The 2005 Coastal Cutthroat Trout Symposium

Status, Management, Biology, and Conservation

Oregon Chapter
American Fisheries Society

THE 2005 COASTAL CUTTHROAT TROUT SYMPOSIUM

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THE 2005
COASTAL CUTTHROAT TROUT SYMPOSIUM

Status, Management, Biology, and Conservation

Proceedings of a Workshop

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Port Townsend, Washington

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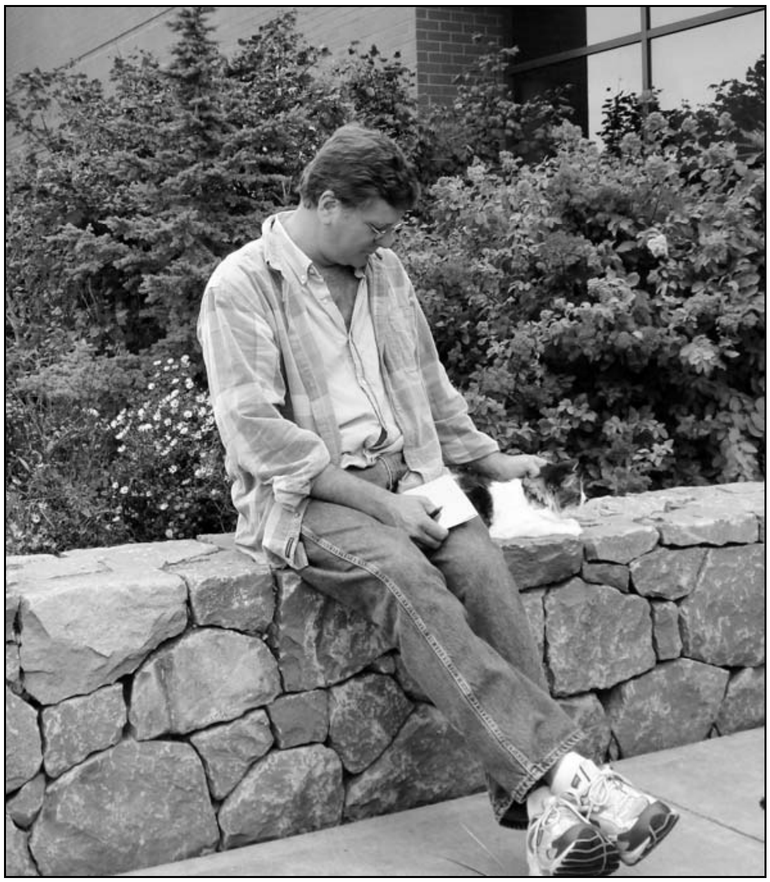
Part Three: Conservation Planning
(Session Chair Doug Young)

Dedicated to the Memory of Tim Cummings

Tim Cummings, one of the original planners and organizers of the 2005 Coastal Cutthroat Trout Symposium, the Symposium's Program Chair, and past-Chair of the Coastal Cutthroat Trout Interagency Executive Committee, passed away in December 2008. Tim's dedication and enthusiasm was instrumental in seeing the 2005 symposium come to fruition. Tim worked for the U.S. Fish and Wildlife Service for 20 years and was instrumental in promoting the conservation of coastal cutthroat trout and many other native fishes of the Pacific Northwest. Western native fish conservation and management were well served by his dedication and enthusiasm.



Introduction

Doug Young, Tim Cummings, and Joe Jauquet
Symposium Organizers

The 2005 Coastal Cutthroat Trout Symposium was organized by the Oregon Chapter American Fisheries Society (AFS) and sponsored by the Oregon, Humboldt, Pacific International, and Alaska Chapters AFS, U.S. Fish and Wildlife Service (USFWS), and Pacific States Marine Fisheries Commission (PSMFC).

The 2005 Coastal Cutthroat Trout Symposium was convened September 29 through October 1, 2005, at Fort Worden State Park, Port Townsend, Washington. A total of 110 people attended the Symposium, representing Pacific coast states of California, Oregon, Washington, and Alaska, as well as British Columbia. In addition, coastal cutthroat trout aficionados trekked from as far away as Maine, Colorado, and Massachusetts to attend the Symposium. Participants reflected the broad array of interests associated with this fascinating fish, and included anglers, environmentalists, scientists, managers, academics, media, and tribal members.

The objectives of the 2005 Coastal Cutthroat Trout Symposium were to:

- update coastal cutthroat trout information presented during the 1995 Sea-run Cutthroat Trout Symposium, held in Reedsport, Oregon;
- enhance knowledge on all facets of coastal cutthroat trout life history and ecology;
- provide current assessment of the range-wide status of coastal cutthroat trout populations; and
- encourage development of a coordinated, range-wide coastal cutthroat trout conservation and monitoring plan.

Thirty-five technical papers and 10 posters were presented, representing the state of knowledge on coastal cutthroat trout. The 2005 Coastal Cutthroat Trout Symposium's technical sessions included Status, Trends, and Management; Biology; and Conservation Planning. This Proceedings contains all the technical paper and poster abstracts or, if provided and peer-reviewed by the Coastal Cutthroat Trout Symposium Editorial Committee and volunteers, extended abstracts or full papers. All the technical paper Powerpoint presentations from the Symposium are available at http://www.fws.gov/columbiariver/cctsym.html. The Symposium presentations indicated that significant progress has been made in the areas of coastal cutthroat trout genetics, habitat use, movement and migrations, and life history strategies. Significant opportunity exists to collaborate on range-wide conservation and monitoring efforts. However, as many Symposium participants noted, 10 years after the 1995 Sea-run Cutthroat Trout Symposium we still lack basic information about status and trends of coastal cutthroat trout.

