin, Oregon

CHAPTER 1

General Introduction

Rainbow trout (*Oncorhynchus mykiss*) east of the Cascade Mountain range in the Pacific Northwest of North America have been classified as redband trout (*Oncorhynchus mykiss gairdneri*). Redband trout are considered a sub-species of rainbow trout based on genetic and morphological differences as well as their inherited ability to withstand higher water temperatures in arid climates (Behnke 1992). Redband trout differ from coastal rainbow trout in physical appearance (more intense coloration, retention of parr marks, larger spots, and light pigment on the tips of the ventral and dorsal fins) (Behnke 1992). Primarily due to variation in coloration and spotting patterns, redband trout are further divided up into several races throughout their range (Behnke 1992), with some populations known to be morphologically unique (Gold 1977). Populations of redband trout can be found in the upper Fraser River basin in Canada and in the Columbia River basin, Upper Klamath Lake basin, and the desert basins of Oregon (Behnke 1992).

Both anadromous (steelhead - migratory fish that have an adfluvial life history) and resident (remain in streams until they mature) stream populations of redband trout were historically found throughout the Columbia River basin

(Northcote 1992). The adfluvial fish migrate from upstream spawning and initial rearing areas downstream to the ocean (anadromous) or in some cases to a freshwater lake to reside for a significant portion of their life. Steelhead typically migrate out to a larger body of water around age two when the fish is approximately 8-10 inches long. During this migration steelhead normally undergo a process of smoltification, which entails some physiological changes along with changes in coloration, morphology, and behavior. As adults, steelhead or adfluvial fish can usually be differentiated from resident fish by differences in physical appearance. Steelhead or migratory redband trout typically reach a larger maximum size than resident stream dwelling fish (Gross 1987), while resident fish normally retain parr marks into adulthood (Behnke 1992).

Redband trout, like rainbow trout, are also known for their variability in life history traits among watersheds or even within streams. Growth rates, condition factors, and fecundity can be highly variable and influenced by age as well as genetic and environmental factors. At this time it is unknown how much of the observed phenotypic or life history variation is due to environmental effects (e.g., temperature, total dissolved solids, food availability, and competition) or changes in genetic diversity resulting from ancient or recent introgression with coastal rainbow trout or hatchery rainbow trout (Barton and Bidgood 1980; Currens et al. 1989; Gipson and Hubert 1991; Hubert and Guenther 1992; Hubert and Chamberlain 1996).

Natural environments are mosaics of habitats affected by a variety of physical and biotic processes that operate on different spatial and temporal scales (Hansson et al. 1995; Collins and Glenn 1997). Real populations are in some sense spatially structured as the habitat is usually heterogeneous and organisms respond in some way to that environment. Assemblies of these spatially structured local or sub-populations can be termed metapopulations. The term metapopulation has been used with a variety of meanings (Hanski and Simberloff 1997) including a concept as described by Szacki (1999) in which a set of local populations is linked together by dispersing individuals, without any assumptions concerning the local population size or probabilities of extinction and recolonization. It is this definition that can be most easily applied to fisheries. Metapopulations appear to be important in the evolutionary history of trout and salmon because the small populations that occur in individual tributaries are a product of local adaptation balanced with incomplete reproductive isolation. Locally adaptive traits include homing behavior, temperature tolerance, and unique local mating behavior (National Research Council 1995). Overall metapopulation structure of trout and salmon depends on genetic variability within local populations, which, in turn, provides the capacity for local adaptation within and variability among local populations (sub-populations).

Metapopulation structure and distribution of salmonids can be highly influenced by a variety of anthropogenic changes including habitat degradation and habitat fragmentation (Williams et al. 1989). In the Pacific Northwest redband trout are one of the most widely distributed native salmonids, found over a wide range of environmental conditions. Although redband trout remain in most of their potential range, declines in abundance, reductions in distribution, and fragmentation into smaller patches are apparent (Thurow et al. 1997) possibly compromising their potential for long-term survival (Dunham et al. 1997; Reiman et al. 1997). Unfortunately many of the anadromous runs of redband trout have already been extirpated due to the construction of impassable dams throughout the Columbia River basin (Fulton 1970).

In 1964, the construction of Round Butte Dam on the Deschutes River created a large reservoir (Lake Billy Chinook) at the junctions of the Crooked, Deschutes, and Metolius Rivers, 161 km upstream of the confluence with the Columbia River (Nehlsen 1995). It is unknown what effect the creation of Lake Billy Chinook had on the native population structure of redband trout in this area because no baseline data were collected before the construction of the dam. Possible effects of the reservoir could have included reduced ecological isolation of the sub-populations in the three tributaries to the reservoir through mixing facilitated by the reservoir (Sakai and Espinos 1994), or it could have increased isolation due to lacustrine habitat avoidance of resident trout (Raleigh and Ebel 1968). Anecdotal accounts have indicated avoidance of the lacustrine habitat and could mean that the reservoir represents a significant barrier to movement among redband trout populations in each tributary and exacerbates the isolation of these sub-populations.

Historically the middle Deschutes sub-basin supported populations of both resident and anadromous redband trout. Today, after three decades of isolation, only resident populations of redband trout are known from the middle Deschutes basin. In addition to the loss of most anadromous populations, past and present land management policies may threaten many remaining native resident populations. Land and water use practices have left sections of historical spawning areas dry or with minimal flow during key spawning periods, reducing amounts of available habitat for spawning adults and juveniles. The resulting depressed reproduction and recruitment, in turn, can decrease effective population sizes and result in a loss of genetic and life history diversity.

In addition, managers have stocked nonnative rainbow trout within the Columbia basin for decades, which may have resulted in out-breeding depression and erosion of the original genetic diversity of resident redband trout populations. Thousands of hatchery rainbow trout have been stocked into the middle Deschutes River basin above Round Butte Dam on a yearly basis (Nehlsen 1995; Stuart et al. 1996). Initially, hatchery stocks included non-native populations of coastal rainbow trout and resident redband trout from both California and Oregon. Eventually a native Deschutes River stock of redband trout was used (Stuart et al. 1996; Ratliff and Schulz 1999). These conditions provide ample opportunities for hybridization between hatchery fish and the native redband trout in this middle basin, possibly compromising the native gene pool.

This study focused on determining the structure of the sub-populations from the three major tributaries of Lake Billy Chinook by monitoring movement and determining if they can be separated and identified based on biological characters. Without knowledge regarding the structure and dynamics of the sub-populations of redband trout in this middle basin and their degree of isolation from other populations, protecting and managing these populations will be difficult and most likely ineffective, resulting in further degradation of the populations of redband trout in this system.

Objectives

The first objective of this study was to determine if there was movement or mixing among redband trout sub-populations and to determine the spawning location(s) and time(s) for the sub-population(s) in the upper arms of Lake Billy Chinook or within the reservoir. Tagging and recapture of individual trout using visible anchor type tags to determine movement patterns is one method that has been used to assess the interactions among sub-populations (Lindsey et al. 1959; Biette et al. 1981; Sakai and Espinos 1994). Using this method, movement or mixing among populations can be represented both graphically and quantitatively and degrees of ecological interactions can be estimated. To assess any genetic interactions (gene flow), observations must also be made during spawning times at each of the major spawning locations for the separate populations. Although tagging studies are limited in that they cannot represent all interactions because information on the location of a fish is only known at the time of recapture, they are adequate for monitoring movement and assessing mixing among populations.

The second objective was to examine the variation in the sub-populations of redband trout from the main tributaries of Lake Billy Chinook and determine if the sub-populations were recognizable as separate stocks or parts of one large panmictic population. Aspects of redband trout biology examined here included life history characteristics (age structure, growth rates, condition factors, and fecundity) in addition to morphometric characters and parasite faunal assemblages. Life history characteristics (Filbert and Hawkins 1995; Rulifson and Dadswell 1995) as well as meristic and morphometric characters (Rinne 1985; Salmanov et al. 1991; Mamontov and Yakhnenko 1995) have been used to assist in stock identification of several species of fish in the past.

Parasite assemblages, used as natural biological "tags", have also been used to identify and monitor movements of discrete sub-populations of fish (Sindermann 1961; Margolis 1963; Kabata 1963; Wood et al. 1989; Moser and Hsieh 1992; Williams et al. 1992). Use of parasites as biological tags has been an invaluable tool in the identification of stocks of several commercially important marine, anadromous, and freshwater fishes (Sindermann 1961; Wood et al. 1989; Moser and Hsieh 1992). Utility of parasites as biological tags found in or on redband trout will depend on the nature of the parasite (its distribution and the complexity of its life cycle) and its means of infection of the host. The distribution of a parasite can be limited either directly or indirectly by environmental conditions interfering with the transmission of parasite to host. Harsh environmental conditions can act directly on free living larval stages of endo-parasites or may act indirectly by limiting the distributions of other essential intermediate hosts needed for the completion of the parasite's life cycle (Williams et al. 1992).

A third objective was to determine if any of these redband trout sub-populations contain significant numbers of trout with an adfluvial life history form. If these fish exist they would migrate from upstream spawning and initial rearing areas downstream into Lake Billy Chinook to reside for a significant portion of their life. Such adfluvial trout could be members of a remnant population of steelhead trapped above the dam or may represent an adfluvial life history that has emerged in response to the construction of the reservoir.

This study of the life history of redband trout in Lake Billy Chinook attempted to address these objectives. The general methodology and objectives for this study were designed and selected by biologists from Portland General Electric and Oregon State University with significant participation by the Oregon Department of Fish and Wildlife, U.S. Forest Service, Bureau of Land Management and the Confederated Tribes of the Warm Springs Reservation of Oregon. In addition to collecting all data, I was responsible for any modifications necessary to the study plan to meet the study objectives, including the addition of examining parasite assemblages of redband trout and choosing appropriate methods of data analysis.

Information collected in this study documents some population dynamics and life history characters of certain populations of redband trout in the Deschutes River System, estimates the degree of interaction among these populations, and will make a significant contribution towards the long-term successful management of these native trout populations in Lake Billy Chinook and its three tributaries. Since baseline data were not collected prior to the construction of Round Butte Dam, it is unknown in what ways and to what extent the creation of the reservoir, Lake Billy Chinook, may have influenced life history characters as well as the ecological and reproductive isolation of redband trout populations in the system.

Study Area

The reservoir

The study area includes Lake Billy Chinook, a 1,585-ha reservoir created by the construction of Round Butte Dam on the Deschutes River in 1964, and portions of its three major tributaries (Crooked, Deschutes, and Metolius rivers) (Figure 1.1). Lake Billy Chinook extends up the Crooked, Deschutes and Metolius canyons to a distance of 11 km, 14 km, and 21 km respectively. Anecdotal accounts indicate that redband trout have not been very abundant in Lake Billy Chinook, except in the fluvial/lacustrine (river-reservoir) transition zones of the upper arms where the three rivers enter the reservoir. The focus of this study was on the river-reservoir transition zones and the lower 2 km of each river between river kilometer (rkm) 9 and 11 in the Crooked, rkm 12 and 14 in the Deschutes and rkm 19 and 21 in the Metolius, as measured from Round Butte Dam, in addition to the forebay area of the reservoir. The transition zones between the rivers and reservoir environment where chosen as study sites because they represent favorable trout habitat and their locations maximize the chance of catching fish moving up into the tributaries or downstream into the reservoir.

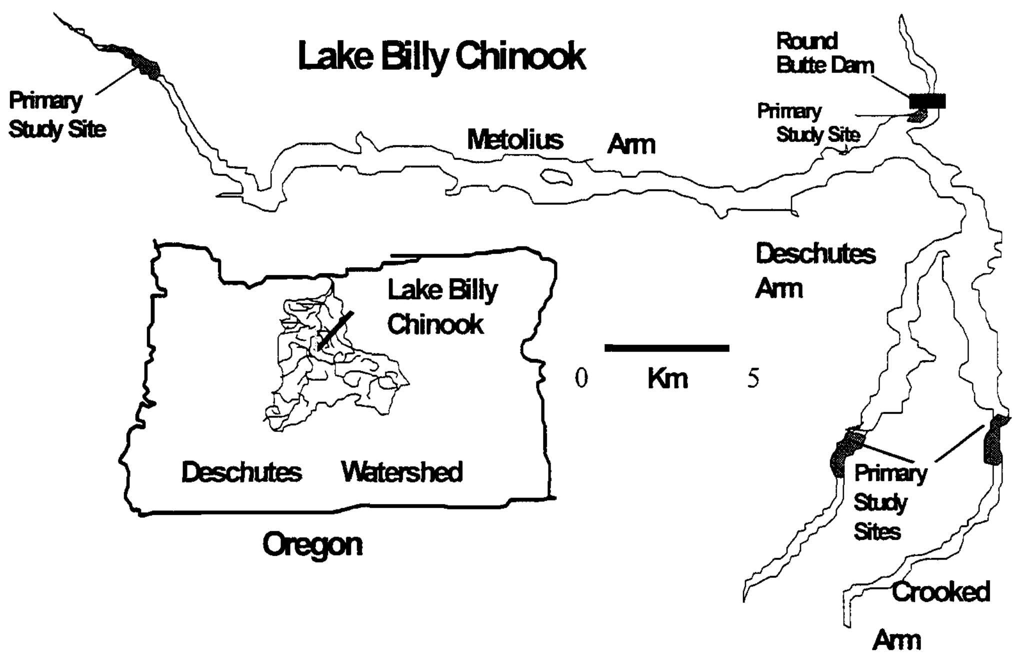

Figure 1.1. Location of primary study sites in Lake Billy Chinook, 1997-1999.

The tributaries

The Crooked River originates in the Ochoco Mountains and is the largest eastern tributary to the Deschutes River. Only the lower 11 km of the river is available for use by redband trout in Lake Billy Chinook due to a diversion dam at the Opal Springs Hydroelectric Project. This dam blocks upstream passage except during very high flows, but downstream movement of trout into the reservoir is possible.

The Deschutes River originates in the Cascade Mountains southwest of Bend and flows north to Lake Billy Chinook for a distance of 212 km. Upstream passage of redband trout is blocked on the Deschutes River by Steelhead Falls except during very high flows, 13 km upstream of Lake Billy Chinook (Nehlsen 1995). The upstream limit to migration during high flows is Big Falls, approximately 34 km upstream of Round Butte Dam (Nielson 1950).

The Metolius River originates as a series of large springs near the base of Black Butte in the Cascade Mountains and flows for a distance of 45 km before reaching Lake Billy Chinook. Multiple tributary inputs greatly influenced by springs in the upper stretch of the Metolius River help to maintain cool temperatures and stable flows throughout most of the year (Nehlsen 1995). Movement throughout in the Metolius River is unhindered.

The following chapters of this thesis are divided to address each of the objectives of this study individually, each written for submission to the North American Journal of Fisheries Management, followed by a general summary of the study. An Appendix that includes all snorkel survey dates and spawning ground survey dates can be found at the end of the thesis.

CHAPTER 2

Movement and Mixing among Three Sub-populations of Redband Trout in the Tributaries to Lake Billy Chinook, Oregon

Kristy L. Groves[1] and **Barbara A. Shields**[2]

Oregon State University
Department of Fisheries and Wildlife
104 Nash Hall
Corvallis, OR 97331

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Abstract

Manipulation of natural streams with the construction of dams is likely to alter fish habitat in many ways and hence select for different life history strategies of those fish. With the construction of Round Butte Dam, a large reservoir (Lake Billy Chinook) was created. Possible effects of the reservoir could have included reduced ecological isolation of the populations in the three tributaries to the reservoir through mixing facilitated by the reservoir, or it could have increased isolation due to lacustrine habitat avoidance of resident trout. The purpose of this study was to determine if Lake Billy Chinook presented a barrier to ecological or reproductive interactions among the populations of redband trout in the middle Deschutes, lower Metolius, and lower Crooked Rivers. Redband trout were captured at each of four locations within the tributaries to Lake Billy Chinook, tagged with Floy® t-bar anchor tags and released to monitor movements among the tributaries. Spawning grounds in each tributary were also monitored for tagged fish to determine if there was any reproductive mixing among populations. Of all recaptured trout, 6% to 75% (dependant on location of tagging) had moved more than 2 km from their original tagging locations. The majority of movement was into the Metolius River. There was also some mixing observed between the Crooked and Deschutes River populations of redband trout. The large number of redband trout observed moving into arms other than where they were originally tagged, suggests that the reservoir is not acting as a barrier to ecological interactions among the sub-populations of redband trout in this system.

Rainbow trout (*Oncorhynchus mykiss*) east of the Cascade Mountain range in the Pacific Northwest of North America have been classified as redband trout (*O. m. gairdneri*). These redband trout differ from coastal rainbow trout in physical appearance (more intense coloration, retention of parr marks, larger spots, and light colored pigmented tips on the ventral and dorsal fins) as well as their inherited ability to withstand higher water temperatures in arid climates (Behnke 1992). Inland redband trout are native to and found throughout the Deschutes River system in central Oregon. In 1964, the construction of Round Butte Dam created a large reservoir (Lake Billy Chinook) at the junctions of the Crooked, Deschutes, and Metolius Rivers (Nehlsen 1995). The effect of the creation of Lake Billy Chinook on the metapopulation structure of the native populations of redband trout in this area is unknown because baseline information was not collected before the construction of the dam.

Manipulation of natural streams with the construction of dams is likely to alter fish habitat in many ways and hence select for different life history strategies in those fish populations (Reyes-Gavilian et al. 1996). Possible effects of creating a reservoir could have included reduced ecological isolation of the populations in the three tributaries to the reservoir through mixing facilitated by the reservoir (Sakai and Espinos 1994), or alternatively, increased isolation due to lacustrine habitat avoidance of resident trout (Raleigh and Ebel 1968). Anecdotal accounts from sport fishermen on Lake Billy Chinook during the spring, summer and fall have suggested that few redband trout utilize the lake during those seasons. This suggests avoidance of the lacustrine habitat and indicates that the reservoir represents a significant barrier to movement among redband trout sub-populations in the tributaries of Lake Billy Chinook.

Tagging and recapture of individual trout using visible anchor type tags to determine movement patterns is one method that has been used to assess the interactions among sub-populations (Lindsey et al. 1959; Biette et al. 1981; Sakai and Espinos 1994). Using this method, ecological interactions in terms of movement or mixing among populations can be represented both graphically and quantitatively. To assess possible genetic interactions, observations must also be made during spawning times at each of the major spawning locations for the separate populations. This method is limited in that it cannot represent all interactions because information on the location of a fish is only known at the time of recapture. However, there are advantages to using visible anchor type tags over other more comprehensive tagging methods. The main advantages to using visible tags over other tagging methods (eg. radio tagging) are that they can be used over longer periods, may have lower tag induced mortality and behavioral changes and have an overall lower cost.

When this study began, the spawning locations, and fidelity to those areas, had not been determined for redband trout populations in the tributaries to Lake Billy Chinook. Although the degree of natal site fidelity of redband trout is unknown, rainbow trout forms show variable fidelity, from as little as 5% up to 90% (Lindsey et al. 1959; Beitte et al. 1981; Sakai and Espinos 1994). Spawning fidelity depends heavily on the stability of environmental conditions in natal streams with the highest fidelity found in the most stable systems. A great deal of variation has also been observed in spawning times of both wild redband and rainbow trout. Typically spawning occurs in spring/early summer but has been observed in the fall and even year round in some populations (Greeley 1934; Narver 1969; Dodge and MacCrimmon 1971; Biette et al. 1981; Sakai and Espinos 1994). In the lower Deschutes River (below Round Butte Dam) spawning redband trout have been observed between March and August (Zimmerman and Reeves 1997). Based on this information from the lower Deschutes, it has been presumed that spawning takes place within this interval in the middle Deschutes and its major tributaries.

The purpose of this study was to determine if Lake Billy Chinook presented a barrier to ecological or reproductive interactions among the populations of redband trout in the middle Deschutes, lower Metolius, and lower Crooked Rivers.

Study area

The study area includes Lake Billy Chinook and portions of its three major tributaries (Crooked, Deschutes, and Metolius rivers) (Figure 2.1). Lake Billy Chinook, a 1,585-ha reservoir created by the construction of Round Butte Dam on the Deschutes River in 1964, extends up the Crooked, Deschutes and Metolius canyons to a distance of 11 km, 14 km, and 21 km respectively. Lake Billy

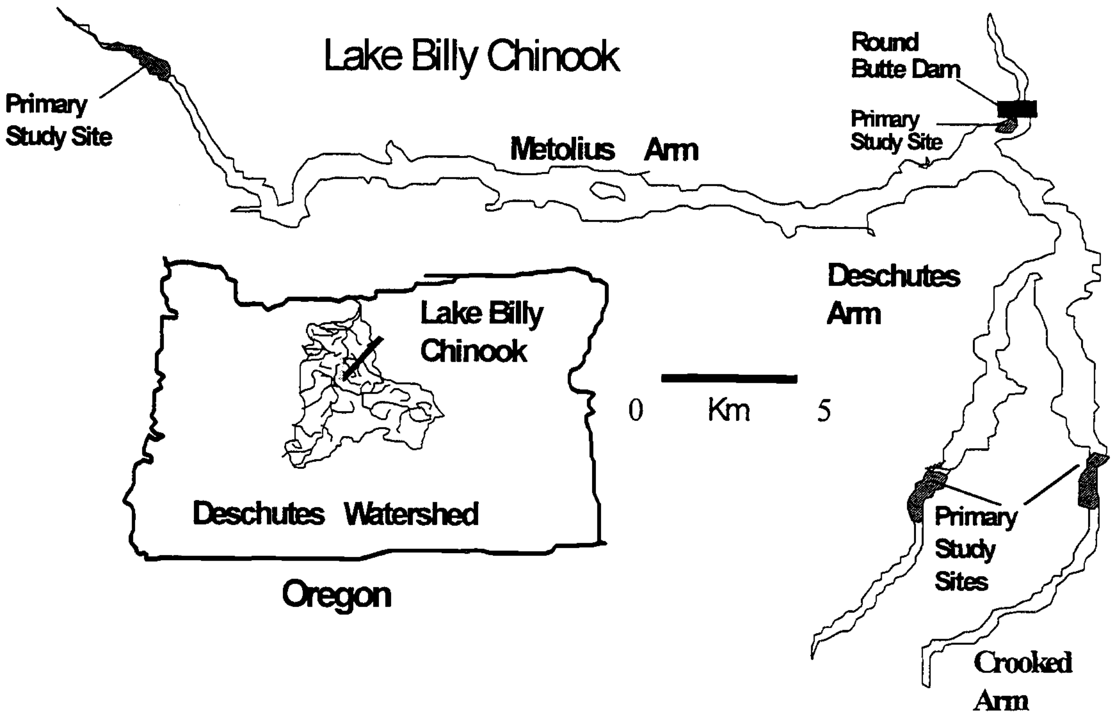


Figure 2.1. Location of primary study sites in Lake Billy Chinook, 1997-1999.

Chinook has a maximum depth of 122m. Water intake for the powerhouse, in the forebay area of the reservoir, is located 83m below full pool level.

Anecdotal accounts of sport fishermen indicate that redband trout are not abundant in Lake Billy Chinook except in reaches of the upper transition zones of each tributary, where each of the rivers enter the reservoir. The focus of this study was on these river-reservoir transition zones extending up to the lower 2 km of each river. Most fish were collected between river kilometer (rkm) 9 and 11 in the Crooked, rkm 12 and 14 in the Deschutes and rkm 19 and 21 in the Metolius, as measured from Round Butte Dam, in addition to the forebay area (near the dam) of the reservoir.

The Crooked River originates in the Ochoco Mountains and is the largest eastern tributary to the Deschutes River. Only the lower 2 km of free flowing river is available for use by redband trout in Lake Billy Chinook in addition to 9 km of lake habitat within the reservoir due to a diversion dam at the Opal Springs Hydroelectric Project. This dam stops upstream passage except during very high flows. Downstream movement of trout from the upper Crooked River into the reservoir is possible.

