AN ABSTRACT OF THE THESIS OF

Lisa K. Krentz for the degree of Master of Science in Fisheries Science presented on
May 11, 2007.
Title: Habitat Use, Movement, and Life History Variation of Coastal Cutthroat Trout
*Oncorhynchus clarkii clarkii* in the Salmon River Estuary, Oregon.


Abstract approved:


Hiram W. Li                                                   Ian A. Fleming

Anadromous coastal cutthroat trout *Oncorhynchus clarkii clarkii* may be

highly dependent on estuaries, passing through them multiple times during their

lifetime. However, few studies have investigated estuarine use by coastal cutthroat

trout and it is often thought that estuaries serve primarily as migration corridors rather

than rearing areas.  We used both PIT tag and acoustic tracking techniques in 2002

and 2003 to investigate habitat use, movement, and life history variation within the

population of coastal cutthroat trout in the Salmon River estuary, Oregon.  Evidence

of site fidelity was observed in both the PIT-tagged and acoustically tagged fish, with

70% of PIT tagged fish being recaptured at their previous capture site and most

acoustically tagged fish residing in one location for at least 25 days.  Ninety percent

of fish relocated 1.7 km upstream or downstream showed directional movement

toward the original site of capture, and half of those eventually took up residence

there.  Cutthroat trout used main channel sites more frequently than marsh channel

sites, and deeper sites more frequently than shallower sites.  Contrary to published

results for most other coastal populations, Salmon River cutthroat trout rear in the

estuary for much of the year.

We identified two main life history types: an "ocean migrant" form that migrates rapidly through the estuary and out to sea, and an "estuarine resident" form that resides in the estuary for the spring and summer. In addition, we found evidence of other life history types: coastal cutthroat trout that rear mainly in the estuary but make brief forays into the near shore ocean, and some that rear in the estuary throughout winter. We saw no difference in mean length at tagging between ocean migrants and estuarine residents, suggesting that the stimulation for migrating to the ocean was not size related. Half of the acoustically tagged fish exhibited the estuarine life history type. We compared growth rates of ocean migrants and estuarine residents by classifying PIT-tagged fish into life history types based on their recapture history. We found no evidence of a growth advantage for ocean migrants, although sample size was small. This study suggests that the estuarine life history is an important migratory behavior within the continuum of life histories for coastal cutthroat trout in the Salmon River. Our results imply that conservation of coastal cutthroat trout may depend on recovery and maintenance of suitable estuarine rearing habitat.

Habitat Use, Movement, and Life History Variation of Coastal Cutthroat Trout
*Oncorhynchus clarkii clarkii* in the Salmon River Estuary, Oregon.


by

Lisa K. Krentz




A THESIS

submitted to

Oregon State University




in partial fulfillment of
the requirements for the
degree of


Master of Science




Presented May 11, 2007
Commencement June 2008

Master of Science thesis of <u>Lisa K. Krentz</u>
presented on <u>May 11, 2007</u>.

APPROVED:

_____

Co-Major Professor, representing Fisheries Science

_____

Co-Major Professor, representing Fisheries Science

_____

Head of the Department of Fisheries and Wildlife

_____

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries.  My signature below authorizes release of my thesis to any reader upon request.

_____

Lisa K. Krentz, Author

ACKNOWLEDGEMENTS

CONTRIBUTION OF AUTHORS

Hiram Li, Ian Fleming, Dan Bottom, and Kim Jones contributed in developing the experimental design and editing of all chapters. Kirk Schroeder contributed to the analysis of all data and the editing of all chapters.

`

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

## LIST OF TABLES

# Chapter 1: Introduction

Estuaries provide an essential link between freshwater and ocean habitats, and are used by anadromous salmonids at all life stages for feeding, as refuges from predators, and for physiological transition (McCabe et al. 1983; Bottom and Jones 1990). However, until recently estuaries have been considered primarily as migration corridors or short-term rearing areas for juvenile anadromous salmonids, and sometimes have been considered as "bottlenecks" to salmon production (Fresh et al. 2005). Perspectives on the role of estuaries have shifted to where they are now viewed as part of the continuum of habitats that salmon use to complete their life cycle and that the number and success of life history strategies within a population are dependent on the quality and distribution of available habitats (NRC 1996; Fresh et al. 2005). Because coastal cutthroat trout *Oncorhynchus clarkii clarkii* are iteroparous, they are likely to be more dependent on estuarine habitat than other Pacific salmon that spend less time in the estuaries. However, most information collected on coastal cutthroat trout suggests relatively extensive use of estuaries by returning adults as staging areas before upstream spawning migrations than the limited use of estuaries by smolts (Giger 1972; Sumner 1972; Tipping 1981). Although some studies have suggested estuaries were used by coastal cutthroat trout as parr (Giger 1972; Tipping 1981) or for all size groups (Tomasson 1978), the importance of estuaries to life history diversity of coastal cutthroat trout and the specific use of habitats in the estuaries by these fish have not been well studied.

Coastal cutthroat trout occur along the Pacific coast of North America, and range from Prince William Sound, Alaska south to the Eel River, California (Behnke 1992). They occur inland to the crest of the Cascade Mountains in Oregon and

Washington and to the crest of the Coast Range in British Columbia and Alaska. Conventional wisdom suggests there are four primary life histories of coastal cutthroat trout: (1) a resident form that rears and spawns entirely in small freshwater streams; (2) a fluvial form that rears in larger streams and rivers of a watershed and migrates to small streams to spawn; (3) an adfluvial form that rears in lakes and migrates to smaller tributaries to spawn; and (4) an anadromous form that rears in saltwater and returns to freshwater streams to spawn (Giger 1972; Trotter 1989; Behnke 1992). The presence of multiple life histories within the same population of fish, from fully resident individuals to anadromous individuals, is a response of individuals to their complex and connected habitats, and reflects the various pathways salmonids choose to move through a diverse ecosystem comprised of freshwater, estuarine, and marine environments (Thompson 1959; Liss et al. 2006). Life history diversity, along with genetic and population diversity, enables salmonids to cope with the environmental variation in freshwater and ocean habitats and allows individuals to survive and reproduce under different environmental conditions, thus leading to long-term productivity and resilience in populations (Healey and Prince 1995; Liss et al. 2006). Anadromous salmonids require multiple habitats to complete their life cycles and the ability to migrate between these habitats, therefore the expression of life history diversity depends on the quantity, quality, and connectivity of diverse habitats (Healey and Prince 1995; Fausch et al. 2002).

Migration, however, is a risky endeavor for fish and has energetic costs that can directly and indirectly affect the survival of migrants. A direct cost of migration is increased predation by other fish (Hvidsten and Lund 1988) or other predators such

as birds (Wood 1987). Mortality from predation and disease is higher for migratory fish than for resident fish (Elliot 1993; Mather 1998; Jonsson and Jonsson 1993). In addition, energetic costs are high for fish that migrate to the ocean and back to freshwater for spawning (Jonsson et al. 1997; Kinnison et al. 2001). In order for a migratory life history to maintain itself in the population in the face of these costs, compensation must be conferred to individual fish that migrate, such as access to more productive habitats (Gross et al. 1988). Theoretically, life history strategies such as migratory behavior are means by which individuals maximize their lifetime reproductive fitness (Gross 1987; Partridge and Harvey 1988; Jonsson and Jonsson 1993). Migratory behavior can vary because individuals within a population that successfully reproduce make the optimum trade-off between costs and benefits of switching or not switching habitats; therefore, the cumulative variation of individual response is expressed in the population. For migratory individuals, reproductive advantages accrue from increased body size (growth) and a subsequent increase in fecundity and mating success that exceed the cost of moving between habitats (Gross 1987; Fleming and Reynolds 2004). Although non-migratory individuals have lower growth rates than migratory individuals, the reproductive advantage for non-migratory individuals is presumably increased probability of survival to maturation partially because of the low costs of migration, thus an increase in the likelihood of reproducing (Gross 1987).

Most studies of coastal cutthroat trout have been focused on freshwater aspects such as habitat use (Bustard and Narver 1975; Glova and Mason 1976; Bisson et al. 1988), interactions with other salmonids (Hartman and Gill 1968; Bustard and

Narver 1975; Glova and Mason 1976), and effects of land use (Hall and Lantz 1969;

Hartman and Scrivener 1990; Reeves et al. 1997). In general, little is known about

the life history, migratory behavior, and habitat use of anadromous cutthroat trout

beyond freshwater habitats (Hall et al. 1997).

Anadromous coastal cutthroat trout are thought to spend about four to six

months in either tidal and ocean habitats (Sumner 1962; Giger 1972), although this

may be highly variable and is not well understood. Only a few studies have

investigated migration of coastal cutthroat trout through estuaries (Giger 1972;

Tomasson 1978; Tipping 1981; Hudson 2005). Giger (1972) collected migration

information in the estuaries of the Alsea, Siuslaw, and Nestucca rivers from angler

catch, nets and traps in rivers and estuaries, and recaptures of tagged fish. However,

many of the fish in the study were of hatchery origin because active stocking took

place in these areas during that time. Most coastal cutthroat trout in these rivers

rapidly migrated downstream through the estuary and spent several months in near-

shore water of the ocean. Rapid movement of coastal cutthroat trout in the Columbia

River estuary also has been noted (Hudson 2005). In contrast, the majority of coastal

cutthroat trout of all sizes in the Rogue River, Oregon, were found to migrate and rear

through spring and summer in the estuary (Tomasson 1978). Fish from this

population rarely migrated out to the ocean. Migrant parr (< 175 mm) were the only

fish thought to remain throughout spring and summer months in three coastal Oregon

estuaries studied by Giger (1972), an observation also noted in the Columbia River

estuary (Tipping 1981). Adult fish returning to these rivers from the ocean held in the

estuary for up to four months before migrating upstream, but did not exhibit active

feeding or growth and moved upstream when fall rains began (Giger 1972; Tipping 1981). Coastal cutthroat trout migrating to the ocean remain close to shorelines in Alaska (Jones and Siefert 1997), in near-shore waters off Oregon (Giger 1972; Sumner 1972), and 10–46 km off the coast of Oregon and Washington in the relatively low salinity waters of the Columbia River plume (Loch and Miller 1988; Pearcy et al. 1990).

Decline of anadromous populations of coastal cutthroat trout in the 1980s and 1990s over much of its range (Williams and Nehlsen 1997) prompted concern about the species and instigated listing actions under the federal Endangered Species Act (ESA). Coastal cutthroat trout in the Umpqua River basin were listed as endangered in 1996 (Johnson et al. 1999) but were delisted in 2000 when they were considered to be part of a larger population segment that did not warrant listing (Federal Register 65:20915–20918). In 1999, a population of coastal cutthroat trout in southwest Washington and the lower Columbia River were proposed for listing under the ESA, but action was declined based on information on the potential for freshwater forms to produce anadromous progeny (Federal Register 67:44934–44961). An apparent increase in the numbers of anadromous coastal cutthroat trout throughout its range has coincided with favorable ocean conditions (Peterson et al. 2006). Throughout the listing process and continuing to a 2005 status review by Oregon Department of Fish and Wildlife, little biological data were available to assess status of populations. Therefore, the professional opinion of field biologists and anecdotal information were the primary knowledge sources. Lack of quantitative data on populations of coastal

cutthroat trout has been a continuing problem that was expressed as long as 50 years ago:

> "Very little is yet known about these fish and they have rightly been called the "problem children" of the State Game Commission….Since insufficient information has been accumulated to justify making recommendations, no changes are suggested…." (FCO and OSGC 1946).

Knowledge about life history variation of coastal cutthroat trout and their specific use of habitats is important for developing conservation and recovery strategies that will encompass the vast range of habitats these fish may use throughout their life cycle. A broader understanding of the complex life histories that may be present in a given population will aid managers in developing policies and practices to conserve all life history types, thus aiding the long term sustainability and resilience of coastal cutthroat trout in their dynamic environment. Increased knowledge of the extent to which salmonids use estuaries may provide additional incentives for managers and the public to restore these highly productive ecosystems, which in turn will benefit a suite of non-salmonid species.

This study was designed to quantify life history variation of anadromous coastal cutthroat trout. Specifically, estuarine rearing in spring and summer, phenotypic characteristics of estuarine residents, and estuarine growth compared to ocean growth. The study also quantified the use of estuarine habitats by coastal cutthroat trout, physical characteristics of habitats, movement of fish within the

estuary, fidelity to specific sites, and strength of site fidelity. Use of estuaries by coastal cutthroat trout was studied to answer questions about: (1) specific estuarine habitats; (2) movement patterns within the estuary and the influence of physical parameters, such as depth and salinity; and (3) fidelity of individuals to specific sties and the strength of site fidelity. In addition, this study was designed to test: (1) if coastal cutthroat trout use estuarine habitat for more than a migratory corridor and to what extent; (2) if patterns of estuarine use are related to size; and (3) if there is a difference in growth between ocean migrants and estuarine residents. This study was conducted in 2002–2003 using both active and passive tracking methods in the Salmon River estuary, Oregon. Our approach combined fine scale, detailed movements of a small group of individual fish with broad scale movements of a larger portion of the population.

**References:**

Behnke, R.J. 1992. Native trout of western North America. American Fisheries Society Monograph 6, Bethesda, Maryland.

Bisson, P.A., K. Sullivan, and J.L. Nielsen. 1988. Channel hydraulics, habitat use, and body from of juvenile coho salmon, steelhead, and cutthroat trout in streams. Transactions of the American Fisheries Society 117:262–273.

Bottom, D.L., and K.K. Jones. 1990. Species composition, distribution, and invertebrate prey fish assemblages in the Columbia River estuary. Progress in Oceanography 25:243–270.

Bustard, D.R., and D.W. Narver. 1975. Preferences of juvenile coho salmon and cutthroat trout relative to simulated alteration of winter habitat. Journal of Fisheries Research Board of Canada 32:81–87.

Elliot, J.M. 1993. The pattern of natural mortality throughout the life cycle in contrasting populations of brown trout, *Salmo trutta*. Fisheries Research 17:123–136.

Fausch, K.D., C.E. Torgersen, C.V. Baxter, and H.W. Li. 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. BioScience 52:483–498.

FCO (Fish Commission of Oregon) and OSGC (Oregon State Game Commission). 1946.

Fleming, I.A. & Reynolds, J.D. 2004 Salmonid breeding systems. Pages 264–294 in A.P. Hendry and S.C. Stearns, editors. Evolution illuminated: salmon and their relatives. Oxford University Press. New York.

Fresh, K.L., E. Casillas, L. Johnson, and D.L. Bottom. 2005. Role of the estuary in the recovery of Columbia River basin salmon and steelhead: an evaluation of the effects of selected factors on salmonid population viability. NOAA Technical Memorandum NMFS-NWFSC-69. 109pp.

Giger, R.D. 1972. Ecology and management of coastal cutthroat trout in Oregon. Oregon State Game Commission, Fishery Research Report 6, Corvallis.

Glova, G.J., and J.C. Mason. 1976. Interactive ecology of juvenile salmon and trout in streams. Fisheries Research Board of Canada Manuscript Report 1391.

Gross, M.R. 1987. Comparison of allopatric cutthroat trout stocks with those sympatric with coho salmon and sculpins in small streams. Environmental Biology of Fishes 20:275–284.

Gross, M.R., R.M. Coleman, and R.M. McDowell. 1988. Aquatic productivity and the evolution of diadromous fish migration. Science 239:1291–1293.

Hall, J.D., and R.L. Lantz. 1969. Effects of logging on the habitat of coho salmon and cutthroat in coastal streams. Pages 355–375 in T.G. Northcote, editor. Symposium on salmon and trout in streams. H.R. MacMillan Lectures in Fisheries, University of British Columbia, Vancouver.

Hall, J.D., P.A. Bisson, and R.E. Gresswell, editors. 1997. Sea-run cutthroat trout: biology, management, and future conservation. Oregon Chapter, American Fisheries Society, Corvallis.

Hartman, G.F., and C.A. Gill. 1968. Distributions of juvenile steelhead and cutthroat trout *(Salmo gairdneri* and *S. clarki clarki)* within streams in southwestern British Columbia. Journal of Fisheries Research Board of Canada 25:33–48.

Hartman, G.F., and J.C. Scrivener. 1990. Impacts of forestry practices on a coastal stream ecosystem, Carnation Creek, British Columbia. Canadian Bulletin of Fisheries and Aquatic Sciences 223.

Healey, M. C., and A. Prince. 1995. Scales of variation in life history tactics of Pacific salmon and the conservation of phenotype and genotype. Pages 176–184 *in* J. L. Nielsen, editor. Evolution and the aquatic ecosystem: defining unique units in population conservation. American Fisheries Society Symposium 17, Bethesda, Maryland.

Hudson, J.M. 2005. Movements of coastal cutthroat trout *(Oncorhynchus clarki clarki)* in the lower Columbia River: tributary, main-stem, and estuary use. U.S. Fish and Wildlife Service, Project Status Report, Draft.

Hvidsten, N.A., and R.A. Lund. 1988. Predation on hatchery-reared and wild smolts of Atlantic salmon, *Salmo sular*, in the estuary of River Orkla, Norway. Journal of Fish Biology 33:121–126.

Johnson, O.W., M.H. Ruckelhaus, W.S. Grant, F.W. Waknitz, A.M. Garrett, G.J. Bryant, K. Neely, and J.J. Hard. 1999. Status review of coastal cutthroat trout from Washington, Oregon, and California. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-MWFSC-37.

Jones, J.D., and C.L. Siefert. 1997. Distribution of mature sea-run cutthroat trout overwintering in Auke Lake and Lake Eva in southeastern Alaska. Pages 27–28 *in* J.D. Hall, P.A. Bisson, and R.E. Gresswell, editors. Sea-run cutthroat trout: biology, management, and future conservation. Oregon Chapter, American Fisheries Society, Corvallis.

Jonsson, B., and N. Jonsson. 1993. Partial migration: niche shift versus sexual maturation in fishes. Reviews in Fish Biology and Fisheries 3:348–365.

Jonsson, N., B. Jonsson, and L.P. Hansen. 1997. Changes in proximate compostition and estimates of energetic costs during upstream migration and spawning in Atlantic salmon *Salmo salar*. Journal of Animal Ecology 66:425–436.

Kinnison, M.T., M.J. Unwin, A.P. Hendry, and T.P. Quinn. 2001. Migratory costs and the evolution of egg size and number in introduced and indigenous salmon populations. Evolution 55:1656–1667.

Liss, W.J., J.A. Stanford, J.A. Lichatowich, R.N. Williams, C.C. Coutant, P.R. Mundy, and R.R. Whitney. 2006. Pages 51–98 *in* R.N. Williams, editor. Return to the river: restoring salmon to the Columbia River. Elsevier Academic Press, New York.

Loch, J.J., and D.R. Miller. 1988. Distribution and diet of sea-run cutthroat trout captured in and adjacent to the Columbia River plume, May–July 1980. Northwest Science 62:41–48.

Mather, M.E. 1998. The role of context-specific predation in understanding patterns exhibited by anadromous salmon. Canadian Journal of Fisheries and Aquatic Sciences 55(Supplement 1):232–246.

McCabe Jr., G.T., W.D. Muir, R.L. Emmett, and J.T. Durkin. 1983. Interrelationships between juvenile salmonids and nonsalmonid fish in the Columbia River estuary. Fishery Bulletin 81:815–826.

NRC (National Research Council). 1996. Upstream: salmon and society in the Pacific Northwest. National Academic Press, Washington D.C.

Partridge, L., and P.H. Harvey. 1988. The ecological context of life history evolution. Science 241:1449–1454.

Pearcy, W.G., R.D. Brodeur, and J.P. Fisher. 1990. Distribution and biology of juvenile cutthroat trout *Oncorhynchus clarki clarki* and steelhead *O. myskiss* in coastal waters off Oregon and Washington. Fishery Bulletin 88:697–711.

Peterson, W.T., R.C. Hooff, C.A. Morgan, K.L. Hunter, E. Casillas, and J.W. Ferguson. 2006. Ocean conditions and salmon survival in the northern California current. NOAA National Marine Fisheries Service, Newport, Oregon. Available: http://www.nwfsc.noaa.gov/research/divisions/fed/ecosysrep.pdf (February 2007).

Reeves, G.H., J.D. Hall, and S.V. Gregory. 1997. The impact of land management activities on coastal cutthroat trout in their freshwater habitats. Pages 138–144 *in* J.D. Hall, P.A. Bisson, and R.E. Gresswell, editors. Sea-run cutthroat trout: biology, management, and future conservation. Oregon Chapter, American Fisheries Society, Corvallis.

Sumner, F.H. 1962. Migration and growth of the coastal cutthroat trout in Tillamook County, Oregon. Transactions of the American Fisheries Society 91:77–83.

Sumner, F.H. 1972. A contribution to the life history of the cutthroat trout in Oregon. Oregon State Game Commission, Corvallis.

Thompson, W.F. 1959. An approach to population dynamics of the Pacific red salmon. Transactions of the American Fisheries Society 88:209–209.

Tipping, J.M. 1981. Cowlitz sea-run cutthroat study 1980-1981. Washington State Game Department, Fisheries Management Division Report 81–12, Olympia.

Tomasson, T. 1978. Age and growth of cutthroat trout, *Salmo clarki clarki* Richardson, in the Rogue River, Oregon. Master's thesis. Oregon State University, Corvallis.

Trotter, P.C.  1989.  Coastal cutthroat trout: a life history compendium.  Transactions of the American Fisheries Society 118:463–473.

Williams, J.E., and W. Nehlsen.  1997.  Status and trends of anadromous salmonids in the coastal zone with special reference to sea-run cutthroat trout.  Pages 37–42 *in* J.D. Hall, P.A. Bisson, and R.E. Gresswell, editors.  Sea-run cutthroat trout: biology, management, and future conservation.  Oregon Chapter, American Fisheries Society, Corvallis.

Wood, C.C.  1987.  Predation of juvenile Pacific salmon by the common merganser *(Mergus merganser)* on eastern Vancouver Island.  I. Predation during the seaward migration.  Canadian Journal of Fisheries and Aquatic Sciences 44:941–949.

**Chapter 2: Estuarine habitat use and movement of coastal cutthroat trout**
***Oncorhynchus clarkii clarkii* in the Salmon River estuary, Oregon**

**<u>Abstract</u>**

Anadromous coastal cutthroat trout *Oncorhynchus clarkii clarkii* may be highly dependent on estuaries, passing through them multiple times during their lifetime. However, it is often thought that estuaries serve primarily as migration corridors rather than rearing areas, and few studies have investigated estuarine use by cutthroat trout. For 18 months in 2002 to 2003, we used both PIT tag and acoustic tracking techniques to investigate habitat use and movement of coastal cutthroat trout in the Salmon River estuary, Oregon. We also conducted a relocation experiment to test the concept of site fidelity. Cutthroat trout were found in the estuary every month of the year, with abundance highest in spring and fall, when both ocean migrants and estuarine residents were present. Evidence of site fidelity was observed in both the PIT-tagged and acoustically tagged fish, with 70% of PIT tagged fish being recaptured at their previous capture site and most acoustically tagged fish residing in one location for at least 25 days. In the relocation experiment, 90% of fish showed directional movement toward the original site of capture, and 40% eventually took up residence there. Cutthroat trout used main channel sites more frequently than marsh channel sites and deeper sites more frequently than shallower sites. Contrary to published results for most other coastal populations, Salmon River cutthroat trout rear in the estuary for much of the year. Our results imply that conservation of coastal cutthroat trout may depend on recovery and maintenance of suitable estuarine rearing habitat.