Other Symposium activities included an angling seminar by two noted coastal cutthroat trout angling guides, Jim Kerr and Les Johnson, and an evening poster/mixer session. A banquet keynote presentation was provided by Dr. Bob Behnke. When Dr. Behnke mentioned that he had never fished for coastal cutthroat trout, conference organizers arranged to take him fishing with Jim Kerr, but alas the cutthroat did not cooperate!

Significant financial assistance for planning and hosting the Symposium was provided by PSMFC, and Symposium leadership, organization, financial assistance, and personnel support was provided by USFWS. Loretta Brenner, the Oregon Chapter AFS's Administrative Assistant, provided excellent services as the Registration Coordinator, and on-site Symposium assistance was provided by USFWS staff John Brunzell, Jeff Hogle, and Danielle Warner.

Clark-Skamania Flyfishers, Lower Columbia Flyfishers, South Sound Flyfishers, Washington Fly Fishing Club, and Port Townsend Chapter of Trout Unlimited provided financial and personnel assistance towards the 2005 Symposium. Washington Trout (now Wild Fish Conservancy), G. Loomis, Bruce Ferguson, and Les Johnson donated fine art and books for the auction and raffle. In total, sponsors donated almost $20,000 to the Symposium. These generous contributions allowed organizers to reduce Symposium registration fees, provide complete travel, food, and lodging subsidies to nine students, and supplement non-student participants and invited speakers with an additional $4,500 in travel, lodging, and food awards.

Symposium contributions and registration proceeds funded two coastal cutthroat trout graduate student research scholarships:

- Allan Costello, University of British Columbia, $5,000 scholarship: *Resolving the Ancestral Polymorphism vs. Hybridization Debate: Congeneric Phylogeography of Coastal Cutthroat Trout and Rainbow Trout*;
- Sarah Haque, Evergreen State College, $3,000 scholarship: *Movement Patterns of Coastal Cutthroat Trout in South Puget Sound, Washington*.

The 2005 Coastal Cutthroat Trout Symposium was a great success. Excellent technical presentations and posters improved our knowledge of coastal cutthroat trout. A large audience of broadly divergent interests participated and enhanced dialog during the Symposium. Remaining funds will be provided as seed money for the next Coastal Cutthroat Trout Symposium.

We hope that another Coastal Cutthroat Trout Symposium will be hosted in the near future. While no single entity has volunteered to host the next Symposium, it seems appropriate that the next Symposium be held in

British Columbia. We hope to see you at the next Symposium, to review the newly generated information resulting from the 2005 Symposium's Graduate Student Research Scholarships, as well as information, activities, and plans generated from range-wide efforts to establish a coastal cutthroat trout conservation and monitoring strategy.

Editors' Note

The editorial committee for the 2005 Coastal Cutthroat Trout Symposium would like to acknowledge a number of individuals that contributed to the effort. Each extended abstract and formal manuscript was critically reviewed by at least two referees and a member of the editorial committee. In addition, all submissions were reviewed by our technical editor. The committee is extremely grateful to the reviewers; their time and effort were extremely appreciated. The committee would also like to acknowledge the tireless efforts of Doug Young, from the initial planning of the 2005 symposium to championing the final efforts to see these proceedings to completion. His dedication to the interest of coastal cutthroat trout was critical to the success of the symposium and the production of the proceedings. The committee also recognizes other symposium planners, Joe Jauquet and Tim Cummings, who were critical in planning and hosting the symposium. The committee was extremely fortunate to gain the expertise of Scott Bischke of MountainWorks, Incorporated as a technical and copy editor. Scott worked closely with the editorial committee during the final throes of the process and worked directly with our publisher, Omnipress, shepherding the proceedings to completion. The committee was also very excited to be able to use the art of Mark Jessop, Troutfin Studio, on the cover. In addition to being an artist, Mark is a fishery biologist and avid flyfisher and he brings these skills to the canvas. Dr. Jim Hall, the lead editor of the 1995 symposium, provided some valuable advice as to how to get these proceedings to print.

In reviewing the presentations at the symposium and the contributions to the proceedings, the editorial committee has the following observations and comments. Like the 1995 symposium, the 2005 meeting brought together a dedicated group of fish biologists, resource managers, and other coastal cutthroat trout enthusiasts in an exchange of the most recent and relevant research and management issues related to *Oncorhynchus clarkii clarkii*. Advances were made on several fronts (e.g., genetics and field identification of hybrids), but unfortunately many of the pressing issues at the 1995 symposium remain pressing today. Comprehensive monitoring programs are still not in place in many areas across the range. Monitoring efforts for the subspecies continue to rely on piggy-back opportunities provided by other anadromous species, but this approach is not appropriate for dealing with the complexity of *O. clarkii clarkii* life history diversity and range of habitat used by coastal cutthroat. As noted by Dr. Jim Hall in the 1995 proceedings, constraints of scientific publishing prohibit multiple publication of the same material and result in abbreviated material of some of the most pressing and current problems for *O. clarkii clarkii*. We encourage these authors to pursue full publication of their material. Again, as with the 1995 proceedings, we anticipate the 2005 proceedings will be the "go to" reference for those working on coastal cutthroat trout. The more developed presentations of the various research and management efforts need to be available for continued advancement of conservation efforts for coastal cutthroat trout.