The Deschutes River originates in the Cascade Mountains southwest of Bend and flows north to Lake Billy Chinook for a distance of 212 km. Upstream passage of redband trout is blocked on the Deschutes River by Steelhead Falls except during very high flows (13 km upstream of Lake Billy Chinook) (Nehlsen

1995). The upstream limit to migration at all times is Big Falls, approximately 34 km upstream of Round Butte Dam (Nielson 1950).

The Metolius River originates as a series of large springs near the base of Black Butte in the Cascade Mountains and flows for a distance of 45 km before reaching Lake Billy Chinook. Input from many spring fed tributaries in the upper stretch of the Metolius River help to maintain cool temperatures and stable flows throughout the year (Nehlsen 1995). Movement throughout in the Metolius River is unhindered.

Methods

Capture of trout

Floating Merwin type trap nets, with leads extending perpendicular to the shore, were set near the upper arms of Lake Billy Chinook (lower 2 km of the tributaries) and in the lower reservoir (forebay) near the dam during the spring and early summer of 1997 and 1999 and also from winter through late summer in 1998 (Figure 2.1). Trap designs used in each of the three arms of Lake Billy Chinook had a 15m x 4.5m lead net set perpendicular to shore. The pot and spiller (holding pen) each measured approximately 5m x 4m x 7m and both were surrounded by and suspended from an aluminum walkway. The Merwin type trap used in the forebay was custom built to nearly twice the dimensions of the traps used in the arms. Merwin traps were placed the transition zones of each of the three arms between the river and reservoir environment because these sites represent favorable trout habitat and maximize the chance of catching fish moving into the river as well as those moving out to the reservoir. A sinking Oneida type trap net (Korn et al. 1967), rotary screw traps (designed expressively for the capture of downstream migrants), and angling were also employed to capture fish at some locations. The Oneida trap was only set in the upper Metolius arm because this was the only location that met the necessary requirements of shallow depth and low current velocity for the use of this trap within the river/reservoir transition zones. Both the Merwin and Oneida traps are designed to capture fish moving laterally along the shoreline. Rotary screw traps were fished in the upper Deschutes and Metolius arms in 1997 and 1998 and in the upper Metolius arm in 1999 to sample migrating juveniles. Traps were typically fished for 24 hour periods, five days a week.

All captured redband trout were anesthetized, measured and weighed, tagged, and allowed to recover prior to release at tagging locations. To distinguish trout caught in the different tributaries and those captured near the dam (forebay), fish greater than 22 cm fork length were marked with color-coded, individually-numbered Floy® T-bar anchor tags. Fish under 22 cm fork length were marked with a unique partial fin clip. Both the color code of the anchor tag and the position of the fin clip were standardized by trap location to show the initial capture site of a given fish. A total of 1,073 redband trout was tagged from 1997 – 1999, with an additional 389 juvenile redband trout fin clipped over this time period (Table 2.1). In addition, 16 adult redband trout were captured using trap nets in

Squaw Creek (a major tributary to the Deschutes River) during peak spawning activity in 1998. These trout were tagged with a uniquely numbered bi-colored (red/white) Floy® anchor tag and released.

All captured redband trout were categorized into one of three groups based on external characters: 1) fish appearing to be of hatchery origin (fin clips and/or deformed fins), 2) fish showing smolt-like characteristics (silvery, long narrow bodies, no ventral fin pigmentation, and deciduous scales) (Hoar 1976), and 3) all other fish, classified as wild resident redband trout.

Table 2.1. Tagging and recapture summaries of redband trout from Lake Billy Chinook and its three major tributaries, 1997-1999.

Year	Location	# Floy Tags	# Recaptured	% Recaptured	Fin Clips	# Recaptured	% Recaptured
1997	**Deschutes**	116	20	17.2	152	7	4.6
	Crooked	94	15	16	15	1	6.7
	Metolius	62	5	8	15	0	0
	Total 1997	**272**	**40**	**14.7**	**182**	**8**	**4.4**
1998	**Deschutes**	106	13	12.3	43	0	0
	Crooked	134	18	13.4	11	2	18.2
	Metolius	204	9	4.4	36	2	5.6
	Forebay	126	6	4.8	15	2	13.3
	Total 1998	**570**	**46**	**8.1**	**105**	**6**	**5.7**
1999	**Deschutes**	102	19	18.6	42	2	4.8
	Crooked	85	12	14.1	37	1	2.7
	Metolius	38	4	10.0	19	1	5.3
	Forebay	6	1	16.7	4	0	0
	Total 1999	**231**	**36**	**15.6**	**102**	**4**	**3.9**
Overall Total		**1073**	**122**	**11.4%**	**389**	**18**	**4.6%**

Intensive recapture efforts were made at various parts of the system using traps, volunteer anglers, and observations both from shore and with the use of snorkeling gear. Snorkel surveys were conducted in all three arms of Lake Billy Chinook on a weekly basis when water clarity allowed. Notices of the ongoing study were posted at all lake and river access sites to encourage participation from anglers in reporting tags.

Spawning ground surveys

Shoreline and snorkel surveys were conducted periodically on discrete stream segments on the middle Deschutes and Metolius systems during presumed spawning periods. Sites surveyed included the middle mainstem of the Deschutes River, Squaw Creek (Deschutes system) and the lower mainstem of the Metolius River (Figure 2.2). Spawning ground surveys were also conducted in conjunction with U.S. Forest Service (USFS) personnel on the upper Metolius River above rkm 33. Surveyors estimated the numbers of redds and spawners at each location when observed.

In the Crooked River, a fyke trap was set up in the fish ladder at Opal Springs Hatchery during both 1998 and 1999 with the assistance of hatchery personnel. The fish ladder was designed only to collect trout for the local hatchery and does not allow for upstream passage past the diversion. Numbers of adult and juvenile redband trout moving up the fish ladder were counted and used as an indication of timing of spawning-associated movement(s). Scale samples were taken and gonads were examined from redband trout captured in the fish ladder on four separate occasions in 1998 to determine their age, sex, and stage of maturity. In 1999, trout were only measured and released.

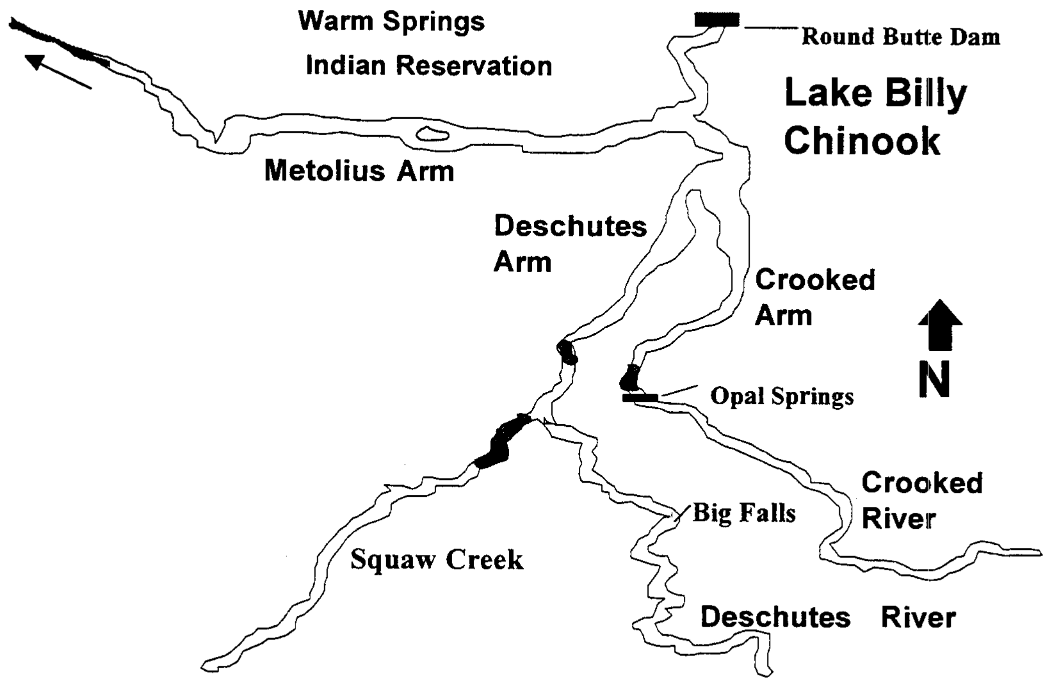


Figure 2.2. Locations of spawning ground surveys, 1998-1999. Areas surveyed indicated by shaded areas.

Results

Movement

Tagging data showed that between 6% and 75% of all recaptured trout from all sites moved more than 2 km from their original tagging site during the study period. The largest percentage of movement was observed from those trout originally tagged in the forebay (Table 2.2). Overall recapture percentages for resident redband trout among locations and likely movement after initial tagging are shown in Table 2.3.

Table 2.2. Percent movement based on number of recaptures from trapping locations in the three arms of Lake Billy Chinook, 1997-1999.

Location of Initial Tagging	Number Recaptured	% Recaptured >2km from tagging location
Deschutes	62	25%
Crooked	73	19%
Metolius	21	6%
Forebay	8	75%

Trout tagged in the Crooked arm moved into the Metolius arm more frequently than into the Deschutes arm, yet trout tagged in the Deschutes arm were more likely to move into the Crooked arm than into the Metolius arm. A higher percentage of fish tagged in the forebay area of the reservoir moved into the Deschutes arm than any other location in the study area. The only movement observed of fish originally tagged in the Metolius arm was movement further upstream in the Metolius River. A graphical representation of the recapture sites of those trout that had moved to other tributary arms is shown in Figure 2.3.

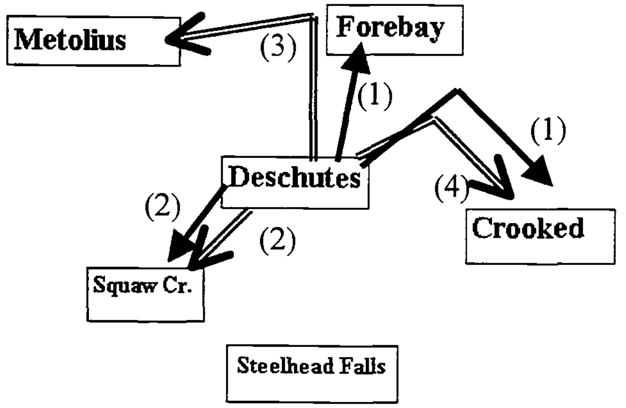
Table 2.3. Number of recaptures and percent movement of recaptured redband trout among locations in the three arms of Lake Billy Chinook, Oregon.

	To			
From	Crooked	Deschutes	Metolius	Forebay
Crooked	39 (76%)	3 (6%)	5 (10%)	4 (8%)
Deschutes	5 (8%)	50 (85%)	3 (5%)	1 (2%)
Metolius	0	0	17 (100%)	0
Forebay	1 (10%)	4 (40%)	3 (30%)	2 (20%)

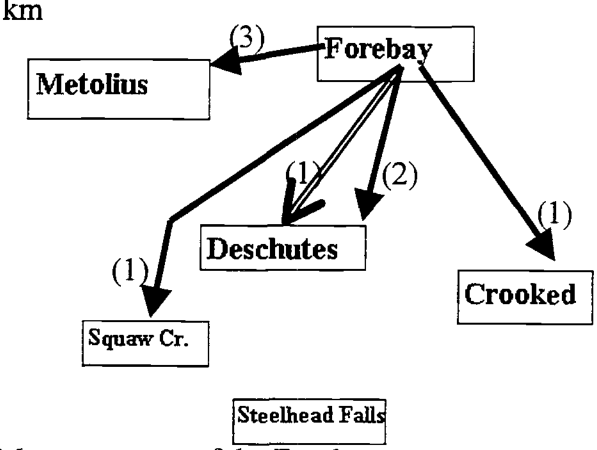
In the Crooked River arm approximately 13% of 45 recaptures were from fish that had moved into the Crooked arm, from either the Deschutes River or the forebay area of the reservoir. In the Deschutes arm 12 % of 56 recaptures had been originally tagged in either the Crooked River or in the forebay area of the reservoir. Approximately 71% of seven fish recaptured in the forebay had been originally tagged in either the Deschutes or Crooked arms of Lake Billy Chinook. No fish originally tagged in the Metolius system were recaptured outside this system although 39% of 28 recaptures within this arm had immigrated from other tagging locations. Of those tagged fish moving into the Metolius, 20% were identified as either hatchery origin or smolt-like.

Data on tagged trout observed during snorkel surveys were not considered in the above analysis because these data may include re-observations of individual fish. Snorkel observations of tagged trout also indicated movement of trout tagged from both the Deschutes and Crooked arms into the Metolius arm of Lake Billy Chinook. In addition, trout tagged in the Deschutes arm were observed in the Crooked arm and vice versa (Table 2.4).

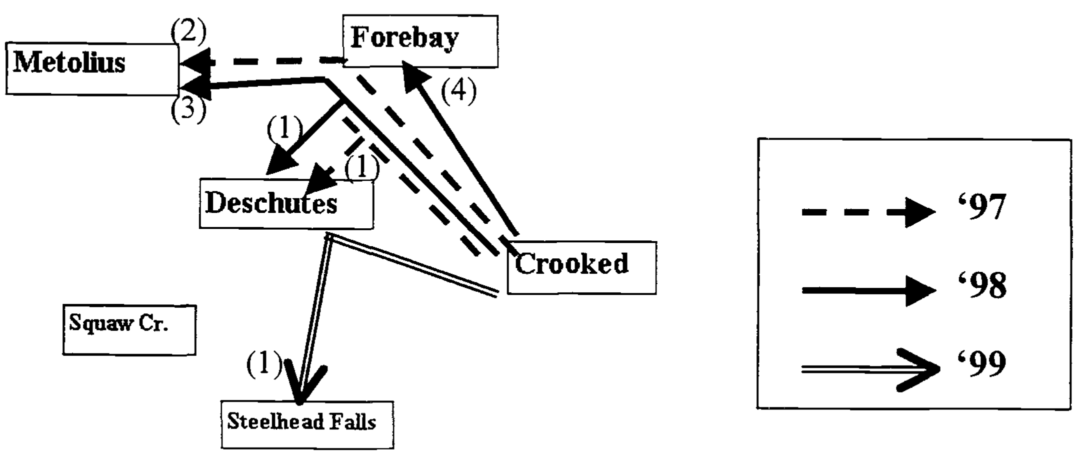
Figure 2.3. Movement of tagged, recaptured redband trout into other tributaries canyons observed from 1997 to 1999 in Lake Billy Chinook, Oregon. No redband trout tagged in the Metolius system were recaptured in other tributary canyons.
(n) = number of tagged trout observed moving to that location.



Movement out of the Deschutes River –
Average Movement – 19.75 km



Movement out of the Forebay – Average
Movement – 17.38 km



Movement out of the Crooked River –
Average Movement – 23.71 km

Figure 2.3.

Table 2.4. Summary of tags observed during snorkel surveys in the three arms of Lake Billy Chinook, 1997-1999.

	Location of Observation			
	Deschutes (orange)	**Crooked (yellow)**	**Metolius (green)**	**Squaw Creek (red/white)**
1997	2 – Orange* 1 – Yellow*	7 – Yellow*		
1998	3 – Orange	8 - Yellow	4 – Green 2 – Yellow	
1999		10 – Yellow 3 – Orange*	1 – Orange*	1 – Orange*

* Indicates fish were observed on the same day. All other tag totals were observed on different days so number of tagged fish may include re-observations of the same fish.

Spawning ground surveys

Squaw Creek

During 1997 few surveys of spawning trout were done on Squaw Creek but some evidence of spawning during the spring was observed. In 1998, ground and snorkel surveys of Squaw Creek showed that peak trout spawning occurred in mid-May (Figure 2.4). During the fall of 1998 a ground survey was conducted on Squaw Creek and no redds or fish were observed. Biweekly surveys during 1999 indicated that redband trout spawning activity began a week earlier than in the spring of 1998 and included larger numbers of fish (Figure 2.5). No spawning fish tagged in Squaw Creek were observed within the mainstem of the Deschutes River.

However, fish tagged in both the mainstem of the Deschutes and near the forebay were observed on the spawning grounds in Squaw Creek during 1998 and 1999.

Metolius River

During intensive snorkel surveys of the upper Metolius River conducted primarily by the USFS, a total of 804 redband trout were counted during the month of December, 1998 and February and April, 1999 (Riehle and Houslet 1999). A total of 348 adult redband trout observed in April 1999 included one redband trout observed with a green tag near the mouth of Lake Creek (a tributary to the upper Metolius River). This tag color indicates the trout had been originally tagged in the lower Metolius River, but because the number of the tag could not be seen during the snorkeling observation, no specifics are known about the original tagging date or exact tagging location.

In the lower mainstem of the Metolius River, ground surveys were conducted during the fall of 1998 and spring of 1999 from approximately river kilometer 31 to the inflow into Lake Billy Chinook at river kilometer 21. These

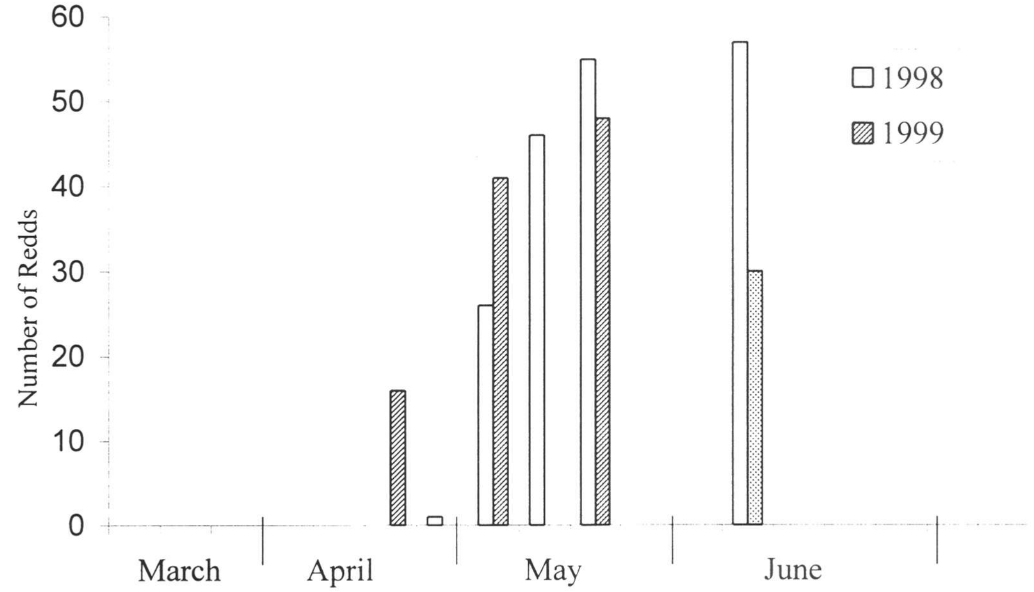


Figure 2.4. Number of new redds observed during 1998 and 1999 surveys in Squaw Creek.

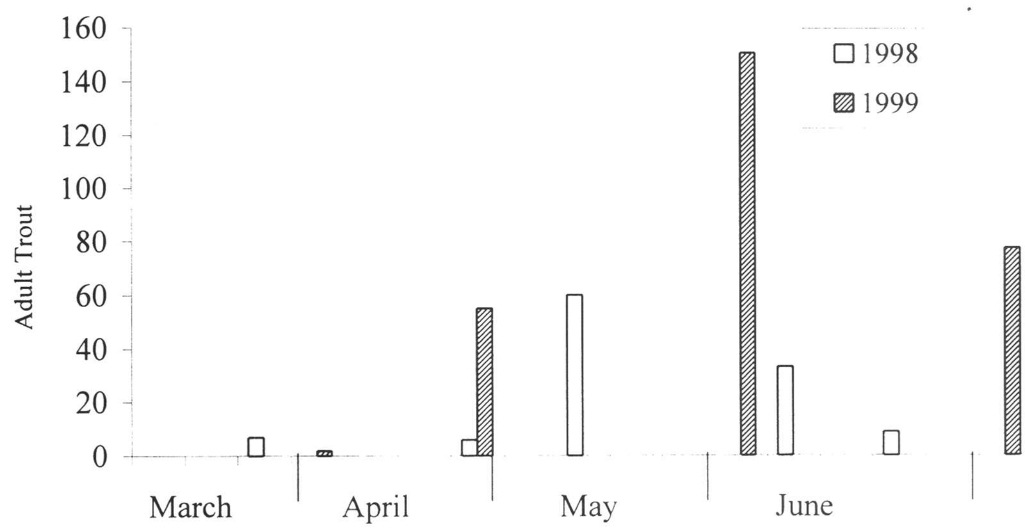


Figure 2.5. Number of adult redband trout observed during snorkel surveys in Squaw Creek, 1998 and 1999.

surveys revealed potentially suitable spawning habitat for redband trout but no evidence of spawning activity. During a sampling trip in late July 1999, two redds were observed near rkm 27. In the early spring of 2000 (January through March), several mature redband trout with ripe gonads were captured in the lower Metolius River by volunteer anglers. Trout eggs were also found in the stomachs of these fish, indicating active spawning in the immediate vicinity.

Crooked River

In the Crooked River, counts of fish per day moving up the Opal Springs fish ladder indicated that peak movement occurred during the third and fourth week of June in both 1998 and 1999 (Figure 2.6). Sub-samples of these fish on four separate occasions in 1998 indicated that the majority (>90%) of fish moving up the fish ladder were mature with ripe gonads and were ready to spawn. A total of six tagged trout were observed in the Opal Springs fish ladder. Five of those tagged trout were originally tagged in the Crooked River arm and one was tagged in the forebay. During the period from late May to mid July, substantial numbers (reaching 711) of redband trout were counted during snorkel surveys in the mainstem of the Crooked River just below the Opal Springs Diversion Dam. Three fish originally tagged in the Deschutes River were observed during these surveys.

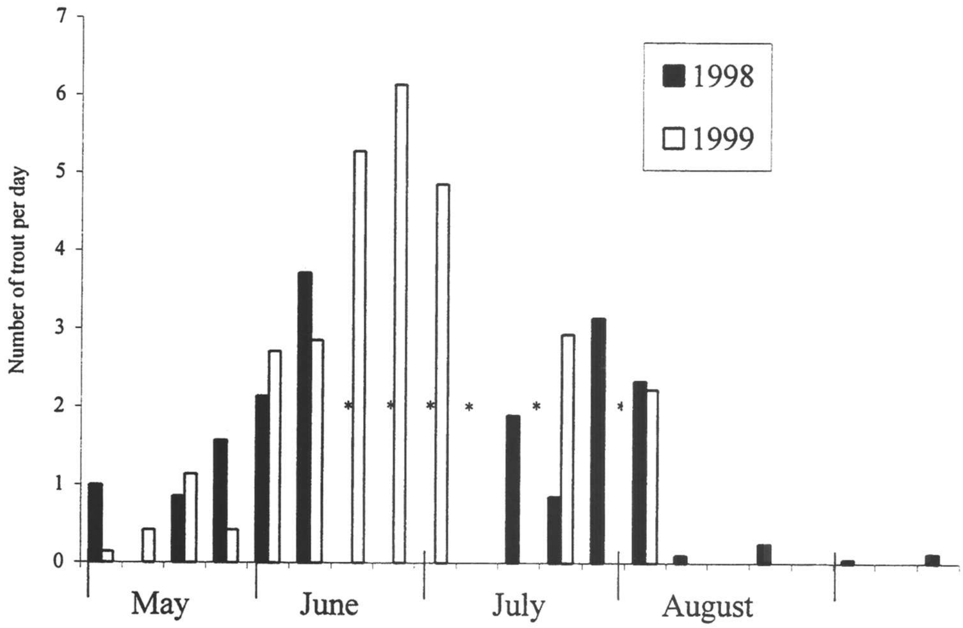


Figure 2.6. Number of adult redband trout moving up the Opal Springs fish ladder per day, 1998-1999. * no data were collected during these weeks.