**<u>Introduction</u>**

The importance of estuaries to salmonids in general and to coastal cutthroat trout *Oncorhynchus clarkii clarkii* in particular has often been overlooked (Fresh et al. 2005), yet estuaries are presumed to provide productive feeding areas, physiological transition zones, and predator refuges (Simenstad et al. 1982; Thorpe 1994). Coastal cutthroat trout are iteroparous and may pass through an estuary multiple times during the course of their lifetime (Northcote 1997), thus they may be more dependent on estuaries than other anadromous *Oncorhynchus* species. However studies of coastal cutthroat trout have suggested limited use of estuaries by ocean-going smolts (Giger 1972; Hudson 2005), with longer periods of residence upon return (Giger 1972; Tipping 1981). Parr reside in some Oregon and Washington estuaries (Giger 1972; Tipping 1981), and all size classes of coastal cutthroat trout rear in the estuary of the Rogue River, Oregon (Tomasson 1978). Although these studies have demonstrated spring and some summer use of estuaries, little is known about the habitat preferences or movements of individuals within the estuary. Here we describe the results of mark-recapture and telemetry studies to examine the habitat use by coastal cutthroat trout within the Salmon River estuary, Oregon.

Quantifying how coastal cutthroat trout use estuaries is important for understanding how changes from anthropogenic and natural causes might affect the expression of life history diversity and the use of estuarine habitat. Ecologically functioning estuaries are important for conserving and restoring anadromous salmonids (Bottom et al. 2005a), and estuaries may be particularly vital for some life histories of coastal cutthroat trout. Specific information on use of estuarine habitats

by coastal cutthroat trout and movement within estuaries is important for developing conservation and recovery strategies that will provide essential rearing and migratory habitats, and the connectivity of habitats within the estuary.

Coastal cutthroat trout, like Chinook salmon, exhibit a range of life history types and would be expected to have a varied pattern of estuarine use among the life histories, as has been reported for juvenile Chinook salmon (Bottom et al. 2005b). However, little is known about the use of estuarine habitats by coastal cutthroat trout, or what specific habitats are important for those fish that rear in the estuary. The estuarine habitat used by juvenile Chinook salmon is influenced by factors such as size of fish and tidal fluctuations, and encompasses a range of habitat types such as nearshore shallow habitats and deeper offshore areas (reviewed in Bottom et al. 2005b). Marsh areas and tidal creeks in the Salmon River estuary are highly productive habitats for invertebrates and prey (Gray et al. 2002; Jones et al. in press), and are important rearing areas for Chinook fry (Bottom et al. 2005a). Because coastal cutthroat trout generally enter estuaries when they are larger in size than Chinook fry, they may be less directly dependent on shallow and tidally flooded marsh habitats. However, the degree to which coastal cutthroat trout use these and other estuarine habitats is unknown. In addition, factors affecting habitat use or movement within the estuary are unknown.

The present study was designed to investigate the use of the Salmon River estuary specifically by resident coastal cutthroat trout that rear through summer and early fall, including the seasonal timing of estuary use, movement within the estuary and specific use of estuarine habitats. A second study investigated the role of the

Salmon River estuary in the life history diversity of coastal cutthroat trout (*see* Chapter 3). Objectives of the present study were to investigate: (1) seasonal use of the estuary and the effect of fish size on duration of use; (2) general movement of fish within the estuary; (3) relative fidelity of fish to specific sites within the estuary; and (4) distribution among habitats within the estuary and the physical characteristics of frequently used habitats. In 2002–2003 we used both active (acoustic telemetry) and passive (passive integrated transponders, PIT tags) tracking to quantify the habitat use and movements of coastal cutthroat trout within the Salmon River estuary, Oregon.

## **Methods**

### *Study Area*

The Salmon River estuary located on the central Oregon coast drains an area of 194 km$^2$ and the estuary is approximately 800 ha (Bottom et al. 2005a; Figure 1). Flow varies annually, with low flows of approximately 1 m³/s in late summer to peak flows of 25 m³/s to 150 m³/s during winter rains. The Salmon River estuary is small compared with other Oregon estuaries, making it suitable for ecological studies. Although the habitats of the estuary range from deep main stem to tidal marsh channels, the area is small enough to adequately sample without being spatially overwhelmed.
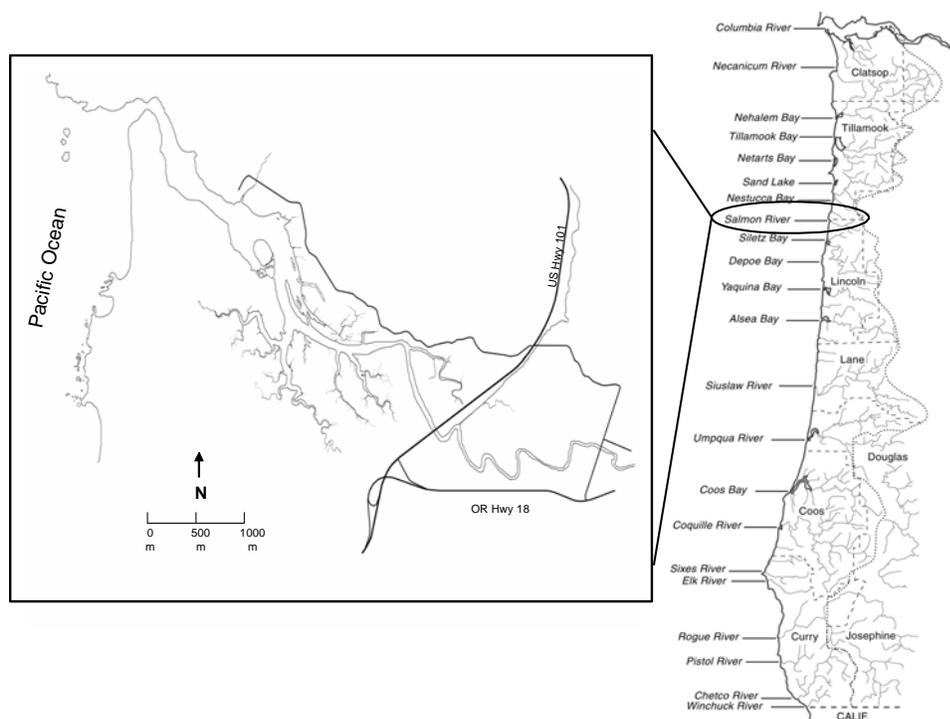
Figure 1.  The Salmon River estuary, located on the Oregon coast.  Inset shows the area of tidal influence.

The Salmon River was altered with earthen dikes and tide gates in the early 1960s to allow agricultural development, resulting in the loss of about 65% of the original marsh habitat (Bottom et al. 2005a).  Three restoration projects were undertaken in 1978, 1987, and 1996 that removed most of the dikes and restored 145 ha to a naturally functioning state (Gray et al. 2002; Bottom et al. 2005a).  As part of the federally designated Cascade Head Research Area, the Salmon River estuary is managed by the U.S. Forest Service to restore the estuary "to its condition…prior to diking and agricultural use."

Other salmonid species that rear in the Salmon River estuary include chinook *Oncorhynchus tshawytscha,* coho *O. kisutch,* and chum salmon *O. keta,* and steelhead

*O. mykiss*.  Chinook salmon are the most abundant salmonid species, and the other species are present in the estuary during certain times of the year.  Nearly 180,000 hatchery coastal cutthroat trout reared at hatcheries on other coastal rivers were released in the watershed between 1949 and 1994 (Johnson et al. 1999).   The annual release of fish from the Salmon River hatchery is approximately 200,000 Coho salmon in May and 200,000 Chinook salmon in August.

### *Capture of fish*

Estuarine habitat use of coastal cutthroat trout was assessed through catch by beach seine and two tagging methods: passive integrated transponder (PIT) tags and acoustic tags.  Fish were captured in 2002 and 2003 both in the river by a 5-m diameter rotary screw trap operated from March to July each year at rkm 7.9, the head of tidal influence (Figure 2), and in the estuary by a beach seine (38 m long and 2.75 m deep with a 0.5 cm mesh).
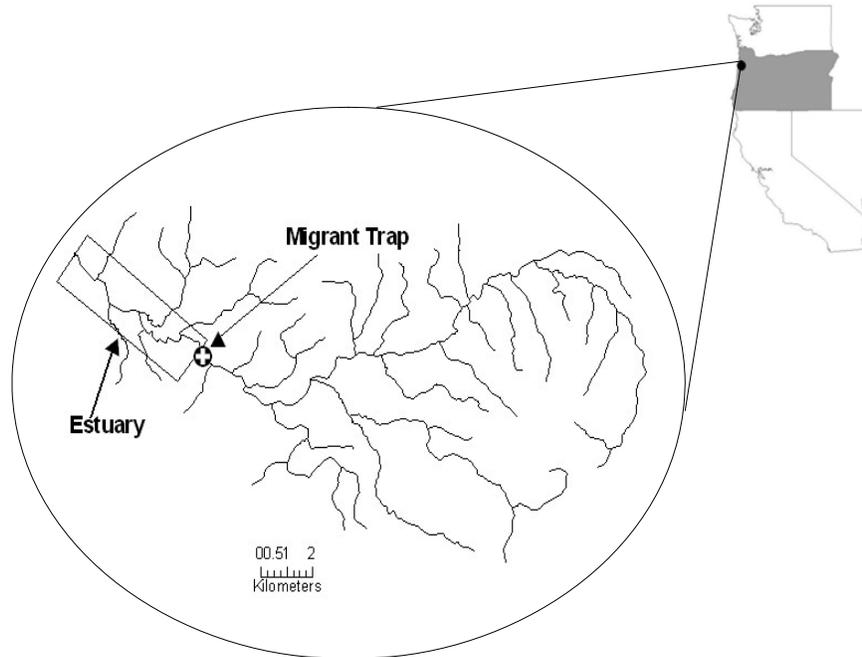
Figure 2.  Salmon River basin, showing the relative size of the estuary and the location of the migrant trap.


We sampled in the estuary with the beach seine weekly or bi-weekly in March–September.  In October–February, sampling occurred an average of twice per month, except in December when it occurred only once.  The beach seine was set with a boat and sampling encompassed a range of water depths within the estuary as well as habitats in fresh, brackish, and marine waters, and habitats located in the main channel and in marshes.  Unless river flows were high, as can happen in winter, marsh channels were sampled only at high tide because they either drained completely at low tide or were too shallow to access by boat.  Based on previous sampling in the estuary, ten sites were selected for regular seining to represent the variation of habitats in the estuary (Figure 3).  Because sampling intensity varied among the ten sites, we chose four sites that were more proportionally sampled to

serve as standard sites for comparison of catch (Figure 3).  Seining occurred

downstream of rkm 3.7 because no suitable sites were found upstream.
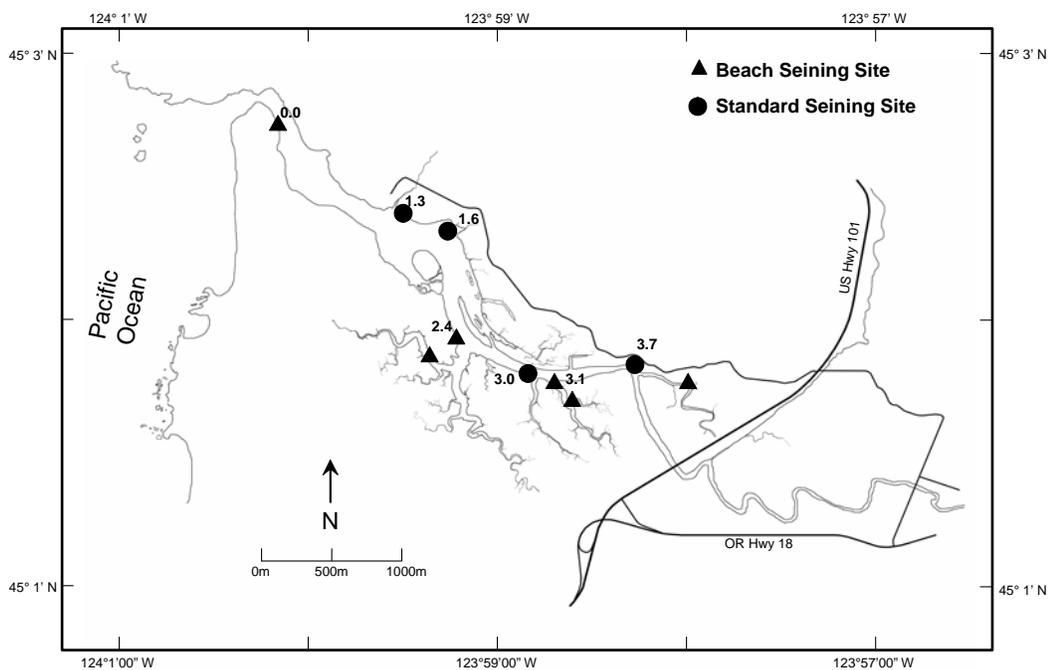


Figure 3.  Location (rkm) of regular and standard beach seining sites in the
Salmon River estuary.

*Surgical procedures for PIT and acoustic tags*

Cutthroat trout > 100 mm captured in the screw trap and beach seine were

PIT-tagged using half-duplex tags that measured 23 mm in length and 3.4 mm in

diameter, and weighed 0.6 g in air.  Of the cutthroat trout captured in the trap, 94%

were > 100 mm; all fish caught with the seine were > 100mm.  Captured fish were

anesthetized (MS 222), measured (FL, $\pm1.0$ mm), scanned for tags using an Allflex®

portable tag reader (model RS-601), and tagged if they were untagged.  Tags were

manually inserted into the peritoneal cavity through a small incision (approximately 5 mm) that was made with a scalpel on the mid-ventral line just posterior to the pectoral fins.  Because the incision was small, no sutures were required to close it.  Tagged fish were held in buckets for recovery and were released within 30 minutes at the site of capture.

Acoustic telemetry was used in 2003 to study detailed habitat use and general movement patterns of coastal cutthroat trout within the estuary.   We tagged 10 coastal cutthroat trout that were captured in the estuary with a beach seine (described above) and that remained in the estuary through summer.  Cutthroat trout were tagged with Vemco® V8SC coded pingers that measured 28 mm long, 9 mm diameter, and weighed 4.7 g in air.  The battery life of the tags was approximately 260 days.  The mean fork length of the tagged fish was 296 mm (range = 193–398 mm).  In half of the tagged fish, the weight of the tags was < 4% of their body weight, whereas the tag weight was between 4.7 and 6.5% of body weight for the rest of the fish.  Tags weighing 4% of body weight of adult westslope cutthroat trout *Oncorhynchus clarkii lewisi,* which were similar in size to the coastal cutthroat trout in this study, had little effect on their behavior (Zale et al. 2005).  Tags were implanted into the peritoneum through a small incision (approximately 10 mm) along the mid-ventral line, and the incision was closed with two to three nylon sutures.  Fish recovered in a 190-L tub of water for about four hours and were released at the capture site.

***Acoustic tracking design***

Vemco® VR2 acoustic receivers were deployed to track the acoustically tagged cutthroat trout and were located 300 m to 1 km apart at 17 sites throughout the estuary: 14 in the main channel and 3 in tidal marsh channels (Figure 4). The range of each receiver is affected by its position in the water column and the level of salinity (Schreck et al. 2001), both of which are constantly changing with incoming and outgoing tides in the Salmon River estuary. Range is shorter in channel areas with high sinuosity. Upstream and downstream receiver range in the Salmon River estuary was 300–500 m, and covered the width of the channel. The range of the receivers frequently overlapped with the next receiver upstream or downstream. However, the nearest receiver to that at the mouth of the estuary was located 1.3 km upstream because other suitable locations were not found (Figure 4). Thus coverage was lacking in approximately 500 m of the lower estuary. The receiver at the mouth of the estuary was washed away or stolen after data were downloaded on July 31. Therefore, data on migration or estuary use at the mouth were unavailable after that date. The range of four receivers in the uppermost reaches of the estuary (rkm 4.8, 5.4, 5.9, and 6.7) did not overlap because of high channel sinuosity. The range of marsh channel receivers at high tide was large enough to overlap the range of receivers in nearby main stem areas. Thus, we could not delineate specific marsh channel use by acoustically tagged fish.

Five receivers were deployed in April and May when tagging began, and twelve additional receivers were deployed in July (Table 1). Because most receiver locations were prone to erosion and subject to high velocity flows during winter floods, we removed them at the end of November. However, four receivers

remained in operation until late January or mid February because they were less

prone to winter disturbance. The receivers continuously recorded data on tag number,

date, and time every 30 seconds on average when fish were in range.
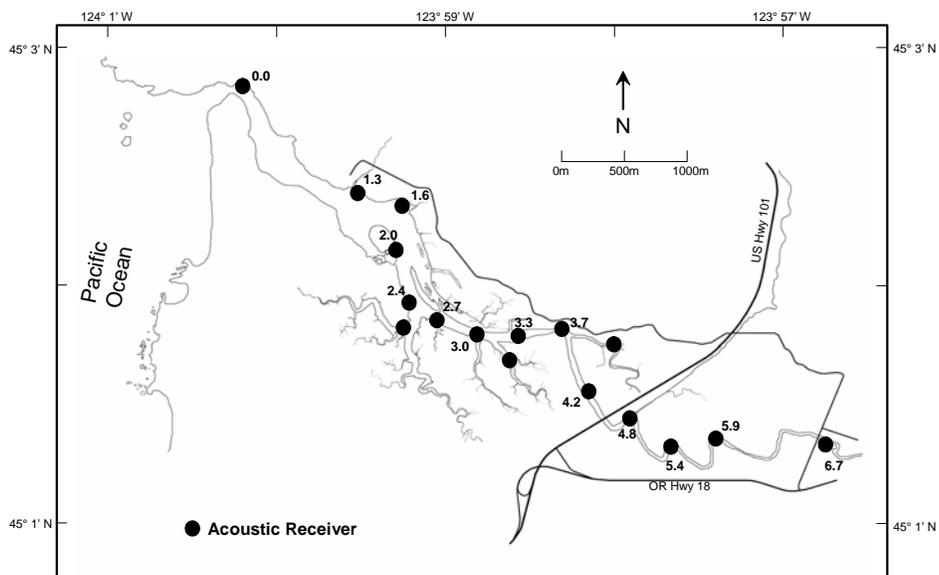


Figure 4. Location (rkm) of acoustic receivers deployed in 2003 in the Salmon River estuary, Oregon.

Table 1. Location of acoustic receivers (rkm) and duration of operation. The first and last X for each receiver denotes that approximately half of the month was sampled. Bold face denotes standard seining sites.

| Location | rkm | 2003 | | | | | | | | | | 2004 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | A | M | J | J | A | S | O | N | D | J | F |
| Estuary Mouth[a] | 0.0 | X | X | X | X | X | | | | | | | |
| **Knight Park** | 1.3 | | | | | X | X | X | X | X | | | |
| **Lighthouse Corner** | 1.6 | | | X | X | X | X | X | X | X | X | X | |
| Golden Crescent | 2.0 | | | | | | X | X | X | X | X | | |
| Below 87 Marsh | 2.4 | | | X | X | X | X | X | X | X | | | |
| 87 Marsh[b] | 2.4 | | | | | | X | X | X | X | | | |
| Ditch | 2.7 | | | | | | X | X | X | X | | | |
| **Lower Control Mouth** | 3.0 | | | X | X | X | X | X | X | X | X | X | |
| Control Marsh[b] | 3.1 | | | | | | X | X | X | X | X[b] | X | |
| Dinosaur | 3.3 | | | | | X | X | X | X | X | | | |
| **96 Mouth** | 3.7 | | X | X | X | X | X | X | X | X | X | X | X |
| 96 Marsh[b] | 3.7 | | | | | | X | X | X | X | | | |
| Below Hwy 101 Bridge | 4.2 | | | | | X | X | X | X | X | | | |
| Salmon Creek Mouth | 4.8 | | | | | X | X | X | X | X | | | |
| Red Barn Hole | 5.4 | | | | | | X | X | X | X | | | |
| Sitka Corner | 5.9 | | | | | | X | X | X | X | | | |
| Deer Creek Mouth | 6.7 | | | | | | X | X | X | X | | | |

[a] Receiver discovered missing in late August. Last download of data occurred on July 31, 2003.
[b] Within marsh receivers, all located 300 m upstream of the confluence of their respective marsh channels with the main stem. River kilometers represent the mouth of each marsh channel.

***Relative abundance and habitat use patterns***

Seasonal estuarine use by coastal cutthroat trout was assessed by comparing the seine catch of fish by month. We used the four standard seining sites (Figure 3; Table 1) for our comparison because they were sampled more frequently than other seining locations and were sampled in relative proportion to each other. Seasonal patterns in fork length of coastal cutthroat trout captured in the estuary were compared by Kruskal-Wallis one way analysis of variance on ranks because the data were non-normally distributed.

The use of specific habitats within the estuary was investigated by comparing the relative abundance (CPUE = catch per seine haul) of coastal cutthroat trout among seining sites. The proportion of the total estuary catch that occurred at each site was expressed as the percentage of the summed CPUE for all sites rather than the percentage of total catch of fish to standardize the catch of fish at each site by effort (number of seine hauls). Because marsh channel habitats are not accessible to cutthroat trout at low tide, we used catch from seine hauls made only during high ebb and flow tides to evaluate differences in CPUE between main channel and marsh channel sites. Because the data were non-normally distributed we used a Wilcoxon rank-sum test to test for differences.

Habitat characteristics of sites were described by water depth (m), water temperature (°C), and salinity (ppt). Measurements were taken monthly from April–August 2003 at each of the regular seining sites during high and low tides. We measured depth at the deepest point at each site as well as temperature and salinity in 0.5 m intervals from the surface to the bottom using an electronic HydroLab®.

During July high tide sampling we were able to measure temperature and salinity

only at the sites upstream of rkm 3.0 because of equipment malfunction. Because

data were non-normally distributed we used a Wilcoxon rank-sum test to test for

differences between the depth of high-use sites and low-use sites.