—Patrick Connolly, Thomas Williams, and Robert Gresswell

PART ONE

STATUS, TRENDS, AND MANAGEMENT

Coastal Cutthroat Trout Symposium: Status, Management, Biology, and Conservation
Oregon Chapter, American Fisheries Society, 2008

Summary of 1998 Coast Wide Coastal Cutthroat Trout Status Review conducted by the National Marine Fisheries Service

Orlay W. Johnson[1], Mary H. Ruckelshaus, W. Stewart Grant, F. William Waknitz, Ann M. Garrett, Gregory J. Bryant, Kathleen Neely, and Jeffrey J. Hard
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Extended Abstract.—In 1997, the National Marine Fisheries Service (NMFS) received a petition requesting listing of all populations of coastal cutthroat trout *Oncorhynchus clarkii clarkii* on the United States west coast as threatened or endangered species under the U.S. Endangered Species Act (ESA). In response to this petition, NMFS initiated an ESA status review for coastal cutthroat in the coterminous U.S.

The ESA allows listing of species, subspecies, and "distinct population segments". The policy of the NMFS for anadromous Pacific salmonids is that a population will be considered "distinct" if it represents an evolutionarily significant unit (ESU) of the species as a whole. To be considered an ESU, a population must 1) be substantially reproductively isolated from other populations, and 2) contribute substantially to the ecological or genetic diversity of the biological species. Once an ESU is identified, a variety of factors related to population abundance are considered in determining whether a listing is warranted (reviewed in Johnson et al. 1998).

The NMFS formed a biological review team (BRT) of federal biologists who considered available biogeographic, life history, and genetic information to develop several possible ESU configurations for the subspecies. As part of this review, NMFS's Northwest Fisheries Science Center developed a genetic (allozyme) database from coastal cutthroat samples collected in British Columbia, Washington, Oregon, and California (Figure 1). After considerable discussion, a majority of BRT members supported a six ESU scenario (Figure 2) from the following geographical areas: Puget Sound, Olympic Peninsula, Southwest Washington / Columbia River, Oregon Coast, and southern Oregon/California. Alternative scenarios were proposed, but the BRT ultimately concluded the six ESU scenario was best supported by the available information (reviewed in Johnson et al. 1999).

In the risk assessment, the BRT wrestled with one of the most challenging aspects of coastal cutthroat, the scarcity of available information. Most of the data collected was for the anadromous life history form and came from studies that primarily focused on Pacific salmon, steelhead, or rainbow trout. After extensive discussion, the majority of the BRT agreed all but two ESUs were not likely to face extinction in the foreseeable future. The BRT was evenly split in determining whether the Oregon Coast ESU was likely to become endangered in the foreseeable future, but were unanimous in concluding that the Southwest Washington / Columbia River ESU was likely to become endangered in the foreseeable future (Johnson et al. 1998).

According to studies by Washington Department of Fish and Wildlife (WDFW) and other sources, the Southwest Washington / Columbia River ESU region historically supported healthy, highly productive anadromous and resident coastal cutthroat populations (reviewed in Leider 1997, WDFW 1998). However, the BRT's review of current information found anadromous and resident populations had declined throughout the ESU. The BRT was especially concerned about the widespread declines in abundance and the small population sizes of anadromous cutthroat trout throughout the lower Columbia River. The severe reductions in abundance of this life

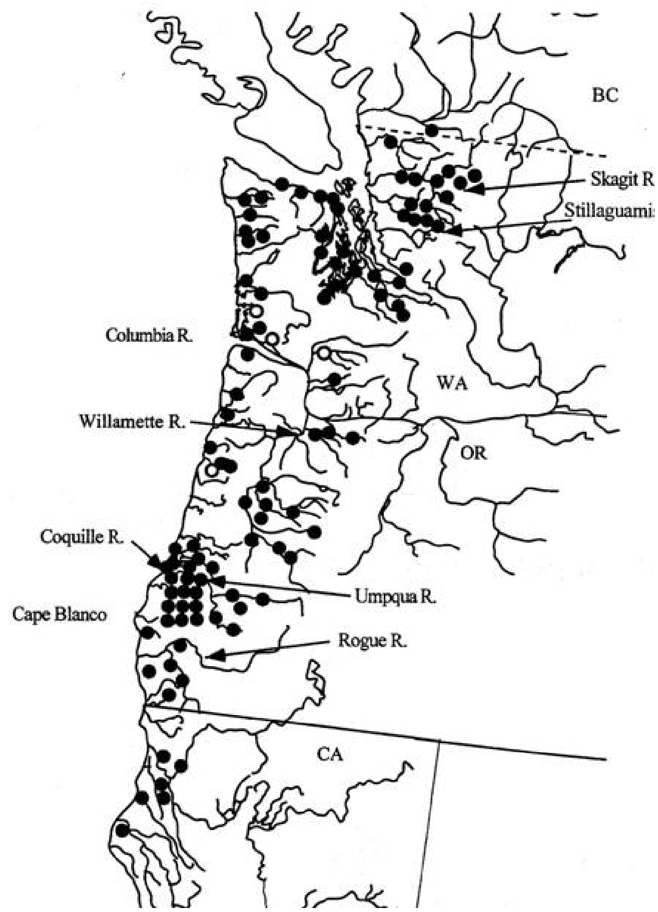

FIGURE 1.—Localities of samples in the NMFS-ODFW-WDFW allozyme database. Open circles represent samples from hatcheries (Johnson et al. 1999).