Discussion

The large number of redband trout observed moving into and through the main body of the reservoir and observed in tributary arms other than where they were originally tagged, suggests that the reservoir does not act as a barrier to movement and interactions among the sub-populations of redband trout in this system. The greatest net movement of trout occurred into the river-reservoir transition zone of the Metolius River from other locations. In addition to the resident redband trout observed, hatchery rainbow trout and trout showing smolt-like characteristics were found in much higher numbers in the Metolius arm than any other trap location. Stocking of hatchery rainbow trout into the Metolius River was halted in 1996 (Fies et al. 1996) and steelhead have never been known to spawn in the Metolius River (Nehlsen 1995), indicating these fish are moving to this location from elsewhere in the system.

Surface currents move from the other arms of Lake Billy Chinook up the Metolius arm during normal dam operation (Ratliff and McCollister 1997). The colder, denser Metolius River water tends to fill the lower portions of the reservoir while the warmer combined water from the Deschutes and Crooked Rivers tends to fill the top portion of the reservoir. This surface water is drawn "upstream" to a mixing/transition zone in the upper Metolius arm (Figure 2.7). If trout are seeking to emigrate from the system utilizing surface currents (Korn et al. 1967) this may cause them to end up in the upper Metolius arm.

Ceratomyxa shasta infection studies also suggest movement of fish into the Metolius arm of Lake Billy Chinook. Experimental exposures of susceptible 'sentinel' hatchery trout have demonstrated high infectivity levels (percent of fish infected with the parasite after a set exposure period) of *C. shasta* in the upper portions of both the Crooked (80-100%) and Deschutes (61-100%) arms of Lake Billy Chinook, while low infectivity levels were found in the forebay, and very low infectivity levels (1-2%) were found in the Metolius arm (Table 2.5; Ratliff 1983; Bartholomew 1999). The low level of infectivity in the Metolius arm may possibly indicate the presence of only a very few infective stages or intermediate hosts in this area. The relatively high percent of infection in samples taken from fish captured in the Metolius arm during this study (Bartholomew 1999) indicates that these fish may have moved into this arm from regions were infectivity is high. However, the latter is unlikely because no observations have been made to suggest movement of redband trout out of the upper Metolius River. In addition, 69% of all hatchery rainbow trout and approximately 20% of trout showing smolt-like characteristics captured in the Metolius arm during this study were also infected with *C. shasta* (Bartholomew 1999) indicating that these fish also moved into the lower Metolius arm from some other location.

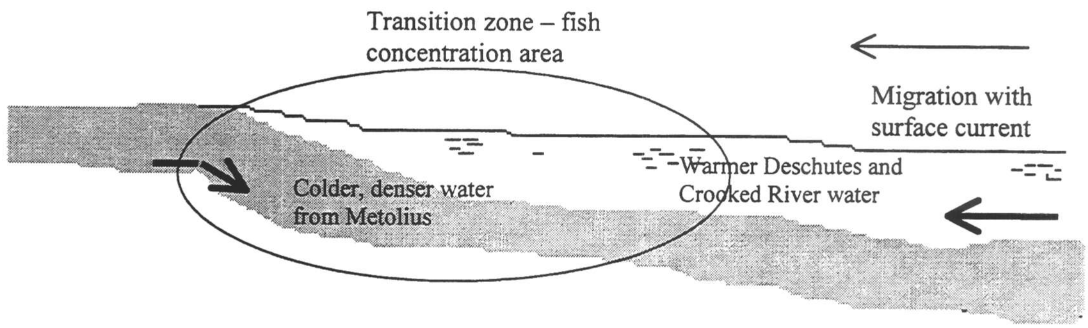


Figure 2.7. Graphic representation of current patterns in the upper Metolius arm of Lake Billy Chinook, Oregon.

Table 2.5. Results of previous and current sentinel studies and current parasite surveys for *Ceratomyxa shasta* at locations within Lake Billy Chinook, Oregon.

	Sentinel Studies (susceptible hatchery rainbow trout) (Ratliff 1981; Bartholomew 1999) %infected/N			Disease survey of local redband trout 1999 (PCR) (Bartholomew 1999) %infected/N		
	1975	**1977**	**1999**	**Resident**	**Hatchery**	**Smolt-like**
Crooked	--	80%/46	100%/100	36%/31	100%/2	33%/3
Deschutes	61%/100	--	100%/100	37%/19	43%/7	0%/2
Metolius	--	0%/49	1-2%/100	16%/25	57%/14	22%/9
Forebay	0%/110	--	--	62%/13	75%/4	29%/7

The observed movement pattern into the Metolius arm indicates some mixing and may indicate recruitment from other populations into the gene pool of the population in the lower Metolius River. However, previous genetic studies using allozymes detected no hatchery introgression into the lower Metolius River population (Currens et al. 1997) or mixing among the resident redband trout populations in this system (Williams et al. 1997). Observations indicate that redband trout in the lower Metolius River may spawn months earlier than populations in the Deschutes and Crooked Rivers. This difference in spawning time may limit opportunities for genetic introgression into the Metolius population despite the amount of movement documented from the other populations into the Metolius River. The extent of introgression by other local populations into this Metolius population cannot be determined until spawning grounds in the lower

Metolius River are located and origins of spawning fish are determined through tagging studies or through genetic analysis.

The lack of observed movement of trout out of the Metolius arm may be an artifact of the low recapture rate of redband trout tagged in this area. High water clarity and large numbers of avian predators in the Metolius arm were observed during this study and may be responsible for the low numbers of recaptures and may have greatly influenced the analysis of movement from this arm. Although juvenile bull trout (*Salvelinus confluentus*) tagged with a different color tag at the same location were recaptured in relatively high numbers in the Metolius arm (Ratliff et al. 1996), differences in behavior, habitat selection, and tag color visibility between the two salmonid species may explain differences in recovery. During snorkel surveys bull trout were typically observed associated with the river bottom or cover that was inaccessible to avian predators while redband trout were observed higher up in the water column in the open, similar to behavior patterns previously described (Warner and Quinn 1995).

In the Crooked River, upstream passage to trout was blocked by the reconstruction of the Opal Springs hydroelectric project in 1982, leaving only a limited fluvial environment available for resident trout between the Opal Springs Dam and Lake Billy Chinook (Nehlsen 1995). As mitigation for this dam, hatchery rainbow trout (Deschutes River stock) have been liberated into the lower Crooked River since the construction of the dam (Stuart et al. 1996). The limited fluvial environment and addition of hatchery trout may have led to increased density dependant effects and/or increased straying (Quinn 1993) which, in turn, could have contributed to the amount of emigration observed of trout tagged in this area.

Based on the extensive fluvial environment available in the Deschutes River compared to the Crooked River, the least amount of movement was expected from the Deschutes population of redband trout. However, similar rates of movement of tagged fish out of both the Deschutes and Crooked arms were seen. Though movement was observed into the Deschutes, no fish identified as emigrating from other tributaries were observed on spawning grounds in this river. However, fish tagged in the Deschutes River were observed during snorkel surveys in the Crooked River during the spawning associated movement of fish captured in the Opal Springs fish ladder. The true origins of these fish, however, remain unclear. These fish may have originated in the Deschutes River or they may have originated in the Crooked River, moved into the Deschutes for some period where they were tagged, and subsequently moved back into the Crooked River to spawn.

This study inferred some direct interactions (mixing) among populations, so the lacustrine habitat of Lake Billy Chinook does not appear to be a barrier to movement among trout populations in the three tributaries. However, the degree of genetic isolation of each population could not be determined. Very few tagged fish were observed on spawning grounds and so contributions of straying trout to local gene pools could not be determined. Future genetic studies using techniques that provide higher resolution than those used in the past could provide insight into metapopulation structure, geographic patterns, genetic diversity, degree of population isolation, and patterns of gene flow among populations of redband trout in the Lake Billy Chinook system.

Acknowledgements

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References

Bartholomew, J. 1999. Fish disease risk assessment: whirling disease and ceratomyxosis, 1998 Annual report, FERC No 2030. Unpublished report. Portland General Electric, Co., Portland, Oregon.

Biette, R. M., D. P. Dodge, R. L. Hassinger and T. M. Stauffer. 1981. Life history and timing of migrations and spawning behavior of rainbow trout (*Salmo gairdneri*) populations of the Great Lakes. Canadian Journal of Fisheries Aquatic Sciences 38:1759-1771

Brewin, M. K., L. L. Stebbins, and J. S. Nelson. 1995. Differential losses of Floy® anchor tags between male and female brown trout. North American Journal of Fisheries Management 15:881-884.

Currens, K. P., A. R. Hemmingsen, R. A. French, D. V. Buchanan, C. B. Schreck, and H. W. Li. 1997. Introgression and susceptibility to disease in a wild population of rainbow trout. North American Journal of Fisheries Management 17:1065-1078.

Fies, T., M. Manion, B. Lewis, and S. Marx. 1996. Metolius River subbasin fish management plan: upper Deschutes fish district. Oregon Department of Fish and Wildlife, Portland, Oregon.

Groves, K., B. A. Shields, and A. Gonyaw. 1999. Lake Billy Chinook rainbow (redband) life history study, 1999 Annual Report, FERC No. 2030, Portland.

Hoar, W. S. 1976. Smolt transformation: evolution, behavior, and physiology. Journal of the Fisheries Research Board, Canada 33:1234-1252.

Houslet B. and M. Riehle. 1997. Inland redband trout spawning survey of the upper Metolius River subbasin. Deschutes and Ochoco National Forest Service report. Sisters, Oregon.

Korn, L., L. H. Hrena, R. G. Montagne, W. G. Mullarkey, and E. J. Wagner. 1967. The effect of small impoundments on the behavior of juvenile anadromous salmonids. Fish Commission of Oregon Research Division (now Oregon Dept. of Fish and Wildlife). Clackamas, Oregon.

Lindsey, C. C., T. G. Northcote, and G. F. Hartman. 1959. Homing of rainbow trout to inlet and outlet spawning streams at Loon Lake, British Columbia. Journal of the Fisheries Research Board of Canada 16:695-719.

Nehlsen, W. 1995 Historical salmon and steelhead runs of the Upper Deschutes River and their environments. Portland General Electric Company, Portland, OR. 65p.

Quinn, T. P. 1993 A review of homing and straying of wild and hatchery-produced salmon. Fisheries Research 18(1-2):29-44.

Raleigh, R. F. and W. J. Ebel. 1968. Effect of Brownlee Reservoir on migration of anadromous salmonids. In Proceedings of the reservoir fishery resources symposium, April 5-7, 1967, Athens, Georgia, pp. 415-443. American Fisheries Society.

Ratliff, D. E. 1983. *Ceratomyxa shasta*: Longevity, distribution, timing, and abundance of the infective stage in central Oregon. Canadian Journal of Fisheries and Aquatic Sciences 40(10):1622-1632.

Ratliff, D. E., S. L. Thiesfeld, W. G. Weber, A. M. Stuart, M. D. Riehle, and D. V. Buchanan. 1996. Distribution, life history, abundance, harvest, habitat, and limiting factors of bull trout in the Metolius River and Lake Billy Chinook, Oregon, 1983-94. Oregon Department of Fish and Wildlife Information Report No 96-7. ODFW, Portland.

Ratliff, D. E. and S. A. McCollister. 1997. Surface currents in Lake Billy Chinook during the spring of 1997. Unpublished Report. Portland General Electric Company, Portland, Oregon.

Riehle, M. and B. Houslet. 1999. Adult redband trout counts in the Metolius River during the winter of 1998-1999. Deschutes and Ochoco National Forest Service Report.

Reyes-Gavilan, F. G., R. Garrido, A. G. Nicieza, M. M. Toledo and F. Brana. 1996. Fish community variation along physical gradients in short streams of northern Spain and the disruptive effect of dams. Hydrobiologia 321:155-163.

Sakai, M. and A. Espinos. 1994. Repeat homing and migration of rainbow trout to the inlet and outlet spawning streams in a Patagonian Lake, Argentina. Fisheries Science 60(2):137-142.

Warner, E. J. and T. P. Quinn. 1995. Horizontal and vertical movements of telemetered rainbow trout (*Oncorhynchus mykiss*) in Lake Washington. Canadian Journal of Zoology 73:146-153.

Williams, R. N., R. F. Leary, and K. P. Currens. 1997. Localized genetic effects of a long-term hatchery stocking program on resident rainbow trout in the Metolius River, Oregon. North American Journal of Fisheries Management 17:1079-1093.

CHAPTER 3

Variation in Biological Characters in Sub-populations of Redband Trout (*Oncorhynchus mykiss gairdneri*) from the Main Tributaries to Lake Billy Chinook, Oregon

Kristy L. Groves and **Barbara A. Shields**

Oregon State University
Department of Fisheries and Wildlife
104 Nash Hall
Corvallis, OR 97331

Abstract

In 1964, the construction of Round Butte Dam created a large reservoir (Lake Billy Chinook) at the junctions of the Crooked, Deschutes, and Metolius Rivers. This study focused on determining if sub-populations from the three major tributaries of Lake Billy Chinook could be separated and identified based on biological characters and attempted to establish guidelines that will assist in identifying fish from these sub-populations in the future. This study confirmed the existence of three identifiable sub-populations of redband trout in this system, each associated with one of the tributary rivers. Redband trout captured in the Deschutes and Crooked Rivers were similar in morphology and in all life history characters examined, yet could be separated based on parasite assemblages. Redband trout captured upstream in the Metolius River were morphologically unique from other populations and were identified most readily using simple morphometric measurements.

Redband trout (*Oncorhynchus mykiss gairdneri*) are native to and found throughout central and eastern Oregon. Redband trout are considered a sub-species of rainbow trout based on genetic and morphological differences as well as their inherited ability to withstand higher water temperatures in arid climates (Behnke 1992). Redband trout differ from coastal rainbow trout in physical appearance (more intense coloration, retention of parr marks, larger spots, and light pigment on the tips of the ventral and dorsal fins) (Behnke 1992). Based largely on variation in coloration and spotting patterns redband trout are further divided up into several races throughout their range (Behnke 1992), with some populations known to be morphologically unique (Gold 1977). Redband and rainbow trout are also known for their variability in life history traits among watersheds or even within streams. Growth rates, condition factors, and fecundity can be highly variable and are influenced by age as well as by genetic and environmental factors. At this time, the proportion of the observed phenotypic or life history variation that is a result of environmental effects (i.e., temperature, total dissolved solids, food availability, and competition) or genetic differences is unknown.

Natural environments are mosaics of habitats affected by a variety of physical and biotic processes that operate on different spatial and temporal scales (Hansson et al. 1995; Collins and Glenn 1997). Real populations are in some sense spatially structured as the habitat is usually heterogeneous and organisms respond in some way to that environment. Assemblies of these spatially structured local or sub-populations can be termed metapopulations. The term metapopulation has been used with a variety of meanings (Hanski and Simberloff 1997) including a concept as described by Szacki (1999) in which a set of local populations is linked together by dispersing individuals, without any assumptions concerning the local population size or probabilities of extinction and recolonization. It is this definition that can be most easily applied to fisheries. Metapopulations appear to be important in the evolutionary history of trout and salmon because the small populations that occur in individual tributaries are a product of local adaptation balanced with incomplete reproductive isolation. Locally adaptive traits include homing behavior, temperature tolerance, and unique local mating behavior (National Research Council 1995). Overall metapopulation structure of trout and salmon depends on genetic variability within local populations, which, in turn, provides the framework for local adaptation within and variability among local populations (sub-populations).

In the Pacific Northwest redband trout are one of the most widely distributed native salmonids, found over a wide range of environmental conditions. Metapopulation structure of redband trout can be influenced by a variety of anthropogenic changes including stocking practices, habitat degradation, and habitat fragmentation (Williams et al. 1989). Although redband trout remain in most of their potential range, declines in abundance, reductions in distribution, and fragmentation into smaller patches are apparent (Thurow et al. 1997) possibly compromising their potential for long-term survival (Dunham et al. 1997; Reiman et al. 1997). In addition, management practices of stocking thousands of hatchery rainbow trout (Nehlsen 1995; Stuart et al. 1996) provide ample opportunities for hybridization between hatchery fish and the native redband trout and may have resulted in erosion of the original genetic diversity of resident trout populations (Behnke 1992). In addition, land and water use practices have left sections of historical spawning and rearing areas dry or with minimal flow during key periods, reducing amounts of available habitat for spawning adults and rearing of juveniles. The resulting depressed reproduction and recruitment, in turn, can decrease effective population sizes and result in a loss of genetic and life history diversity (National Research Council 1996).

In 1964, the construction of Round Butte Dam created a large reservoir (Lake Billy Chinook) at the junctions of the Crooked, Deschutes, and Metolius Rivers. The effect of the creation of Lake Billy Chinook on the native metapopulation structure of redband trout in this area is unknown because baseline population information was not determined before the construction of the dam. Possible effects of the reservoir could include reduced ecological isolation of the sub-populations in the three tributaries through mixing facilitated by the reservoir (Sakai and Espinos 1994), or it could have increased isolation due to lacustrine habitat avoidance of resident trout (Raleigh and Ebel 1968). Anecdotal observations by sport anglers have indicated avoidance of the lacustrine habitat and could indicate that the reservoir is a significant barrier to movement among redband trout populations in each tributary increasing the isolation of these sub-populations. This study focused on determining if the wild resident redband trout from the three major tributaries of Lake Billy Chinook can be distinguished based on biological characters (including life history characters, morphology, and parasite assemblages), and if so, will attempt to establish guidelines that will assist in identifying fish from any of these sub-populations in the future.

Many characters have been used to assist in stock identification of fish. These characters include life history characteristics (Filbert and Hawkins 1995; Rulifson and Dadswell 1995), meristic and morphometric characters (Rinne 1985; Salmanov et al. 1991; Mamontov and Yakhnenko 1995), and parasite faunal assemblages (Sindermann 1961; Margolis 1963; Kabata 1963; Wood et al. 1989; Moser and Hsieh 1992; Williams et al. 1992).

Many life history characters, such as growth rates, condition factors, and fecundity can be highly variable and influenced by age as well as by genetic and environmental factors (i.e., temperature, total dissolved solids, food availability, and competition) (Barton and Bidgood 1980; Gipson and Hubert 1991; Hubert and Guenther 1992; Hubert and Chamberlain 1996).

Traditional morphometric and meristic measurements include specific length, size, or count measurements recorded for each specimen. Most of these measurements concentrate in the head, tail, or fin regions of the body (i.e., snout length, caudal peduncle depth, eye diameter, etc.); (Winans 1985). Traditional morphometrics have been criticized for producing uneven and biased coverage of the entire body form (Strauss and Bookstein 1982). A more complete coverage of the body that characterizes the geometry of the fish's shape would give the highest likelihood of finding differences that have biological meaning both within and among species (Bookstein 1991). This method is different from more traditional morphometric measurements in that it uses coordinates of homologous landmarks on specimens and makes it possible to reconstruct and compare forms while maintaining their 3-dimensional properties in space.

Parasite assemblages, used as natural biological "tags", have also been used to identify discrete sub-populations of fish (Sindermann 1961; Kabata 1963; Wood et al. 1989; Moser and Hsieh 1992; Williams et al. 1992) and has been an invaluable tool in the identification of stocks of several commercially important marine and freshwater fishes (Sindermann 1961; Margolis 1963; Wood et al. 1989; Moser and Hsieh 1992). Utility of parasites as biological tags found in or on redband trout will depend on the nature of the parasite (its distribution and the complexity of its life cycle) and its means of infection of the host. The distribution of a parasite can be limited either directly or indirectly by environmental conditions interfering with the transmission of parasite to host. Harsh environmental conditions can act directly on free living larval stages of endo-parasites or may act indirectly by limiting the distributions of other essential intermediate hosts needed for the completion of the parasite's life cycle (Williams et al. 1992).

Study Area

The study area includes Lake Billy Chinook and portions of its three major tributaries (Crooked, Deschutes, and Metolius rivers) (Figure 3.1). Lake Billy

Chinook, a 1,585-ha reservoir created by the construction of Round Butte Dam on the Deschutes River in 1964, extends up the Crooked, Deschutes and Metolius canyons to a distance of 11 km, 14 km, and 21 km respectively. Anecdotal accounts of sport fishermen indicate that redband trout are not abundant in Lake Billy Chinook, except in the river-reservoir transition zones in the reaches of the upper arms where each of the three rivers enter the reservoir. The focus of this study was on these river-reservoir transition zones in addition to the lower 2 km of each river — between river kilometer (rkm) 8 and 10 in the Crooked, rkm 12 and 14 in the Deschutes, and rkm 19 and 21 in the Metolius, as measured from Round Butte Dam. In addition, the forebay area of the reservoir was also chosen as a truly lacustrine study site.

The Crooked River originates in the Ochoco Mountains and is the largest eastern tributary to the Deschutes River. Only the lower 2 km of the free-flowing river is available for use by the redband trout that inhabit Lake Billy Chinook. A diversion dam at the Opal Springs Hydroelectric Project stops upstream passage except during very high flows; however, downstream movement of trout from above the diversion dam into the reservoir is possible.

The Deschutes River originates in the Cascade Mountains southwest of Bend and flows north to Lake Billy Chinook for a distance of 212 km. Upstream

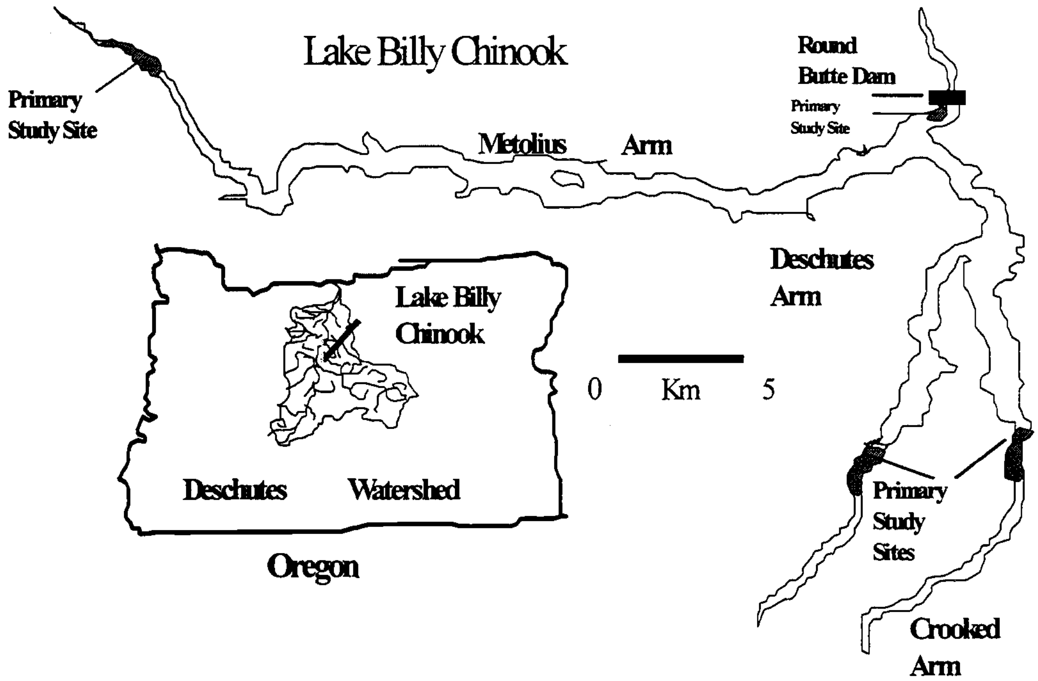


Figure 3.1. Location of primary study sites in Lake Billy Chinook, 1997-1999.

passage of redband trout is blocked on the Deschutes River by Steelhead Falls 13 km upstream of Lake Billy Chinook except during very high flows (Nehlsen 1995). Prior to the installation of a fish ladder in the 1950s, the upstream limit to all migration is Big Falls, approximately 34 km upstream of Round Butte Dam (Nielson 1950).