*Relocation experiment*

We conducted a pilot study in 2002 to investigate the feasibility of using

acoustic tags to study the behavior and habitat use of coastal cutthroat trout in the

estuary. Because we saw evidence of strong site fidelity during this study, we

designed an experiment in 2003 to test the strength of site fidelity by relocating 10

acoustically tagged coastal cutthroat trout. Three holding sites were identified from

the 2002 acoustic and PIT tagging data (rkm 1.6, 3.0, and 3.7). We captured and

tagged fish in the middle site (rkm 3.0) and relocated them to release sites 1.7 km

upstream or downstream (Figure 5). Release sites were chosen because fish would

have to move through known holding sites in order to return to the original site of

capture. The fish were captured in July by beach seine and were implanted with

acoustic tags using the methods outlined above. We tracked the movement of these

fish with the 17 receivers deployed throughout the estuary. The mean length at

tagging of the relocated fish was not statistically different between those moved

upstream and those moved downstream (t-statistic = 0.15, $P$ = 0.9, df = 8).
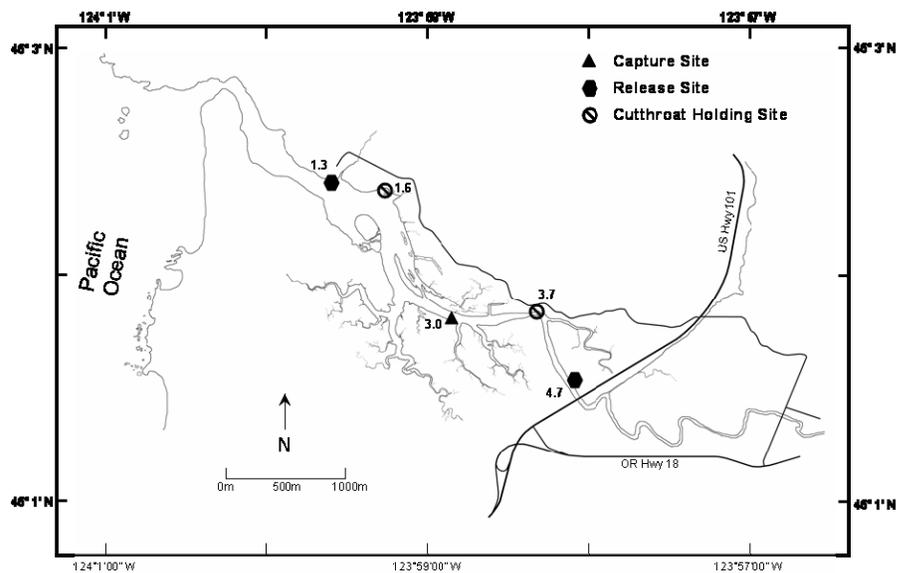
Figure 5.  Salmon River estuary showing locations (rkm) of capture and release sites used in a relocation experiment.  Other main holding sites are also shown.

## Results

### *Seasonal use and movement*

Coastal cutthroat trout were found in the estuary every month during the 18 months of this study.  The seasonal pattern of relative abundance in the estuary generally showed high catch in late April and early May, followed by a sharp drop in late May as ocean migrants left, and relatively low catch in summer (Figure 6). Relative abundance increased in late August when ocean migrants returned and dropped again in September when fish began to move upstream (Figure 6).
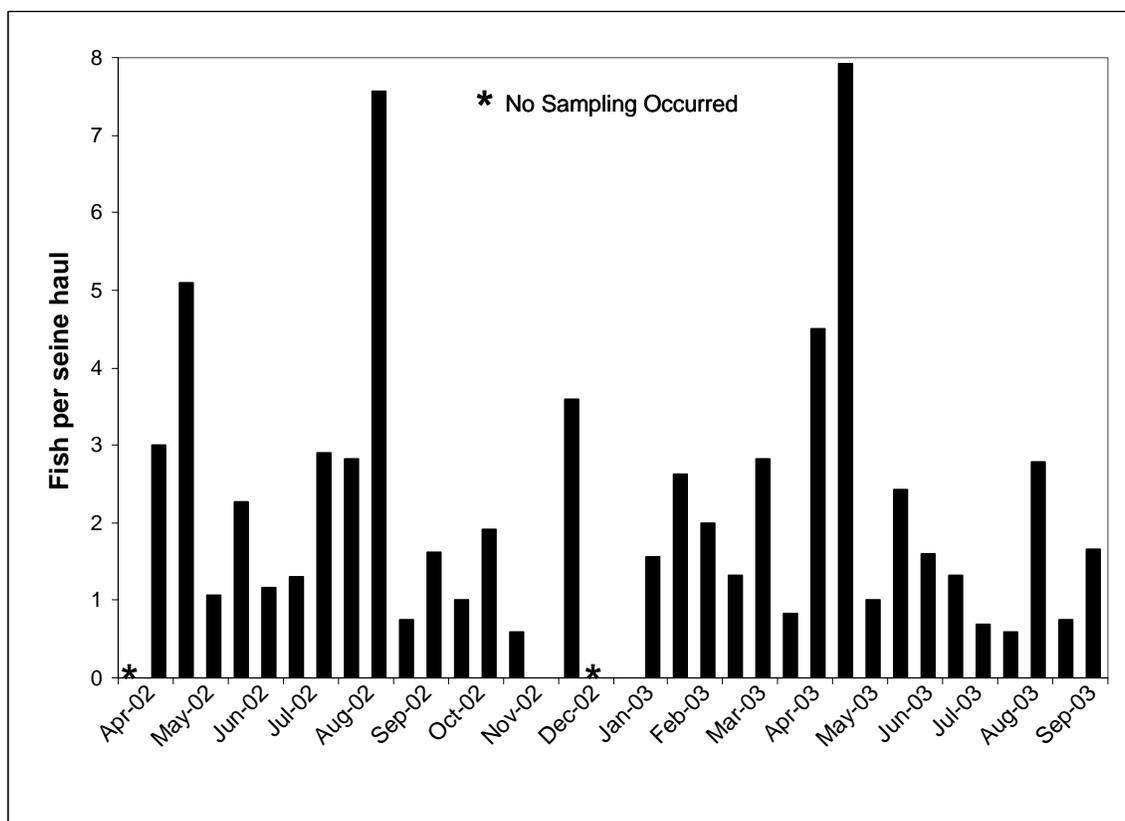
Figure 6.  Bi-weekly catch per unit effort (fish per seine haul) of coastal cutthroat trout captured with a beach seine in the Salmon River estuary.  Only standard sites are included.

The movements of acoustically tagged fish in the estuary were variable and showed upstream and downstream patterns among locations, but coastal cutthroat trout generally resided at a single site for a few weeks to several months (Figure 7). The date of upstream migration for 10 of 20 acoustically tagged fish was determined by the last detection at our uppermost receiver and ranged from late July to mid-November (Table 2).  Of the fish that moved upstream, three were detected again in the estuary after 17–65 days (Table 2).  However, the final receiver was removed

from operation on February 13<sup>th</sup>; therefore fish returning to the estuary after that date would not have been detected.
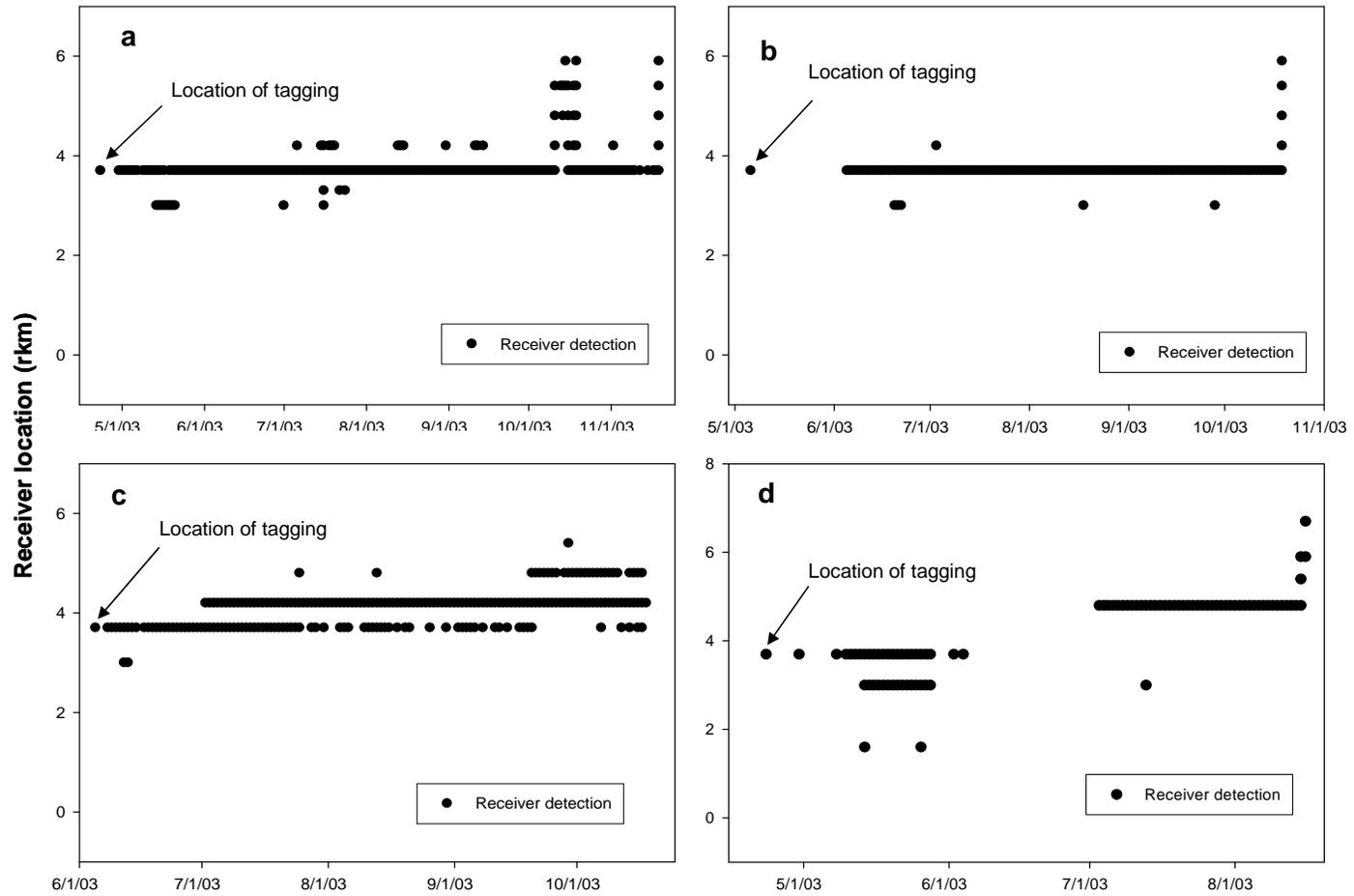
Figure 7.  Variation in movement patterns for four estuarine resident cutthroat trout acoustically tagged in spring, 2003. Points represent at least one detection on a given day.  For graph simplicity, detections on receivers only at rkm 1.6. 3.0, 3.7, 4.8, 5.4, and 5.9 are plotted to eliminate overlapping detections.

Table 2.  Movement and habitat use of acoustically tagged coastal cutthroat trout in the Salmon River estuary, 2003.

| Tag ID | Fish length (mm) | Date tagged | Date of upstream migration | Detected seasons of use[a] |
|---|---|---|---|---|
| 101 | 398 | 4/28/2003 | 8/15/2003 | Summer |
| 103 | 193 | 4/30/2003 | 9/2/2003 | Summer |
| 105 | 285 | 4/30/2003 | -- | b |
| 106 | 310 | 4/30/2003 | -- | Summer/Fall |
| 107 | 304 | 4/30/2003 | 11/19/2003 [c] | Summer/Fall/Winter |
| 108 | 205 | 5/6/2003 | -- | Summer/Fall/Winter |
| 109 | 326 | 5/8/2003 | 8/16/2003 | Summer |
| 117 | 282 | 5/19/2003 | 9/11/2003 | Summer |
| 119 | 270 | 6/5/2003 | -- | Summer/Fall |
| 120 | 376 | 7/3/2003 | 10/19/2003 | Summer/Fall |
| 123 | 257 | 7/3/2003 | -- | Summer |
| 125 | 320 | 7/3/2003 | -- | Summer/Fall/Winter |
| 126 | 363 | 7/3/2003 | 7/29/2003 | Summer |
| 127 | 210 | 7/3/2003 | -- | Summer/Fall |
| 129[d] | 251 | 7/3/2003 | -- | Summer |
| 130 | 229 | 7/3/2003 | -- | Summer/Fall |
| 124 | 288 | 7/7/2003 | 10/25/2003 [c] | Summer/Fall |
| 128 | 363 | 7/7/2003 | 10/8/2003 [c] | Summer/Fall/Winter |
| 121 | 259 | 7/9/2003 | 9/4/2003 | Summer |
| 122 | 335 | 7/9/2003 | -- | Summer |

[a] Reflects minimum seasons of use only because we cannot determine estuarine use before tagging or after the tags stopped working. Fish tagged prior to June 5th are also known to use the estuary during the spring.
[b] Detections stopped abruptly after 25 days.
[c] Returned to the estuary after migrating upstream.  Days spent upstream: tag 107 = 65 days; tag 124 = 17 days; tag 128 = 41 days.
[d] Migrated to the ocean on 7/15/2003.

Over half of the acoustically tagged cutthroat trout remained in the estuary into the fall (September–November) and four of these were in the estuary through part of the winter (December–February) (Table 2). Because the fish were tagged after they had been in the estuary for an unknown length of time, the seasonal use should be considered a minimum estimate. In addition, because some tags stopped abruptly when the fish were still in the estuary, the full use of the estuary could not be determined. One fish had detection gaps in December and was detected only at the lower most receiver in operation at that time (rkm 1.6). With no receiver deployed at the mouth, it is uncertain whether this fish had made brief forays in the ocean. Two other fish were monitored continuously at rkm 1.6, until detections abruptly stopped in September and November. Although these fish may have migrated downstream and potentially to the ocean, their last detections were in September and November, suggesting that the tags likely ceased operation rather than the fish having migrated to the ocean.

### *Seasonal patterns in fish size*

The monthly median length of coastal cutthroat trout captured in the estuary by beach seine was lowest in May 2003 (161 mm) and highest in February and September 2003 (264 mm) (Figure 8; Table 3). The median length of fish captured in April and May 2003 was significantly smaller than fish captured in the previous 7 months ($P < 0.05$), except November which had a sample size of only 3. Median

length of fish in April and May 2003 was also significantly smaller than fish in June,

August, and September 2003 ($P < 0.05$).
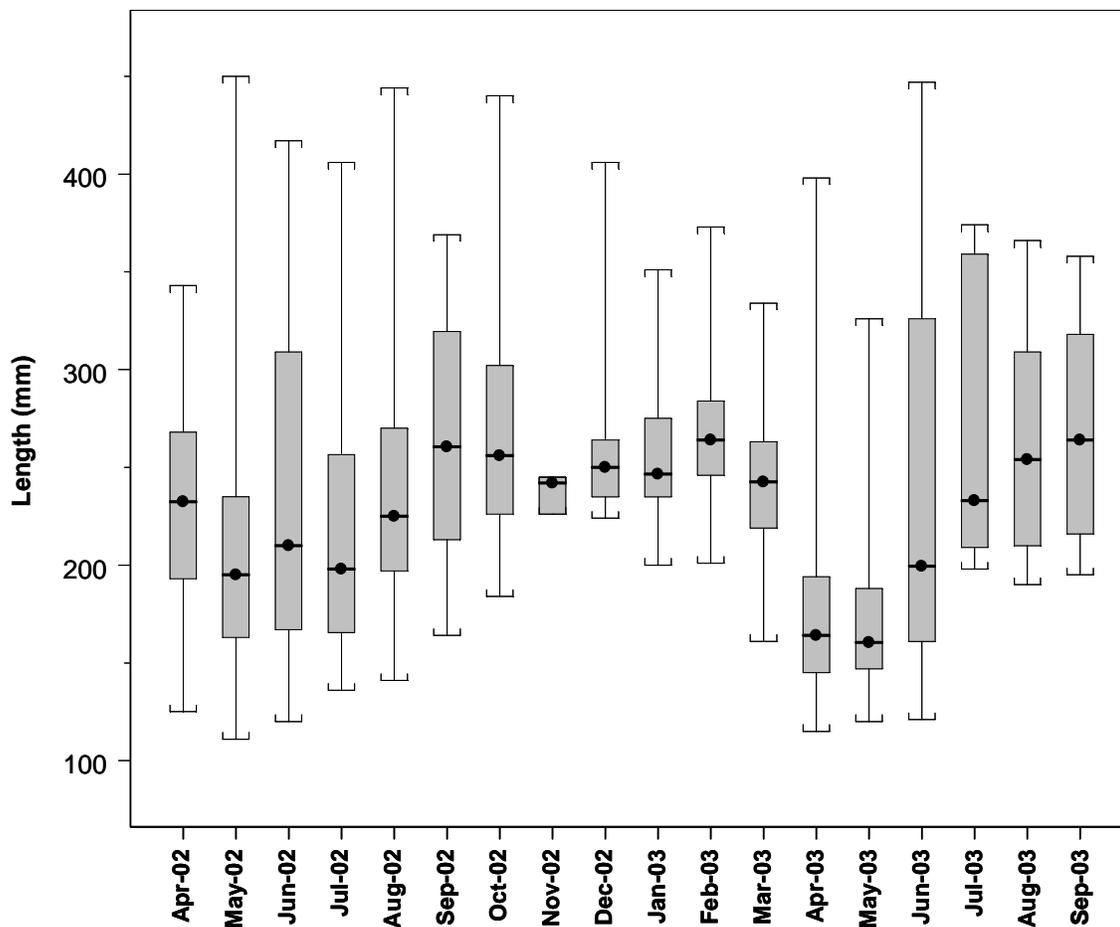


Figure 8. Median fork length (mm) of coastal cutthroat trout captured in the Salmon River estuary by beach seine. Sample sizes are given in Table 2. The median is indicated by the closed circle and the solid line. The box contains the middle 50% of data, bounded by the 75th percentile of the data set on top and the 25th percentile on bottom. Whiskers indicate the range.

Table 3.  Number and length of coastal cutthroat trout, caught in the estuary by beach seine at all regular sites for each month of the study.

| Month | Number caught | Number measured | Fork Length (mm) | | | Seine Hauls |
|---|---|---|---|---|---|---|
| | | | median | mean | range | |
| Apr-02 | 65 | 54 | 233 | 229 | 125-343 | 35 |
| May-02 | 77 | 77 | 195 | 203 | 111-450 | 56 |
| Jun-02 | 59 | 59 | 210 | 231 | 120-417 | 59 |
| Jul-02 | 94 | 92 | 198 | 218 | 136-406 | 70 |
| Aug-02 | 146 | 141 | 225 | 236 | 141-444 | 61 |
| Sep-02 | 28 | 28 | 261 | 261 | 164-369 | 38 |
| Oct-02 | 38 | 38 | 256 | 265 | 184-440 | 53 |
| Nov-02 | 3 | 3 | 242 | 238 | 226-245 | 30 |
| Dec-02 | 18 | 18 | 250 | 262 | 224-406 | 15 |
| Jan-03 | 14 | 14 | 247 | 256 | 200-351 | 23 |
| Feb-03 | 27 | 27 | 264 | 268 | 201-373 | 18 |
| Mar-03 | 54 | 54 | 243 | 243 | 161-334 | 36 |
| Apr-03 | 97 | 97 | 164 | 180 | 115-398 | 43 |
| May-03 | 112 | 112 | 161 | 174 | 120-326 | 25 |
| Jun-03 | 42 | 38 | 200 | 237 | 121-447 | 39 |
| Jul-03 | 16 | 15 | 233 | 279 | 198-374 | 36 |
| Aug-03 | 33 | 31 | 254 | 264 | 190-366 | 25 |
| Sep-03 | 14 | 14 | 264 | 268 | 195-358 | 22 |

*Patterns of habitat use*

The ten beach seining sites were classified by the percent of the total catch per unit effort (CPUE measured as fish per seine haul) into high-use sites (> 10% of total CPUE) and low-use sites (< 5%).  All high-use sites at high tide for coastal cutthroat trout occurred in the main channel habitats (Table 4).  The low-use sites at high tide included all marsh channel sites and two of the seven main channel sites.  The median CPUE of coastal cutthroat trout was significantly lower at marsh sites than at main channel sites (Wilcoxon $Z = 6.20$, $P < 0.001$).  Median CPUE at high tide was 0.4 for main channel sites combined (range = 0–21) and 0.0 at marsh channel sites combined

(range = 0–6).  The seven main channel sites accounted for 94.3% of the total CPUE

at high tide (Table 4).

Table 4.  Catch per unit effort (fish per seine haul) at high tide of coastal cutthroat
trout and percent of the total catch per unit effort for ten regular beach seining sites in
the Salmon River estuary, April 2002–September 2003.

| Location | River Km | CPUE | % of total CPUE | Level of use |
|---|---|---|---|---|
| **Main channel sites** | | | | |
| Estuary Mouth | 0.0 | 0.04 | 0.4 | Low-use |
| Knight Park | 1.3 | 2.29 | 22.4 | High-use |
| Lighthouse Corner | 1.6 | 2.39 | 23.4 | High-use |
| Below 87 Marsh | 2.4 | 0.17 | 1.6 | Low-use |
| Lower Control Mouth | 3.0 | 1.90 | 18.7 | High-use |
| Control Mouth | 3.3 | 1.16 | 11.4 | High-use |
| 96 Mouth | 3.7 | 1.67 | 16.4 | High-use |
| **Marsh channel sites** | | | | |
| 87 Marsh[a] | 2.4 | 0.04 | 0.4 | Low-use |
| Control Marsh[a] | 3.1 | 0.15 | 1.5 | Low-use |
| 96 Marsh[a] | 3.7 | 0.38 | 3.8 | Low-use |

[a] Within marsh receivers, all located 300 m upstream of the confluence of their respective
marsh channels with the main stem.  River kilometers measured from the mouth of each
marsh channel.

Detections of acoustically tagged fish similarly revealed that individuals

primarily resided in main channels rather than in marsh-channel habitats.  Because

the range of marsh receivers overlapped with the range of adjacent main-channel

receivers, we could not determine if the occasional detections on marsh receivers

indicated that some fish had entered the marsh channels.  Five of the 20 acoustically

tagged fish (10 fish tagged in spring and classified as estuarine residents and 10 fish

used in the relocation study) were detected for more than 20 minutes on a marsh

receiver, but were simultaneously recorded on the main channel receivers.  Even if

these individuals had entered the marsh channel they remained in the lowermost

reaches within the detection range of the nearest main-channel receiver.

Two of the seven sites in the main channel had a catch < 5% of the total

CPUE (Table 4).  One of these sites (rkm 2.4) was shallower than other main channel

sites and was often completely exposed at low tide.  The other site was located at the

mouth of the estuary, in an area subject to strong tidal currents and shifting sandy

substrate and may have been a poor location for coastal cutthroat trout to hold for

extended periods.