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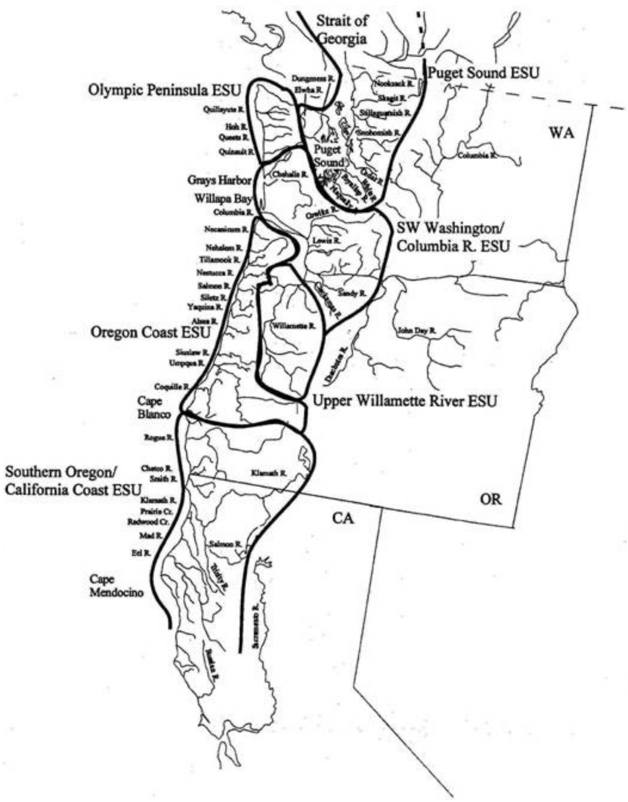

Figure 2.—Proposed Evolutionarily Significant Units (ESUs) for coastal cutthroat (Johnson et al. 1999).

history form could have deleterious effects on the ability of this ESU to recover from widespread declines. Reductions in the quantity and quality of nearshore ocean, estuarine, and riverine habitat have probably contributed to declines, but the relative importance of these risk factors is not well understood. Recent steps taken by the states of Washington and Oregon to reduce mortality due to directed and incidental harvest of coastal cutthroat encouraged the BRT.

On December 8th, 1998, the NMFS and U.S. Fish and Wildlife Service (USFWS, jointly, the Services) proposed a rule to list the Southwest Washington / Columbia River ESUs as threatened under the ESA. The Services also proposed to delist the Umpqua River ESU that was then currently listed as endangered. This proposal was based on the finding in the BRT status review that Umpqua River cutthroat trout are part of a larger ESU encompassing coastal cutthroat from the coast of Oregon. NMFS considered this ESU a candidate for listing and proposed to collect further information on the population abundance and structure of the subspecies. At this time, USFWS requested sole ESA jurisdiction over the subspecies and NMFS agreed to resolve this matter before the final listing determination for the Southwest Washington / Columbia River ESU. On July 20, 1999, NMFS transferred sole jurisdiction over coastal cutthroat to USFWS for ESA consideration.

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The Status of Four Species Management Units of Coastal Cutthroat Trout in Oregon

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Abstract.—The Oregon Department of Fish and Wildlife used the six interim criteria in Oregon's Native Fish Conservation Policy to assess the status and overall conservation risk classification of four species management units of coastal cutthroat trout *Oncorhynchus clarkii clarkii* in Oregon. This assessment was part of the Oregon Native Fish Status Report that the Oregon Department of Fish and Wildlife produced to help prioritize fish management and conservation efforts. Long-term datasets for each population of coastal cutthroat trout were mostly non-existent. Available datasets were used to infer the status of the populations and species management units. The assessment found that the conservation of three of the four species management units was not at risk. For the Lower Columbia River species management unit, the assessment found that the productivity of two populations could be below criterion level and therefore the conservation of the species management unit was potentially at risk. Current management activities are adequate to ensure the conservation of coastal cutthroat trout in Oregon.

Introduction

The State of Oregon's Native Fish Conservation Policy (NFCP) was developed by Oregon Department of Fish and Wildlife (ODFW) and adopted by the Oregon Fish and Wildlife Commission in November, 2002. The intent of the policy is to provide a basis for managing hatcheries, fisheries, habitat, predators, competitors, and pathogens in balance with sustainable production of naturally produced native fish in Oregon. The NFCP is to be implemented through the development of conservation plans for individual collections of fish populations from a common geographic region that share similar genetic and ecological characteristics. These groupings of populations are called species management units (SMUs) in the NFCP.