The Metolius River originates as a series of large springs near the base of Black Butte in the Cascade Mountains and flows for a distance of 45 km before reaching Lake Billy Chinook. Input from several spring-fed tributaries in the upper stretch of the Metolius River helps to maintain cool temperatures and stable flows throughout most of the year (Nehlsen 1995). Movement throughout this river is unhindered.

Methods

Fish collection

Floating Merwin type trap nets were set near the upper arms of Lake Billy Chinook (river-reservoir transition zone) and in the lower reservoir (forebay) near the dam during the spring and early summer of 1997 and 1999 and from winter through late summer in 1998. Trap designs used in each of the three arms of Lake Billy Chinook had a 15m x 4.5m lead net set perpendicular to shore. The pot and spiller (holding pen) each measured approximately 5m x 4m x 7m and both were surrounded by and suspended from an aluminum walkway. The Merwin type trap used in the forebay was custom built to nearly twice the dimensions of the traps used in the arms. In addition, a sinking Oneida type trap net (Korn et al. 1967) was also used in the Metolius River. Both the Merwin and Oneida traps are designed to capture fish moving laterally along the shoreline by placing lead nets set perpendicular to the shore and placed in locations that optimized chances of collecting trout moving into or out of the reservoir. Rotary screw traps designed expressively for the capture of downstream migrants were used in both the Deschutes and Metolius Rivers. Angling was also employed to capture fish in the fluvial portions of each of the three rivers.

A total of 1,636 redband trout were captured from 1997-1999. All redband trout were categorized into one of three groups: 1) fish appearing to be of hatchery origin (fin clips and/or deformed fins), 2) fish showing smolt-like characteristics (silvery, long narrow bodies, no ventral fin pigmentation, and deciduous scales); (Hoar 1976), and 3) all other fish were classified as wild resident redband trout. This wild resident group may also include descendants of hatchery trout that survived to reproduce in the wild. In order to establish guidelines that may help to identify unmarked and possibly feral hatchery trout, the morphology of known hatchery trout was analyzed and compared to that of the other two forms of trout identified. It was hoped that by characterizing a unique morphology of the known hatchery trout, unmarked and feral hatchery trout might also be identified.

Wild resident trout were further classified into groups or sub-populations based on the location of capture. Sub-populations included the Deschutes River, Crooked River, Metolius arm (all trout captured in the river-reservoir transition zone of the Metolius arm), and the Metolius River (captured by angling further upstream). All wild trout captured in the main body of the reservoir were classified as forebay trout.

From June through the end of July of each year wild redband, hatchery rainbow trout, and smolt-like trout were retained and frozen for later analysis. A total of 326 trout were retained from 1997 through 1999 for morphometric and parasite assemblage analysis (97 from the Metolius, 98 from the Deschutes, 98 from the Crooked, and 33 from the forebay). Total numbers of fish retained of each form (hatchery, wild resident, smolt-like) are shown Table 3.1.

Table 3.1. Numbers of trout retained from Lake Billy Chinook from 1997-1999 of each of three forms identified during the study. Hatchery trout were identified by fin clips, smolt-like trout were identified based on phenotypic characters (silvery coloration, long narrow bodies, no ventral fin pigmentation, and deciduous scales). All other fish were classified as wild resident trout.

	Resident	**Hatchery**	**Smolt-like**
1997	39	20	1
1998	78	31	57
1999	78	20	2
Total	195	71	60

Fish measurement and analysis

All redband trout captured and not retained were anesthetized, weighed, measured for fork length, total length, and maximum thickness, tagged, had a scale sample removed, and were allowed to recover prior to release at capture locations. Scale samples from 1,155 trout were aged by two independent readers. Additional morphometric measurements taken on 154 retained trout included maximum body depth, snout length, and minimum depth of the caudal peduncle, all standardized by fork length (traditional morphometric measurements); (Table 3.2). Condition factors were also calculated for each trout using Fulton's equation for condition factors:

$$F_c = W \times 10^5/FL^3$$

where W is the weight of the fish in grams and FL is the fork length of the fish in millimeters.

A thickness condition factor was also calculated using the equation:

$$TH_c = TH \times 10/FL$$

where TH is the maximum body thickness in millimeters measured at the lateral line and FL is the fork length of the fish in millimeters.

Table 3.2. Three traditional morphometric measurements (Hubbs and Lagler 1958) used to discriminate among forms of redband trout in Lake Billy Chinook.

Character	**Measurement**
Snout length	Front of eye to tip of snout
Caudal Peduncle Depth	Minimum caudal peduncle depth
Body Depth	Maximum body depth just anterior to dorsal fin

In addition to the traditional morphometric characters, a landmark-based geometric morphometric technique was used to examine specimens. Based on specific landmark coordinates, the non-uniform variation in shape (variation that is not geometrically uniform over the entire body) between each specimen and a 'reference' specimen (average configuration of Metolius River trout) was examined using relative warp analysis developed by Bookstein (1989, 1991).

Coordinates were recorded at 10 landmarks around the perimeter of the body of 154 trout (Figure 3.2) using an image analysis system (Optimas system, v. 5.1). The coordinates from each trout were then scaled by its centroid size, which is the square root of the sum of the squared distances between all landmarks and their centroid. These coordinates were then aligned to the same coordinate system where landmark 1 (tip of snout) was set to 0,0 and landmark 10 (fork length) was set to 1,0. This scaling and aligning was done using the program 'shape coordinates'.

The standardized coordinates were then used to calculate the partial warp scores, which express the landmarks of each trout as a deviation from the reference trout. Relative warp scores for each trout were then calculated from those partial warp scores (essentially principal components of the partial warp scores); (Fink and Zelditch 1997). The first relative warp axis was placed through the cloud of points represented by the partial warp scores in a way that maximizes the variance along that axis. The center point (zero point) of the cloud of points and of the axis represents the 'reference' specimen. The relative warp score for each trout was recorded as its distance from the reference organism along that axis. The second and subsequent axes were placed perpendicular to the preceding axes in a manner that maximized the remaining variance. Only the first nine relative warp axes explained significantly more variation than would expected by chance and so only relative warp scores from these axes were included in further analysis. The calculation of both partial warp scores and relative warp scores was done with the program TPSRW, which can be obtained at http://life.bio.sunysb.edu/morph.

In order to test the utility of morphometric characters, condition factors, and relative warp scores as stock identifiers among sub-populations of redband trout, discriminant function analysis (Statgraphics Plus, v. 3.0) was used. Discriminant function analysis allowed for discrimination among known groups by creating linear combinations of quantitative variables for fish in each group (discriminant function scores). Axes (discriminant functions) were then found that maximized the among-group variation in relation to the within-group variation using those discriminant function scores. This analysis technique provided both the ability to predict which group a new fish was most likely to fall into and to obtain a small number of useful 'predictor variables'. The contribution of each predictor variable was determined by examining the standardized discriminant function coefficients; the greater the magnitude (either positive or negative) of the coefficient, the greater the influence it has on group separation.

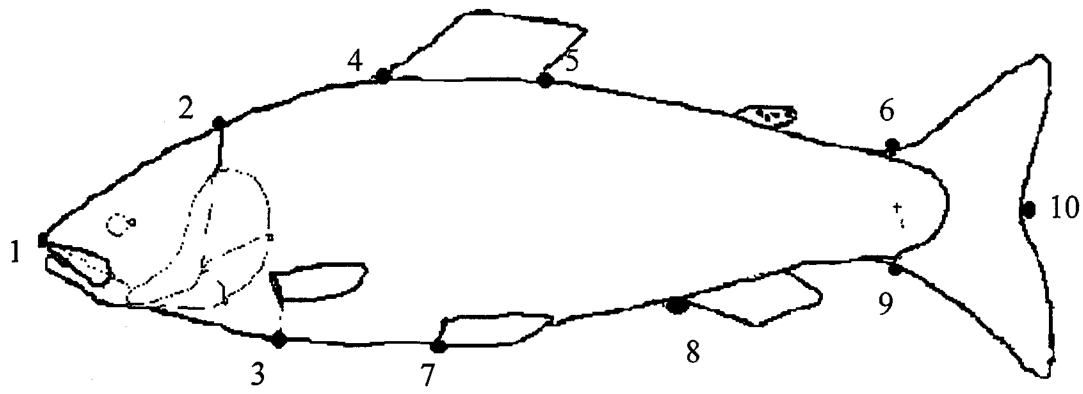


Figure 3.2. Location of landmarks around perimeter of trout used in relative warp analysis.

Average length-at-age was calculated for each wild resident population, and von Bertalanffy growth curves were constructed (Ricker 1975). Growth parameters ($L\infty$, k, and t_o) calculated from those curves were compared among populations using a likelihood method described by Kimura (1980). Fish lengths-at-age were also back-calculated for a sub-sample of fish to obtain relative growth rates for each population, calculated as millimeters of growth per year per millimeter of fish length.

Although most fish captured were immature, 12 mature fish were found among those retained for morphometric analysis and parasite assemblage analysis. The gonads from these fish were removed, weighed, and eggs were counted by hand. Sample sizes were too small to make statistical comparisons of fecundity among sub-populations, so only preliminary generalizations from these data can be made.

All fish specifically retained for parasite assemblage analysis, as well as all mortalities, were examined for both external and internal macro-parasites. To minimize the effect of seasonal variation on parasitic infection and abundance, all fish were retained between June 1 and July 31, 1998 and 1999. The total number of wild resident trout examined for parasites from each location was: 72 in the Crooked, 52 in the Deschutes, 44 in the Metolius, and 20 in the forebay. In addition, 52 trout determined to be of hatchery origin and 62 smolt-like trout were examined. All macro-parasites removed from the fish were enumerated, fixed, and stored in 70% ETOH for later staining and identification. Parasites were identified to genus when possible using a variety of taxonomic keys. Prevalence and mean intensity were then calculated for each parasite and compared among locations. Parasite abundance data were then transformed to reduce heterogeneity [($X_i = \ln(1 + X)$, where X_i is the transformed data)].

Combined data analysis

The transformed parasite abundance data were used in addition to relative warp scores and traditional morphometric measurements for further analysis. Differences in groupings among sub-populations of resident redband trout were compared using a multi-response permutation procedure (MRPP), which compares differences in within-group variation. A description of this procedure can be found in the appendix in Biondini et al. (1985). Tests for groupings were based on all morphometric characters, parasite assemblage data alone, and on combined data. Discriminant function analysis was then used to determine which set of variables were most accurate at reclassifying fish to the predetermined groups based on location of capture.

Results

General

In comparisons of the three forms of trout identified (hatchery, smolt-like, or wild resident), fish were reclassified to their original groupings 66-67% of the time when using either traditional morphometric characters or relative warp scores alone and 78% of the time when using all morphometric characters (Table 3.3).

Table 3.3. Discriminant function percent reclassification of forms of redband trout into predetermined groups (wild resident, hatchery, or smolt-like) in Lake Billy Chinook, from all collection sites.

Variables Used	**Total %**	N=52 Hatchery %	N=188 Resident %	N=62 Smolt-like %
Relative warp scores	**67**	70	65	72
Traditional morph characters	**66**	44	69	75
Relative warp + traditional morph characters	**78**	67	79	83

The most distinct of these three forms was the smolt-like trout, which was separated from hatchery and wild resident trout primarily by components of body depth, caudal peduncle length and depth, and thickness along discriminant function 1. Discriminant function 2 separated the hatchery and resident forms by components of caudal peduncle depth and thickness (Figure 3.3). Smolt-like trout were thinner, more streamlined, and had a longer, narrower caudal peduncle when compared to the other two forms. Although individuals from each form clustered in proximity to other members of that group, only the group centroid value for smolt-like trout was significantly different among groups. Because the analysis showed that the initially defined groups (wild resident, hatchery, smolt-like) were in fact distinct morphologically, trout identified as being of hatchery origin and those identified as smolt-like were excluded from subsequent analyses.

Analysis of data collected from the tagging studies on Lake Billy Chinook (Groves et al. 2000a) indicated that up to 39% of fish captured in the Metolius river-reservoir transition zone may have originated from one of the other arms of Lake Billy Chinook. Therefore, it was unclear if resident redband trout captured in this trap were true representatives of the Metolius River population. To increase the possibility of characterizing a "true" Metolius population, only redband trout captured in 1998 and 1999 by angling further upstream were used to represent this population. The following data are presented separately for Metolius trout collected in the river-reservoir transition area (Metolius trap) and for trout caught further upstream in the fluvial portion of the river (Metolius River).

Wild resident trout

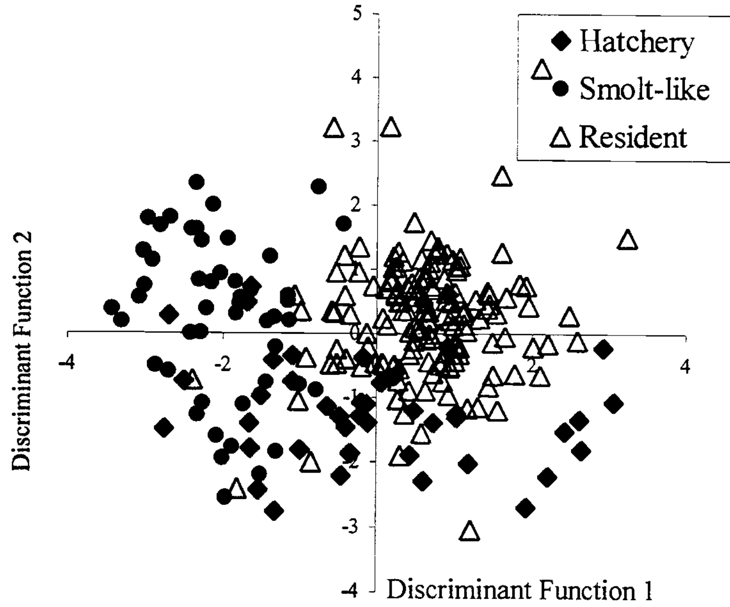
Age structures

Overall, the age structure of trout was similar among trap locations. The majority of fish captured (38 to 65 percent of fish captured at a given location) were age two in all trap locations in all years except at the forebay trap in 1998, which was characterized by a higher percentage of age three fish (Figure 3.4a-c). The second highest percentage of fish were age three at all other locations. Younger, smaller fish were not well sampled by the gear due to the mesh size used on traps. Hook and line sampling for redband trout in the Metolius River above the trap location was also biased towards larger fish and a full size range of fish were not captured so the age structures of these fish were not included in this analysis, but the majority of fish captured at that location were age two as well.

Growth

Analysis of average fork-length-at-age (mm) data for 1,155 (370 from the Crooked, 394 from the Deschutes, 131 from the forebay, 241 from the Metolius trap, 19 from the Metolius River) redband trout captured in floating traps found significant differences in length-at-age among locations for only age two and age three redband trout (p-value < 0.05, Tukey's HSD). Locations at which significant differences were observed were as follows. In 1997, age two Metolius redband trout captured in floating traps were significantly larger than age two fish from other locations, while age three redband trout from each location were significantly different in terms of length from those at other locations. In 1998, redband trout captured in the Deschutes and forebay traps were significantly different in length at age two, and age three. Metolius redband trout captured in the trap were significantly larger than age three fish captured at other locations. In 1999, no differences in length-at-age among locations were seen in age two trout; however, age three Metolius trout captured in the Merwin trap were significantly larger than age three trout from both the Deschutes and Crooked Rivers (but not the forebay). Length-at-age of trout captured by angling in the Metolius River were no different from those captured in the Crooked and Deschutes traps for age three fish and were smaller than age two fish caught at all locations.

Von Bertalanffy growth curves were constructed using average fork-length-at-age data for each location. A total number of 1,136 trout were used in this analysis (370 from the Crooked, 394 from the Deschutes, 131 from the forebay, 241 from the Metolius trap). In 1997, overall growth curves were significantly different among locations, though individual parameters ($L\infty$, k, t_0) were not. Cumulative non-significant small differences in individual parameters, when combined, led to an overall significant difference. In 1998, no significant differences were seen in growth curves among trap locations.



Standardized Coefficients

	DF1	DF2
cp depth	0.41	0.44
depth	0.58	0.20
Fulton	-0.09	-0.41
relwarp1	0.13	0.52
relwarp2	0.71	-0.58
relwarp3	-0.29	-0.36
relwarp4	0.03	0.32
relwarp5	0.14	0.28
relwarp6	-0.23	-0.25
relwarp7	-0.03	-0.01
relwarp8	-0.06	-0.18
relwarp9	-0.07	-0.06
snout	-0.28	-0.10
ThicknC	-0.30	0.32

Figure 3.3. A plot of the first two discriminant functions for separation of the three forms of redband trout captured in Lake Billy Chinook. Magnitude of the standardized coefficients (either positive or negative) indicates the importance of the variable in the separation of groups.

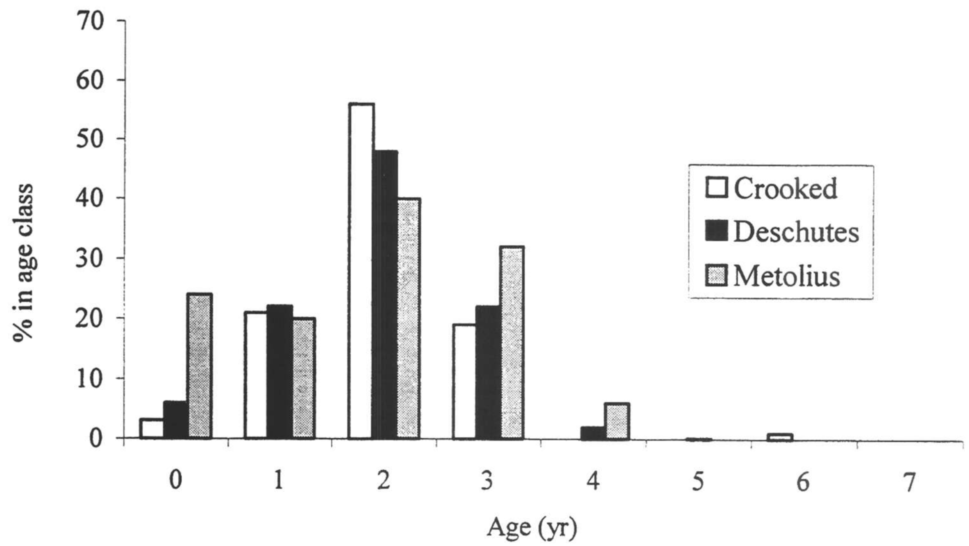


Figure 3.4a. Percent of redband trout captured in the three tributaries to Lake Billy Chinook in each age class in 1997.

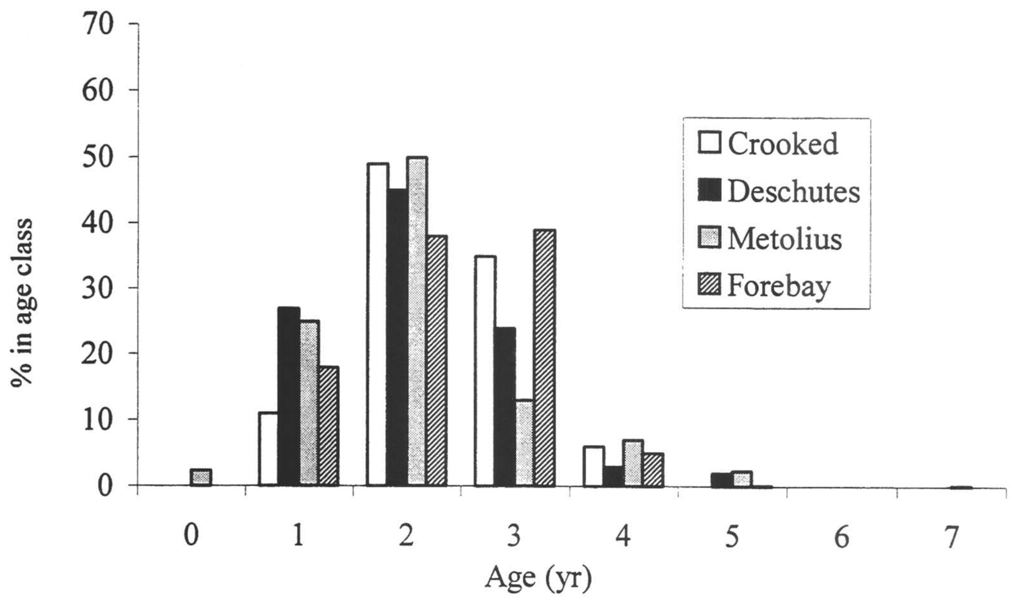


Figure 3.4b. Percent of redband trout captured in the three tributaries to Lake Billy Chinook in each age class in 1998.

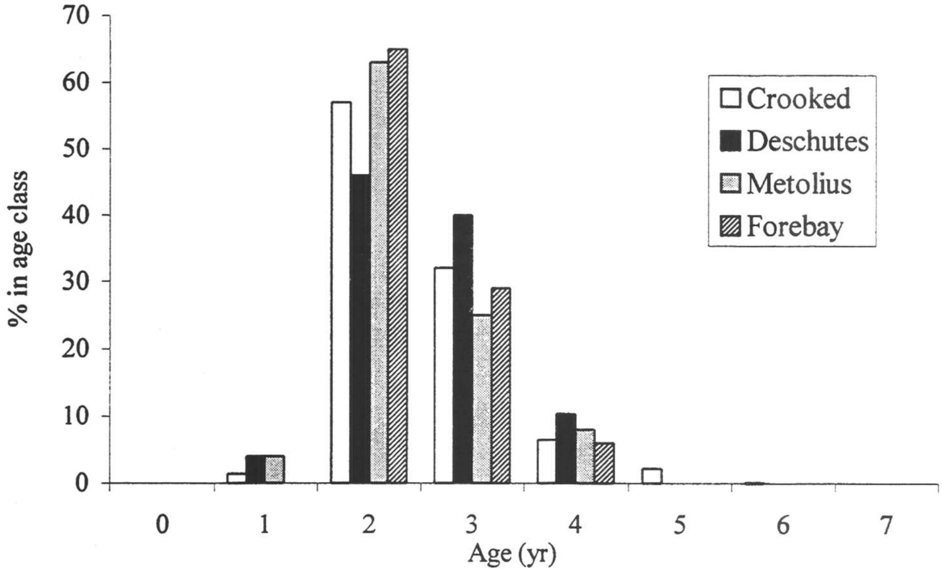


Figure 3.4c. Percent of redband trout captured in the three tributaries to Lake Billy Chinook in each age class in 1999.

In 1999, fish captured in the Crooked River trap showed a growth curve that was linear from age one to age five, which was significantly different growth curve than the other sub-populations. Based on $L_{\square}$ values from the von Bertalanffy growth curves, the redband trout captured in the Metolius River trap were expected to reach a larger maximum size than redband trout captured from other locations, except for those captured in the Crooked River in 1999. Parameters for those growth curves for all three years of data are shown in Table 3.4. Trout captured by angling in the Metolius River were excluded from this analysis because a full size range of trout was not captured from this location and a reliable growth curve could not be developed.