We compared mean high tide depth between high-use sites and low-use sites

(Table 5).  Mean high tide depth was statistically greater in high-use sites than in low-

use sites when the estuary mouth site was excluded (Wilcoxon $Z = 2.3$ , $P = 0.02$).  Of

the five sites with the largest CPUE, three were located at the mouth of a marsh

channel (rkm 3.0, 3.3, 3.7) and one at the mouth of a small stream (rkm 1.3).  The

other site (rkm 1.6) is an eel grass bend located at a bend in the river.

Table 5.  Mean depth (m) and standard error (+/-, in parenthesis) of regular beach seining sites at high and low tide, April 2003 – August 2003.

| | High-use sites (rkm) | | | | | Low-use sites (rkm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1.3 | 1.6 | 3.0 | 3.3 | 3.7 | 0.0 | 2.4 | 2.4[a] | 3.1[a] | 3.7[a] |
| High Tide | 1.6 | 2.1 | 2.0 | 1.6 | 4.1 | 2.6 | 1.3 | 0.9 | 1.0 | 1.5 |
| | (.05) | (.13) | (.09) | (.10) | (.46) | (.06) | (.06) | (.05) | (.05) | (.06) |
| Low Tide | 0.7 | 1.1 | 1.1 | 0.7 | 3.1 | 1.8 | 0.5 | b | b | b |
| | (.16) | (.08) | (.09) | (.10) | (.26) | (.10) | (.08) | | | |

[a] Within marsh sites, all located 300 m upstream of the confluence of their respective marsh channels with the main steam.  River kilometers were measured from the mouth of each marsh channel.
[b] No water at low tide

Water temperatures in spring and summer varied and were affected by tide level and freshwater influence.  In the spring, freshwater input tended to be cooler than marine water input, as indicated by the cooler water closer to the surface (Table 6).  Conversely, water temperatures in the summer were lower farther downstream in the estuary because marine water input was cooler than freshwater input and the range of temperatures was greater than that during the spring months.  A thermocline was present at several sites in the summer.  A temperature difference of 5.6°C between 0.5 m and the bottom was observed at the deepest site (rkm 3.7) and occurred in June and July.

Table 6. Mean high tide water temperature (°C) and salinity (ppt), 0.5 m below surface and bottom (s/b) for high-use sites (rkm 1.3, 1.6, 3.0, 3.3, 3.7) and low-use sites (rkm 0.0, 2.4, 2.4[a], 3.1[a], 3.7[a]) in the Salmon River estuary, 2003. Data gaps in July were the result of malfunctioning equipment.

| | Apr | May | Jun | Jul | Aug |
|---|---|---|---|---|---|
| **rkm** | **Temperature at 0.5m/bottom (°C):** | | | | |
| High-use sites: | | | | | |
| 1.3 | 12.0/12.0 | 10.2/10.2 | 8.6/8.6 | -- | 10.2/9.6 |
| 1.6 | 12.1/11.9 | 10.6/10.3 | 9.5/8.9 | -- | 10.4/9.8 |
| 3.0 | 10.3/11.9 | 12.2/10.8 | 10.1/10.0 | -- | 12.8/12.0 |
| 3.3 | 10.2/11.8 | 12.1/10.8 | 12.0/11.0 | 12.6/11.9 | 14.5/12.6 |
| 3.7 | 9.5/11.2 | 11.5/11.1 | 19.6/11.4 | 12.6/11.8 | 17.5/15.9 |
| Low-use sites: | | | | | |
| 0.0 | 11.6/11.6 | 10.1/10.1 | 8.2/7.8 | -- | 9.0/9.0 |
| 2.4 | 11.3/11.8 | 10.8/10.6 | 9.8/9.7 | -- | 11.5/11.2 |
| 2.4[a] | 11.0/11.7 | 10.7/10.6 | 10.1/10.1 | 14.5/14.3 | 16.5/13.5 |
| 3.1[a] | 11.4/11.4 | 12.4/12.3 | 16.0/13.5 | 20.1/14.5 | 21.0/24.3 |
| 3.7[a] | 10.7/10.5 | 12.0/12.0 | 21.6/21.6 | 20.2/14.6 | 19.5/17.9 |
| | **Salinity at 0.5m/bottom (ppt):** | | | | |
| High-use sites: | | | | | |
| 1.3 | 33.1/33.1 | 34.5/34.5 | 36.6/36.6 | -- | 36.1/35.9 |
| 1.6 | 32.6/32.9 | 33.3/34.1 | 36.3/36.5 | -- | 35.5/35.9 |
| 3.0 | 0.2/29.2 | 18.3/30.8 | 35.7/35.8 | -- | 33.2/35.0 |
| 3.3 | 1.1/1.1 | 5.0/28.7 | 33.7/34.6 | 34.0/35.1 | 32.6/34.7 |
| 3.7 | 0.0/20.8 | 0.5/24.2 | 8.0/32.4 | 34.1/34.7 | 26.0/30.0 |
| Low-use sites: | | | | | |
| 0.0 | 32.0/33.1 | 34.0/34.4 | 35.8/36.5 | -- | 36.2/36.4 |
| 2.4 | 24.7/31.6 | 28.6/30.2 | 36.2/36.3 | -- | 35.5/35.5 |
| 2.4[a] | 10.6/26.0 | 16.8/28.5 | 36.0/35.9 | 34.5/35.3 | 30.4/33.5 |
| 3.1[a] | 0.6/11.7 | 1.1/1.2 | 17.2/29.9 | 22.0/33.0 | 21.0/24.3 |
| 3.7[a] | 0.0/0.1 | 0.7/0.7 | 4.1/4.1 | 20.7/31.4 | 19.8/25.8 |

[a] Within marsh sites, all located 300 m upstream of the confluence of their respective marsh channels with the main stem. River kilometers measured from the mouth of each marsh channel.

Salinity levels decreased upstream and a halocline was present at many of the sites (Table 6). The depth of the freshwater lens over the denser saltwater varied by the depth of the site and the tide level. Deeper sites had a more extreme halocline than the shallow sites. Salinity at low tide was more uniform throughout the estuary

because the marine input was less, although a halocline was still observed in the deepest site (rkm 3.7), suggesting that the denser saltwater lower in the water column was not completely flushed out on each outgoing tide.

*Site Fidelity*

Coastal cutthroat trout exhibited strong site fidelity while in the estuary. Of the PIT-tagged fish recaptured in the estuary in the same year, 70% were recaptured at the original site of tagging (Figure 9). Over a third of the fish (39%) were recaptured multiple times (Figure 10). Median days between recapture was 21 and ranged from 0 to 178 days (Figure 11). All 10 fish that were acoustically tagged in spring and that remained in the estuary through summer had a maximum holding time in one location of 25 days or greater (mean = 102 days, median = 79 days, range = 25–283 days) (Table 7). One fish held for 283 days in the same location (rkm 3.7) until the receiver was removed in February 2004. Several fish took up residence at a particular site, held there for a period of several weeks to a few months, and then moved to another site and resided there.
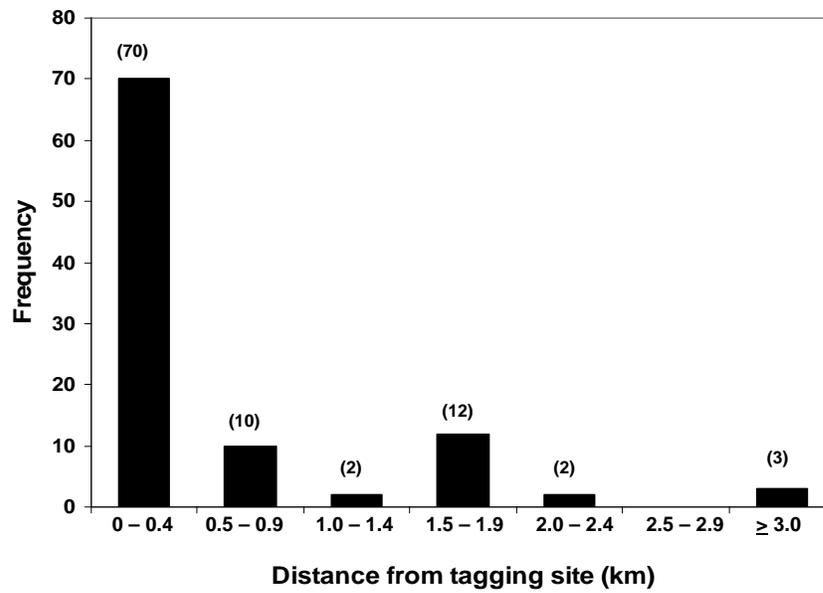
Figure 9.  Frequency of movement between capture site and recapture site for PIT-tagged coastal cutthroat trout in the Salmon River estuary, April 2002–September 2003.  Includes within year recaptures only.  Sample size is shown in parenthesis.
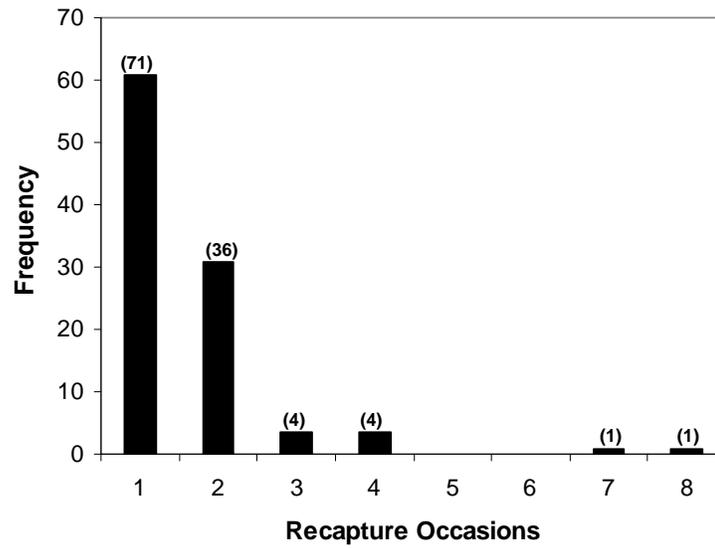
Figure 10.  Frequency of recapture occasions for PIT-tagged coastal cutthroat trout in the Salmon River estuary, April 2002–September 2003.  Sample size is shown in parenthesis.
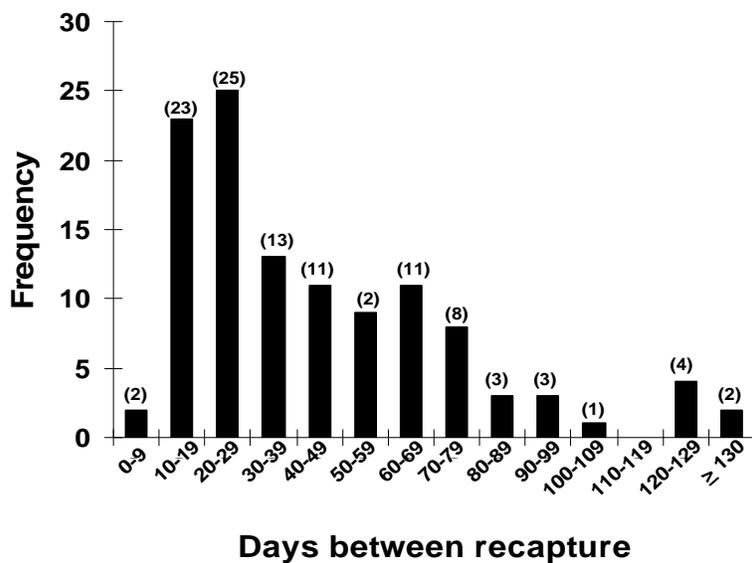
Figure 11.  Frequency of the days between recapture for PIT-tagged coastal cutthroat trout in the Salmon River estuary, April 2002–September 2003. Includes multiple recaptures of the same fish and within-year recaptures only. Sample size is shown in parenthesis.

Table 7.  Maximum number of days that acoustically tagged coastal cutthroat trout were continuously detected in one location in the Salmon River estuary, May 2003– February 2004.

| | Tag ID | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 101 | 103 | 105 | 106 | 107 | 108 | 109 | 117 | 119 | 120 |
| Location (rkm) | 3.7 | 6.7 | 3.7 | 3.7 | 3.7 | 3.7 | 4.8 | 5.4 | 4.2 | 3.7 |
| Days | 109 | 25 | 25 | 49 | 194 | 283 | 43 | 50 | 108 | 136 |

*Relocation Experiment*

All fish that were relocated from their capture site left the release site within three hours (median 1 h: 21 min), and 9 exhibited directional movement back to the capture site, where they were eventually detected (Table 8).  Of the nine fish that returned to the capture site, eight were detected there within 14 hours of release (median = 8 h: 54 min) and one fish returned five days later (Table 8).  However, only one fish returned immediately to the capture site and remained there for more than 24 hours, and four other fish remained at the capture site for 5–7 hours upon return (Table 8).  After movement to other sites, four fish returned to the capture site and remained there for 11–79 days.  One fish that was relocated to rkm 4.2 moved upstream and resided between rkm 5.4 and 5.9 for 25 days before continuing upstream and out of range of our receivers.

Table 8.  Movement of acoustically tagged coastal cutthroat trout that were captured at rkm 3.0 and relocated 1.7 km upstream or downstream in the Salmon River estuary, July 2003.

| Tag ID | Date Tagged | Release Site (rkm) | Fork Length (mm) | Time at release site (hrs:min) | Time to capture site (hrs:min) | Duration at capture site upon first return (hrs:min) | Most frequently occupied site (rkm) | Maximum holding time (days) |
|---|---|---|---|---|---|---|---|---|
| 125 | July 3 | 1.3 | 320 | 2:12 | 6:09 | 17:13 | 3.7 | 173 |
| 129 | July 3 | 1.3 | 251 | 0:14 | 7:55 | 0:48 | a | a |
| 130 | July 3 | 1.3 | 229 | 1:07 | 8:54 | 5:12 | 3.0 | 69 |
| 124 | July 7 | 1.3 | 288 | 1:35 | 8:46 | 182:30 | 5.9 | 94 |
| 128 | July 7 | 1.3 | 363 | 1:06 | 9:33 | 0:10 | 3.0 | 79 |
| 123 | July 3 | 4.2 | 257 | 0:41 | 13:39 | 1:36 | 3.0 | 58 |
| 126 | July 3 | 4.2 | 363 | 1:49 | b | b | 4.8 | 2[b] |
| 127 | July 3 | 4.2 | 210 | 2:44 | 12:22 | 1:01 | 3.0 | 11[c] |
| 121 | July 9 | 4.2 | 259 | 2:44 | 7:34 | 10:13 | 6.7 | 40 |
| 122 | July 9 | 4.2 | 335 | 0:17 | 122:17 | 12:39 | 1.6 | 8[d] |

[a] Detected daily at numerous locations downstream of rkm 4.2 and migrated to the ocean on July 15.
[b] Did not return to capture site.  Moved upstream and out of range on July 29.
[c] Unexplained gaps in detections, but detected at rkm 3.7 for 1 – 7 days at a time.
[d] Detections ended abruptly on July 24.

Of the ten relocated fish, three were detected for 25 days or less: one migrated to the ocean in 12 days, one migrated upstream and out of range in 25 days, and one was detected for 14 days, after which the tag likely malfunctioned. Of the seven fish that were detected for more than 25 days, six showed fidelity to a site for at least 40 days. The remaining fish was detected continuously at rkm 3.7 for periods of 1–7 days, but had gaps in detections of 1–32 days, during which it was not detected on receivers upstream or downstream of this site, making movement from the site unlikely. This fish may have remained at or near rkm 3.7 but in a location where the receiver could not detect it or the tag may have malfunctioned and transmitted irregular pulses. We divided the six fish exhibiting strong site fidelity into two main movement categories: (1) fish (three) that returned to the original capture site briefly and, after wandering among sites, took up residence at another site; and (2) fish (three) that initially returned to the capture site briefly, but subsequently moved among other sites before taking up residence at the capture site.

**<u>Discussion</u>**

The Salmon River estuary plays an important role in the life history of coastal cutthroat trout and provides rearing habitats that are used throughout the year. Estuarine habitats were used as: (1) transitional habitat for outgoing ocean migrants in the spring and as rearing habitat for returning ocean migrants in the fall; (2) summer rearing habitat for both parr and adult estuarine residents; and (3) winter rearing habitat for some fish.

The first objective of this study was to determine seasonal estuarine use by coastal cutthroat trout and if fish size affected the time fish spent in the estuary. Coastal cutthroat trout were found in the estuary during every month of the study. The highest abundances of cutthroat trout occurred in spring and late summer, when both ocean migrants and estuarine residents are likely to be in the estuary (*see* Chapter 3; Giger 1972). Although late upstream migrants and early downstream migrants have been documented in other systems (Sumner 1962; Giger 1972), we are unaware of other studies that document winter rearing in estuaries by coastal cutthroat trout. We observed relatively high catch of coastal cutthroat trout on several occasions during the winter. In addition, several of the acoustically tagged fish stayed in the estuary for the duration of their tag life and several were still holding in the estuary when the final receivers were taken out of operation in February 2004.

Coastal cutthroat trout sampled in the estuary were largest in late summer, which likely reflects spring and summer growth of estuarine residents and ocean growth of returning migrants. Large fish were also observed in the winter and may reflect spent adults returning to the estuary after spawning (Sumer 1962; Giger 1972), or fish that reared in the estuary through winter. The lowest median length was observed in April and May, which may be due to the movement of migrant parr into the estuary. Migrant parr are reported to reside in other estuaries (Giger 1972; Tipping 1981), which is consistent with our results. However, this study also documented that larger adult fish resided in the estuary throughout the year.

The second objective was to describe seasonal movement of coastal cutthroat trout in the estuary. Most of the coastal cutthroat trout in the Salmon River estuary

began migrating upstream in the fall, but a few fish migrated in late July and mid August. Similar results have been reported for coastal cutthroat trout populations in other Northwest river basins (Giger 1972; Sumner 1962). Because the battery life of the tags was limited, we could not monitor fish returning to the estuary after mid-winter or estimate the average time fish remained upstream. Two of the three fish that returned to the estuary spent a short amount of time upstream (17 and 41 days) and returned to the estuary by mid-November. Coastal cutthroat trout spawn in late winter to early spring, thus it is unlikely that these brief upstream movements coincided with a spawning run.

The third objective was to examine the relative fidelity of fish to specific sites within the estuary. The results at Salmon River reveal a high degree of estuarine site fidelity by coastal cutthroat trout. The acoustic telemetry results indicate that most individuals remained at a single site for many months and some fish used several sites for extended periods. PIT-tagged fish were more likely to be found in their previous site of capture than at another site, and acoustically tagged fish were observed to stay within approximately 300 meters of one site for weeks to months at a time. Although attachment to freshwater sites has been documented for several salmonid species, including cutthroat trout (Bridcut and Giller 1993; Armstrong et al. 1997; Huntingford et al. 1998), this behavior has not been previously documented in estuaries.

The relocation experiment provided further evidence that individuals may have a strong affinity for particular estuarine sites. Nine of ten displaced fish showed directional movement towards the original site whether they were displaced upstream

or downstream. Thus, the results are not simply evidence of rheotaxis because fish did not move in response to current. The relocation experiment assumes that the fish had fidelity to the capture site prior to being relocated and were holding in that site as opposed to moving through when they were captured, which may explain why only half of the fish preferred the original site. In addition, we cannot determine whether relocating fish altered their behavior.

Our results are similar to those seen for displaced salmonids, including cutthroat trout, in several freshwater studies (Miller 1954; Halvorsen and Stabell 1990; Armstrong and Herbert 1997; Huntingford et al. 1998). Homing in streams may be achieved by recognition of specific odors (Hara 1993); by positive rheotaxis (de Leaniz 1989) or by chemical, hydraulic, or topographical cues in stream stretches that fish had previously explored (Armstrong and Herbert 1997; Belanger and Rodriguez 2001). In freshwater, cutthroat trout showed a homing response after being displaced from their home site and relocated 820–2285 m up or downstream (Miller 1954). Fish displaced downstream homed more effectively than those displaced upstream, and homing success declined with displacement distance (Miller 1954; de Leaniz 1989; Halvorsen and Stabell 1990). We did not see evidence of a difference in behavior for those fish relocated upstream compared to those relocated downstream and, because all fish were relocated the same distance from the capture site, we cannot determine if homing success in the estuary is affected by distance moved.

Because many fish moved among multiple home sites, we have little evidence to suggest that coastal cutthroat trout in the Salmon River estuary have restricted

home ranges. Most stream-dwelling salmonids, including coastal cutthroat trout, were thought to have a fairly restricted home range, and spend most of their lives within short (20–50 m) reaches (Gerking 1959). However, recent studies have documented that, even though the majority of fish in a population may exhibit limited movement, a portion of fish will move greater distances (Solomon and Templeton 1976; Heggenes 1988; Heggenes et al. 1991, Smithson and Johnston 1999). In addition, some large adult brown trout in the Au Sable River, Michigan used multiple home sites separated by an average distance of 500 m (Diana et al. 2004). Similar studies of salmonid home range have not been conducted in estuaries.

The fourth objective was to determine use of particular habitats and if frequently used habitats had specific characteristics. Coastal cutthroat trout used main channel sites over marsh channel sites. The marsh channel sites accounted for only 6% of the total CPUE during sampling at high tide when all habitats were accessible. Three of the five high-use sites were located at the mouth of a marsh channel where cutthroat trout may benefit from the delivery of abundant prey resources through the marsh-channel network as the tide recedes. Many species of fish rear in these channels during high tide (Bottom et. al 2005a). In addition, aquatic insect and benthic invertebrate production and terrestrial input of invertebrates can be high in marsh channels (Gray et. al 2002). A diet study of coastal cutthroat trout in the Salmon River estuary in conjunction with the present study suggests that cutthroat trout feed opportunistically and that the estuary provides ample prey (Jones et al. 2007), some of which are likely derived from marsh habitats.

Selection of deeper pools by coastal cutthroat trout may afford refuge from common avian predators at Salmon River, such as bald eagles and herons. Deep holes also could serve as thermal refugia from high temperatures during summer and early fall. We recorded a substantial thermocline at the deepest site (rkm 3.7) during the summer when surface water temperatures were as high as 21°C in the upper reaches of the estuary. For example, water temperature at rkm 3.7 was 20.2°C at 0.5m below the surface but was only 14.6°C near the bottom of the site.