Six interim NFCP criteria provide temporary guidance to ensure the conservation of native fish prior to the completion of conservation plans. The interim criteria are used to assess the conservation status of species management units. The six interim criteria are defined as follows:

(1) *Existing Populations.*—No more than 20% of the historical populations within the species management unit have become extinct.
(2) *Habitat Use Distribution.*—Naturally produced members of a population must occupy at least 50% of a population's historic habitat.
(3) *Abundance.*—The number of naturally produced spawners must be greater than 25% of the average abundance of naturally produced spawners over the most recent 30 year time period.
(4) *Productivity*.—In years when the total spawner abundance is less than the average abundance of naturally produced spawners over the past 30 years, then the rate of population increase shall be at least 1.2 adult offspring per parent. Offspring are defined as naturally produced adults that survive to spawn and parents are defined as those adults of both natural plus hatchery origin that spawned and collectively produced the observed offspring.
(5) *Reproductive Independence.*—At least 90% of the spawners within a population must be naturally produced and not hatchery produced fish, unless ODFW determines the hatchery produced fish are being used in a short-term experimental program to help restore a population in its natural habitat or are otherwise directed by a court order.
(6) *Hybridization.*—The occurrence of individuals that are the product of deleterious hybridization with species that are non-native to the basin in which they are found must be rare or nonexistent.

In 2005, ODFW utilized the interim criteria in the NFCP to conduct an assessment of 69 species management units in Oregon. The assessments included four coastal cutthroat trout SMUs (Oregon Coast, Southern Oregon, Lower Columbia River, and Willamette River). These assessments were compiled into the Oregon Native Fish Status Report (Status Report). The Status Report may be found at http://www.dfw.state.or.us/fish/ONFSR. A brief description of the methods used to assess coastal cutthroat trout for the Status Report and the outcome of the assessment are provided below.

Coastal Cutthroat Trout Assessment Methods

Conservation status of coastal cutthroat trout was assessed using the six interim criteria outlined in the NFCP. For the abundance and productivity criteria, we assessed the coastal cutthroat trout populations based on the intent of the criteria (described below). The coastal cutthroat trout assessments were based on available data in conjunction with anecdotal evidence and the professional opinion of local ODFW biologists. The available data came from a variety of sources. Some were from efforts directed at enumerating coastal cutthroat trout, but much of the data came from efforts directed at salmon or steelhead in coastal basins. The datasets were for various time periods and geographic areas. No datasets were available that have collected abundance information on coastal cutthroat trout in a consistent manner over the fishes' entire Oregon range. Many of the available datasets resulted from different sampling methodologies, making comparisons problematic. Lack of quantitative coastal cutthroat trout spawning data limited our ability to assess populations for the abundance and productivity criteria consistent with the method used for many of the salmon and steelhead populations assessed in the Status Report. In addition, time and staff were not available to analyze all of the available coastal cutthroat trout data and to develop relationships between datasets. ODFW hopes to expend this level of effort when a conservation plan is developed for each of the coastal cutthroat trout SMUs.

Species Management Units and populations.—SMUs for coastal cutthroat trout correspond to the National Marine Fisheries Service (NMFS) coastal cutthroat trout Evolutionarily Significant Units (ESU) (Johnson et al. 1999). Four coastal cutthroat trout SMUs have been identified for this report: Oregon Coast, Southern Oregon, Lower Columbia River, and Willamette River.

Recent evidence (Wenburg and Bentzen 2001) indicates that coastal cutthroat trout populations are structured at the creek or tributary level, however, for the ease of these NFCP assessments, and since ODFW often manages fisheries at the level of a basin or sub-basin, the population boundaries identified for the assessment are groupings of creeks or tributaries. Populations were identified geographically by grouping fifth field hydrologic unit codes (HUCs) to identify major basins or sub-basins. Populations were kept within the area of a fourth field HUC to allow for greater detail within large basins. ODFW also recognizes that within the boundaries of most of these populations there are isolated groups of cutthroat trout that have evolved above barriers and should be considered unique.

Because of an apparent intermingling of life-history strategies, all life-history strategies of coastal cutthroat trout present within the boundaries of a population are considered for this assessment to be components of one diverse population. This assessment approach is consistent with the approach adopted by the U.S. Fish and Wildlife Service (USFWS) (Bown and Craig 2002) and is supported by Wenburg and Bentzen (2001), who indicated that coastal cutthroat trout populations are structured at the creek or tributary level, rather than among individual life history types within a basin.

Assessing existing populations.—This assessment sought to determine the existence of historic coastal cutthroat trout populations. Since genetic sampling has found differentiation of coastal cutthroat trout at the stream or tributary level (Wenburg and Bentzen 2001), we employed genetic testing to see if genetic differentiation existed within the population boundaries. The existence criterion used was the same criterion used for the habitat use distribution: populations were considered to exist and not be at risk of extinction if coastal cutthroat trout were found to be distributed throughout more than 50% of their historic habitat. This existence standard is much higher than for most of the other species assessed in this report.

Assessing habitat use distribution.—A population passed the habitat use distribution criterion if coastal cutthroat trout inhabited 50% or more of their historic habitat. We used the results of fish presence surveys on private and public forestland compiled by ODFW, Oregon Department of Forestry (ODF), the US Forest Service (USFS) and the Bureau of Land Management (BLM); juvenile fish sampling focused on other fish species; and routine or occasional sampling conducted by ODFW watershed district biologists. These sources of data were used to make an assessment of the frequency and distribution of coastal cutthroat trout throughout a geographic area. Coastal cutthroat trout distribution patterns seen in sampling were expanded for the entire population. If similar distribution patterns were observed within the boundaries of several populations within an SMU, it was presumed that a similar distribution would be seen in the remaining populations that did not have sufficient data.