Relative growth rates were estimated for both back-calculated age-at-length data estimates and average fork-length-at-age data. No differences were seen in relative growth rates by age class or year class for data taken by trap location. Relative growth rates calculated for redband trout captured using hook and line in the Metolius River using length-at-age data indicated that their relative growth rates were also not different from other groups of fish.

Condition factors

Condition factors, calculated for 154 trout from all locations, were compared using an analysis of variance (ANOVA) (22 from the Crooked, 46 from the Deschutes, 15 from the forebay, 20 from the Metolius trap, 18 from the Metolius River). Significant differences were seen in both condition factors among locations. Generally, condition factors from trout captured in the forebay, Metolius trap, and Metolius arm were higher than those from trout in the Deschutes or Crooked Rivers (Table3.5).

Table 3.4. Von Bertalanffy growth parameter comparisons among sampling locations in Lake Billy Chinook, 1997-1999.

Year	Parameter	Crooked	Deschutes	Metolius	*Significance*
1997	L_{∞}	318.6	491.6	574.6	--
	k	0.37	0.20	0.17	--
	t_0	-1.42	-1.11	-1.15	--
1998	L_{∞}	438.6	403.7	481.1	--
	k	0.28	0.34	0.23	--
	t_0	-0.95	-0.61	-1.15	--
1999	L_{∞}	623.5	397.2	405.4	*
	k	0.12	0.37	0.39	*
	t_0	-1.99	-0.38	-0.36	*

* denotes significant difference among parameters ($p<.05$, Likelihood method)
$L\infty$ = maximum average predicted size, k = indication of the rate of growth, t_0 = predicted age at zero length.

No significant differences were found between the Deschutes and Crooked Rivers for either of the condition factors. In addition, no significant differences were seen for either condition factor among trout captured in the Metolius trap, Metolius River, or the forebay. However, condition factors for fish captured in both the Deschutes and Crooked Rivers were significantly different from all other locations ($p< 0.05$, Tukey's HSD).

Table 3.5. Mean condition factors calculated for trout captured in five locations in Lake Billy Chinook.

Location	Mean Thickness Condition Factor	Variance	Mean Fulton's Condition Factor	Variance
Deschutes (N=46)	1.01	0.008	1.15	0.025
Crooked (N=22)	1.02	0.005	1.15	0.028
Forebay (N=15)	1.11	0.006	1.32	0.011
Metolius trap (N=20)	1.12	0.010	1.31	0.025
Metolius River (N=18)	1.14	0.003	1.36	0.011

Fecundity

A total of 12 mature female redband trout that still retained all of their eggs were examined in1998 and 1999 (four from the Crooked, two from the Deschutes, two from the forebay, two from the Metolius trap, and two from the Metolius River). Number of eggs per female ranged from 266 to 1,438, with highest fecundities occurring in fish captured in the Merwin trap in the Metolius River. One gonad sample from the Deschutes River was not weighed and was excluded from the analysis. The number of eggs per trout was generally found to increase with increasing age (Figure 3.5).

Morphometric analysis

Based on initial groups classified by location of capture, the highest overall reclassification to initial groups (60%) was found using all morphometric variables. Percent reclassification to initial groups ranged from 35% for trout captured in the Metolius trap to 78% for trout captured by angling above the river/reservoir transitional zone in the Metolius River (Table 3.6). A plot of the first two discriminant functions generated from all morphometric data on wild resident redband trout is represented in Figure 3.6. Discriminant function one separated Metolius fish from Deschutes and Crooked river fish using components of overall body depth along with both condition factors. Discriminant function two separated Metolius River fish from Merwin trap fish by components of body and caudal peduncle depth. Individuals from each sampling location clustered in proximity to one another; however, there were no significant differences found among discriminant function's group centroids (p-value > 0.05, Scheffe's Multiple Comparison). All points plotted for fish captured while angling in the Metolius River showed little overlap with scores for redband trout from other locations, except for the Metolius Merwin trap, indicating the body shape of this group separates them from the Deschutes and Crooked River groups.

The initial forebay classification was removed from the data set to predict the most likely origin of those fish. The majority of the fish were classified as Metolius trap fish (60% Metolius trap, 13% Deschutes, 0% Crooked, and 20% Metolius River).

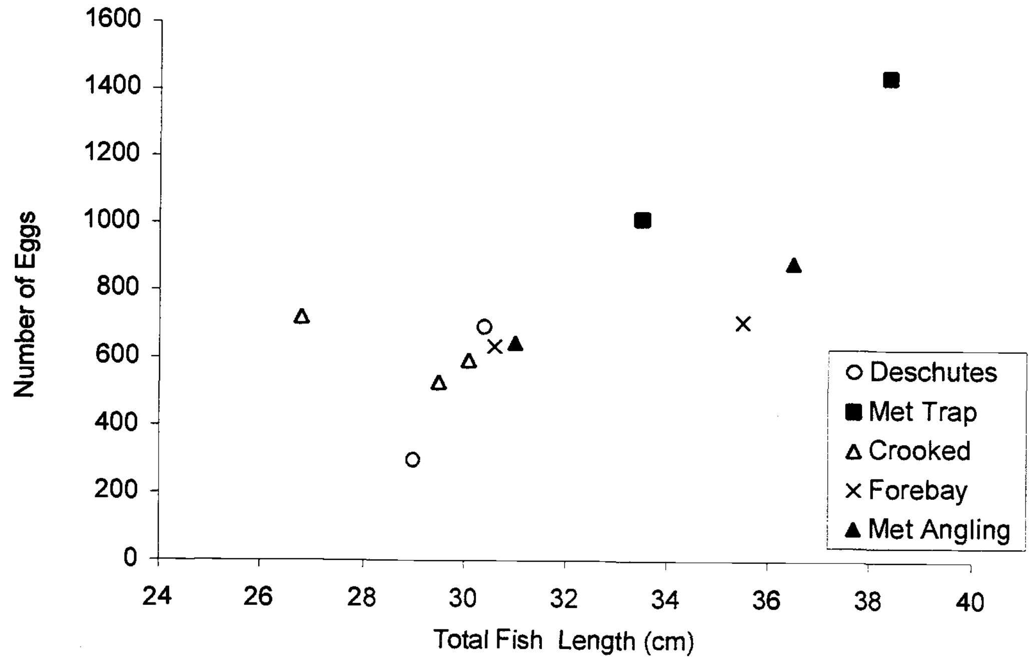
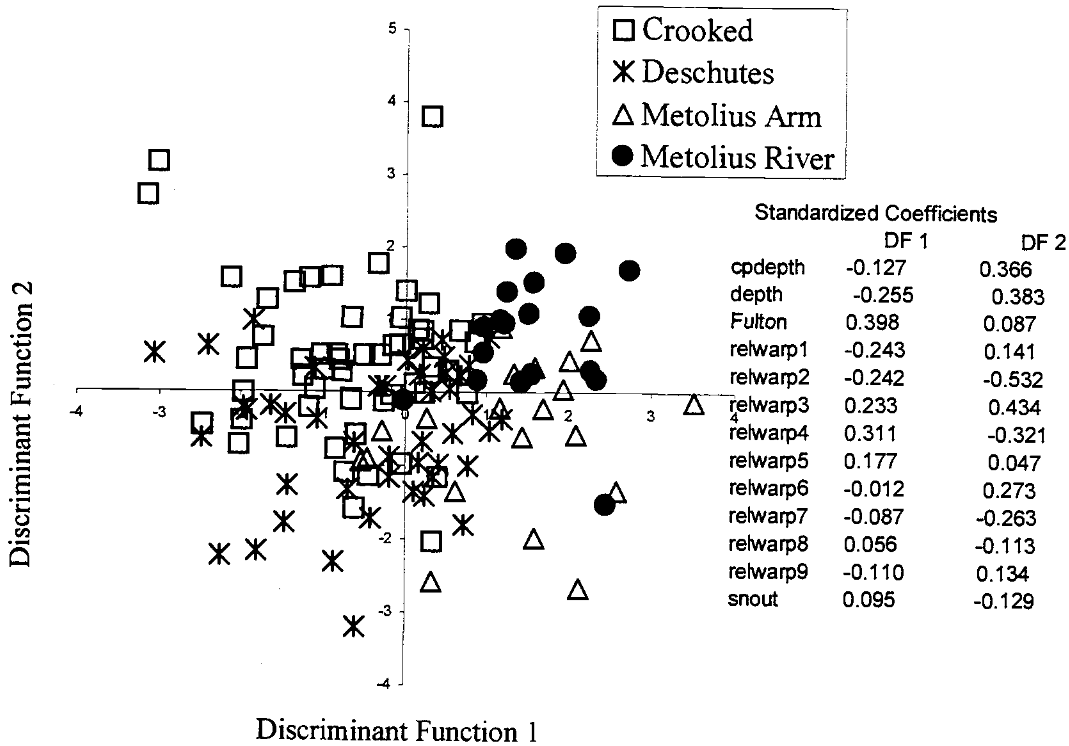


Figure 3.5. Relationship between number of eggs and total length for mature females captured in the three arms of Lake Billy Chinook, 1998 and 1999.



Standardized Coefficients

	DF 1	DF 2
cpdepth	-0.127	0.366
depth	-0.255	0.383
Fulton	0.398	0.087
relwarp1	-0.243	0.141
relwarp2	-0.242	-0.532
relwarp3	0.233	0.434
relwarp4	0.311	-0.321
relwarp5	0.177	0.047
relwarp6	-0.012	0.273
relwarp7	-0.087	-0.263
relwarp8	0.056	-0.113
relwarp9	-0.110	0.134
snout	0.095	-0.129

Figure 3.6. Plot of the first two discriminant functions in the separation of wild resident trout from each of the capture locations in Lake Billy Chinook and its major tributaries using morphological characters.

Table 3.6. Percent group reclassification of wild resident redband trout from discriminant function analysis. Numbers shown are the percent reclassification of wild resident trout into groups based on initial capture locations in Lake Billy Chinook.

Variables Used	**Deschutes**	**Crooked**	**Metolius Trap**	**Metolius River**	**Total**
Traditional morph characters	43.5	56.4	35.0	77.8	51.8
% forebay classification	13.3	7.0	53.3	26.7	
Relative warp scores	45.7	40.0	55.0	61.1	46.8
% forebay classification	26.7	13	40	20	
Relative warp + traditional morph characters	50.0	60.0	65.0	83.3	60.4
% forebay classification	**13.3**	**0**	**66.7**	**20.0**	

Parasite assemblage analysis

Seven parasite genera were commonly found in redband trout from the four sampling locations in Lake Billy Chinook in both 1998 and 1999 (Figure 3.7). Prevalence and mean intensity of the seven genera found during each year of the study can be found in Appendix 1. Two of these genera (*Neoechinorhynchus* sp. and *Crepidostomum* sp.) were not suitable for use as biological tags because they were found in very low prevalence.

Two of the parasites, *Cystidicoloides* sp., and *Cucullanus* sp. (stomach and intestinal nematodes, respectively) were found together almost exclusively in the Deschutes population of redband trout and could be used to identify members of this population. The highest prevalence of these parasites alone or in combination occurred in redband trout captured in the Deschutes River, followed closely by those captured in the forebay area of the reservoir (originally part of the Deschutes River prior to construction of the dam).

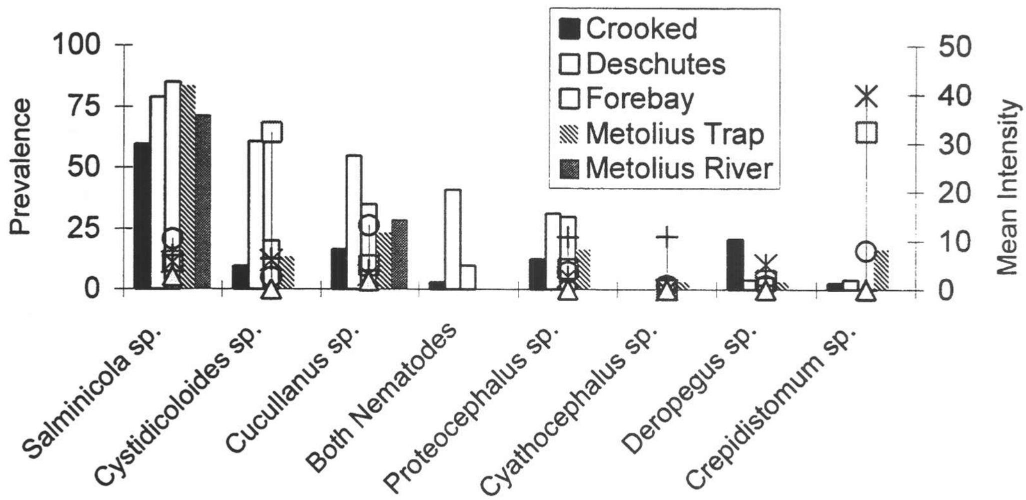


Figure 3.7. Prevalence and mean intensity of seven parasites commonly found in redband trout in Lake Billy Chinook. Prevalence is indicated by the bars, while mean intensity is indicated by the symbols. □– Deschutes, X– Crooked trout, +- Forebay, □- Metolius trap, and □- Metolius River.

Proteocephalus sp. (intestinal tapeworm) was found in a higher prevalence in the Deschutes River in both 1998 and 1999 than any other location. However, mean intensities were variable among locations and between years, so this parasite was not an effective biological tag for this population.

Deropegus sp. (stomach trematode) was more commonly found in the Crooked River population but not at a high enough prevalence to unquestionably identify all members of this population.

Salminicola sp. (parasitic copepod) was found on the majority of fish at all locations, with a higher prevalence generally found on Deschutes River and forebay fish. It was found at a higher mean intensity on Metolius River fish in both 1998 and 1999 although not significantly higher than other locations.

These remaining five genera of parasites at least partially fulfilled the criteria for suitable biological tags and were subjected to a discriminant function analysis to test the utility of using these parasites as stock identifiers. Discriminant function analysis of the parasite data revealed that Deschutes River fish could be reclassified to location of initial capture only 50% of the time, Metolius trap fish 75% of the time, Metolius River fish 72% of the time, and the Crooked River fish less than 30% of the time.

Combined analysis

The multi-response permutation procedure (MRPP) revealed significant differences between within-group variances for all sets of variables (Table 3.7). Discriminant function analysis revealed that the highest total percent reclassification to initial groups was found using all variables (morphometric and parasite assemblage data) (Figure 3.8). Though all variables were chosen as the best overall model for reclassification at all locations, fewer variables resulted in higher percent reclassifications for individual locations. For example, Metolius River trout could be reclassified at a higher percentage using only the morphometric data.

Table 3.7. Multi-response permutation procedure results from comparison of within-group variances.

Grouping Variables	Average within group distance				A-statistic	p-value
	C*	**D**	**MT**	**MR**		
Traditional morph. Characters	0.22	0.22	0.22	0.14	0.130	0.000
Relative warp values	0.46	0.46	0.51	0.29	0.015	0.007
All morph characters	0.22	0.22	0.22	0.13	0.130	0.000
Parasites	1.88	2.78	1.79	1.22	0.090	0.000
All morph + Parasites	1.92	2.8	1.82	1.23	0.091	0.000

* (C) Crooked *N*=55, (D) Deschutes *N*=46, (MT) Metolius trap *N*=20, (MR) Metolius River *N*=18.

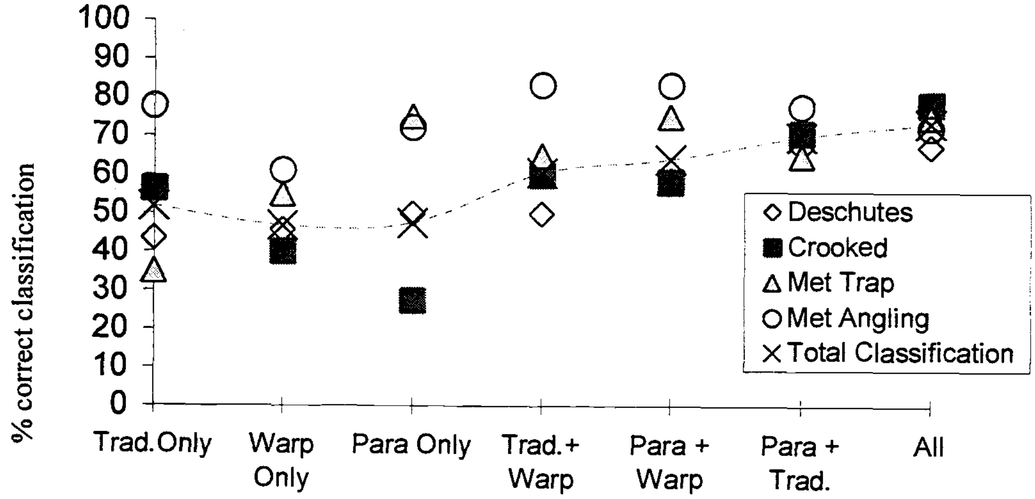


Figure 3.8. Individual and total percent reclassification to original groupings from discriminant function analysis using a variety of variable combinations. Trad. =5 traditional morphometric characters, Warp = Relative warp scores, Para = Parasites community abundance data.

Discussion

Discriminant analysis of morphometric characters revealed that there was justification for the separation of the fish into the preliminary groupings (wild resident trout, hatchery, or smolt-like). Although trout of known hatchery origin could be reclassified to that original grouping approximately 67% of the time, there was still a great deal of overlap in morphological characters with both the smolt-like and wild resident groups. This variability in the shape of this group of fish is most likely due to the variable environments in the multiple hatcheries where these fish were reared prior to release and the variable conditions found in the natural environments where these trout were released. The lack of a unique body shape for known hatchery trout did not allow for conclusive identification of unmarked hatchery or feral hatchery trout that may have been included in the wild resident grouping.

Discriminant function analysis was less conclusive for separation of wild resident populations. Trout captured by angling in the Metolius River were quite distinct in body shape, and tended to be heavier and thicker for a given length than other wild resident trout. Morphologically, redband trout from the Deschutes and Crooked Rivers were very similar. The basis for the observed morphological similarities or differences may be genetic factors, environmental factors or both. Since very few tagged fish were observed on spawning grounds and very little genetic information is available for these populations of redband trout genetic differences among populations cannot be addressed here.

The majority of fish used in the morphometric analysis were similar to the sizes of fish observed on spawning runs and on spawning grounds in both the Deschutes and Crooked Rivers and so those analyzed were likely close to sexual maturity. Relative size of body parts typically changes much more rapidly in young fish and seldom occurs after sexual maturity (Barlow 1961) so similarities in age structures among the sampled populations reduce the likelihood of phenotypic differences caused by allometric growth and suggests true morphological differences.

The stable environmental conditions in the Metolius River may be a factor in the distinct body shape of these resident Metolius trout. The Deschutes and Crooked Rivers experience significantly wider seasonal ranges of temperatures and discharge levels, while the Metolius River (a spring-brook system) remains relatively stable with low temperatures and high velocities year-round. Trout rearing in colder water tend to grow slower and attain larger body sizes than fish from warmer waters (Barlow 1961). In addition, fish from streams with higher velocities tend to be more streamlined (Barlow 1961; Karakousis et al. 1991).

Only 60% of the fish in the Crooked River and only half of the fish in the Deschutes River could be classified correctly to location of initial capture based on morphometric data alone. The majority of the incorrect classifications misidentified Crooked River trout as being from the Deschutes River, and vice versa. Overlap in the range of body shape between the Crooked and Deschutes sub-populations may be due to the variability in the local environments leading to greater variability in the morphological characters of each of the populations. This in turn would decrease the likelihood of finding unique morphological characters for each sub-population.

Another possibility is that the morphological similarities may be explained by the frequency of movement between these sub-populations that has been documented with tagging studies (Groves et al. 2000a) leading to one large homogenous population or two local populations connected via high migration rates. However, evidence collected on the parasite fauna indicates that this is not the case and that populations of trout from the Deschutes and Crooked Rivers are not a homogenous population.

Differences in parasite assemblages are best understood in terms of the ecology of the parasite, intermediate host(s), and final host that determine the risk of infection for each population. *Cystidicoloides sp.* (syn. *Metabronema*), one of the parasites found in the Deschutes River, has been studied in other parts of its range. These studies have found infective stages in intermediate hosts (mayfly nymphs) throughout the year but mature females, requiring a minimum of 1-3 months to reach maturity depending on water temperature, are not observed until June and July (Aho and Kennedy 1984, 1987). Since eggs are shed well into the fall, these nematodes would be present in their host a minimum of three months to over a year depending on the time of the year they became infected.

The intermediate host for *Cucullanus sp.*, also a nematode found in the Deschutes River, is unknown in North America but new infections of this parasite are also found throughout the year. This parasite also matures much more slowly in trout than *Cystidicoloides* and mature females are found both in early summer and late fall (Moravec 1979, 1980). It would be expected then that the duration of this parasite in its host would possibly be longer than that of *Cystidicoloides*. Based on the possibility of picking up either of these parasites year round and the length of time either one of these parasites could be found in a host, it would be expected that a single large continuously intermixing population of hosts would have a more uniform parasite assemblage with few discernable differences among locations.

Fish captured in the forebay trap and the majority of fish captured in the Metolius Merwin trap had a similar body shape. There was also a consistent difference in length-at-age data and growth rates for those fish captured in the Metolius trap. Typically, rainbow trout residing or spending a significant portion of their lives in lakes are larger for a given age than resident trout found in flowing water (Simpkins and Hubert 1996). Fecundities from trout captured in the Metolius Merwin trap were also more similar to that reported from steelhead and lake-dwelling rainbow trout (DuBois et al. 1989; Behnke 1992). Because redband trout captured in the forebay and those captured in the Metolius Merwin trap must have originated from one of the sub-populations above the reservoir, and because these fish appear physically different from those in the Metolius River, the unique morphological and life history characters may be a consequence of the influence of the lacustrine environment on phenotype. The differences between trout captured in the forebay and Metolius trap and all other locations may signify a different life history type of redband trout in this system. The possibility of resident redband trout developing an adfluvial life history in response to the construction of the reservoir is discussed further in Groves et al. (2000c).

Documentation of differences in biological characters (morphology, fecundity, and rates of growth), as well as differences in parasite faunal assemblages, has provided evidence that some degree of isolation exists among the wild redband trout populations found in the tributaries to Lake Billy Chinook. Redband trout captured by angling in the Metolius River displayed unique phenotypic characters and may constitute a distinct population, although it is not known whether this difference in body shape is a product of heredity, the environment, or both.

The degree of accuracy in predicting location-of-origin for an individual trout changes with the variables included in the analysis (traditional morphometric, relative warp scores, parasites faunal assemblages). Morphological characters alone can differentiate the Metolius River population due to their unique morphology. Using only five traditional morphological characters, members of this population can be reclassified correctly to their original grouping 78% of the time. Separation along the discriminant functions for this population was primarily based on Fulton's condition factor, a thickness condition factor, and depth of the caudal peduncle, measurements that can all be made in the field without the need to sacrifice any fish.

The Deschutes and Crooked River populations of redband trout were morphologically similar, so additional variables were needed to identify these populations. The addition of parasite faunal data into the analysis greatly improved the capacity to identify these populations. This was primarily due to the unique combination of two nematodes that was found almost exclusively in the Deschutes River population of redband trout. Although parasite data alone were not significant enough to identify the Deschutes population, it was more useful than morphological characters and was much stronger when combined with morphological characters.

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References

Aho, J. M. and C. R. Kennedy. 1984. Seasonal population dynamics of the nematode *Cystidicoloides tenuissima* (Zeder) from the River Swincombe, England. Journal of Fish Biology 25:473-489.

Aho, J. M. and C. R. Kennedy. 1987. Circulation pattern and transmission dynamics of the supra-population of the nematode *Cystidicoloides tenuissima* (Zeder) in the River Swincombe, England. Journal of Fish Biology 31:123-141.