Although acoustic tags enabled us to describe general movement patterns in the estuary, the method was not ideal for studying habitat use at fine scales. The precision of estimating the location of acoustically tagged fish was affected by tidal cycles because the range of acoustic receivers varied with water level and salinity — increased range at higher water levels and higher salinity. We conducted one range test for six receivers at high tide and ranges averaged 300 m but extended to 1km for two receivers, which is similar to reported ranges of the same equipment in the Nestucca River estuary on the Oregon Coast (Schreck et al. 2001). Because we did not conduct range tests at varying tides, we could not estimate the effect of tide on the range of each receiver. Based on the number of simultaneous detections on adjacent receivers, we are confident we located fish to the nearest 300 m in most cases but we were unable determine movement at a finer scale. In addition, the pulse rate set on the tags in our study was too frequent to easily examine the behavior of fish residing within range of the receivers for long periods of time. The average pulse rate of two minutes was necessary to detect fish that moved quickly through an area, which was an objective of this study (*see* Chapter 3). However, for fish holding in one location,

the pulse rate resulted in a large data sets that were difficult to summarize and analyze. For example, many fish in this study had 300,000 or more detections.

This study provided evidence that estuarine environments may be important rearing areas for coastal cutthroat trout, as is certainly the case in the Salmon River estuary, Oregon. Estuaries contain a continuum of habitats that link freshwater and marine environments and that vary in attributes such as salinity, depth, and water velocities. How coastal cutthroat trout use these habitats for feeding and refuge and how they move within the estuarine environment is important for developing strategies to conserve and restore habitats.

In Oregon, as much as 70% of functioning estuarine wetland habitat has been altered through anthropogenic activities such as flow regulation, diking, and habitat modification (Fresh et al. 2004). The habitat of most estuaries where coastal cutthroat trout have been studied has been simplified from development and other human activities. For example, Giger (1972) studied coastal cutthroat trout in the Alsea, Nestucca, and Siuslaw river estuaries. In the Alsea and Nestucca rivers, 38% and 94% of salt marsh area has been lost since 1850 (Christy 2005). However, the Siuslaw River has lost only 13%. The Salmon River estuary has been restored and 74% of its historic salt marsh habitat is intact, and may represent more historic conditions than other estuaries along the Oregon Coast. For example, life history variation in juvenile Chinook salmon increased in response to the increase in habitat opportunities following restoration of tidal marshes in the Salmon River estuary (Bottom et al. 2005a).

Each phase of the anadromous life cycle requires access to and quality of specific habitats. Development and implementation of conservation and recovery strategies require knowledge about the importance of habitats and how fish access and use habitats. Simplification of habitat can reduce the life history diversity expressed in salmonid populations and can occur within watersheds or within specific habitats such as estuaries. Estuaries are a critical interface between freshwater and marine environments. Disturbance in a watershed upstream of estuaries from natural and anthropogenic causes may influence habitat in distant estuaries because the longitudinal nature of streams and watersheds can transport the cumulative effects of disturbance downstream (Fausch et al. 2002). Therefore, if extensive rearing of coastal cutthroat trout in estuaries is important for completion of their life cycle, as this study suggests, it will require protection of the estuarine habitat as well as the watershed that contributes to the overall health of the estuary, and connectivity of habitats within the watershed.

## References

Armstrong, J. D., and N. A. Herbert. 1997. Homing movements of displaced steam-dwelling brown trout. Journal of Fish Biology 50:445–449.

Armstrong, J. D., V. A. Braithwaite, and F. A. Huntingford. 1997. Spatial strategies of wild Atlantic salmon parr: exploration and settlement in unfamiliar areas. Journal of Animal Ecology 66:203–211.

Bélanger, G., and M. A. Rodríguez. 2001. Homing behavior of stream-dwelling brook charr following experimental displacement. Journal of Fish Biology 59:987–1001.

Bottom, D.L., K.K. Jones, T.J. Cornwell, A. Gray, and C.A. Simenstad. 2005a. Patterns of Chinook salmon migration and residency in the Salmon River estuary (Oregon). Estuarine, Coastal, and Shelf Science 64:79–93.

Bottom, D.L., C.A. Simenstad, J. Burke, A.M. Baptista, D.A. Jay, K.K. Jones, E. Casillas, and M.H. Schiewe. 2005b. Salmon at river's end: the role of the estuary in the decline and recovery of Columbia River salmon. NOAA Technical Memorandum NMFS-NWFSC-68. 246pp.

Bridcut, E.E., and P.S. Giller. 1993. Movement and site fidelity in young brown trout *Salmo trutta* populations in a southern Irish stream. Journal of Fish Biology 43:889–899.

de Leañiz, C. G. 1989. Site fidelity and homing of Atlantic salmon parr in a small Scottish stream. Pages 70–80 *in* E. L. Brannon and B. Jonsson, editors. Proceedings of the salmon migration and distribution symposium. University of Washington, School of Fisheries, Seattle.

Diana, J.S., J.P. Hudson, R.D. Clark Jr. 2004. Movement patterns of large brown trout in the mainstream Au Sable River, Michigan. Transactions of the American Fisheries Society. 133:34–44.

Fausch, K.D., C.E. Torgersen, C.V. Baxter, and H.W. Li. 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. BioScience 52:483–498.

Fresh, K.L., E. Casillas, L. Johnson, and D.L. Bottom. 2005. Role of the estuary in the recovery of Columbia River basin salmon and steelhead: an evaluation of the effects of selected factors on salmonid population viability. NOAA Technical Memorandum NMFS-NWFSC-69. 109pp.

Gerking, S.D. 1959. The restricted movements of fish populations. Biological reviews of the Cambridge Philosophical Society. 34:221–242.

Giger, R.D. 1972. Ecology and management of coastal cutthroat trout in Oregon. Oregon State Game Commission, Fishery Research Report 6, Corvallis.

Gray, A., C.A. Simenstad, D.L. Bottom, and T. Cornwell. 2002. Contrasting functional performance of juvenile salmon habitat in recovering wetlands of the Salmon River estuary, Oregon, USA. Restoration Ecology 10(3):514–526.

Halvorsen, M., and O. B. Stabell. 1990. Homing behavior of displaced stream-dwelling brown trout. Animal Behavior 39:1089–1097.

Hara, T. J. 1993. Role of olfaction in fish behaviour. Pages 171–199 *in* T. J. Pitcher, editor. Behaviour of teleost fishes. Chapman and Hall, London.

Heggenes, J. 1988. Effect of experimentally increased intraspecific competition on sedentary adult brown trout *Salmo trutta* movement and stream habitat choice. Canadian Journal of Fisheries and Aquatic Sciences 45:1163–1172.

Heggenes, J., T.G. Northcote, and A. Peter. 1991. Spatial stability of cutthroat trout *Oncorhynchus clarki* in a small, coastal stream. Canadian Journal of Fisheries and Aquatic Sciences 48:757–762.

Hudson, J.M. 2005. Movements of coastal cutthroat trout *Oncorhynchus clarki clarki* in the lower Columbia River: tributary, main-stem, and estuary use. U.S. Fish and Wildlife Service, Project Status Report, Draft.

Huntingford, F. A., V. A. Braithwaite, J. D. Armstrong, D. Aird, and P. Joiner. 1998. Homing in juvenile salmon in response to imposed and spontaneous displacement: experiments in an artificial stream. Journal of Fish Biology 53:847–852.

Jones, D.S., I.A. Fleming, L.K. Krentz, and K.K. Jones. In press. Feeding Ecology of Cutthroat Trout in the Salmon River Estuary, Oregon. P. Connally, T. Williams, and R. E. Gresswell, editors. Sea-run cutthroat trout. Oregon Chapter, American Fisheries Society, Corvallis.

Miller, R. B. 1954. Movements of cutthroat trout after different periods of retention upstream and downstream from their homes. Journal of the Fisheries Research Board of Canada 11: 550–558.

Northcote, T.G. 1997. Why sea-run? An exploration into the migratory/residency spectrum of coastal cutthroat trout. Pages 20–26 *in* J.D. Hall, P.A. Bisson, and R.E. Gresswell, editors. Sea-run cutthroat trout: biology, management, and future conservation. Oregon Chapter, American Fisheries Society, Corvallis.

Schreck, C.B., M.D. Karnowski, S. Clements, and D.B. Jepsen. 2001. Evaluation of delayed mortality of juvenile salmonids in the near-ocean environment following passage through the Columbia River hydrosystem. Annual report; Oregon Cooperative fish and Wildlife Research Unit.

Simenstad, C.A., K.L. Fresh., and E.O. Salo. 1982. The role of Puget sound and Washington coastal estuaries in the life history of Pacific salmon: an unappreciated function. In: kennedy, V.S. (Ed.), Estuarine Comparisons. Academic Pres, New York, pp. 343–364.

Smithson, E.B., and C.E. Johnston. 1999. Movement patterns of stream fishes in a Ouachita Highlands stream: an examination of the restricted movement paradigm. Transactions of the American Fisheries Society 128:847–853.

Solomon, D.J., and R.G. Templeton. 1976. Movement of brown trout *Salmo trutta* L. in a chalk stream. Journal of Fish Biology. 9:411–423.

Sumner, F.H.  1962.  Migration and growth of the coastal cutthroat trout in Tillamook County, Oregon.  Transactions of the American Fisheries Society 91:77–83.

Tipping, J.M.  1981.  Cowlitz sea-run cutthroat study 1980-1981.  Washington State Game Department, Fisheries Management Division Report 81–12, Olympia.

Thorpe, J.E. 1994.  Performance thresholds and life-history flexibility in salmonids. Conservation Biology 8:877–879.

Tomasson, T.  1978.  Age and growth of cutthroat trout, *Salmo clarki clarki* Richardson, in the Rogue River, Oregon.  Master's thesis, Oregon State University, Corvallis.

Zale, A.V., C. Brooke, and W. C. Fraser.  2005.  Effects of surgically implanted transmitter weights on growth and swimming stamina of small adult westslope cutthroat trout.  Transactions of the American Fisheries Society 134:653–660.

**Chapter 3: Life history variation and migratory behavior of coastal cutthroat trout *Oncorhynchus clarkii clarkii* in the Salmon River estuary, Oregon**

**<u>Abstract</u>**

Coastal cutthroat trout *O. clarkii clarkii* exhibit a continuum of migratory behaviors from residency to anadromy, but their migration patterns in the estuary and ocean are poorly understood.  This study was initiated to quantify estuarine life history and migratory patterns of anadromous cutthroat trout and to determine whether they use estuaries as more than a migratory corridor.  From 2002 to 2003, we used both PIT tag and acoustic tracking techniques to monitor the movement of individuals through the Salmon River estuary, Oregon.  Over the course of 18 months, 713 fish were PIT- tagged and 20 were tagged using acoustic transmitters. We identified two main life history types: an "ocean migrant" form that migrates rapidly through the estuary and out to sea and an "estuarine resident" form that resides in the estuary for the spring and summer.  We saw no difference in mean length at tagging between the two groups.  PIT-tagged fish were classified as "ocean migrants" or "estuarine residents" based on their recapture history in order to examine growth rates of each life history type.  We found no difference in growth rates between ocean migrants and estuarine residents.  Half of the acoustically tagged fish exhibited the estuarine life history type.  This, coupled with our high recapture rate of PIT tagged fish in the summer, suggests that the estuarine life history is an important migratory behavior within the continuum of life histories for coastal cutthroat trout in the Salmon River estuary.

**Introduction**

Coastal cutthroat trout *O. clarkii clarkii* exhibit a continuum of migratory
behaviors from residency to anadromy (Trotter 1989). However, the frequency of an
individual adopting an anadromous life history is considered to be the least among the
Pacific salmon (Rounsefell 1958; Quinn and Myers 2004), and the residence time in
the ocean is often short (Trotter 1997). The oceanic distribution of coastal cutthroat
trout has been reported to be restricted primarily to areas close to shorelines in Alaska
(Jones and Siefert 1997) and up to 10–46 km off the coast of Oregon and Washington
(Loch and Miller 1988; Pearcy et al. 1990). In the latter case, the greater distances
were usually reported for areas influenced by the Columbia River plume (Loch and
Miller 1988; Pearcy et al. 1990). Because anadromy is not as highly developed trait
in coastal cutthroat trout as in many other Pacific salmonids (i.e. both migration
distances and ocean residency times are relatively short), estuaries may play a
particularly vital role in their life history. In this paper we describe the migration and
residency of coastal cutthroat trout in a small estuary on the central Oregon coast.

Descriptions of the migratory patterns and use of estuaries by coastal cutthroat
trout appear diverse and at times contradictory. Some authors report coastal cutthroat
trout residing in estuaries as migrant parr (Giger 1972; Tipping 1981), though most
fish are believed to migrate rapidly through the estuary, making little use of it as a
rearing environment (Giger 1972, Hudson 2005). Adults returning from their ocean
migration may hold in some Oregon estuaries for up to four months, waiting the
arrival of fall and winter rains before proceeding upriver to spawn (Giger 1972;
Tipping 1981). However, this has not been considered a strategy for active feeding or

growth in the estuary (Giger 1972). In contrast, coastal cutthroat trout of all sizes

reportedly reside in the Rogue River estuary during spring and summer, but few

migrate to the ocean (Tomasson 1978). The diversity of published observations

indicates that our understanding of the role of estuaries in the expression of life

history traits in coastal cutthroat trout remains rudimentary.

Anadromous life histories in fishes, whereby individuals breed in freshwater

and migrate to the ocean to rear, are thought to evolve under conditions where the

fitness benefits gained through access to rich food sources and favorable temperatures

outweigh the costs of migration. The benefits of anadromy may include increased

growth and thus increased fecundity, which may be traded off against costs such as

the energy and osmoregulatory demands of migration, and increased exposure to

predation (Gross et al. 1988; McDowell 2001). Although anadromy is a common

trait in Pacific salmon *Oncorhynchus*, many species are polytypic, even within

populations (Northcote 1997; Willson 1997). Multiple life histories within salmonid

populations have been described as alternative survival strategies that maximize

reproductive success and minimize the risk of brood failure in variable aquatic

environments (Thorpe 1994).

The maintenance of life history variation and an understanding of how coastal

cutthroat trout use estuaries are not only theoretically interesting, but also important

in developing conservation strategies for such exploited species. Life history

diversity may increase the evolutionary potential of a population (Barlow 1995) and it

is vital to identify habitats and habitat linkages that allow for diverse life history

expression (Ruckelhaus et al. 2002). This study provides more information about the

importance of estuarine habitat to the life history of coastal cutthroat trout.
Specifically, the study was designed to test: (1) whether coastal cutthroat trout use estuarine habitats for more than a migratory corridor and, if so, to what extent; (2) whether migratory patterns are related to fish phenotype (e.g., size at and time of estuarine entry); and (3) whether estuarine residence is associated with a cost in growth. This study was conducted in 2002–2004 using a combination of active tracking by acoustic telemetry and passive tracking by passive integrated transponders (PIT) to quantify the movements of coastal cutthroat trout in the Salmon River estuary, Oregon.

**Methods**

*Study Area*

The Salmon River estuary is located on the central Oregon coast and is approximately 800 ha (Bottom et al. 2005: Figure 12). It is part of the Salmon River watershed, which drains an area of 194 km$^2$ and has a discharge that varies annually from approximately 1 m³/s in late summer to peak winter flows of 25 m³/s to 150 m³/s. The small size of the Salmon River estuary, compared to other Oregon estuaries, makes it an ideal location for studying the life history and ecology of estuarine resident fishes. It contains a variety of habitat types, from deep main stem to tidal marsh channels, but is small enough to study variations in habitat use, residency, and growth of individuals using mark-recapture techniques (Bottom et al. 2005).
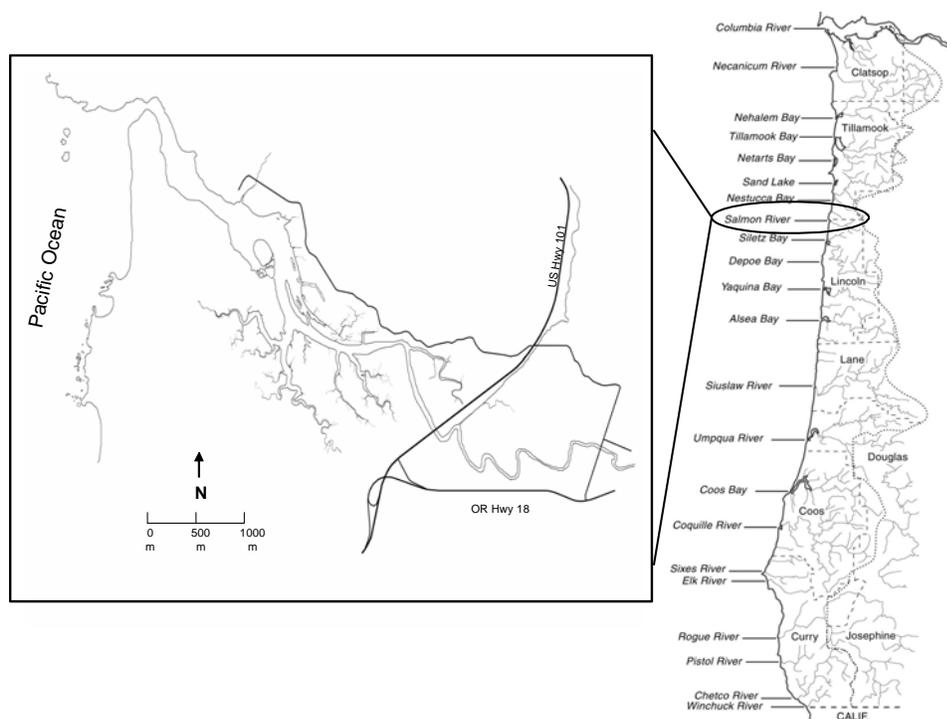
Figure 12.  The Salmon River estuary, located on the Oregon coast.  Inset shows the area of tidal influence.

Earthen dikes and tide gates were constructed in the Salmon River estuary during the 1960s to allow agricultural development, which resulted in the loss of about 65% of the original marsh habitat (Bottom et al. 2005).  Most dikes have been removed during three restoration projects (1978, 1987, 1996), and 145 ha was restored to a naturally functioning state (Gray et al. 2002; Bottom et al. 2005).  The estuary is part of the federally designated Cascade Head Research Area, and is managed by the U.S. Forest Service with the goal of restoring the estuary "to its condition…prior to diking and agricultural use."

Chinook salmon *Oncorhynchus tshawytscha* is the most abundant salmonid species rearing in the Salmon River estuary, but coho salmon *O. kisutch*, chum salmon *O. keta,* and steelhead *O. mykiss* are also present during certain times of the

year.  Nearly 180,000 hatchery coastal cutthroat trout reared at hatcheries on other

coastal rivers were released in the watershed between 1949 and 1994 (Johnson et al.

1999).    Presently, the Salmon River hatchery releases approximately 200,000 Coho

salmon in May and 200,000 Chinook salmon in August of each year.


*Migration timing*

Migration timing of coastal cutthroat trout from the Salmon River to the

estuary was assessed in 2001 and 2002 by capturing individuals in a 5-m diameter

rotary screw trap located at rkm 7.9 just above the upstream limit of tidal influence

and estuarine entrance (Figure 13).  The trap was operated daily from late March to

July in both years, except during major storm events on March 26–28; April 27–May

4, 2001; and April 11–17, 2002.  Trap efficiency for coastal cutthroat trout could not

be assessed because the few fish captured daily (2–4 on average) made undertaking a

mark and release study difficult.  Large fish, however, may have been able to avoid

the trap or escape from it once captured (S. Johnson, ODFW, personal

communication) thus biasing our sample towards smaller fish.  As our focus was on

relative timing of migration rather than the proportional composition of the

population by fish size, this should not bias our results.
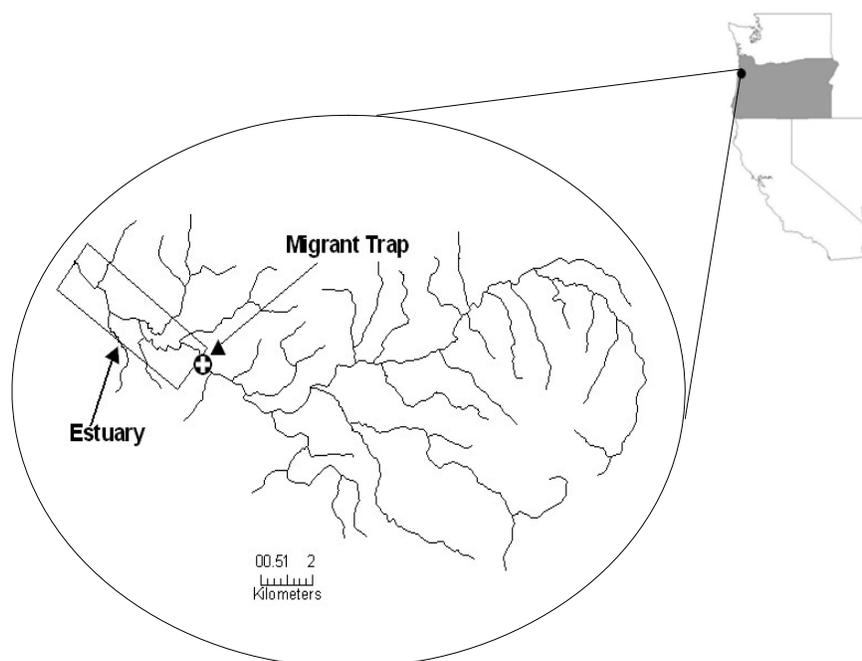
Figure 13.  Salmon River basin, showing the relative size of the estuary and the location of the migrant trap.


***Migratory behavior***

In 2003, we used acoustic telemetry to study migratory behavior and movement patterns of coastal cutthroat trout.   We tagged 20 coastal cutthroat trout that were captured in the estuary with a beach seine measuring 38 m long and 2.75 m deep with a 0.5 cm mesh.  Anesthetized cutthroat trout were tagged with Vemco® V8SC coded pingers (28 mm long, 9 mm diameter, 4.7 g in air) with a battery life of at least 260 days.  Fish size averaged 268.5 mm and ranged from 187.0 mm to 398.0 mm).  The weight of the tags was < 4% of a fish's body weight for all fish except five individuals with tags between 4.7% and 6.5% of body weight.  Tags weighing 4% of body weight had little effect on behavior of westslope cutthroat trout *O. c. lewis*  that

were similar in size to the coastal cutthroat trout in this study (Zale et al. 2005). We

gently inserted a tag into the body cavity of each individual through a small incision

(approximately 10 mm) cut with a scalpel and used two to three nylon sutures to close

each incision. Fish were held in a 190-L tub of water for four hours prior to release at

the capture site. Most fish were tagged in April and May during peak migration to

provide a representative sample of the population and to study variability in migration

patterns. Two additional fish were tagged in early June.