Assessing abundance.—Populations were assessed to determine whether coastal cutthroat trout abundance was below a critical level in three of the last five years. A "critical level" was considered to occur when sampling within the distribution range of a population found very few to no cutthroat in a significant portion (greater than 50%) of the sampling sites. Because we had no data to determine the abundance of an entire population, we relied on the assumption that when populations are near carrying capacity, most of the habitat will be occupied at reasonable abundances. In addition, there were no spawner abundance data for coastal cutthroat trout in any of the SMUs that could be used to assess the abundance criterion as written in the NFCP's interim criteria.

Therefore, utilizing the following data and methods we felt there was significant evidence to assess the "intent" of the abundance criterion. The main data sets to determine coastal cutthroat trout abundance were from sampling conducted for forest practices on headwater streams, and from sampling related to monitoring of salmon and steelhead populations. Abundance was measured in coastal cutthroat trout densities (fish/m^2) observed in these surveys. All available data was not thoroughly compiled and analyzed for this assessment. In some cases, we relied on the local ODFW biologists' assessment of the available data to help determine the abundance of coastal cutthroat trout populations.

Where data was not compiled and analyzed or where data was not available or was not consistently collected, the abundance of populations was inferred from other populations within the same SMU. We used a series of assumptions to make the inferences on abundance. We assumed that conditions seen as a consistent pattern among the populations were indicative of the entire SMU. It was the professional opinion of the local ODFW biologists (Confer, VanDyke—Rogue Watershed District; Gray, Muck—Umpqua Watershed District; Buckman, Braun—North Coast Watershed District; Alsbury—North Willamette Watershed District; Ziller, Mamoyac—South Willamette Watershed District; French—Deschutes Watershed District) that freshwater habitat conditions have remained fairly stable in most areas where surveys were conducted over the last 10-15 years and therefore surveys conducted only once were likely to be indicative of what would be seen in adjacent years.

Assessing productivity.— Existing data were analyzed to determine whether populations (or life history types within populations) had the ability to rebound to average densities after a period of low abundance, showed long periods of stable abundance, or rebounded after a catastrophic event. In those situations where the biologists believed the abundance of coastal cutthroat trout had rebuilt after catastrophic events, it was taken as evidence of a productive population and was used to pass the productivity criterion. It was also possible to compare density data for some coastal cutthroat trout populations, or the anadromous portion of the population, for several years in a row or at times that were many years apart. Consistent densities over a period of time that were believed by the local biologists to represent full utilization of the habitat were also used to pass this criterion.

The loss of an historical life history strategy in a population was deemed a threat to the productivity of a population and caused the population to fail the productivity criterion. Data showing a prolonged period of very low abundances of a particular life history type was considered the same as the loss of that life history.

Assessing reproductive independence.—This criterion was assessed based on the presence of hatchery coastal cutthroat trout on the spawning grounds in three of the last five years.

Assessing hybridization.—Cutthroat trout populations passed the hybridization criterion if the occurrence of interspecific hybridization with non-native trout was rare or non-existent. It is important to note that hybridization of coastal cutthroat trout with native rainbow trout and steelhead is likely occurring naturally where the species are sympatric (Hawkins 1997). Natural hybridization between two native species in their historic range, however, was not the focus of this criterion.

Assessment Results

Oregon Coast Species Management Unit.—The Oregon Coast coastal cutthroat trout SMU includes 24 historical populations of coastal cutthroat trout inhabiting ocean tributary streams from the Necanicum River south to the Sixes River (Table 1). All four life history types are present within the SMU, and several populations exhibit all four life history types. All historical populations were found to be in existence and not at risk of extinction in the near future. The assessment for the Oregon Coast coastal cutthroat trout SMU found that all populations passed all of the interim criteria and therefore, the conservation of the SMU was not at risk.

Southern Oregon Species Management Unit.—The Southern Oregon coastal cutthroat trout SMU includes 12 historical populations of coastal cutthroat trout inhabiting ocean tributary streams from Elk River south to the Oregon/California border (Table 2). Resident, fluvial, and anadromous life-history types are present within the SMU. All historical populations were found to be in existence and not at risk of extinction in the near future. The assessment for the Southern Oregon coastal cutthroat trout SMU found that all populations passed all of the interim criteria and therefore, the conservation of the SMU was not at risk.

Lower Columbia River Species Management Unit.—The Lower Columbia River coastal cutthroat trout SMU includes eight historical populations of coastal cutthroat trout inhabiting tributary streams of the Columbia River from the mouth of the Columbia River upstream to The Dalles Dam, including tributaries of the Willamette River below Willamette Falls (Table 3). All populations include resident, fluvial, and anadromous fish. All historical populations were found to be in existence and not at risk of extinction in the near future. The anadromous life history strategy in the Hood and Fifteenmile populations were found to have been at depressed levels for some time and caused these populations and the SMU to fail the productivity criterion. The assessment for the Lower Columbia River coastal cutthroat trout SMU found that all populations below Bonneville Dam passed all of the interim criteria. Because the Hood and Fifteenmile populations did not pass the productivity criteria, the conservation of the SMU was found potentially at risk.

Willamette River Species Management Unit.—The Willamette River coastal cutthroat trout SMU includes 14

TABLE 1.—Description, status, and life history of Oregon Coast coastal cutthroat trout SMU populations. Life history strategies are shown as resident (R), fluvial (F), adfluvial (Ad), and anadromous (An).