Barlow, G. W. 1961. Causes and significance of morphological variation in fishes. Systematic Zoology 10: 105-117.

Bartholomew, J. 1999. Fish disease risk assessment: whirling disease and ceratomyxosis, 1998 Annual report, FERC No 2030. Unpublished report. Portland General Electric, Co., Portland, Oregon.

Barton, B. A. and B. F. Bidgood. 1980. Competitive feeding habits of rainbow trout, white sucker and longnose sucker in Paine Lake, Alberta. Fisheries Report 16, Alberta Energy and Natural Resources, Calgary.

Behnke, R. J. 1992. Native trout of western North America. American Fisheries Society Monographs; No. 6. 275p.

Biondini, M. E., C. D. Bonham, and E. F. Redente. 1985. Secondary successional patterns in a sagebrush (*Artemisia tridentate*) community as they relate to soil disturbance and soil biological activity. Vegetation 60:25-36.

Bookstein, F. L. 1991. Morphometric tools for landmark data: geometry and biology. Cambridge University Press, New York.

Collins, S. L. and S. M. Glenn. 1997. Effects of organismal and distance scaling on analysis of species distribution and abundance. Ecological Applications 7:543-551.

Currens, K. P., C. S. Sharpe, R. Hjort, C. B. Schreck, and H. W. Li. 1989. Effects of different feeding regimes on the morphometrics of chinook salmon (*Oncorhynchus tshawytscha*) and rainbow trout (*O. mykiss*). Copeia 1989(3):689-695.

Downs, C. C., R. G. White, and B. B. Shepard. 1997. Age at sexual maturity, sex ratio, fecundity, and longevity of isolated headwater populations of Westslope cutthroat trout. North American Journal of Fisheries Management 17: 85-92.

DuBois, R. B., S. D. Plaster, and P. W. Rasmussen. 1989. Fecundity of spring- and fall-run steelhead from two western Lake Superior tributaries. Transactions of the American Fisheries Society 118: 311-316.

Filbert, R. B. and C. P. Hawkins. 1995. Variation in condition of rainbow trout in relation to food, temperature, and individual length in the Green River, Utah. Transactions of the American Fisheries Society 124:824-835.

Fink, W. L. and M. L. Zelditch. 1997. Shape analysis and taxonomic status of *Pygocentrus* piranhas (Ostariophysi, Characiformes) from the Paraguay and Paraná River basins of South America. Copeia 1997(1):179-182.

Gipson, R. D. and W. A. Hubert. 1991. Factors influencing the body condition of rainbow trout in small Wyoming reservoirs. Journal of Freshwater Ecology 6:327-334.

Gold, J. R. 1977. Systematics of western North American trout (*Salmo*) with notes on the redband trout of Sheephaven Creek, California. Canadian Journal of Zoology 55:1858-1873.

Groves, K., B. A. Shields. 2000a. Movement and mixing among three sub-populations of redband trout in the tributaries to Lake Billy Chinook, Oregon.

Groves, K., B. A. Shields. 2000c. To migrate or residualize: the fate of steelhead above Round Butte Dam.

Hanski, I. And D. Simberloff. 1997. The metapopulation approach, its history, conceptual domain and application to conservation. Pgs. 5-26 *in* I. Hanski and M. Gilpin, editors. Metapopulation biology: ecology, genetics, and evolution. Academic Press. London, UK.

Hansson, L., L. Fahrig, and G. Merriam, editors. 1995. Mosaic landscapes and ecological processes. Chapman and Hall. New York.

Hoar, W. S. 1976. Smolt transformation: evolution, behavior, and physiology. Journal of the Fisheries Research Board, Canada 33:1234-1252.

Hubbs, C. L. and K. F. Lagler. 1958. Fishes of the Great Lakes region. The University of Michigan Press, Ann Arbor, MI. 213pp.

Hubert, W. A. and C. B. Chamberlain. 1996. Environmental gradients affect rainbow trout populations among lakes and reservoirs in Wyoming. Transactions of the American Fisheries Society 125:925-932

Hubert, W. A. and P. M. Guenther. 1992. Non-salmonid fishes and morphoedaphic features affect abundance of trouts in Wyoming reservoirs. Northwest Science 66(4):224-228.

Kabata, Z. 1963. Parasites as biological tags. ICNAF Special Publication 4(6):31-37.

Karakousis, Y., C. Triantaphyllidis, and P. S. Economidis. 1991. Morphological variability among seven populations of brown trout, *Salmo trutta* L., in Greece. Journal of Fish Biology 38:807-817.

Kimura, D. K. 1980. Likelihood methods for the Von Bertalanffy growth curve. Fishery Bulletin 77(4):765-776.

Korn, L., L. H. Hrena, R. G. Montagne, W. G. Mullarkey, and E. J. Wagner. 1967. The effect of small impoundments on the behavior of juvenile anadromous salmonids. Fish Commission of Oregon Research Division (now Oregon Dept. of Fish and Wildlife). Clackamas, Oregon.

Mamontov, A. M. and V. M. Yakhnenko. 1995. Morphological, genetic, and biochemical estimate of population differentiation of Lake Baikal whitefish, *Coregonus lavaretus pidschian* (Coregonidae). Journal of Ichthyology 35(5):136-146.

Margolis, L. 1963. Parasites as indicators of the geographical origin of sockeye salmon, *Oncorhynchus nerka* (Wallbaum), occurring in the north Pacific and adjacent seas. Bulletin of the International North Pacific Fisheries Commission 11:101-156.

Moravec, F. 1979. Observations on the development of *Cucullanus* (Truttaedacnitis) *truttae* (Fabricius, 1794) (Nematoda: Cucullanidae). Folia Parasitologica 26:295-307.

Moravec, F. 1980. Biology of *Cucullanus truttae* (Nematoda) in a trout stream. Folia Parasitologica 27:217-226.

Moser, M. and J. Hsieh. 1992. Biological tags for stock separation in Pacific herring *Clupea harengus pallasi* in California. Journal of Parasitology 78(1):54-60.

Nehlsen, W. 1995. Historical salmon and steelhead runs of the Upper Deschutes River and their environments. Portland General Electric Company, Portland, OR. 65p.

Raleigh, R. F. and W. J. Ebel. 1968. Effect of Brownlee Reservoir on migration of anadromous salmonids. *In* Proceedings of the reservoir fishery resources symposium, April 5-7, 1967, Athens, Georgia, pp. 415-443. Am. Fish. Soc.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board, Bulletin 191, 382p.

Rinne, J. N. 1985. Variation in Apache trout populations in the White Mountains, Arizona. North American Journal of Fisheries Management 5:146-158.

Rulifson, R. A. and M. J. Dadswell. 1995. Life history and population characteristics of striped bass in Atlantic Canada. Transactions of the American Fisheries Society 124:477-507.

Sakai, M. and A. Espinos. 1994. Repeat homing and migration of rainbow trout to the inlet and outlet spawning streams in a Patagonian Lake, Argentina. Fisheries Science 60(2):137-142.

Salmanov, A. V., N. S. Rostova, and Y. A. Dorofeyeva. 1991. Morphometric features of the Amu Darya trout (*Salmo trutta oxianus*, Salmonidae). Journal of Ichthyology 31(6):58-79.

Simpkins, D. G. and W. A. Hubert. 1996. Proposed revision of the standard weight equation for rainbow trout. Journal of Freshwater Ecology 11(3):319-325.

Sindermann, C. J. 1961. Parasite tags for marine fish. Journal of Wildlife Management. 25(1):41-47.

Strauss, R. E., and F. L. Bookstein. 1982. The truss: body form reconstruction in morphometrics. Systematic Zoology 31:113-135.

Szacki, J. 1999. Spatially structured populations: how much do they match the classic metapopulation concept? Landscape Ecology 14:369-379.

Whitaker, D. J., and G. A. McFarlane. 1997. Identification of sablefish, *Anoplopoma fimbria* (Pallas, 1811), stocks from seamounts off the Canadian Pacific Coast using parasites as biological tags. NOAA Technical Report NMFS 130:131-136.

Williams, H. H., K. MacKenzie and A. M. McCarthy. 1992. Parasites as biological indicators of the population biology, migrations, diet, and phylogenetics of fish. Reviews in Fish Biology and Fisheries 2:144-176.

Winans, G. A. 1985. Using morphometric and meristic characters for identifying stocks of fish. In Proceedings of the stock identification workshop 1985, Panama City, Florida. NOAA Technical Memorandum NMFS-SEFC 199:25-62.

Winans, G. A. and R. S. Nishioka. 1987. A multivariate description of change in body shape of coho salmon (Oncorhynchus kisutch) during smoltification. Aquaculture 66:235-245.

Wood, C. C., D. T. Rutherford and S. McKinnell. 1989. Identification of sockeye salmon (*Oncorhynchus nerka*) stocks in mixed-stock fisheries in British Columbia and southeast Alaska using biological markers. Canadian Journal of Fisheries and Aquatic Sciences 46:2108-2128.

APPENDIX

Appendix. Prevalence, mean intensity and range of the most common parasites found in redband trout in Lake Billy Chinook, 1998-1999.

	Species	Prevalence	Mean Intensity	Range
Crooked 98	*Salminicola sp.*	58.5	4.17	0-13
	Cystidicoloides sp.	9.76	4.75	0-15
	Cucullanus sp.	14.63	2.5	0-5
	Proteocephalus sp.	9.75	3.5	0-8
	Deropegus sp.	24.39	6.6	0-36
	Crepidostomum sp.	2.44	79	0-79
	Neoechinorhynchus sp.	2.44	2	0-2
Deschutes 98	*Salminicola sp.*	81.82	3.83	0-18
	Cystidicoloides sp.	59.09	39	0-326
	Cucullanus sp.	63.64	5.36	0-14
	Proteocephalus sp.	40.9	5.55	0-16
	Deropegus sp.	9.09	2	0-3
	Crepidostomum sp.	4.54	26	0-26
	Neoechinorhynchus sp.	4.54	2	0-2
Metolius 98	*Salminicola sp.*	82.76	9.83	0-28
	Cystidicoloides sp.	13.79	2.5	0-5
	Cucullanus sp.	24.14	13.29	0-85
	Proteocephalus sp.	17.24	3.8	0-11
	Deropegus sp.	3.45	1	0-1
	Crepidostomum sp.	17.24	8.2	0-14
Forebay 98	*Salminicola sp.*	81.25	6.08	0-18
	Cystidicoloides sp.	12.5	7.5	0-13
	Cucullanus sp.	31.26	3.8	0-10
	Proteocephalus sp.	37.6	10.83	0-41
	Deropegus sp.	6.25	1	0-1
	Crepidostomum sp.	0	0	0
Crooked - 99	*Salminicola sp.*	61.29	7.42	0-24
	Cystidicoloides sp.	9.68	7.67	0-18
	Cucullanus sp.	19.35	3.33	0-6
	Proteocephalus sp.	16.13	2	0-3
	Deropegus sp.	16.13	2.60	0-6
	Crepidistomum sp.	3.23	1	0-1
Deschutes - 99	*Salminicola sp.*	77.42	7.67	0-20
	Cystidicoloides sp.	60	27.28	0-146
	Cucullanus sp.	46.67	4.50	0-13
	Proteocephalus sp.	23.33	2.71	0-5
	Deropegus sp.	0	0	
	Crepidistomum sp.	3.33	39	0-39
Metolius - 99	*Salminicola sp.*	75	12.50	0-26
	Cystidicoloides sp.	6.25	9.25	0-3
	Cucullanus sp.	25	8	0-3
	Proteocephalus sp.	0	0	
	Deropegus sp.	6.25	7.25	0-1

Appendix. continued.

	Crepidistomum sp.	0	0	
Forebay - 99	*Salminicola sp.*	100	10	3-27
	Cystidicoloides sp.	50	5	0-6
	Cucullanus sp.	50	4	0-4
	Proteocephalus sp.	0	0	
	Deropegus sp.	0	0	
	Crepidistomum sp.	0	0	

CHAPTER 4

To Migrate or Residualize: The Fate of Steelhead above Round Butte Dam.

Kristy L. Groves and **Barbara A. Shields**

Oregon State University
Department of Fisheries and Wildlife
104 Nash Hall
Corvallis, OR 97331

Abstract

Redband and rainbow trout (*Onchorhynchus mykiss sub spp.*) can be divided into two general life history forms, resident fish (remain in streams until they mature) and steelhead (migratory fish that have an anadromous or adfluvial life history). Steelhead can usually be differentiated from resident fish by differences in physical appearance and behavior. Steelhead trout typically migrate out to a larger body of water around age two and then undergo a process of smoltification, which entails some physiological changes along with changes in coloration and morphology. Non-anadromous adfluvial rainbow trout however do not undergo this process of smoltification. Due to the construction of Round Butte Dam on the Deschutes River system in central Oregon, a population of summer steelhead was trapped above the dam. The fate of this population remains unknown. Differences in morphology, growth, movement patterns, fecundity and disease and parasites are presented here that suggest the possible continued persistence of a native, landlocked population of steelhead above Round Butte Dam.

Redband and rainbow trout (*Onchorhynchus mykiss spp.*) can be categorized into general life history forms, resident fish (remain in streams until they mature), adfluvial trout, and anadromous steelhead (Northcote 1992). Adfluvial trout migrate from upstream spawning and initial rearing areas downstream to a freshwater lake to reside for a significant portion of their life. Anadromous steelhead, on the other hand, migrate from upstream spawning and initial rearing areas downstream to the ocean to reside for a significant portion of their life. Steelhead typically migrate out to a larger body of water around age two when approximately 6-10 inches long. During this migration, steelhead undergo a process of smoltification, which entails physiological changes, including changes in coloration and morphology, and changes in behavior. Smolts become silvery with an elongated caudal peduncle (Hoar 1976). As adults, steelhead or adfluvial fish can usually be differentiated from resident fish by differences in physical appearance. Steelhead or migratory redband trout typically reach a larger maximum size than resident stream dwelling fish (Gross 1987), while resident redband trout normally retain parr marks into adulthood (Behnke 1992).

When a population of steelhead becomes landlocked, the question of interest is what happens to them behaviorally and physiologically. Do these fish still migrate and continue to undergo the process of smoltification? Pacific Coast steelhead have been stocked into tributaries of the Great Lakes since the 1800s and have developed naturally reproducing populations (Biette et al. 1981). These naturalized steelhead have retained the migratory life history patterns of their

Pacific Coast ancestors (Biette et al. 1981). Juvenile steelhead in the Great Lakes undergo the physiological and morphological changes associated with smoltification and typically migrate to the lake in spring at ages 1-3.

Another population of landlocked steelhead found in the Upper San Leandro Reservoir in northern central California has also retained its migratory behavior. The construction of an impassible dam, Upper San Leandro Dam, has effectively blocked the ocean migration of these steelhead since the late 1800s (Gall et al. 1990). The adult trout migrate out of the reservoir to spawn in the tributaries in the spring. After rearing for 1-2 years in the streams, juveniles then migrate back to the lake. This behavior suggested that these fish are descendants of anadromous steelhead trapped behind the Upper San Leandro Dam (Gall et al. 1990). Further genetic analysis of these fish indicated that they were more genetically similar to coastal steelhead than to any other population and have most likely not hybridized with domestic resident trout (Gall et al. 1990).

In the Deschutes River system, summer-run anadromous redband trout (steelhead) were historically present in the Deschutes (Squaw Creek) and Crooked Rivers, but not confirmed from the Metolius River (Nehlsen 1995). In 1964, the construction of Round Butte Dam created a large reservoir (Lake Billy Chinook) at the junctions of the Crooked, Deschutes, and Metolius rivers. Anadromous fish were transported across Round Butte dam until 1968, when transport was terminated due to inadequate collection of juvenile fish at the dam. The last survey for spawning steelhead in the Deschutes River or Squaw Creek was in 1966

(Nehlsen 1995). Initial work on the migration patterns of juvenile steelhead and salmon above Round Butte Dam by Korn et al. (1967) indicated that populations of both steelhead and salmon were present and attempting to migrate downstream past the dam just prior to the decision to halt fish passage across the dam. The fate of those steelhead trapped above the dam is unknown.

The purpose of this report is to examine the evidence collected during a life history study of resident redband trout in Lake Billy Chinook suggesting the existence of an adfluvial life history type, possibly remnants of a native steelhead population, above Round Butte Dam. Pertinent results and evidence will be presented here from a study on mixing and movement and a study of variation in biological characters of the sub-populations of resident redband trout from Lake Billy Chinook (Groves and Shields 2000a, b).

Study area

The study area includes Lake Billy Chinook, a 1,585-ha reservoir created by the construction of Round Butte Dam on the Deschutes River in 1964, and portions of its three major tributaries (Crooked, Deschutes, and Metolius rivers); (Figure 4.1). A detailed description of the study area can be found in Groves and Shields (2000a).

Historically steelhead were observed in the Crooked River as far upstream as 200 km from the mouth (Nehlsen 1995). No reports of steelhead spawning in

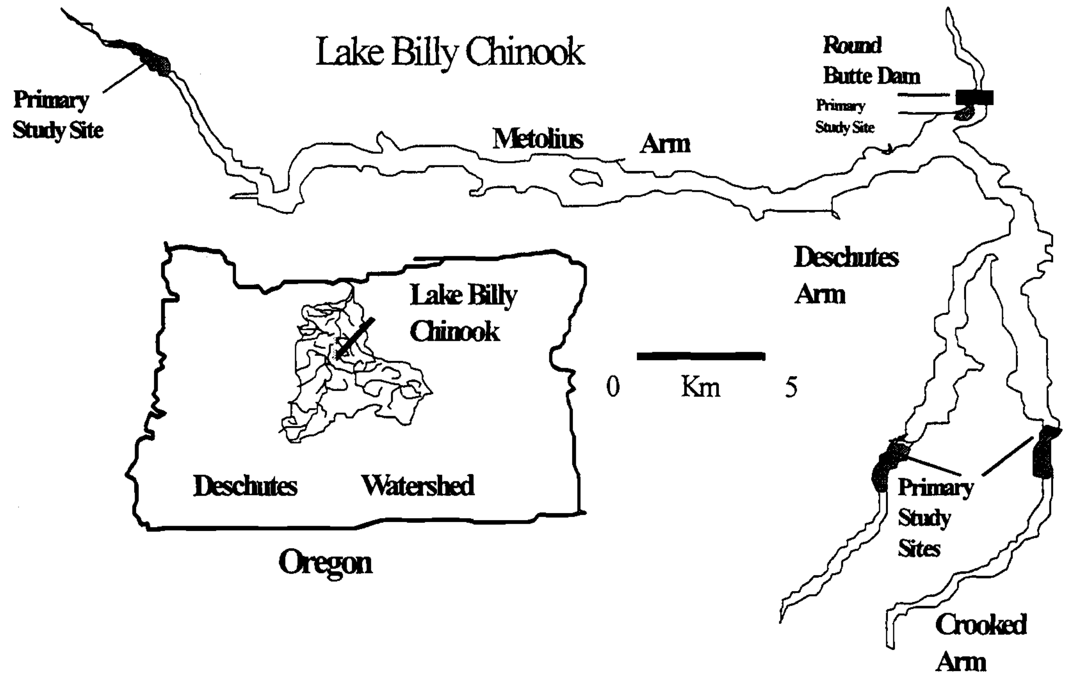


Figure 4.1. Location of primary study sites in Lake Billy Chinook, 1997-1999.

the mainstem of the middle Deschutes River have been made. Prior to the construction of Round Butte Dam, the majority of steelhead spawning was observed in Squaw Creek, a tributary to the Deschutes River below Steelhead Falls. There are conflicting reports on whether or not steelhead utilized the Metolius River for spawning. It is believed that steelhead did not historically spawn in the Metolius and that large rainbow trout observed there were mistakenly identified as steelhead (Nehlsen 1995).

Squaw Creek, a tributary to the Deschutes River, originates in the Three Sisters Wilderness area of the Cascade Mountains and flows approximately 64 kilometers to the Deschutes River at river kilometer (rkm) 197. Prior to the construction of the dams on the Deschutes River, steelhead were typically found to utilize only the lower portions of Squaw Creek, however, during heavy flows steelhead were observed moving upstream past the town of Sisters located at rkm 32.

Methods

Detailed methods on the capture, handling, and tagging of trout captured during a redband trout life history project above Round Butte Dam have been described in (Groves and Shields 2000a, b).

Redband trout captured during this study were categorized into one of three groups: 1) fish appearing to be of hatchery origin (fin clips), 2) fish showing smolt-like characteristics (silvery, long narrow bodies, no ventral fin pigmentation, and deciduous scales) (Hoar 1976), and 3) all other fish, classified as wild resident redband trout. The numbers of trout captured in each category is summarized in Table 4.1.

Table 4.1. Total number of trout classified as either wild resident, hatchery, or smolt-like, captured at each of the trap locations in Lake Billy Chinook, 1997-1999.

Location	Resident	Hatchery	Smolt-like
Deschutes	805	50	32
Crooked	563	65	36
Forebay	145	17	43
Metolius	420	91	183
Total	**1933**	**223**	**294**

Results

Morphological observations

Smolt-like trout were classified in the field based on phenotypic characters including silvery coloration, highly deciduous scales, and an elongate body with a long narrow caudal peduncle. Further analysis in the lab also showed that smolt-like trout had unique morphometric characteristics in terms of body shape compared to the other two forms of redband trout identified. Discriminant function analysis of morphological characters including relative warp scores (Groves et al. 2000b) and 5 traditional morphometric characters (Table 4.2) revealed that fish could be reclassified to their original groupings (wild resident, hatchery, or smolt-like) 77% of the time (Table 4.3). Components of body depth and caudal peduncle length separated the smolt-like trout from resident and hatchery forms of redband trout (Figure 4.2). Smolt-like trout were generally more streamlined with a thinner body and a longer narrower caudal peduncle.

Table 4.2. Five traditional morphometric measurements used to discriminant among forms of redband trout in Lake Billy Chinook.

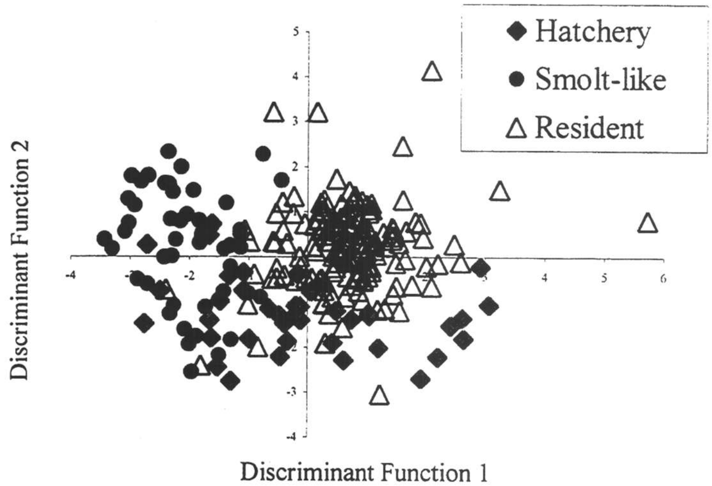
Character	**Measurement**
Snout length	Front of eye to tip of snout
Caudal Peduncle Depth	Minimum caudal peduncle depth
Body Depth	Maximum body depth just anterior to dorsal fin
Fulton's condition factor	10^5 x WT(g) / FL^3(mm)
Thickness condition factor	10 x TH(mm) / FL(mm)

Table 4.3. Discriminant function percent reclassification to original groupings of the three forms of redband trout found in Lake Billy Chinook.

Form	**% Classification**
Resident	79%
Hatchery	67%
Smolt-Like	83%

Analysis of scale growth patterns also revealed differences among the three forms of redband trout. All trout showing smolt-like characteristics showed a pattern (rapid uniform growth) distinct from all hatchery trout captured in Lake Billy Chinook and from all hatcheries stocks planted in Lake Billy Chinook (Figure 4.3). Total length indicated that all smolt-like trout were approximately age two.