Tagged cutthroat trout were tracked with Vemco® VR2 acoustic receivers

deployed 300 m to 1 km apart at 17 locations throughout the estuary: 14 in the main

channel and 3 in tidal marsh channels (Figure 14). Each receiver had a range of 300–

500 m. Five receivers were deployed once tagging was initiated in April and May,

and twelve receivers were deployed in July (Table 9). Most receivers were removed

at the end of November because their locations were prone to erosion and subject to

high velocity flows during winter floods. However, four receivers located in more

secure areas were not removed until late January or mid February. The receivers

recorded the tag number, date, and time when a tagged fish entered the effective

range, and continuously recorded data every 30 seconds on average until the fish

moved out of range. Receivers covered the width of the channel and their range

frequently overlapped with the next receiver upstream or downstream. However, the

nearest receiver to that located at the mouth of the estuary was 1.3 km upstream

because no other suitable location was found (Figure 14). This resulted in a river

section of approximately 500 m with no receiver coverage. In addition, the receiver

at the mouth was swept away or stolen after the July 31 download. Therefore, no data

were available for the station from that date onwards.  The range of receivers in the

uppermost reaches of the estuary (rkm 4.8, 5.4, 5.9, and 6.7) did not overlap because

of channel sinuosity.
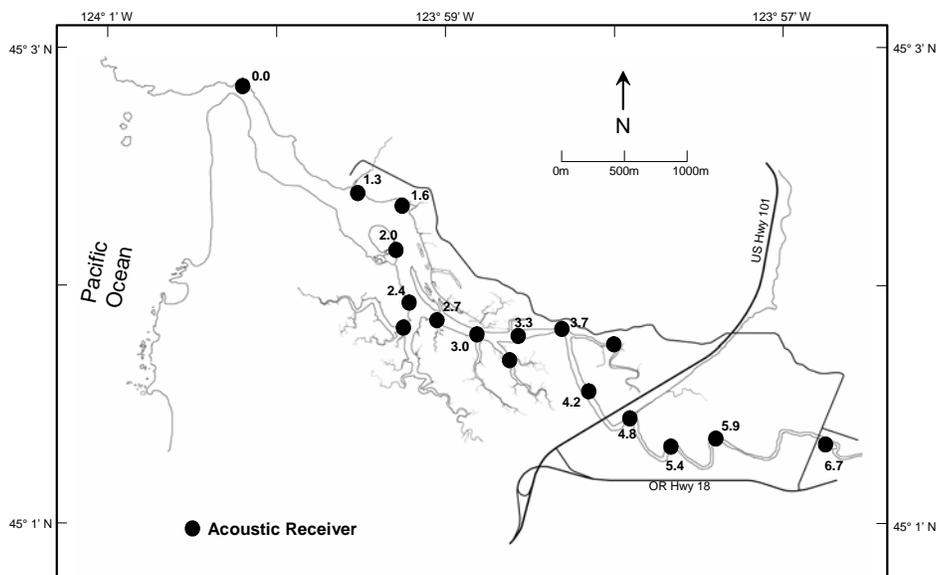


Figure 14.  Location (rkm) of regular and standard beach seining sites in the
Salmon River estuary.

Table 9. Location of acoustic receivers (rkm) and duration of operation. The first and last X for each receiver denotes that approximately half of the month was sampled.

| Location | rkm | 2003 | | | | | | | | | | 2004 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | A | M | J | J | A | S | O | N | D | J | F |
| Estuary Mouth[a] | 0.0 | X | X | X | X | X | | | | | | | |
| **Knight Park** | 1.3 | | | | | X | X | X | X | X | | | |
| **Lighthouse Corner** | 1.6 | | | X | X | X | X | X | X | X | X | X | |
| Golden Crescent | 2.0 | | | | | X | X | X | X | X | | | |
| Below 87 Marsh | 2.4 | | | X | X | X | X | X | X | X | | | |
| 87 Marsh[b] | 2.4 | | | | | | X | X | X | X | | | |
| Ditch | 2.7 | | | | | | X | X | X | X | | | |
| **Lower Control Mouth** | 3.0 | | | X | X | X | X | X | X | X | X | X | |
| Control Marsh[b] | 3.1 | | | | | | X | X | X | X | X | X | |
| Dinosaur | 3.3 | | | | | X | X | X | X | X | | | |
| **96 Mouth** | 3.7 | | X | X | X | X | X | X | X | X | X | X | X |
| 96 Marsh[b] | 3.7 | | | | | | X | X | X | X | | | |
| Below Hwy 101 Bridge | 4.2 | | | | | X | X | X | X | X | | | |
| Salmon Creek Mouth | 4.8 | | | | | X | X | X | X | X | | | |
| Red Barn Hole | 5.4 | | | | | | X | X | X | X | | | |
| Sitka Corner | 5.9 | | | | | | X | X | X | X | | | |
| Deer Creek Mouth | 6.7 | | | | | | X | X | X | X | | | |

[a] Receiver discovered missing in late August. Last download of data occurred on July 31, 2003.
[b] Within marsh receivers, located 300 m upstream of the confluence of their respective marsh channels with the main stem, designated by rkm at the mouth of each marsh channel.

*Growth*

We captured coastal cutthroat trout in the estuary in 2002 and 2003 with a beach seine (described above) to tag with passive integrated transponders (PIT tags) and to obtain recaptures. A total of 713 fish were tagged—610 captured in the estuary and 103 captured in the screw trap. We sampled weekly or bi-weekly in March–September, although the number of hauls per site varied. During October– February, we sampled an average of twice per month, except in December when we sampled only once. The number of beach seine hauls per site varied among sampling dates and encompassed a range of water depths and channel substrates. We selected ten regular sampling sites to encompass the variation of available habitats in the estuary (Figure 15), including fresh, brackish, and marine portions of the estuary and main-channel and marsh-channel habitats. The regular seining occurred downstream of rkm 3.7 because no suitable sites were found further upstream. To eliminate sampling bias that can occur when comparing sites sampled in uneven proportions, four main stem standard sites were chosen to compare seasonal use by coastal cutthroat trout. These four sites, located at rkm 1.3, 1.6, 3.0, and 3.7, were sampled more often than other beach seining locations and generally proportional to each other.
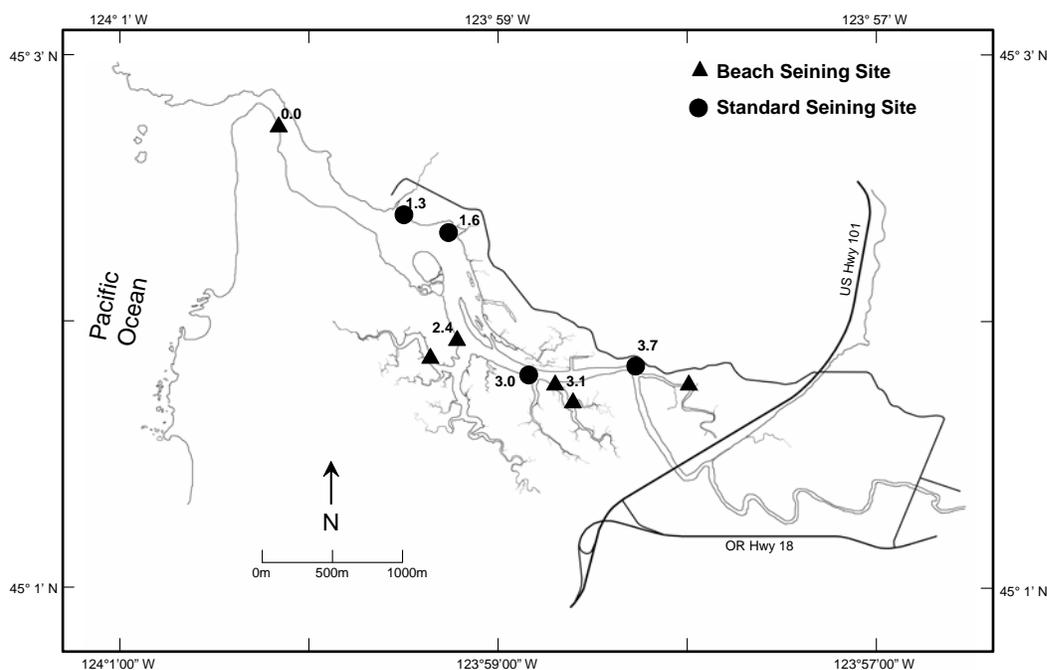
Figure 15. Salmon River estuary showing locations (rkm) of beach seining sites.


Cutthroat trout captured in the screw trap and beach seine were anesthetized (MS 222), measured (FL, $\pm1.0$ mm), and scanned with an Allflex® portable tag reader (model RS-601). We tagged all healthy, untagged fish > 100 mm with PIT tags (23 mm long, 3.4 mm diameter, 0.6 g in air). All cutthroat trout captured in the beach seine and 94% of the individuals captured in the screw trap were > 100 mm. To PIT tag each individual, we made a small incision (approximately 5 mm) on the midventral line just posterior to the pectoral fins, deep enough to insert the tag into the peritoneum. The tag was pushed gently through the incision and into the body cavity. No sutures were required to close the incision. All tagged fish were held in

buckets and released at the site of capture once they were swimming normally. All fish were released within 30 minutes of tagging.

PIT-tagged fish were classified as ocean migrant or estuarine resident based on their capture history to compare growth of the two life history types. Growth was estimated from length at initial capture and length at last capture. We did not use additional length measurements when fish were recaptured multiple times to insure independence in the data used to estimate growth. We used multiple linear regression to test for differences in the growth rates of estuarine residents and ocean migrants. Because smaller fish generally grow at a faster rate than larger fish we adjusted for initial length at tagging by incorporating this variable in our multiple regression equation (Ramsey and Schafer 2002):

$\mu$ {growth rate | initial length, life history type} $= \beta_0 + \beta_1$initial length $+ \beta_2$life history type

Where growth rate is the percent increase per day (instantaneous growth rate), initial length is the initial length at tagging, and life history type is the categorical variable "estuarine resident" or "ocean migrant".

## **Results**

### *Migration timing*

Peak downstream migration of coastal cutthroat trout smolts (> 160 mm) occurred the first three weeks of May 2001 and 2002, with a less pronounced peak in

late March and early April (Figure 16). Because we were unable to estimate trap efficiency and regular flow measurements were not taken we could not assess the effect of flow on catch. High flows likely reduced trap efficiency in the spring such that the relative proportion of spring to summer migrants may have been higher than the catch data suggest. Reduced numbers of juvenile cutthroat trout continued to be captured in July when the trap operation was discontinued.

**Cutthroat Trout Smolts (>160mm)**
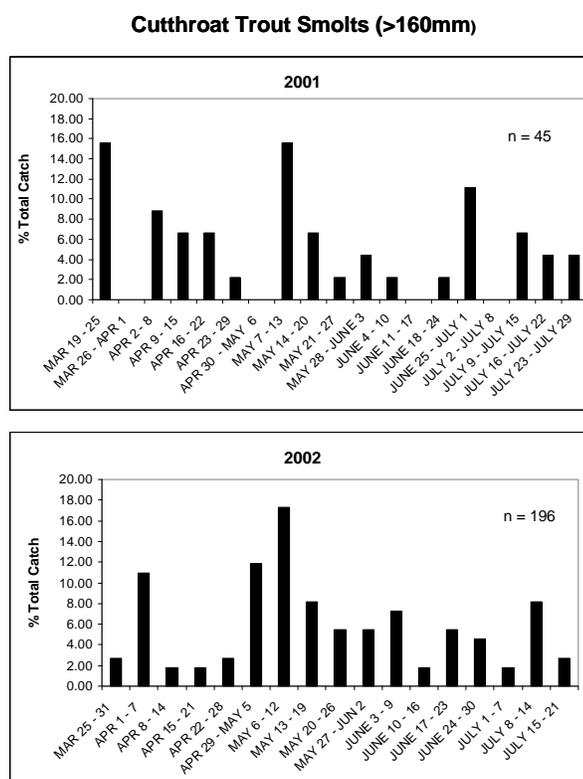


Figure 16. Catch of coastal cutthroat in a 5-m diameter screw trap located at the head of tide. The screw trap was not operated March 26–March 28 and April 27–May 4, 2001 or April 11–April 17, 2002 because of major storms.

*Migratory behavior*

Although the acoustically tagged fish exhibited a variety of migratory behaviors, two main life history types were evident: (1) ocean migrants that moved

relatively rapidly through the estuary in the spring and out to the ocean (Figure 17);

and (2) estuarine residents that remained in the area of tidal influence for the duration

of the spring and summer months before migrating upstream in the fall or early winter

(Figure 18). Among the acoustically tagged fish, we classified ocean migrants as

individuals that migrated past the lowermost receiver at the estuary mouth and

estuarine residents as individuals that were detected in the estuary throughout the

spring and summer.
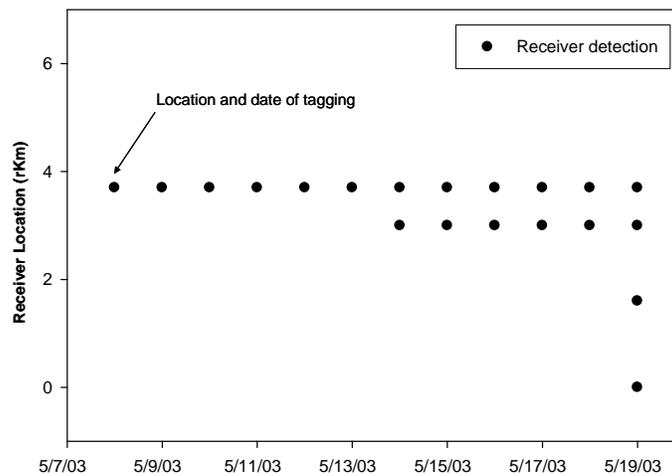


Figure 17. Movement pattern of an ocean migrant coastal cutthroat trout (Tag ID 114) characterized by rapid movement through the estuary to the ocean. Each point represents at least one detection at a receiver on a given day. For simplicity, data are shown only for receivers at rkm 0, 1.6, 3.0, and 3.7. This fish was not detected upstream of the tagging location (rkm 3.7).
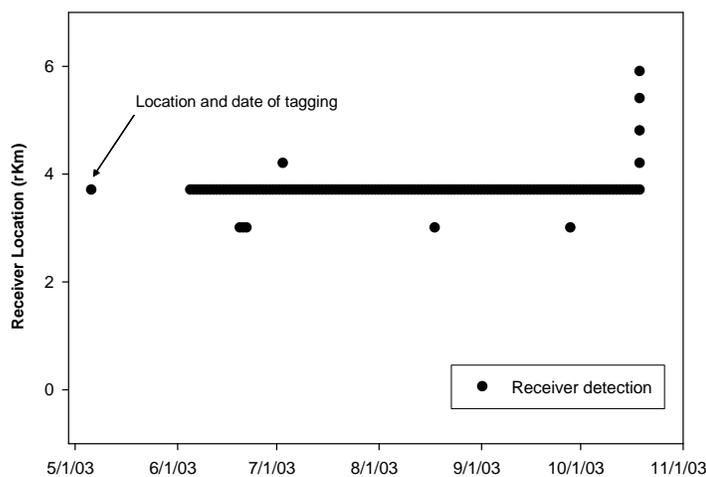
Figure 18. Movement pattern of an estuarine resident coastal cutthroat trout (Tag ID 120) characterized by limited movement through the estuary, strong site fidelity, and upstream migration to freshwater in mid fall. Each point represents at least one detection at a receiver on a given day. For simplicity, data are shown only for receivers at rkm 3.0, 3.7, 4.2, 4.8, 5.4, and 5.9. This fish was not detected downstream of rkm 3.0.

Of the 20 fish tagged with acoustic transponders in April and May 2003, seven were classified as ocean migrants (Table 10). Only one of the ocean migrants was detected again in the estuary after migrating to the ocean, where it spent 56 days. The other six were not detected again. Ten individuals resided in the estuary throughout the spring and summer, and were classified as estuarine residents. We could not classify the remaining three tagged fish as estuarine or ocean residents: Detections stopped abruptly for two individuals, and one individual did not fit into either life history category. This latter fish resided in the estuary most of the spring through early fall, but was detected at the mouth for several days at a time on three separate occasions, apparently making brief forays into the near shore ocean (Figure 19).

Table 10.  Classification of coastal cutthroat trout by life history type (estuarine resident and ocean migrant) based on migratory behavior of acoustically tagged fish, 2003.

| Tag ID | Tagging Date | Tagging Location (Rkm) | Fork Length (mm) | Classification |
|--------|--------------|------------------------|------------------|----------------|
| 100 | 4/24/2003 | 3.7 | 187 | a |
| 101 | 4/28/2003 | 3.7 | 398 | Estuarine Resident |
| 102 | 4/30/2003 | 3.7 | 198 | Ocean Migrant |
| 103 | 4/30/2003 | 3.7 | 193 | Estuarine Resident |
| 105 | 4/30/2003 | 3.7 | 285 | Estuarine Resident |
| 106 | 4/30/2003 | 3.7 | 310 | Estuarine Resident |
| 107 | 4/30/2003 | 3.7 | 304 | Estuarine Resident |
| 108 | 5/6/2003 | 3.7 | 205 | Estuarine Resident |
| 110 | 5/7/2003 | 3.7 | 305 | Ocean Migrant |
| 109 | 5/8/2003 | 3.0 | 326 | Estuarine Resident |
| 114 | 5/8/2003 | 3.0 | 313 | Ocean Migrant |
| 116 | 5/8/2003 | 3.0 | 239 | Ocean Migrant |
| 111 | 5/15/2003 | 1.6 | 253 | b |
| 112 | 5/19/2003 | 3.0 | 272 | Ocean Migrant |
| 113 | 5/19/2003 | 3.0 | 229 | Ocean Migrant |
| 115 | 5/19/2003 | 3.0 | 230 | Ocean Migrant |
| 117 | 5/19/2003 | 3.0 | 282 | Estuarine Resident |
| 118 | 6/5/2003 | 3.7 | 195 | a |
| 119 | 6/5/2003 | 3.7 | 270 | Estuarine Resident |
| 120 | 6/5/2003 | 3.7 | 376 | Estuarine Resident |

[a] Detections ended abruptly after 2–3 weeks.

[b] Migratory behavior included long periods of estuarine residency and possible short ocean forays (see Figure 9).
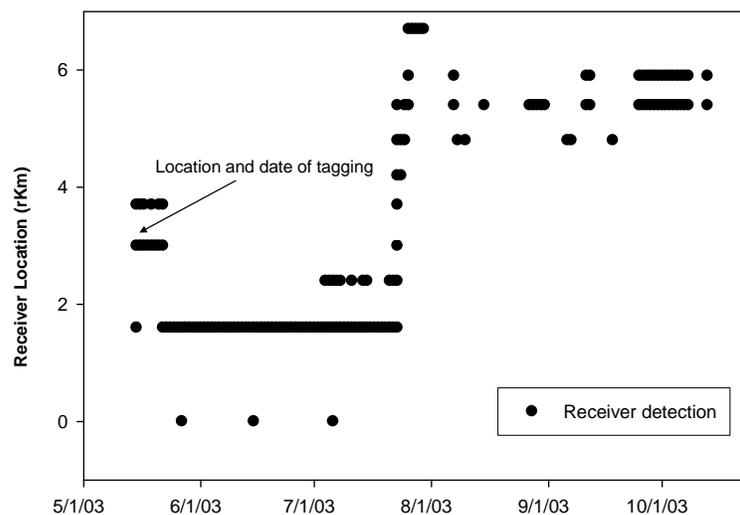
Figure 19. Movement pattern of a coastal cutthroat trout (Tag ID 111) that resided primarily in the estuary but may have made short forays to the ocean. Each point represents at least one detection at a receiver on a given day.

Because fish with acoustic tags were first captured and tagged in the estuary, we were unable to calculate their total time of estuarine residence. Estimated estuarine residency values therefore represent minimum values. The mean minimum estuarine residence time for the ocean migrants was 8.1 days (range 1–14 days, n = 7), and average value for individuals classified as estuarine residents was 123.1 days (range 75–190, n = 10). Minimum residence time did not include two fish that were detected in the estuary through winter and for the entire duration of their battery life (260+ days). After July these tags were detected only at one location (rkm 3.7), suggesting that the tags had been shed (Figure 20). However, gaps of several hours occasionally occurred between detections, suggesting that the fish were moving in and out of range but not so far as to be detected on another receiver. We cannot

confirm whether the lack of detections reflected fish movement but note that an

overwintering estuarine resident life history may also exist.
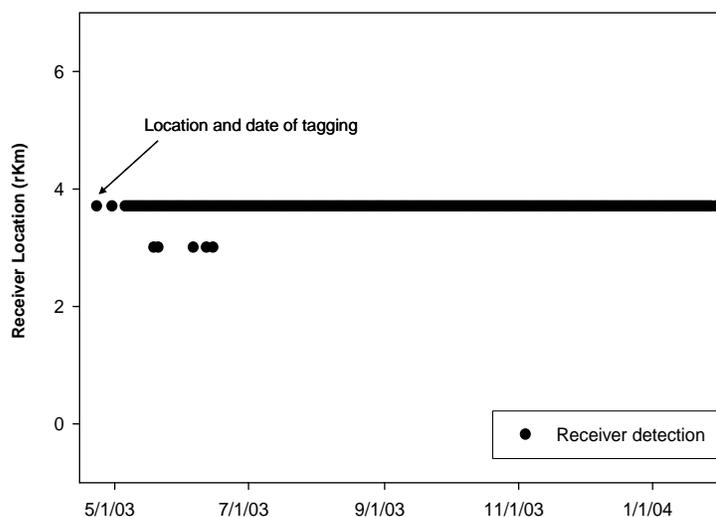


Figure 20. Movement pattern of a coastal cutthroat trout (Tag ID 108) that may
have either shed its tag or overwintered in the estuary at river kilometer 3.7. Each
point represents at least one detection at a receiver on a given day. This fish was
not detected downstream of rkm 3.0 or upstream of rkm 3.7.

### *Life history classification*

Among PIT-tagged fish, we classified ocean migrants as any individual that

was tagged prior to May 10 and not recaptured for at least 85 days. Estuarine catch of

coastal cutthroat trout per unit effort declined by May 10 and increased approximately

85 days later in mid-August 2002 and to a lesser degree in 2003 (*see* Chapter 2). We

hypothesized that the increased catch corresponds with a return of ocean migrants to

the estuary. This assumes it is unlikely that fish residing in the estuary could have

eluded capture for 85 days. We classified estuarine residents as any individuals that

were recaptured at least once between June and September and within 7–40 days of

tagging.  We chose a minimum of seven days between captures to avoid

misclassification of fish caught on subsequent days, and a maximum of 40 days to

minimize the possibility of an individual migrating to and residing in the ocean

between captures.

*Growth*

We estimated growth of coastal cutthroat trout from lengths of 38 fish that

were classified into life history types based on the above criteria.  Eight of these fish

were classified as ocean migrants and 30 as estuarine residents.  Twenty-eight percent

of all estuarine residents were recaptured more than once, averaging 20 days between

recaptures (Median = 21, Range 7–39) (Figure 21).  Accounting for initial length at

tagging, we found no convincing evidence that growth rate differed significantly

between ocean migrants and estuarine residents ($P = 0.25$, df $= 35$) (Figure 22).  The

mean percent increase in growth per day for ocean migrants was 0.23% (Median =

0.15%, Range 0.09–0.54%) and for estuarine residents was 0.18% (Median = 0.19%,

Range 0.0–0.48%).