Exist	Population	Description	Life history strategies present
Yes	Necanicum	Necanicum River	R/F/An
Yes	Nehalem	Nehalem River	R/F/Ad/An
Yes	Rockaway	Coastal tributaries near Rockaway	R/Ad/An
Yes	Tillamook	All tributaries to Tillamook Bay	R/F/An
Yes	Netarts	Netarts Bay and surrounding coastal tributaries	R/An
Yes	Nestucca	Nestucca River	R/F/An
Yes	Neskowin	Neskowin Creek and Sand Lake watersheds	R/An
Yes	Salmon	Salmon River	R/F/An
Yes	Devils Lake	Devils Lake	R/Ad/An
Yes	Siletz	Siletz River	R/F/An
Yes	Depoe Bay	Coastal tributaries near Depot Bay	R/An
Yes	Yaquina	Yaquina River	R/F/Ad/An
Yes	Beaver	Beaver Creek plus coastal tributaries between the Alsea and Yaquina	R/An
Yes	Alsea	Alsea River	R/F/Ad/An
Yes	Yachats	Coastal tributaries from Siuslaw River to Alsea River	R/F/Ad/An
Yes	Siuslaw	Siuslaw River	R/F/Ad/An
Yes	Siltcoos	Tributaries to Siltcoos and Tahkenitch lakes	R/Ad/An
Yes	Lower Umpqua	Umpqua River basin upstream to mouth of North Fork Umpqua River	R/F/Ad/An
Yes	Upper Umpqua	North and South Fork Umpqua River basins	R/F/Ad/An
Yes	Tenmile	Tributaries to Tenmile and Eel lakes	R/Ad/An
Yes	Coos	Coos River	R/F/An
Yes	Coquille	Coquille River	R/F/An
Yes	Floras	Floras Creek basin plus coastal tributaries north to the Coquille River	R/Ad/An
Yes	Sixes	Sixes River	R/F/An

TABLE 2.—Description, status, and life history of Southern Oregon coastal cutthroat trout SMU populations. Life history strategies are shown as resident (R), fluvial (F), adfluvial (Ad), and anadromous (An).

Exist	Population	Description	Life history
Yes	Upper Rogue	Upstream of Gold Ray Dam	F/R
Yes	Middle Rogue	Illinois River to Gold Ray Dam	R/F/An
Yes	Lower Rogue	Mouth to Illinois River	R/F/An
Yes	Applegate	Applegate River	F/R
Yes	Illinois	Illinois River	R/F/An
Yes	Elk	Elk River	R/F/An
Yes	Euchre	Euchre Creek and coastal tributaries from Elk River to Rogue River	R/An
Yes	Hunter	Hunter Creek	R/F/An
Yes	Pistol	Pistol River	R/F/An
Yes	Coastal creeks	Coastal Creeks between Rogue River and Chetco River	R/An
Yes	Chetco	Chetco River	R/F/An
Yes	Winchuck	Winchuck River	R/F/An

TABLE 3.—Description, status, and life history of Lower Columbia River Coastal Cutthroat Trout SMU populations. Life history strategies are shown as resident (R), fluvial (F), adfluvial (Ad), and anadromous (An).

Exist	Population	Description	Life history
Yes	Youngs	Young's Bay tributaries / Big Creek	R/F/An
Yes	Clatskanie	Clatskanie River / Beaver Creek / Plympton Creek	R/F/An
Yes	Scappoose	Scappoose Creek / Johnson Creek	R/F/An
Yes	Clackamas	Clackamas River	R/F/An
Yes	Sandy	Sandy River	R/F/An
Yes	Columbia Gorge	Columbia Gorge Tributaries	R/F/An
Yes	Hood	Hood River	R/F/An
Yes	Fifteen Mile	Mill Creek / Five Mile / Fifteen Mile	R/F/An

historical populations of coastal cutthroat trout inhabiting tributary streams to the Willamette River above Willamette Falls, as well as portions of the main stem Willamette (Table 4). The SMU for this report is comprised of resident, fluvial, and adfluvial cutthroat trout life histories believed to occur in each population that contains access to areas that would support such strategies. The assessment for the Willamette River coastal cutthroat trout SMU found that all populations passed all of the interim criteria and therefore, the conservation of the SMU was not at risk.

TABLE 4.—Description, status, and life history of Willamette River coastal cutthroat trout SMU populations. Life history strategies are shown as resident (R), fluvial (F), adfluvial (Ad), and anadromous (An).

Exist	Population	Description	Life history
Yes	Lower Willamette	Willamette Falls upstream to Santiam River	R/F
Yes	Tualatin	Tualatin River	R/F
Yes	Yamhill	Yamhill River	R/F
Yes	Molalla	Molalla River	R/F
Yes	Luckiamute	Luckiamute River	R/F
Yes	North Santiam	North Santiam River	R/F/Ad
Yes	South Santiam	South Santiam River	R/F/Ad
Yes	Mid Willamette	Willamette River from Santiam River upstream to Coast and Middle Fork	R/F
Yes	Marys	Marys River	R/F
Yes	Calapooia	Calapooia River	R/F
Yes	Long Tom	Long Tom River	R/F
Yes	McKenzie	McKenzie River	R/F/Ad
Yes	Middle Fork Willamette	Middle Fork Willamette River	R/F/Ad
Yes	Coast Fork Willamette	Coast Fork Willamette River	R/F/Ad

Management of Coastal Cutthroat Trout in Oregon

Management of coastal cutthroat trout in Oregon is designed to provide local fishery opportunities while ensuring the conservation of each SMU. Management ranges from stream closures in some areas to a consumptive fishery in others. Almost all areas open to angling for coastal cutthroat trout have flies and artificial lures only gear restrictions. In areas open to a consumptive fishery, ODFW biologists believe harvest rates are below the maximum sustained yield levels for those populations affected.