A discriminant function analysis of relative warp scores and traditional morphometric characters of wild resident redband trout was also done. Wild resident trout were classified into groups based on the location of capture. Groups included the Deschutes River, Crooked River, Metolius arm (all trout captured in the river-reservoir transition zone of the Metolius arm), and the Metolius River (captured by angling further upstream). All wild trout captured in the main body of the reservoir were classified as forebay trout. The analysis revealed that wild resident redband trout captured in the forebay area of the reservoir and in the Metolius arm of Lake Billy Chinook were most similar in shape. The trout captured in the forebay were most often classified as members of the Metolius trap population (53% Metolius arm, 20% Deschutes, 0% Crooked, and 27% Metolius River) using discriminant function analysis.



Standardized Coefficients

	1	2
cp depth	0.41	0.44
depth	0.58	0.20
Fulton	-0.09	-0.41
relwarp1	0.13	0.52
relwarp2	0.71	-0.58
relwarp3	-0.29	-0.36
relwarp4	0.03	0.32
relwarp5	0.14	0.28
relwarp6	-0.23	-0.25
relwarp7	-0.03	-0.01
relwarp8	-0.06	-0.18
relwarp9	-0.07	-0.06
snout	-0.28	-0.10
ThicknC	-0.30	0.32

Figure 4.2. A plot of the first two discriminant functions for separation of the three forms of redband trout captured in Lake Billy Chinook.

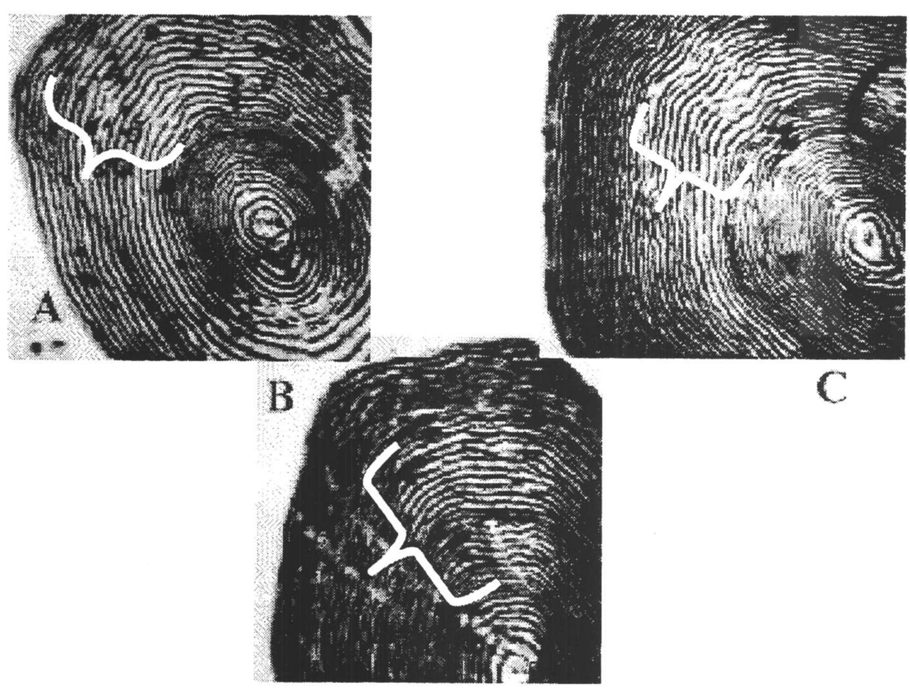


Figure 4.3. Differences in scale growth patterns of three forms of redband trout captured in Lake Billy Chinook during their second growth season. A – smolt-like, B – Resident, C – Hatchery.

Utilization of the reservoir

A large number of redband trout were observed in the main body of the reservoir during this study including a significant portion of trout showing smolt-like characteristics during the summer of 1998 and to a lesser extent 1999. A total of 184 trout was captured in the forebay area of the reservoir during 1998. Thirty five of the fish captured in the forebay displayed smolt-like characteristics. During 1999, unlike the previous year, only 20 redband trout were captured in the forebay, 11 of which had smolt-like characteristics.

Few juvenile redband trout immigrated into Lake Billy Chinook from the Metolius River during the spring and early summer. In the Deschutes River however, a large pulse of juvenile (age 0) redband trout was trapped while moving downstream into the reservoir during 1997. This large pulse was not observed in 1998 and no data are available for 1999 (Figure 4.4a-b).

Movement

Tagging studies revealed that many of the redband trout tagged in the forebay during 1998 also utilize the tributaries, since 75% of recaptured fish originally tagged in the forebay were found to have moved into one of the three arms of Lake Billy Chinook (Figure 4.5), the majority of which appeared to be wild resident redband trout (Groves et al. 2000a).

Substantial movement of tagged wild resident type redband trout into the Metolius arm of Lake Billy Chinook from the other tributaries was observed throughout the study (Figure 4.5). Two of these trout that were tagged in the forebay were observed in the Metolius arm seven days later, an average movement rate of approximately 2.9 kilometers per day. In addition to wild resident type fish, large numbers of smolt-like trout were also observed in this arm (Table 4.1) and were presumed to have moved there from one of the other arms (Groves et al. 2000a).

Disease/parasites

Two macro-parasites found in this study, *Cystidicoloides* sp. and *Cucullanus* sp. (stomach and intestinal nematodes, respectively) were found in the highest prevalence in redband trout captured in the Deschutes River, followed closely by those captured in the forebay area of the reservoir and in Squaw Creek, a tributary to the Deschutes River (Figure 4.6). Although the majority of trout showing smolt-like characteristics and hatchery trout had few macroparasties, *Cystidicoloides* sp. was observed in several of the smolt-like trout suggesting possible similarities to wild resident trout.

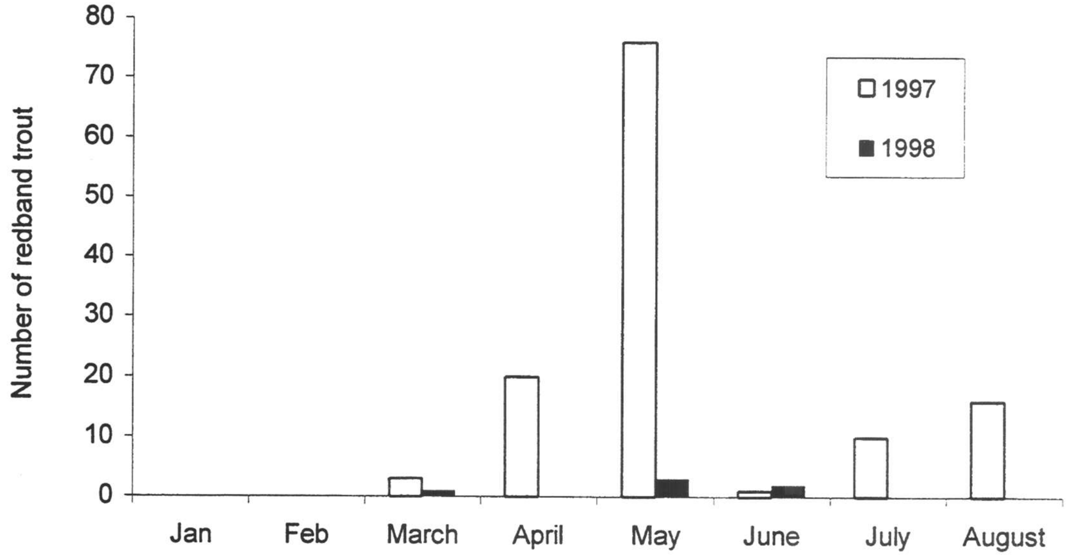


Figure 4.4a. Numbers of <100mm juvenile redband trout captured in the Deschutes River screw trap, 1997-1998.

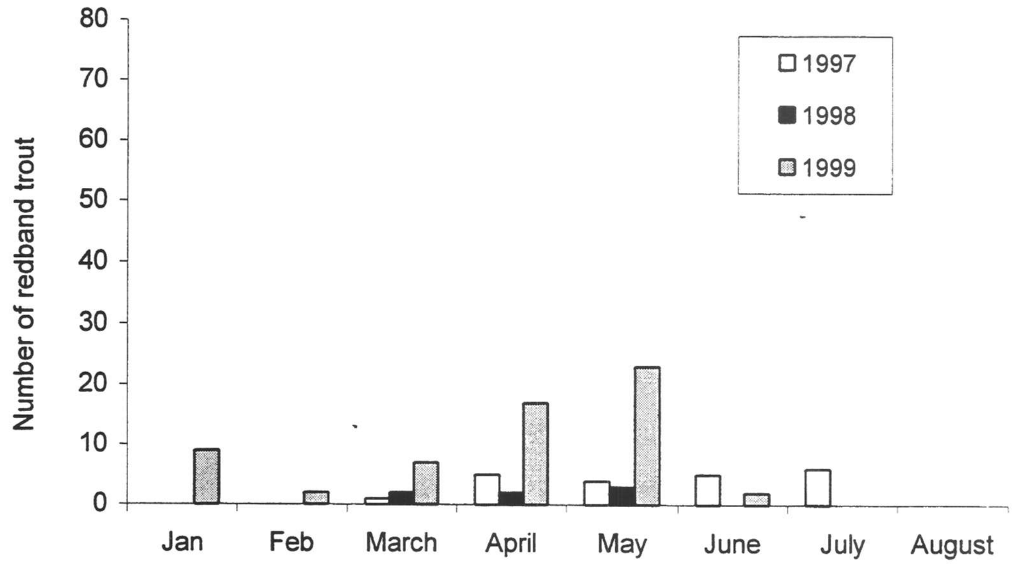
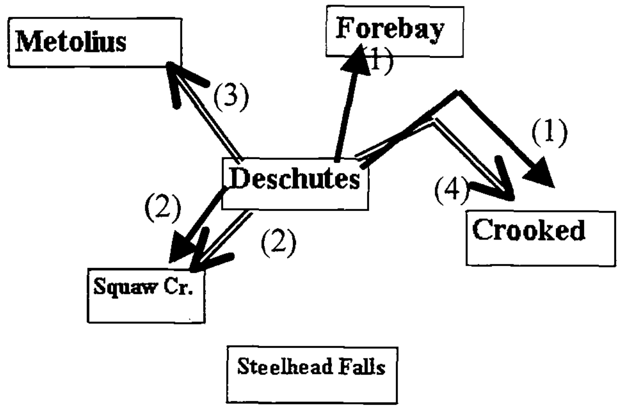
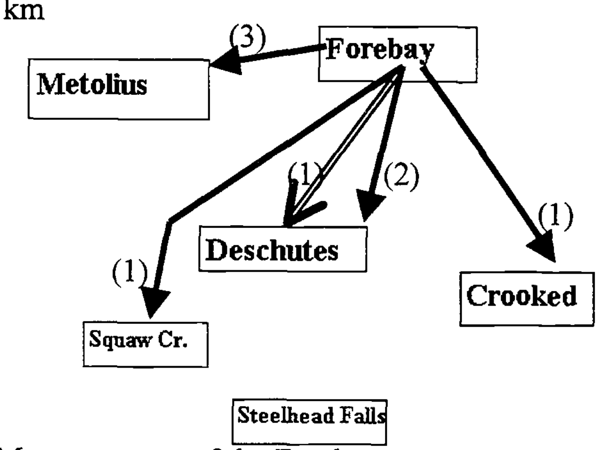


Figure 4.4b. Number of <100mm juvenile redband trout captured in the Metolius River screw trap, 1997-1999.

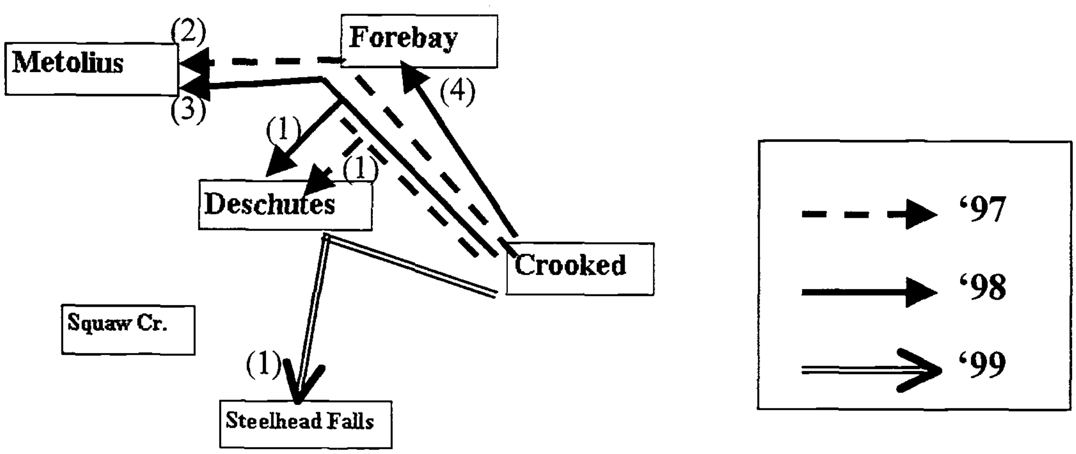
Figure 4.5. Movement of tagged, recaptured redband trout into other tributaries canyons observed from 1997 to 1999 in Lake Billy Chinook, Oregon. No redband trout tagged in the Metolius system were recaptured in other tributary canyons.



Movement out of the Deschutes River – Average Movement – 19.75 km



Movement out of the Forebay – Average Movement – 17.38 km



Movement out of the Crooked River – Average Movement – 23.71 km

Figure 4.5.

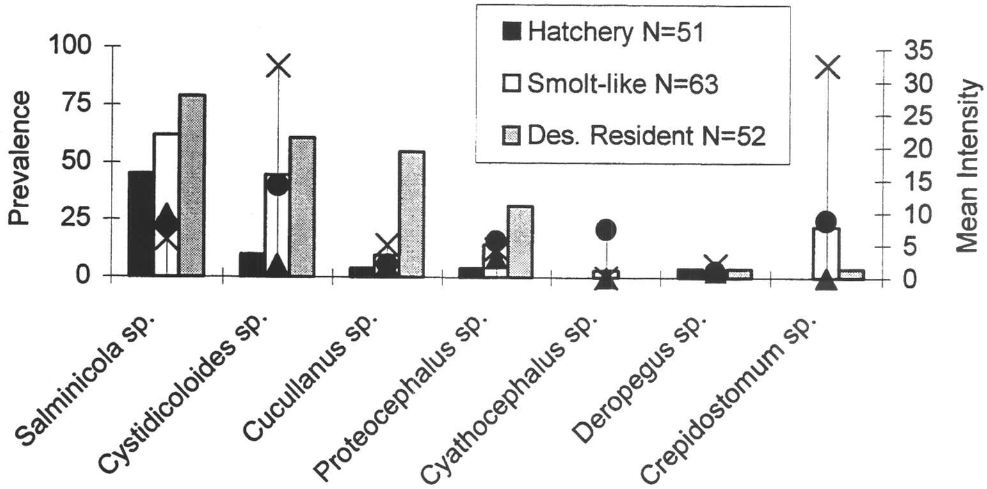


Figure 4.6. Prevalence and mean intensity of the most common parasites found in resident redband trout captured in the Deschutes River and hatchery and smolt-like trout captured throughout Lake Billy Chinook. Prevalence indicated by the bars, while mean intensity is indicated by symbols. X – Deschutes resident, □ – Smolt-like trout, and □- hatchery trout.

Discussion

Perhaps the strongest piece of evidence for the continued existence of steelhead above the dam is the physical appearance of the smolt-like trout observed moving through Lake Billy Chinook. When steelhead or other salmon juveniles prepare for migration to the ocean they typically undergo a series of morphological changes. Smolts become silvery in body color and develop a more streamlined body than seen in resident trout, with an elongated caudal peduncle (Hoar 1976). The elongation in the body is usually reflected by a lower condition factor (Winans and Nishioka 1987). Smolt-like trout captured in Lake Billy Chinook fit the descriptions of smolts given by Hoar (1976).

Previous studies have shown that steelhead are typically surface oriented during downstream migration (Smith 1974). It has been found that surface currents move from the other arms of Lake Billy Chinook up the Metolius arm during normal dam operation (Ratliff and McCollister 1997). The colder, denser Metolius River water tends to fill the lower portions of the reservoir while the warmer combined water from the Deschutes and Crooked Rivers tends to fill the top portion of the reservoir and is drawn "upstream" to a mixing/transition zone in the upper Metolius arm (Figure 4.7). Because of these current patterns, fish attempting to emigrate from the reservoir following surface currents may end up in the upper Metolius arm. Large numbers of redband trout showing smolt-like characteristics

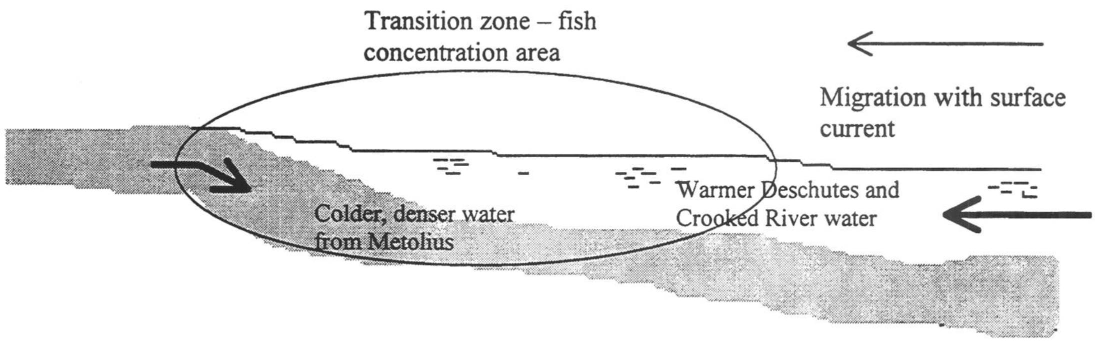


Figure 4.7. Graphic representation of current patterns in the upper Metolius arm of Lake Billy Chinook, Oregon.

were found both in the forebay and in the Metolius arm of Lake Billy Chinook. This may suggest that there is a significant number of redband trout attempting to migrate downstream past the dam. These current patterns have been observed to interfere with the normal migration patterns of smolts and other salmonids seeking to emigrate from the system utilizing surface currents in the past (Korn et al. 1967).

Typically the speed of smolt migration is highly correlated with current velocity. The average speed of migration for juvenile steelhead observed in the lower Columbia River was around 30 km/day (Giorgi et al. 1997) and was highly correlated to a mean discharge of approximately 4000 m^3/sec. Two smolt-like trout tagged in the forebay area were observed in the Metolius arm seven days later (2.9 km/day). Because there are minimal to negligible current velocities in Lake Billy Chinook this may account for the particularly slow migration rate.

There is a possibility that trout showing smolt-like characteristics are of hatchery origin. However, scale growth patterns from smolt-like trout were different from all hatchery trout captured within Lake Billy Chinook as well as from those sampled from all hatchery sources for the system. All trout showing smolt-like characteristics showed rapid uniform growth during their second growth season, as indicated by the widely spaced circuli (Figure 4.3). This rapid uniform growth was not observed in any scales taken from hatchery trout. In addition, data from *Ceratomyxa shasta* studies (Bartholomew 1999) suggests that these fish are also different from hatchery trout in respect to prevalence of this parasite. Of trout retained during this study, approximately 30% of the wild resident redband trout (range-16-37%) and 21% of redband trout showing smolt-like characteristics were infected with *C. shasta* while 69% of all hatchery rainbow trout were infected (Bartholomew 1999). Historically both resident redband trout and steelhead had low susceptibility and high genetic resistance to this parasite (Johnson 1975).

In addition to the *C. shasta* data, those smolt-like trout examined for macro-parasites from all trap locations in Lake Billy Chinook in 1998 had both high prevalence and high mean intensity of *Cystidicoloides* sp., which is characteristic of the Deschutes population of wild resident redband trout and is absent in most trout identified to be of hatchery origin. The presence of this parasite supports the evidence that these smolt-like trout are not of hatchery origin.

A confounding variable in the attempt to identify an ancestral run of steelhead in this system is that it is well known that rainbow trout readily develop adfluvial life histories in large inland freshwater lakes (Barnhart 1991). These trout, however, do not typically undergo the process of smoltification. Presently it is unknown whether a significant number of wild resident redband trout reside in or spend a significant portion of their life in Lake Billy Chinook. Recaptures of tagged redband trout indicate that the majority of these fish may only be passing through the reservoir, and not spending significant portions of their life rearing there. Most fish originally tagged in the forebay were recaptured after only short period of time in one of the three arms of Lake Billy Chinook. More extensive trapping and perhaps radio-tagging with stationary receivers within the reservoir is needed to answer this question.

Large numbers of juvenile (age 0) redband trout were trapped while moving into the reservoir during 1997 from the Deschutes River (Shields et al. 1998). However this was not observed in 1998. It is possible that this downstream migration may have been due to density dependant displacement associated with an unusually strong year class.

There are many biological and morphological characters observed in redband trout from this study that are applicable to both a persistent run of steelhead and to a more recently derived adfluvial life history form. Because both of these adfluvial forms would be utilizing the same habitat and food sources, growth rates, and fecundity would tend to be similar. In addition, as adults, coloration of both of these adfluvial forms would be more silvery than a wild resident trout as all trout living in a lacustrine environment are more silvery than resident trout (Behnke 1992).

While trout captured in the Metolius arm of Lake Billy Chinook shared some characters with those from the Deschutes and Crooked arms, many characters were also unique to this group of fish and to those captured in the forebay area of the dam. Redband trout in the Metolius Arm were generally larger at a given age than trout captured in other locations except those captured in the forebay (Groves and Shields 2000b). Typically, rainbow trout residing or spending a significant portion of their lives in lakes are larger for a given age than resident trout found in flowing water (Simpkins and Hubert 1996).

In addition to higher growth rates, fecundities of trout captured in the Metolius arm were higher than similar-sized females from other locations (Groves and Shields 2000a) and were more similar to those reported from steelhead and lake-dwelling rainbow trout (DuBois et al. 1989; Behnke 1992). The difference in fecundity between the possible adfluvial redband trout and wild resident redband trout is similar to that seen between resident and adfluvial Westslope cutthroat trout (Downs et al. 1997). Because sample sizes were small, additional egg counts from mature trout at all locations would be required to confirm this evidence.

Although the evidence presented in this report is suggestive of the existence of an adfluvial life history form that may or may not be a remnant stock of steelhead, the evidence does not permit a firm conclusion. Genetic studies may be required to allow a clear determination of the possible persistence of steelhead trout in the Lake Billy Chinook system.

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References

Bartholomew, J. 1999. Fish disease risk assessment: Whirling disease and ceratomyxosis, 1998 Annual report, FERC No 2030. Unpublished report. Portland General Electric, Co., Portland, Oregon.

Behnke, R. J. 1992. Native trout of western North America. American Fisheries Society Monographs; No. 6. 275p.

Biette, R. M., D. P. Dodge, R. L. Hassinger, and T. M. Stauffer. 1981. Life history and timing of migrations and spawning behavior of rainbow trout (*Salmo gairdneri*) populations of the Great Lakes. Canadian Journal of Fisheries Aquatic Sciences 38:1759-1771.

Downs, C. C., R. G. White, and B. B. Shepard. 1997. Age at sexual maturity, sex ratio, fecundity, and longevity of isolated headwater populations of Westslope cutthroat trout. North American Journal of Fisheries Management 17:85-92.

DuBois, R. B., S. D. Plaster, and P. W. Rasmussen. 1989. Fecundity of spring- and fall-run steelhead from two western Lake Superior tributaries. Transactions of the American Fisheries Society 118:311-316.