78
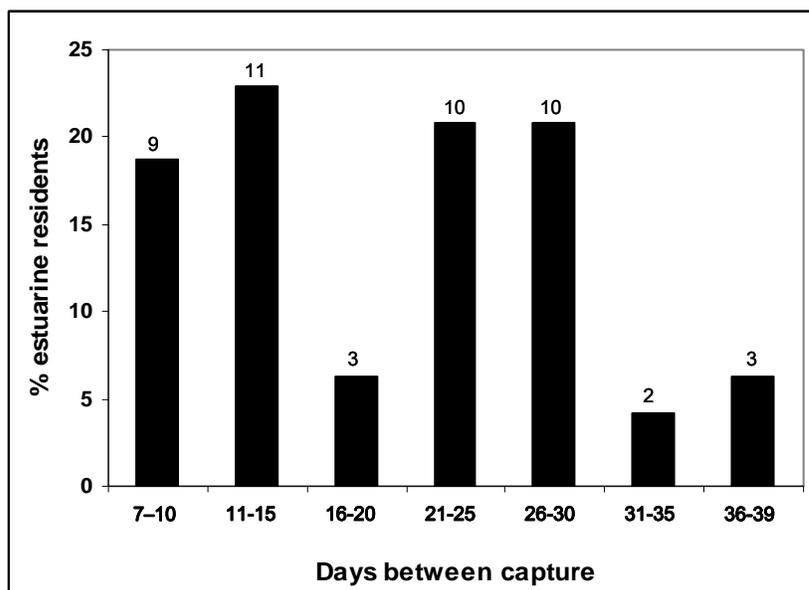


Figure 21.  Days between captures for PIT-tagged fish classified as estuarine residents based on capture history. Sample sizes are shown above the bars.
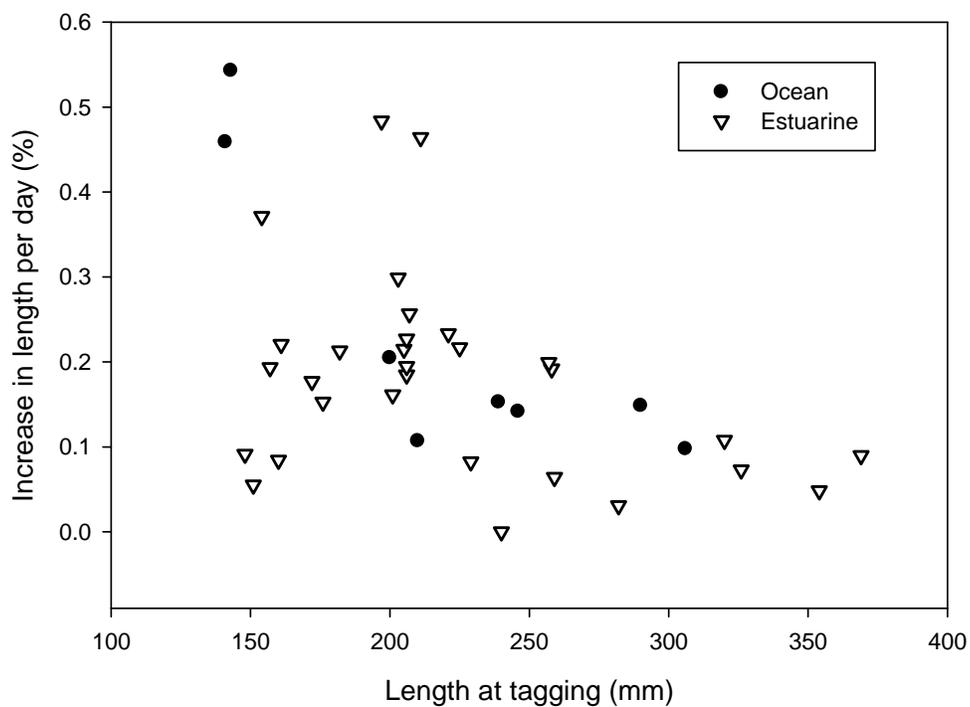


Figure 22.  Growth rates of ocean migrants (solid circles) and estuarine residents (triangles) expressed as percent increase in length per day.

*Comparison of mean length at tagging*

The mean length at time of acoustic tagging was not significantly different for ocean migrants and estuarine residents (t = -1.58, df = 15, $P$ = 0.17; Figure 23a). Similarly, the mean initial length of PIT-tagged fish was not significantly different for fish classified as ocean migrants or estuarine residents (t = -.02, df = 36, $P$ = 0.99; Figure 23b).
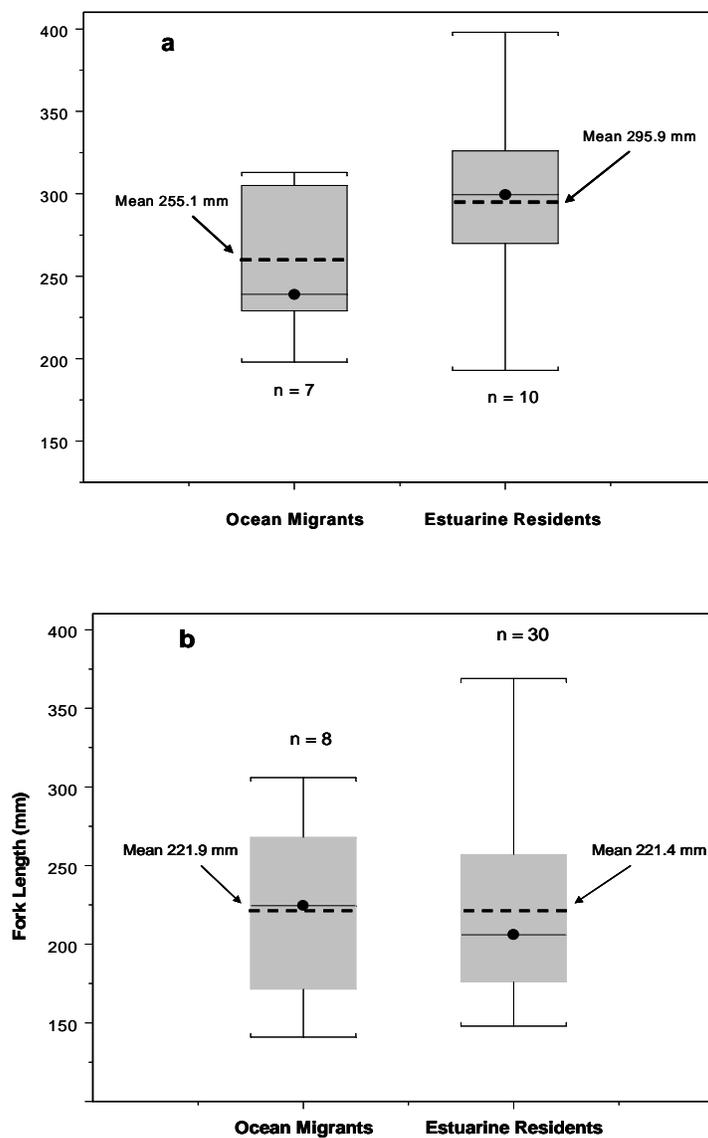
Figure 23. Comparison of initial length at tagging for ocean migrants and estuarine residents of (a) acoustically tagged fish and (b) PIT-tagged fish. The median is indicated by the closed circle and solid line. The box contains the middle 50% of data, bounded by the 75th percentile of the data set on top and the 25th percentile on bottom. Whiskers indicate the range.

**<u>Discussion</u>**

Adult coastal cutthroat trout migrating to the Salmon River estuary exhibited two main life history types: ocean migrants and estuarine residents.  Ocean migrants moved rapidly through the estuary with a mean minimum residence time of approximately one week.  In contrast, the estuarine residents migrated to the estuary in spring where they resided for an average of 4 months before returning upstream, presumably to spawn.  In addition to these two general patterns, other behaviors may exist, including individuals that rear briefly in the estuary before migrating back upstream, fish that overwinter in the estuary, and others that rear primarily in the estuary but make occasional short forays into the near-shore ocean.  Thus, rather than discrete life history "types" it may be better to describe coastal cutthroat trout as having a continuum of migratory life histories similar to that documented in brown trout (Cucherousset et al. 2005).

Only one of the acoustically-tagged ocean migrants was recorded returning to the estuary after entering the sea, where it spent 56 days.  The poor return rate of ocean migrants could be explained by tagging mortality, tag loss or malfunction, ocean mortality, or straying.  Although three fish had a tag weight to body weight ratio higher than the suggested 4% (Zale et al. 2005), tagging mortality seems an unlikely explanation for all six ocean migrants that subsequently went undetected. Moreover, the two non-ocean migrants that had tag to body weight ratios greater than 4% did not incur such mortality. Based on a study of steelhead trout (Welch et al. 2007) the expected loss from the combined effects of tag loss and mortality for fish of

the size tagged in the present study would be about 5% (i.e. one of the twenty fish acoustically tagged).

Out-of-system straying and ocean mortality could also affect the rate of return of ocean-migrant cutthroat trout to the Salmon River estuary. In hatchery releases of coastal cutthroat trout in Oregon, average stray rates between three Oregon rivers (Alsea, Siuslaw, and Nestucca) varied from 0% to 18.4% depending on year and location (Giger 1972). Likewise, coastal cutthroat trout released from Beaver Creek hatchery in the Lower Columbia River have been documented to have stray rates of up to 30% (Hisata 1973, Randolph 1986). However, the stray rates of naturally produced coastal cutthroat trout have not been studied. If naturally produced fish stray at rates similar to those for hatchery fish, we would expect no more than one of the seven acoustically tagged ocean migrants to have strayed to another basin. Ocean mortality rates for naturally produced fish are not well documented; although many cutthroat trout have been captured with scars most likely from predator attacks while at sea (Giger 1972). Estimates from hatchery returns to the Alsea, Nestucca, and Siuslaw rivers in Oregon indicate 20% to 40% survival of cutthroat trout following their first ocean migration. Thus, ocean mortality may be a major contributor to the poor return rates of acoustically tagged ocean migrants to the Salmon River estuary.

Based on direct observations of acoustically tagged fish and seine catch of fish in the estuary, estuarine residency is an important life history trait of the Salmon River cutthroat trout population. With the exception of the Rogue River population (Tomasson 1978), this study documented the most extensive estuarine use by coastal cutthroat trout. Because of the differing findings among studies we hypothesize that

estuarine habitat availability and quality may determine whether the estuarine resident life history pattern is commonly expressed within a population. Similarly, the quality of near-shore ocean habitats may affect the expression of ocean migrants. Anadromy is a life history trait with adaptive and selective advantages in terms of growth and increased fecundity (Gross et al. 1988). However, if estuarine habitat provides equal opportunity for growth, then ocean migration may not be the most strongly expressed trait in adult coastal cutthroat trout. Moreover, the proportion of life history types may vary between years as ocean and estuarine conditions change. In the Salmon River, cutthroat trout have adapted juvenile and adult rearing behaviors that encompass the entire continuum of aquatic environments: freshwater (river residents), estuary (estuarine residents), and ocean (ocean migrants).

The relatively recent development of tracking technology could also explain why the estuarine life history of cutthroat trout has not been widely documented. The use of active tracking methods, such as acoustic telemetry, has eliminated the need to recapture an individual to obtain information. Passive tagging methods, such as PIT tags and Floy tags, require assumptions about the behavior of fish between recaptures. Although coastal cutthroat trout have been studied in a few estuaries (Sumner 1962; Giger 1972; Tipping 1981), only two estuarine studies have investigated migratory behavior (Tomasson 1978; Hudson 2005), with contrasting results. Adult coastal cutthroat trout in the Rogue River resided in the estuary during the spring and summer (Tomasson 1978). In contrast, coastal cutthroat trout in the Columbia River estuary moved rapidly through the estuary and out to the near shore ocean (Hudson 2005) and may remain in the highly productive waters of the

Columbia River Plume. Our results showed both of these migratory patterns present in the Salmon River estuary: rapid migration to the ocean and residency in the estuary.

An expected benefit for an ocean migrant life history is access to the productive feeding environment, resulting in increased growth and body size and a subsequent increase in fecundity (Gross et al. 1988). Growth rate of ocean migrants, however, was not significantly different than that of estuarine residents. This may explain why many fish appeared to remain within the estuary or close to it, rather than migrating farther and incurring associated costs (e.g., energetic costs and exposure to potentially higher mortality rates). The Salmon River estuary appears to be functioning as a highly productive ecosystem based on the array of life histories expressed by chinook salmon, and the high productivity of invertebrates and prey (Gray et al. 2002, Bottom et al. 2005, Jones et al. 2007).

The "decision" to migrate through, or remain resident in the estuary, however, will depend not only on growth opportunities but also survival probabilities, both of which may be affected by individual phenotype (e.g., body size and condition, timing of estuarine entry, competitive ability) and density dependent factors. Size can influence the migratory behavior of individuals within populations. Fish with higher growth rates often migrate at a younger age than those with lower growth rates (Jonsson 1985, Forseth et al. 1999, Theriault and Dodson 2003). In the Salmon River, initial length at tagging was similar for ocean migrants and estuarine residents, suggesting that ocean migration was not stimulated by size. Because fish were tagged in the estuary, the time of estuarine entrance for the two life history types could not

be determined. However, both migration timing data from the screw trap and catch per effort data in the beach seine suggests most migratory coastal cutthroat trout enter the estuary in April and May. Catch data and direct observations of acoustically tagged fish indicates ocean migrants leave the estuary before mid May and return in August. This is similar to migration timing reported for coastal cutthroat trout in other studies (Sumner 1962, Giger 1972).

The comparison of growth between ocean migrants and estuarine residents is dependent on the rigor of the criteria used to classify PIT-tagged fish into life history categories. The identification of the two main life history types was determined by direct observations of acoustically tagged fish and the classification criteria was then based on the behavior of the acoustically tagged fish and on the capture history of PIT-tagged fish. We chose conservative criteria to avoid misclassifying fish actually residing in the estuary as ocean migrants. The one acoustically tagged ocean migrant that returned to the estuary spent a total of 56 days in the ocean. However, we used a minimum of 85 days between recapture for classification of PIT-tagged fish as ocean migrants to minimize the possibility that a fish reared in the estuary but avoided capture and because this time frame corresponded with the increase in catch per effort in early August. Fish recaptured within 40–85 days were not classified. Because coastal cutthroat trout residing in the estuary exhibited strong site fidelity, 70% were recaptured at the original site of tagging (*see* Chapter 2). If a fish was in the estuary we would have a high likelihood of recapturing it. Although differences in growth may have been undetected with the methodology used in this study, a large difference in growth was not observed.

Density-dependence could influence migratory patterns through competition for space or food. Evidence suggests that residency in salmonid fishes is favored when density is low and growth rates are high, whereas migratory behavior is favored when density is high and growth rates are low (Jonsson and Jonsson 1993). Thus, the driving force for ocean migration may be lack of available sites in the estuary. A prior resident effect may also exist whereas estuarine residents could be those that migrate earliest and take up the best foraging sites. Prior residents would have greater knowledge of the environment than new arrivals and may out-compete new arrivals for resources, such as prey (Hsu et al 2006). The first Atlantic salmon *Salmo salar* to establish themselves at a given site fed at a higher rate and had higher rates of growth than later arrivals, despite no significant differences in dominance status (O'Connor et al. 2000), as did brown trout *Salmo trutta* stocked at high densities with low food abundance (Brannas et al. 2004). Therefore, prior residents, regardless of size, can gain foraging benefits without excluding later arrivals from the territory. Although larger fish may compete more successfully for resources and smaller fish would more likely be displaced, we did not see evidence of this.

An understanding of life history diversity in coastal cutthroat trout and how it is expressed is important in developing appropriate conservation, management, and restoration strategies. Because life history diversity is an expression of adaptations that evolved in a dynamic environment, loss of diversity within populations would put the population at risk. Loss of habitat would result in loss of population diversity thus potentially affecting resilience of populations over evolutionary time (Waples et al. 2001). Wide variations in migratory life histories are expressed in coastal cutthroat

trout similar to that seen in other salmonid species (Northcote 1997; Willson 1997; Cucherousset et al. 2005) and they require an array of habitats to complete their life history (freshwater, estuarine, and ocean). Alteration of these habitats could affect the success of life history types, thereby affecting the productivity of populations. Ecologically functioning estuaries may provide a buffer against poor ocean conditions, especially if functioning marsh habitats provide access to productive food sources even if the ocean-derived food sources in the estuary decrease during cycles of poor ocean productivity.

Results of this study demonstrated that estuarine residents were clearly a significant component of the coastal cutthroat trout population in Salmon River. This life history type may be more important than previously thought and its expression in the Salmon River may be in response to restoration of the estuarine ecosystem. The life history diversity of coastal cutthroat trout in the Salmon River may indicate that the restored estuary provides necessary habitat connectivity, allowing these fish to complete their life histories. If this is the case, then restoration of other estuaries should result in an expression of estuarine residency within other coastal cutthroat trout populations.

## **References**

Barlow, G.W. 1995. The relevance of behavior and natural history to evolutionarily significant units. Pages 169–175 *in* J. L. Nielsen, editor. Evolution and the aquatic ecosystem: defining unique units in population conservation. American Fisheries Society Symposium 17, Bethesda, Maryland

Bottom, D.L., K.K. Jones, T.J. Cornwell, A. Gray, and C.A. Simenstad. 2005. Patterns of Chinook salmon migration and residency in the Salmon River estuary (Oregon). Estuarine, Coastal, and Shelf Science 64:79–93.

Brannas, E., S. Jonsson, and K. Brannas. 2004. Density-dependent effects of prior residence and behavioural strategy on growth of stocked brown trout (*Salmo trutta*). Canadian Journal of Zoology 82:1638–1646.

Cucherousset, J., D. Ombredane, K. Charles, F. Marchand, and J. Baliniere. 2005. A continuum of life history tactics in a brown trout *(Salmo trutta)* population. Canadian Journal of Fisheries and Aquatic Science 62:1600–1610.

Forseth, T., T.F. Naesje, B. Jonsson, and K. Harsaker. 1999. Juvenile migration of brown trout: a consequence of energetic state. Journal of Animal Ecology 68:783-793.

Giger, R.D. 1972. Ecology and management of coastal cutthroat trout in Oregon. Oregon State Game Commission, Fishery Research Report 6, Corvallis.

Gray, A., C.A. Simentstad, D.L. Bottom, and T. Cornwell. 2002. Contrasting functional performance of juvenile salmon habitat in recovering wetlands of the Salmon River estuary, Oregon, USA. Restoration Ecology 10(3):514–526.

Gross, M.R., R.M. Coleman, and R.M. McDowell. 1988. Aquatic productivity and the evolution of diadromous fish migration. Science 239:1291–1293.

Hisata, J.S. 1973. An evaluation of stocking semi-natural pond reared sea-run cutthroat trout in streams of Hood Canal, Washington State. Washington State Department of Fish and Game. Job Completion Report. AFS 44-1,2, Olympia, WA. 38pp.

Hsu, Y., R.L. Earley, and L.L. Wolf. 2006. Modulation of aggressive behavior by fighting experience: mechanisms and contest outcomes. Biological Review 81:33–74.

Hudson, J.M. 2005. Movements of coastal cutthroat trout *(Oncorhynchus clarki clarki)* in the lower Columbia River: tributary, main-stem, and estuary use. U.S. Fish and Wildlife Service, Project Status Report, Draft.

Jones, J.D., and C.L. Siefert. 1997. Distribution of mature sea-run cutthroat trout overwintering in Auke Lake and Lake Eva in southeastern Alaska. Pages 27–28 *in* J.D. Hall, P.A. Bisson, and R.E. Gresswell, editors. Sea-run cutthroat trout: biology, management, and future conservation. Oregon Chapter, American Fisheries Society, Corvallis.

Jones, D.S., I.A. Fleming, L.K. Krentz, and K.K. Jones. In press. Feeding Ecology of Cutthroat Trout in the Salmon River Estuary, Oregon. P. Connally, T. Williams, and R. E. Gresswell, editors. Sea-run cutthroat trout. Oregon Chapter, American Fisheries Society, Corvallis.

Jonsson, B. 1985. Life history patterns of freshwater resident and sea-run migrant brown trout in Norway. Transactions of the American Fisheries Society 114:182–194.

Jonsson, B., and N. Jonsson. 1993. Partial migration: niche shift versus sexual maturation in fishes. Reviews in Fish Biology and Fisheries 3:348–365

Loch, J.J., and D.R. Miller. 1988. Distribution and diet of sea-run cutthroat trout captured in and adjacent to the Columbia River plume, May–July 1980. Northwest Science 62:41–48.

McDowell, R.M. 2001. Anadromy and homing: two life-history traits with adaptive synergies in salmonid fishes? Fish Fish 2:78–85.

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

O'Connor, K.I., N.B. Metcalfe, and A.C. Taylor. 2002. The effect of prior residence on behavior and growth rates of juvenile Atlantic salmon *(Salmo salar).* Behavioral Ecology 11(1):13–18.

Pearcy, W.G., R.D. Brodeur, and J.P. Fisher. 1990. Distribution and biology of juvenile cutthroat trout *Oncorhynchus clarki clarki* and steelhead *O. myskiss* in coastal waters off Oregon and Washington. Fishery Bulletin 88:697–711.

Quinn, T.P., and K.W. Myers. 2004. Anadromy and the marine migrations of Pacific salmon and trout: Rounsefell revisited. Reviews in Fish Biology and Fisheries 14:421–442.

Ramsey, F. L., and D. W. Schafer. 2002. The statistical sleuth: a course in methods of data analysis. California: Duxbury.

Randolph, C. 1986. Characteristics of Skamania and Beaver Creek hatchery anadromous stocks. Washington Department of Fish and Game. Management Division, Olympia, WA. 154pp.

Rounsefell, G.A. 1958. Anadromy in North American Salmonidae. Fisheries Bulletin 131:171–185.

Ruckelshaus, M.H., P. Levin, J.B. Jonhson, and P.M. Kareiva. 2002. The Pacific salmon wars: what science brings to the challenge of recovering species. Annual Review of Ecology and Systematics 33:665–706.

Sumner, F.H.  1962.  Migration and growth of coastal cutthroat trout in Tillamook County, Oregon.  Transactions of the American Fisheries Society 91(1):77–83.

Tipping, J.M.  1981.  Cowlitz sea-run cutthroat study 1980–1981.  Washington State Game Department, Fisheries Management Division Report 81–12, Olympia.

Theriault, V., and J.J. Dodson.  2003.  The role of size in determining Anadromy or residency in brook charr *(Salvelinus fontinalis)*.  Journal of Fish Biology 63:1–16.

Thorpe, J.E. 1994.  Performance thresholds and life-history flexibility in salmonids.  Conservation Biology 8:877-879.