Gall, G. A. E., B. Bentley, and R. C. Nuzum. 1990. Genetic isolation of steelhead rainbow trout in Kaiser and Redwood Creeks, California. California Fish and Game 76(4):216-223.

Giorgi, A. E., T. W. Hillman, J. R. Stevenson, S. G. Hays, and C. M. Peven. 1997. Factors that influence the downstream migration rates of juvenile salmon and steelhead through the hydroelectric system in the mid-Columbia River Basin. North American Journal of Fisheries Management 17:268-282.

Gross, M. R. 1987. Evolution of diadromy in fishes. *in* Common strategies of anadromous and catadromous fishes, ed. M. J. Dodswell, R. J. Klauda, C. M. Moffit, R. L. Saunders, R. A. Rulifson, and J. E. Cooper (AFS, Bethesda, Maryland), American Fisheries Society Symposia, 1:14-25.

Groves, K., B. A. Shields. 2000a. Movement and mixing among three sub-populations of redband trout in the tributaries to Lake Billy Chinook, Oregon.

Groves, K., B. A. Shields. 2000b. Variation in biological characters in sub-populations of redband trout (*Oncorhynchus mykiss gairdneri*) from the main tributaries to Lake Billy Chinook, Oregon.

Johnson, K. A. 1975. Host susceptibility, histopathologic, and transmission studies on *Ceratomyxa shasta*, a myxosporidan parasite of salmonid fish. Ph.D. thesis, Oregon State University, Corvallis, OR. 134p.

Korn, L., L. H. Hrena, R. G. Montagne, W. G. Mullarkey, and E. J. Wagner. 1967. The effect of small impoundments on the behavior of juvenile anadromous salmonids. Fish Commission of Oregon Research Division (now Oregon Dept. of Fish and Wildlife). Clackamas, Oregon.

Nehlsen, W. 1995. Historical salmon and steelhead runs of the Upper Deschutes River and their environments. Portland General Electric Company, Portland, OR. 65p.

Northcote, T. G. 1992. Migration and residency in stream salmonids- some ecological considerations and evolutionary consequences. Nordic Journal of Freshwater Research. 67:5-17.

Ratliff, D. E. and S. A. McCollister. 1997. Surface currents in Lake Billy Chinook during the spring of 1997. Unpublished Report. Portland General Electric Company, Portland, Oregon.

Shields, B. A., K. Groves and A. Gonyaw. 1998. Lake Billy Chinook rainbow (redband) life history study. 1997 Annual Report, FERC No. 2030. Portland, Oregon.

Simpkins, D. G. and W. A. Hubert. 1996. Proposed revision of the standard-weight equation for rainbow trout. Journal of Freshwater Ecology 11(3):319-325.

Winans, G. A. and R. S. Nishioka. 1987. A multivariate description of change in body shape of coho salmon (*Oncorhynchus kisutch*) during smoltification. Aquaculture 66:235-245.

CHAPTER 5

Summary and Conclusions

The ways in which the construction of Round Butte Dam and Lake Billy Chinook has influenced life history characters as well as the ecological, reproductive, and genetic isolation of redband trout populations in the upper Deschutes River system are unknown. Utilization of the lacustrine environment by trout may facilitate interaction among populations, whereas avoidance of the lacustrine environment created by the reservoir may have increased isolation among populations. This study attempted to characterize the current life history characters, ecological, and reproductive isolation of redband trout residing in the three major tributaries to this reservoir.

Evidence of limited movement among river systems was documented by tagging studies. Metolius River wild resident trout show the greatest fidelity to their system while some mixing between the Deschutes and Crooked arm populations was observed. These tagging studies demonstrated some direct interaction among populations however; they were inconclusive for demonstrating the degree of reproductive isolation of each population. Very few tagged fish were observed on spawning grounds. Although movement of resident trout into the Metolius arm was observed, differences in observed spawning times between the Metolius population and the Deschutes and Crooked River populations may limit the amount of recruitment into the gene pool of the Metolius River population.

Documentation of phenotypic, morphometric, and life history characters (fecundity, rates of growth, and age structure of populations), as well as differences in parasite assemblages, provided evidence that demonstrated some degree of isolation among these redband trout populations. Redband trout captured upstream in the Metolius River displayed unique morphometric characters and these fish may constitute a distinct population, although it is still unclear whether the observed difference in body shape is a product of genes or the environment.

The Deschutes and Crooked River populations of redband trout however, are morphologically similar so additional variables were needed to characterize these populations. The addition of parasite faunal data into the analysis greatly improved the ability to distinguish these populations. This was primarily due to the unique combination of two nematodes that was found almost exclusively in the Deschutes River population of redband trout. Although parasite data alone was not strong enough to absolutely identify the Deschutes population, it was stronger than morphological characters alone and was much stronger when the two were combined.

The degree of accuracy in reclassifying an individual trout to its location of original capture changed with the different sets of variables used in the analysis (traditional morphometric characters, relative warp scores (characterizing overall body shape), or parasites faunal assemblages). Because resident trout from upstream in the Metolius River were morphologically unique and lacked most internal parasites, morphological characters alone could be used to distinguish this population. Using only the five traditional morphological characters, members of this population were correctly identified 78% of the time. Separation of this population from the others was primarily based on Fulton's condition factor, a thickness condition factor, and depth of the caudal peduncle. These measurements can all be made simply in the field without the need to sacrifice fish. For the morphologically similar Deschutes and Crooked River populations of redband trout, all morphological measurements in addition to parasite faunal assemblage data were required in order to distinguish these two populations.

There appears to be some evidence suggesting either the persistence of a stock of remnant steelhead trapped above Round Butte Dam or a population of adfluvial trout that adapted to the available habitat provided by the reservoir. While trout captured in the Metolius arm of Lake Billy Chinook shared some life history characters with those from the Deschutes and Crooked arms, some characters were unique to this group of fish and those captured in the forebay area of the dam. Redband trout in the Metolius Arm were found to be generally larger at a given age than trout captured in other locations except the forebay. This is a characteristic typical of trout utilizing a lacustrine environment (Simpkins and Hubert 1996).

In addition to specific life history characters, large numbers of trout showing smolt-like characteristics moved into the Metolius arm of Lake Billy Chinook during both 1998 and 1999. Water current studies in Lake Billy Chinook have shown that prevailing surface currents during normal operation of the dam moved down the Deschutes and Crooked arms and up the Metolius Arm (Ratliff and McCollister 1997). If fish were attempting to migrate downstream, these current patterns may be responsible for the large numbers of smolt-like redband trout captured in the Metolius arm.

Because the native populations of redband trout in Lake Billy Chinook evolved in rivers characterized by very different physical conditions, genetic diversity probably does exist among the major trout populations of these three river systems. Although evidence presented in this report supports the existence of functionally separate redband trout populations and the existence of an adfluvial life history form that may or may not be a remnant stock of steelhead, absolute conclusions cannot be drawn. Genetic studies could provide a more conclusive insight into geographic patterns, genetic diversity, degree of population isolation, and patterns of gene flow among populations of redband trout and possible steelhead-like trout in the Lake Billy Chinook system.

The data reported here will make a significant contribution towards the long-term management of these native redband trout populations. Should more strict management of these stocks become necessary in the future, knowing the functional stock structure of these sub-populations will allow them to be managed more efficiently. Variable closure dates and locations can be used that best suit the characteristics of each of the sub-populations.

BIBLIOGRAPHY

Aho, J. M. and C. R. Kennedy. 1984. Seasonal population dynamics of the nematode *Cystidicoloides tenuissima* (Zeder) from the River Swincombe, England. Journal of Fish Biology 25:473-489.

Aho, J. M. and C. R. Kennedy. 1987. Circulation pattern and transmission dynamics of the supra-population of the nematode *Cystidicoloides tenuissima* (Zeder) in the River Swincombe, England. Journal of Fish Biology 31:123-141.

Barlow, G. W. 1961. Causes and significance of morphological variation in fishes. Systematic Zoology 10: 105-117.

Bartholomew, J. 1999. Fish disease risk assessment: Whirling disease and ceratomyxosis, 1998 Annual report, FERC No 2030. Unpublished report. Portland General Electric, Co., Portland, Oregon.

Barton, B. A. and B. F. Bidgood. 1980. Competitive feeding habits of rainbow trout, white sucker and longnose sucker in Paine Lake, Alberta. Fisheries Report 16, Alberta Energy and Natural Resources, Calgary.

Behnke, R. J. 1992. Native trout of western North America. American Fisheries Society Monographs; No. 6. 275p.

Biette, R. M., D. P. Dodge, R. L. Hassinger and T. M. Stauffer. 1981. Life history and timing of migrations and spawning behavior of rainbow trout (*Salmo gairdneri*) populations of the Great Lakes. Canadian Journal of Fisheries Aquatic Sciences 38:1759-1771

Biondini, M. E., C. D. Bonham, and E. F. Redente. 1985. Secondary successional patterns in a sagebrush (Artemisia tridentate) community as they relate to soil disturbance and soil biological activity. Vegetation 60:25-36.

Bookstein, F. L. 1991. Morphometric tools for landmark data: geometry and biology. Cambridge University Press, New York.

Brewin, M. K., L. L. Stebbins, and J. S. Nelson. 1995. Differential losses of Floy® anchor tags between male and female brown trout. North American Journal of Fisheries Management 15:881-884.

Collins, S. L. and S. M. Glenn. 1997. Effects of organismal and distance scaling on analysis of species distribution and abundance. Ecological Applications 7:543-551.

Currens, K. P., A. R. Hemmingsen, R. A. French, D. V. Buchanan, C. B. Schreck, and H. W. Li. 1997. Introgression and susceptibility to disease in a wild population of rainbow trout. North American Journal of Fisheries Management 17:1065-1078.

Currens, K. P., C. S. Sharpe, R. Hjort, C. B. Schreck, and H. W. Li. 1989. Effects of different feeding regimes on the morphometrics of chinook salmon (*Oncorhynchus tshawytscha*) and rainbow trout (*O. mykiss*). Copeia 1989(3):689-695.

Downs, C. C., R. G. White, and B. B. Shepard. 1997. Age at sexual maturity, sex ratio, fecundity, and longevity of isolated headwater populations of Westslope cutthroat trout. North American Journal of Fisheries Management 17: 85-92.

DuBois, R. B., S. D. Plaster, and P. W. Rasmussen. 1989. Fecundity of spring- and fall-run steelhead from two Western Lake Superior tributaries. Transactions of the American Fisheries Society 118: 311-316.

Dunham, J. B., G. L. Vinyard, and B. E. Rieman. 1997. Habitat fragmentation and extinction risk of Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*). North American Journal of Fisheries Management 17:1126-1133.

Fies, T., M. Manion, B. Lewis, and S. Marx. 1996. Metolius River subbasin fish management plan: upper Deschutes fish district. Oregon Department of Fish and Wildlife, Portland, Oregon.

Filbert, R. B. and C. P. Hawkins. 1995. Variation in condition of rainbow trout in relation to food, temperature, and individual length in the Green River, Utah. Transactions of the American Fisheries Society 124:824-835.

Fink, W. L. and M. L. Zelditch. 1997. Shape analysis and taxonomic status of *Pygocentrus* piranhas (Ostariophysi, Characiformes) from the Paraguay and Paraná River basins of South America. Copeia 1997(1):179-182.

Fulton, L. A. 1970. Spawning areas and abundance of steelhead trout and coho, sockeye, and chum salmon in the Columbia River basin—past and present. National Marine Fisheries Service Special Scientific Report—Fisheries 618.

Gall, G. A., E. B. Bentley, and R. C. Nuzum. 1990. Genetic isolation of steelhead rainbow trout in Kaiser and Redwood Creeks, California. California Fish and Game 76(4):216-223.

Giorgi, A. E., T. W. Hillman, J. R. Stevenson, S. G. Hays, and C. M. Peven. 1997. Factors that influence the downstream migration rates of juvenile salmon and steelhead through the hydroelectric system in the mid-Columbia River Basin. North American Journal of Fisheries Management 17:268-282.

Gipson, R. D. and W. A. Hubert. 1991. Factors influencing the body condition of rainbow trout in small Wyoming reservoirs. Journal of Freshwater Ecology 6:327-334.

Gold, J. R. 1977. Systematics of western North American trout (*Salmo*) with notes on the redband trout of Sheephaven Creek, California. Canadian Journal of Zoology 55:1858-1873.

Gross, M. R. 1987. Evolution of diadromy in fishes. *in* Common strategies of anadromous and catadromous fishes, ed. M. J. Dodswell, R. J. Klauda, C. M. Moffit, R. L. Saunders, R. A. Rulifson, and J. E. Cooper (AFS, Bethesda, Maryland), American Fisheries Society Symposia, 1:14-25.

Groves, K., B. A. Shields, and A. Gonyaw. 1999. Lake Billy Chinook rainbow (redband) life history study, 1999 Annual Report, FERC No. 2030, Portland.

Groves, K., B. A. Shields. 2000a. Movement and mixing among three sub-populations of redband trout in the tributaries to Lake Billy Chinook, Oregon.

Groves, K., B. A. Shields. 2000b. Variation in biological characters in sub-populations of redband trout (*Oncorhynchus mykiss gairdneri*) from the main tributaries to Lake Billy Chinook, Oregon.

Hanski, I. And D. Simberloff. 1997. The metapopulation approach, its history, conceptual domain and application to conservation. Pgs. 5-26 *in* I. Hanski and M. Gilpin, editors. Metapopulation biology: ecology, genetics, and evolution. Academic Press. London, UK.

Hansson, L., L. Fahrig, and G. Merriam, editors. 1995. Mosaic landscapes and ecological processes. Chapman and Hall. New York.

Houslet B. and M. Riehle. 1997. Inland redband trout spawning survey of the upper Metolius River subbasin. Deschutes and Ochoco National Forest Service report. Sisters, Oregon.

Hubbs, C. L. and K. F. Lagler. 1958. Fishes of the Great Lakes region. The University of Michigan Press, Ann Arbor, MI. 213pp.

Hubert, W. A. and C. B. Chamberlain. 1996. Environmental gradients affect rainbow trout populations among lakes and reservoirs in Wyoming. Transactions of the American Fisheries Society 125:925-932

Hubert, W. A. and P. M. Guenther. 1992. Non-salmonid fishes and morphoedaphic features affect abundance of trouts in Wyoming reservoirs. Northwest Science 66(4):224-228.

Johnson, K. A. 1975. Host susceptibility, histopathologic, and transmission studies on *Ceratomyxa shasta*, a myxosporidan parasite of salmonid fish. Ph.D. thesis, Oregon State University, Corvallis, OR. 134p.

Kabata, Z. 1963. Parasites as biological tags. ICNAF Special Publication 4(6):31-37.

Karakousis, Y., C. Triantaphyllidis, and P. S. Economidis. 1991. Morphological variability among seven populations of brown trout, *Salmo trutta* L., in Greece. Journal of Fish Biology 38:807-817.

Kimura, D. K. 1980. Likelihood methods for the Von Bertalanffy growth curve. Fishery Bulletin 77(4):765-776.

Korn, L., L. H. Hrena, R. G. Montagne, W. G. Mullarkey, and E. J. Wagner. 1967. The effect of small impoundments on the behavior of juvenile anadromous salmonids. Fish Commission of Oregon Research Division (now Oregon Dept. of Fish and Wildlife). Clackamas, Oregon.

Lindsey, C. C., T. G. Northcote, and G. F. Hartman. 1959. Homing of rainbow trout to inlet and outlet spawning streams at Loon Lake, British Columbia. Journal of the Fisheries Research Board of Canada 16:695-719.

Mamontov, A. M. and V. M. Yakhnenko. 1995. Morphological, genetic, and biochemical estimate of population differentiation of Lake Baikal whitefish, *Coregonus lavaretus pidschian* (Coregonidae). Journal of Ichthyology 35(5):136-146.

Margolis, L. 1963. Parasites as indicators of the geographical origin of sockeye salmon, *Oncorhynchus nerka* (Wallbaum), occurring in the north Pacific Ocean and adjacent seas. Bulletin of the International North Pacific Fisheries Commission 11:101-156.

Moravec, F. 1979. Observations on the development of *Cucullanus* (Truttaedacnitis) *truttae* (Fabricius, 1794) (Nematoda: Cucullanidae). Folia Parasitologica 26:295-307.

Moravec, F. 1980. Biology of *Cucullanus truttae* (Nematoda) in a trout stream. Folia Parasitologica 27:217-226.

Moser, M. and J. Hsieh. 1992. Biological tags for stock separation in Pacific herring *Clupea harengus pallasi* in California. Journal of Parasitology 78(1):54-60.

National Research Council. 1995. Science and the endangered species act. National Academy Press, Washington, D. C., USA.

Nehlsen, W. 1995. Historical salmon and steelhead runs of the Upper Deschutes River and their environments. Portland General Electric Company, Portland, OR. 65p.

Nielson, R. S. 1950. Survey of the Columbia River and its tributaries. Part V. U.S. Fish and Wildlife Service Special Scientific Report: Fisheries No. 38.

Northcote, T. G. 1992. Migration and residency in stream salmonids- some ecological considerations and evolutionary consequences. Nordic Journal of Freshwater Research. 67:5-17.

Quinn, T. P. 1993. A review of homing and straying of wild and hatchery-produced salmon. Fisheries Research 18(1-2):29-44.

Raleigh, R. F. and W. J. Ebel. 1968. Effect of Brownlee Reservoir on migration of anadromous salmonids. In Proceedings of the reservoir fishery resources symposium, April 5-7, 1967, Athens, Georgia, pp. 415-443. American Fisheries Society.

Ratliff, D.E. 1983. *Ceratomyxa shasta*: Longevity, distribution, timing, and abundance of the infective stage in central Oregon. Canadian Journal of Fisheries and Aquatic Sciences 40(10):1622-1632.

Ratliff, D. E., S. L. Thiesfeld, W. G. Weber, A. M. Stuart, M. D. Riehle, and D. V. Buchanan. 1996. Distribution, life history, abundance, harvest, habitat, and limiting factors of bull trout in the Metolius River and Lake Billy Chinook, Oregon, 1983-94. Oregon Department of Fish and Wildlife Information Report No 96-7. ODFW, Portland.

Ratliff, D. E. and S. A. McCollister. 1997. Surface currents in Lake Billy Chinook during the spring of 1997. Unpublished Report. Portland General Electric Company, Portland, Oregon.

Riehle, M. and B. Houslet. 1999. Adult redband trout counts in the Metolius River during the winter of 1998-1999. Deschutes and Ochoco National Forest Service Report.

Rinne, J. N. 1985. Variation in Apache trout populations in the White Mountains, Arizona. North American Journal of Fisheries Management 5:146-158.

Reyes-Gavilan, F. G., R. Garrido, A. G. Nicieza, M. M. Toledo and F. Brana. 1996. Fish community variation along physical gradients in short streams of northern Spain and the disruptive effect of dams. Hydrobiologia 321:155-163.

Rieman, B. E., D. C. Lee, and R. F. Thurow. 1997. Distribution, status, and likely future trends of bull trout within the Columbia River and Klamath basins. North American Journal of Fisheries Management 17:1111-1125.

Rulifson, R. A. and M. J. Dadswell. 1995. Life history and population characteristics of striped bass in Atlantic Canada. Transactions of the American Fisheries Society 124:477-507.

Sakai, M. and A. Espinos. 1994. Repeat homing and migration of rainbow trout to the inlet and outlet spawning streams in a Patagonian Lake, Argentina. Fisheries Science 60(2):137-142.

Salmanov, A. V., N. S. Rostova, and Y. A. Dorofeyeva. 1991. Morphometric features of the Amu Darya trout (*Salmo trutta oxianus*, Salmonidae). Journal of Ichthyology 31(6):58-79.

Shields, B. A., K. Groves and A. Gonyaw. 1998. Lake Billy Chinook rainbow (redband) life history study. 1997 Annual Report, FERC No. 2030. Portland, Oregon.

Simpkins, D. G. and W. A. Hubert. 1996. Proposed revision of the standard weight equation for rainbow trout. Journal of Freshwater Ecology 11(3):319-325.

Sindermann, C. J. 1961. Parasite tags for marine fish. Journal of Wildlife Management. 25(1):41-47.

Strauss, R. E., and F. L. Bookstein. 1982. The truss: body form reconstruction in morphometrics. Systematic Zoology 31:113-135.

Stuart, A. M., S. L. Thiesfeld, T. K. Nelson, and T. M. Shrader. 1996. Crooked River basin plan, Ochoco fish district. Oregon Department of Fish and Wildlife.

Szacki, J. 1999. Spatially structured populations: how much do they match the classic metapopulation concept? Landscape Ecology 14:369-379.

Thurow, R. F., D. C. Lee, B. E. Reiman. 1997. Distribution and status of seven native salmonids in the interior Columbia River basin and portions of the Klamath River and Great Basins. North American Journal of Fisheries Management 17(4):1094-1110.

Warner, E. J. and T. P. Quinn. 1995. Horizontal and vertical movements of telemetered rainbow trout (*Oncorhynchus mykiss*) in Lake Washington. Canadian Journal of Zoology 73:146-153.

Whitaker, D. J., and G. A. McFarlane. 1997. Identification of sablefish, *Anoplopoma fimbria* (Pallas, 1811), stocks from seamounts off the Canadian Pacific Coast using parasites as biological tags. NOAA Technical Report NMFS 130:131-136.

Williams, J. E. and seven co-authors. 1989. Fishes of North America endangered, threatened, or of special concern: 1989. Fisheries 14(6):2-20.

Williams, H. H., K. MacKenzie and A. M. McCarthy. 1992. Parasites as biological indicators of the population biology, migrations, diet, and phylogenetics of fish. Reviews in Fish Biology and Fisheries 2:144-176.

Williams, R. N., R. F. Leary, and K. P. Currens. 1997. Localized genetic effects of a long-term hatchery stocking program on resident rainbow trout in the Metolius River, Oregon. North American Journal of Fisheries Management 17:1079-1093.

Winans, G. A. 1985. Using morphometric and meristic characters for identifying stocks of fish. In Proceedings of the stock identification workshop 1985, Panama City, Florida. NOAA Technical Memorandum NMFS-SEFC 199:25-62.

Winans, G. A. and R. S. Nishioka. 1987. A Multivariate description of change in body shape of coho salmon (Oncorhynchus kisutch) during smoltification. Aquaculture 66:235-245.

Wood, C. C., D. T. Rutherford, and S. McKinnell. 1989. Identification of sockeye salmon (*Oncorhynchus nerka*) stocks in mixed-stock fisheries in British Columbia and southeast Alaska using biological markers. Canadian Journal of Fisheries and Aquatic Sciences 46:2108-2128.

APPENDIX

Appendix. Dates of snorkel surveys and spawning ground surveys in the three arms of Lake Billy Chinook including Squaw Creek and tributary to the Deschutes River.

Snorkel Surveys			
	Deschutes	**Crooked**	**Metolius**
1997	July 10, 23	July 22	July 9 August 4
1998	June 11, 26 July 9, 27 September 8 October 1, 15	July 9, 28 August 14 September 9 October 2	March 6 April 24 June 12, 26 July 9, 27 September 8 October 1, 15
1999	April 4, 18 May 22, 31 July 19 August 18, 31 September 13	May 29 June 15, 28 July 2, 19 August 18, 31 September 13	May 8, 22 June 15, 28 July 1, 19 August 18, 31 September 13
Spawning Ground Surveys			
	Deschutes River	**Metolius River**	**Squaw Creek**
1998		September	March 27 April 3, 7 May 8, 16, 22, 30 June 7, 19, 28 July 2
1999	April 5, 8, 15, 18, 29 May 8, 20, 22, 27	May 2	April 12, 24 May 3, 17 June 18