Tomasson, T.  1978.  Age and growth of cutthroat trout, *Salmo clarki clarki* Richardson, in the Rogue River, Oregon.  Master's thesis. Oregon State University, Corvallis.

Trotter, P.C.  1989.  Coastal cutthroat trout: a life history compendium.  Transactions of the American Fisheries Society 118:463–473.

Trotter, P.C.  1997. Sea-run cutthroat trout:life history profile.  Pages 7–15 *in* J.D. Hall, P.A. Bisson, and R.E. Gresswell, editors.  Sea-run cutthroat trout: biology, management, and future conservation.  Oregon Chapter, American Fisheries Society, Corvallis.

Waples, R.S., R.G. Gustafson, L.A. Weitkamp, J.M. Myers, O.W. Johnson, P.J. Busby, J.J. Hard, G.J. Bryant, F.W. Waknitz, K. Nelly, D. Teel, W.S. Grant, G.A. Winans, S. Phelps, A. Marshall, and B.M. Baker.  2001.  Characterizing diversity in salmon from the Pacific Northwest.  Journal of Fish Biology 59(Supplement A):1–41.

Willson, M.F.  1997.  Variation in salmonid life histories: patterns and perspectives.  USDA Forest Service, Research Paper PNW-RP-498, Portland, Oregon.

Welch, D.W., S.D. Batten, and B.R. Ward.  2007.  Growth, survival, and tag retention of surgically implanted acoustic tags in steelhead trout *(Oncorhynchus mykiss)*.  Hydrobiologia 582:289–299.

Zale, A.V., C. Brooke, and W. C. Fraser.  2005.  Effects of surgically implanted transmitter weights on growth and swimming stamina of small adult westslope cutthroat trout.  Transactions of the American Fisheries Society 134:653–660.

**Chapter 4: Conclusion**

This study provided insight into the life history variation of migratory coastal cutthroat trout in the Salmon River estuary, Oregon and contributed to our understanding of estuarine habitats and their importance as year-round rearing areas. Coastal cutthroat trout used the Salmon River estuary year-round, although abundance was higher at certain times of the year. Relative abundance was high in spring and late summer, when both ocean migrants and estuarine residents were likely to be in the estuary. Cutthroat trout preferred main stem sites over marsh channel sites and deeper sites to shallower sites. Within the estuary, most cutthroat trout exhibited strong site fidelity, residing at one site for several weeks to several months. However, all fish did move among sites within the estuary, and some fish moved rapidly between sites and exhibited no site fidelity. Therefore habitat use in the estuary is likely a continuum of migratory and rearing behaviors. .

We identified two main life history types for coastal cutthroat trout in the Salmon River estuary, Oregon — ocean migrants and estuarine residents — although we also observed migratory behaviors that were intermediate between the two main forms. Ocean migrants moved rapidly through the estuary and generally migrated in less than two weeks. Estuarine residents migrated to the estuary in spring where they resided for a number of months before returning upstream. Other migratory behaviors included fish that resided in the estuary for most of the spring and summer but may have made short forays into the ocean, and fish that remained in the estuary through winter. Thus, coastal cutthroat trout in the Salmon River exhibited a continuum of life history types.

The growth of estuarine residents in the Salmon River did not differ from that of ocean migrants.  However, because of the short duration of this study (18 months) we cannot determine if a growth advantage of one life history is evident during different time periods, which is probable in an environment where ocean and estuarine conditions vary on a temporal scale.  Therefore, maintaining life history diversity will aid the long term sustainability of the species.

The findings of this study suggested that estuarine habitats are used by coastal cutthroat trout as more than just migratory corridors and may be more important in the life history of this species than previously thought.  Thus, conserving and restoring these habitats will benefit coastal cutthroat trout.  In Oregon, as much as 70% of functioning estuarine wetland habitat have been altered through anthropogenic activities such as flow regulation, diking, and habitat modification.  The habitat of most estuaries where coastal cutthroat trout have been studied has been simplified because of development and other human activities.  The Salmon River estuary has been restored and may represent more historic conditions than other estuaries along the Oregon Coast.  Therefore, restoration of other coastal estuaries may allow for increased expression of estuarine life histories in populations of coastal cutthroat trout.

## **References**

Armstrong, J. D., and N. A. Herbert.  1997.  Homing movements of displaced steam-dwelling brown trout.  Journal of Fish Biology 50:445–449.

Armstrong, J. D., V. A. Braithwaite, and F. A. Huntingford.  1997.  Spatial strategies of wild Atlantic salmon parr: exploration and settlement in unfamiliar areas.  Journal of Animal Ecology 66:203–211.

Barlow, G.W.  1995.  The relevance of behavior and natural history to evolutionarily significant units.  Pages 169–175 *in* J. L. Nielsen, editor.  Evolution and the aquatic ecosystem:  defining unique units in population conservation.  American Fisheries Society Symposium 17, Bethesda, Maryland

Behnke, R.J.  1992.  Native trout of western North America.  American Fisheries Society Monograph 6, Bethesda, Maryland.

Bélanger, G., and M. A. Rodríguez.  2001.  Homing behavior of stream-dwelling brook charr following experimental displacement.  Journal of Fish Biology 59:987–1001.

Bisson, P.A., K. Sullivan, and J.L. Nielsen.  1988.  Channel hydraulics, habitat use, and body from of juvenile coho salmon, steelhead, and cutthroat trout in streams.  Transactions of the American Fisheries Society  117:262–273.

Bottom, D.L., and K.K. Jones.  1990.  Species composition, distribution, and invertebrate prey fish assemblages in the Columbia River estuary.  Progress in Oceanography 25:243–270.

Bottom, D.L., K.K. Jones, T.J. Cornwell, A. Gray, and C.A. Simenstad.  2005.  Patterns of Chinook salmon migration and residency in the Salmon River estuary (Oregon).  Estuarine, Coastal, and Shelf Science 64:79–93.

Bottom, D.L., C.A. Simenstad, J. Burke, A.M. Baptista, D.A. Jay, K.K. Jones, E. Casillas, and M.H. Schiewe.  2005.  Salmon at river's end: the role of the estuary in the decline and recovery of Columbia River salmon.  NOAA Technical Memorandum NMFS-NWFSC-68. 246pp.

Brannas, E., S. Jonsson, and K. Brannas.  2004.  Density-dependent effects of prior residence and behavioural strategy on growth of stocked brown trout (*Salmo trutta)*.  Canadian Journal of Zoology 82:1638–1646.

Bridcut, E.E., and P.S. Giller.  1993.  Movement and site fidelity in young brown trout *Salmo trutta* populations in a southern Irish stream.  Journal of Fish Biology 43:889–899.

Bustard, D.R., and D.W. Narver. 1975. Preferences of juvenile coho salmon and cutthroat trout relative to simulated alteration of winter habitat. Journal of Fisheries Research Board of Canada 32:81–87.

Cucherousset, J., D. Ombredane, K. Charles, F. Marchand, and J. Baliniere. 2005. A continuum of life history tactics in a brown trout *(Salmo trutta)* population. Canadian Journal of Fisheries and Aquatic Science 62:1600–1610.

de Leañiz, C. G. 1989. Site fidelity and homing of Atlantic salmon parr in a small Scottish stream. Pages 70–80 *in* E. L. Brannon and B. Jonsson, editors. Proceedings of the salmon migration and distribution symposium. University of Washington, School of Fisheries, Seattle.

Diana, J.S., J.P. Hudson, R.D. Clark Jr. 2004. Movement patterns of large brown trout in the mainstream Au Sable River, Michigan. Transactions of the American Fisheries Society. 133:34-44.

Elliot, J.M. 1993. The pattern of natural mortality throughout the life cycle in contrasting populations of brown trout, *Salmo trutta*. Fisheries Research 17:123–136.

Fausch, K.D., C.E. Torgersen, C.V. Baxter, and H.W. Li. 2002. Landscapes to riverscapes: bridging the gap between research and conservation of stream fishes. BioScience 52:483–498.

FCO (Fish Commission of Oregon) and OSGC (Oregon State Game Commission). 1946.

Fleming, I.A. & Reynolds, J.D. 2004 Salmonid breeding systems. Pages 264-294 in A.P. Hendry and S.C. Stearns, editors. Evolution illuminated: salmon and their relatives. Oxford University Press. New York.

Forseth, T., T.F. Naesje, B. Jonsson, and K. Harsaker. 1999. Juvenile migration of brown trout: a consequence of energetic state. Journal of Animal Ecology 68:783-793.

Fresh, K.L., E. Casillas, L. Johnson, and D.L. Bottom. 2005. Role of the estuary in the recovery of Columbia River basin salmon and steelhead: an evaluation of the effects of selected factors on salmonid population viability. NOAA Technical Memorandum NMFS-NWFSC-69. 109pp.

Gerking, S.D. 1959. The restricted movements of fish populations. Biological reviews of the Cambridge Philosophical Society. 34:221-242.

Giger, R.D. 1972. Ecology and management of coastal cutthroat trout in Oregon. Oregon State Game Commission, Fishery Research Report 6, Corvallis.

Glova, G.J., and J.C. Mason. 1976. Interactive ecology of juvenile salmon and trout in streams. Fisheries Research Board of Canada Manuscript Report 1391.

Gray, A., C.A. Simenstad, D.L. Bottom, and T. Cornwell. 2002. Contrasting functional performance of juvenile salmon habitat in recovering wetlands of the Salmon River estuary, Oregon, USA. Restoration Ecology 10(3):514–526.

Gross, M.R. 1987. Comparison of allopatric cutthroat trout stocks with those sympatric with coho salmon and sculpins in small streams. Environmental Biology of Fishes 20:275–284.

Gross, M.R., R.M. Coleman, and R.M. McDowell. 1988. Aquatic productivity and the evolution of diadromous fish migration. Science 239:1291–1293.

Hall, J.D., and R.L. Lantz. 1969. Effects of logging on the habitat of coho salmon and cutthroat in coastal streams. Pages 355–375 *in* T.G. Northcote, editor. Symposium on salmon and trout in streams. H.R. MacMillan Lectures in Fisheries, University of British Columbia, Vancouver.

Hall, J.D., P.A. Bisson, and R.E. Gresswell, editors. 1997. Sea-run cutthroat trout: biology, management, and future conservation. Oregon Chapter, American Fisheries Society, Corvallis.

Halvorsen, M., and O. B. Stabell. 1990. Homing behavior of displaced stream-dwelling brown trout. Animal Behavior 39:1089–1097.

Hara, T. J. 1993. Role of olfaction in fish behaviour. Pages 171–199 *in* T. J. Pitcher, editor. Behaviour of teleost fishes. Chapman and Hall, London.

Hartman, G.F., and C.A. Gill. 1968. Distributions of juvenile steelhead and cutthroat trout *(Salmo gairdneri* and *S. clarki clarki)* within streams in southwestern British Columbia. Journal of Fisheries Research Board of Canada 25:33–48.

Hartman, G.F., and J.C. Scrivener. 1990. Impacts of forestry practices on a coastal stream ecosystem, Carnation Creek, British Columbia. Canadian Bulletin of Fisheries and Aquatic Sciences 223.

Healey, M. C., and A. Prince. 1995. Scales of variation in life history tactics of Pacific salmon and the conservation of phenotype and genotype. Pages 176–184 *in* J. L. Nielsen, editor. Evolution and the aquatic ecosystem: defining unique units in population conservation. American Fisheries Society Symposium 17, Bethesda, Maryland.

Heggenes, J. 1988. Effect of experimentally increased intraspecific competition on sedentary adult brown trout *Salmo trutta* movement and stream habitat choice. Canadian Journal of Fisheries and Aquatic Sciences 45:1163-1172.

Heggenes, J., T.G. Northcote, and A. Peter. 1991. Spatial stability of cutthroat trout *Oncorhynchus clarki* in a small, coastal stream. Canadian Journal of Fisheries and Aquatic Sciences 48:757-762.

Hisata, J.S. 1973. An evaluation of stocking semi-natural pond reared sea-run cutthroat trout in streams of Hood Canal, Washington State. Washington State Department of Fish and Game. Job Completion Report. AFS 44-1,2, Olympia, WA. 38pp.

Hsu, Y., R.L. Earley, and L.L. Wolf. 2006. Modulation of aggressive behavior by fighting experience: mechanisms and contest outcomes. Biological Review 81:33–74.

Hudson, J.M. 2005. Movements of coastal cutthroat trout *(Oncorhynchus clarki clarki)* in the lower Columbia River: tributary, main-stem, and estuary use. U.S. Fish and Wildlife Service, Project Status Report, Draft.

Huntingford, F. A., V. A. Braithwaite, J. D. Armstrong, D. Aird, and P. Joiner. 1998. Homing in juvenile salmon in response to imposed and spontaneous displacement: experiments in an artificial stream. Journal of Fish Biology 53:847–852.

Hvidsten, N.A., and R.A. Lund. 1988. Predation on hatchery-reared and wild smolts of Atlantic salmon, *Salmo sular*, in the estuary of River Orkla, Norway. Journal of Fish Biology 33:121–126.

Johnson, O.W., M.H. Ruckelhaus, W.S. Grant, F.W. Waknitz, A.M. Garrett, G.J. Bryant, K. Neely, and J.J. Hard. 1999. Status review of coastal cutthroat trout from Washington, Oregon, and California. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-MWFSC-37.

Jones, J.D., and C.L. Siefert. 1997. Distribution of mature sea-run cutthroat trout overwintering in Auke Lake and Lake Eva in southeastern Alaska. Pages 27–28 *in* J.D. Hall, P.A. Bisson, and R.E. Gresswell, editors. Sea-run cutthroat trout: biology, management, and future conservation. Oregon Chapter, American Fisheries Society, Corvallis.

Jones, D.S., I.A. Fleming, L.K. Krentz, and K.K. Jones. In press. Feeding Ecology of Cutthroat Trout in the Salmon River Estuary, Oregon. P. Connally, T. Williams, and R. E. Gresswell, editors. Sea-run cutthroat trout. Oregon Chapter, American Fisheries Society, Corvallis.

Jonsson, B. 1985. Life history patterns of freshwater resident and sea-run migrant brown trout in Norway. Transactions of the American Fisheries Society 114:182–194.

Jonsson, B., and N. Jonsson.  1993.  Partial migration: niche shift versus sexual maturation in fishes.  Reviews in Fish Biology and Fisheries 3:348–365.

Jonsson, N., B. Jonsson, and L.P. Hansen.  1997.  Changes in proximate compostition and estimates of energetic costs during upstream migration and spawning in Atlantic salmon *Salmo salar*.  Journal of Animal Ecology 66:425–436.

Kinnison, M.T., M.J. Unwin, A.P. Hendry, and T.P. Quinn.  2001.  Migratory costs and the evolution of egg size and number in introduced and indigenous salmon populations.  Evolution 55:1656–1667.

Liss, W.J., J.A. Stanford, J.A. Lichatowich, R.N. Williams, C.C. Coutant, P.R. Mundy, and R.R. Whitney.  2006.  Pages 51–98 *in* R.N. Williams, editor.  Return to the river: restoring salmon to the Columbia River.  Elsevier Academic Press, New York.

Loch, J.J., and D.R. Miller.  1988.  Distribution and diet of sea-run cutthroat trout captured in and adjacent to the Columbia River plume, May–July 1980.  Northwest Science 62:41–48.

Mather, M.E.  1998.  The role of context-specific predation in understanding patterns exhibited by anadromous salmon.  Canadian Journal of Fisheries and Aquatic Sciences 55(Supplement 1):232–246.

McCabe Jr., G.T., W.D. Muir, R.L. Emmett, and J.T. Durkin.  1983.  Interrelationships between juvenile salmonids and nonsalmonid fish in the Columbia River estuary.  Fishery Bulletin 81:815–826.

McDowell, R.M.  2001.  Anadromy and homing: two life-history traits with adaptive synergies in salmonid fishes?  Fish Fish 2:78–85.

Miller, R. B.  1954.  Movements of cutthroat trout after different periods of retention upstream and downstream from their homes.  Journal of the Fisheries Research Board of Canada 11: 550–558.

Northcote, T.G.  1997.  Why sea-run?  An exploration into the migratory/residency spectrum of coastal cutthroat trout.  Pages 20–26 *in* J.D. Hall, P.A. Bisson, and R.E. Gresswell, editors.  Sea-run cutthroat trout: biology, management, and future conservation.  Oregon Chapter, American Fisheries Society, Corvallis.

NRC (National Research Council).  1996.  Upstream: salmon and society in the Pacific Northwest.  National Academic Press, Washington D.C.

O'Connor, K.I., N.B. Metcalfe, and A.C. Taylor.  2002.  The effect of prior residence on behavior and growth rates of juvenile Atlantic salmon *(Salmo salar)*.  Behavioral Ecology 11(1):13–18.

Partridge, L., and P.H. Harvey. 1988. The ecological context of life history evolution. Science 241:1449–1454.

Pearcy, W.G., R.D. Brodeur, and J.P. Fisher. 1990. Distribution and biology of juvenile cutthroat trout *Oncorhynchus clarki clarki* and steelhead *O. myskiss* in coastal waters off Oregon and Washington. Fishery Bulletin 88:697–711.

Peterson, W.T., R.C. Hooff, C.A. Morgan, K.L. Hunter, E. Casillas, and J.W. Ferguson. 2006. Ocean conditions and salmon survival in the northern California current. NOAA National Marine Fisheries Service, Newport, Oregon. Available: http://www.nwfsc.noaa.gov/research/divisions/fed/ecosysrep.pdf (February 2007).

Quinn, T.P., and K.W. Myers. 2004. Anadromy and the marine migrations of Pacific salmon and trout: Rounsefell revisited. Reviews in Fish Biology and Fisheries 14:421–442.

Ramsey, F. L., and D. W. Schafer. 2002. The statistical sleuth: a course in methods of data analysis. California: Duxbury.

Randolph, C. 1986. Characteristics of Skamania and Beaver Creek hatchery anadromous stocks. Washington Department of Fish and Game. Management Division, Olympia, WA. 154pp.

Reeves, G.H., J.D. Hall, and S.V. Gregory. 1997. The impact of land management activities on coastal cutthroat trout in their freshwater habitats. Pages 138–144 *in* J.D. Hall, P.A. Bisson, and R.E. Gresswell, editors. Sea-run cutthroat trout: biology, management, and future conservation. Oregon Chapter, American Fisheries Society, Corvallis.

Rounsefell, G.A. 1958. Anadromy in North American Salmonidae. Fisheries Bulletin 131:171–185.

Ruckelshaus, M.H., P. Levin, J.B. Jonhson, and P.M. Kareiva. 2002. The Pacific salmon wars: what science brings to the challenge of recovering species. Annual Review of Ecology and Systematics 33:665–706.

Schreck, C.B., M.D. Karnowski, S. Clements, and D.B. Jepsen. 2001. Evaluation of delayed mortality of juvenile salmonids in the near-ocean environment following passage through the Columbia River hydrosystem. Annual report; Oregon Cooperative fish and Wildlife Research Unit.

Simenstad, C.A., K.L. Fresh., and E.O. Salo. 1982. The role of Puget sound and Washington coastal estuaries in the life history of Pacific salmon: an

unappreciated function.  In: kennedy, V.S. (Ed.), Estuarine Comparisons. Academic Pres, New York, pp. 343-364.

Smithson, E.B., and C.E. Johnston.  1999.  Movement patterns of stream fishes in a Ouachita Highlands stream: an examination of the restricted movement paradigm.  Transactions of the American Fisheries Society 128:847-853.

Solomon, D.J., and R.G. Templeton.  1976.  Movement of brown trout *Salmo trutta* L. in a chalk stream.  Journal of Fish Biology.  9:411-423.

Sumner, F.H.  1962.  Migration and growth of the coastal cutthroat trout in Tillamook County, Oregon.  Transactions of the American Fisheries Society 91:77–83.

Sumner, F.H.  1972.  A contribution to the life history of the cutthroat trout in Oregon.  Oregon State Game Commission, Corvallis.

Thompson, W.F.  1959.  An approach to population dynamics of the Pacific red salmon.  Transactions of the American Fisheries Society 88:209–209.

Tipping, J.M.  1981.  Cowlitz sea-run cutthroat study 1980-1981.  Washington State Game Department, Fisheries Management Division Report 81-12, Olympia.

Theriault, V.,  and J.J. Dodson.  2003.  The role of size in determining Anadromy or residency in brook charr *(Salvelinus fontinalis)*.  Journal of Fish Biology 63:1–16.

Thorpe, J.E. 1994.  Performance thresholds and life-history flexibility in salmonids.  Conservation Biology 8:877-879.

Tomasson, T.  1978.  Age and growth of cutthroat trout, *Salmo clarki clarki* Richardson, in the Rogue River, Oregon.  Master's thesis.  Oregon State University, Corvallis.

Trotter, P.C.  1989.  Coastal cutthroat trout: a life history compendium.  Transactions of the American Fisheries Society 118:463-473.

Trotter, P.C.  1997. Sea-run cutthroat trout:life history profile.  Pages 7–15 *in* J.D. Hall, P.A. Bisson, and R.E. Gresswell, editors.  Sea-run cutthroat trout: biology, management, and future conservation.  Oregon Chapter, American Fisheries Society, Corvallis.

Waples, R.S., R.G. Gustafson, L.A. Weitkamp, J.M. Myers, O.W. Johnson, P.J. Busby, J.J. Hard, G.J. Bryant, F.W. Waknitz, K. Nelly, D. Teel, W.S. Grant, G.A. Winans, S. Phelps, A. Marshall, and B.M. Baker.  2001.  Characterizing diversity in salmon from the Pacific Northwest.  Journal of Fish Biology 59(Supplement A):1-41.

Williams, J.E., and W. Nehlsen.  1997.  Status and trends of anadromous salmonids in the coastal zone with special reference to sea-run cutthroat trout.  Pages 37–42 *in* J.D. Hall, P.A. Bisson, and R.E. Gresswell, editors.  Sea-run cutthroat trout: biology, management, and future conservation.  Oregon Chapter, American Fisheries Society, Corvallis.

Willson, M.F.  1997.  Variation in salmonid life histories: patterns and perspectives.  USDA Forest Service, Research Paper PNW-RP-498, Portland, Oregon.

Welch, D.W., S.D. Batten, and B.R. Ward.  (2007).  Growth, survival, and tag retention of surgically implanted acoustic tags in steelhead trout *(Oncorhynchus mykiss)*.  Hydrobiologia 582:289–299.

Wood, C.C.  1987.  Predation of juvenile Pacific salmon by the common merganser *(Mergus merganser)* on eastern Vancouver Island.  I. Predation during the seaward migration.  Canadian Journal of Fisheries and Aquatic Sciences 44:941–949.

Zale, A.V., C. Brooke, and W. C. Fraser.  2005.  Effects of surgically implanted transmitter weights on growth and swimming stamina of small adult westslope cutthroat trout.  Transactions of the American Fisheries Society 134:653–660.