In the Oregon Coast SMU, management of coastal cutthroat trout includes a catch and release fishery in the northern portion, from the Necanicum River to Neskowin Creek, and a consumptive fishery (two fish per day) from Salmon River south to the Sixes River, as well as several areas where tributaries are closed to coastal cutthroat trout angling. The Umpqua basin is an exception in the southern portion of the SMU where some tributaries are closed and the majority of the basin is catch and release. The Oregon Coast SMU trout fishery season is from late May until mid-September or late October and has artificial flies and lures gear restrictions.

The Southern Oregon SMU is managed with a consumptive fishery in most basins, a few closed areas, and a more complex combination of management in the Rogue River basin. Consumptive fisheries in the SMU limit harvest to two fish over eight inches (20 cm) per day. The Rogue River basin has some tributaries open for a consumptive fishery, but the main stem has catch and release regulations. Bait is allowed in the main stem Rogue and Illinois River. Artificial fly and lure gear restrictions apply in most other open areas in the SMU. The Southern Oregon Coast SMU trout season (except the Rogue and its major tributaries) extends from late May through mid-September. The Rogue, Applegate, and Illinois rivers are open to trout angling January through March and again from late May through December

In the Lower Columbia River SMU, the tributaries and main stem Columbia River have catch and release regulations for coastal cutthroat trout with bait allowed. The Lower Columbia River SMU trout season runs from late May through the end of October.

In the Willamette River SMU, coastal cutthroat trout are managed for both consumptive and catch and release fisheries. Areas with native winter steelhead have catch and release regulations for coastal cutthroat trout with artificial flies and lures gear restrictions. Streams in the southwestern portion of the Willamette basin are open to a consumptive fishery with a bag limit of five trout over eight inches (20 cm) per day and bait is allowed. The McKenzie River and main stem Willamette River directly downstream of the McKenzie River have catch and release regulations. The Willamette River SMU trout season begins in late May and runs through October (in areas with native winter steelhead), and late April through October (in areas without native winter steelhead).

Management of coastal cutthroat trout in Oregon is based on the professional opinion of ODFW biologists. While ODFW is confident our management approach will maintain healthy and diverse populations of coastal cutthroat trout throughout their historic range in Oregon, we recognize that a) there are uncertainties about the plasticity of the various life history strategies, and b) that data are not available in all areas to adequately monitor the health of some coastal cutthroat trout populations.

In January 2005, ODFW signed a Memorandum of Understanding (MOU) with the USFWS to jointly develop conservation plans for each coastal cutthroat trout SMU. The MOU identifies that the first step in developing conservation plans is to develop a joint research, monitoring, and evaluation (RME) plan. That process is currently underway and the joint RME plan should be finalized in early 2006. Once this plan is agreed to by Oregon and the USFWS, both parties will begin to seek funding for the highest priority research and monitoring programs identified in the plan. The information that these efforts collect will help provide a stronger basis for management of coastal cutthroat trout and will serve as the background information needed to develop conservation plans.

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Coastal Cutthroat Trout in Washington State: Status and Management

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The coastal cutthroat trout *Oncorhynchus clarkii clarkii* inhabits a diverse and ecologically varied suite of habitats in Washington State. Cutthroat have responded to this variability, as evidenced by their exhibiting four basic life history forms (Wydoski and Whitney 2003): anadromous, adfluvial, fluvial, and resident. A summary of the status of the anadromous form of coastal cutthroat trout in Washington State was published by Leider (1997).

The Washington Department of Fish and Wildlife (WDFW) completed the salmonid stock inventory (SaSI) assessment process for coastal cutthroat trout (Blakley et al. 2000), which expanded upon the Washington Department of Game Sea-Run Cutthroat Status Report (DeShazo 1980). In the SaSI, the coastal cutthroat populations were described as "stock complexes". These complexes were defined as a group of closely related stocks located within a single watershed or other relatively limited geographic area. The number of stocks within a stock complex may never be known with any confidence. The inventory identified 40 coastal cutthroat stock complexes and determined their status (healthy, depressed, critical, unknown, or extinct), origin (native, non-native, or unknown), and production type (wild, cultured, or unknown).

This paper is intended to provide updated information subsequent to that paper, and to document the response of the WDFW to the proposed listing of this population under the Endangered Species Act.

In response to a petition to list coastal cutthroat trout as threatened or endangered under the U.S. Endangered Species Act, Johnson et al. (1999) completed a status review of coastal cutthroat trout, focusing on the anadromous forms of the species. Subsequently, the U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS) jointly published a proposal to list the "Southwest Washington/Columbia River" coastal cutthroat trout population as threatened in April 1999 (U.S. Office of the Federal Register 1999). The proposal to list the population was based on suspected declines in anadromous cutthroat abundance, habitat losses, and effects of hatchery-reared coastal cutthroat trout on wild cutthroat. In December 2001, the WDFW provided information and analysis on the abundance, life history, genetics, and distribution of coastal cutthroat in the proposed distinct population segment.

A decision was ultimately made not to list the species in June 2002 (USFWS 2002). The USFWS found that recent changes in regulations had reduced threats to the population, while also noting that the latest information indicated a) relatively healthy-sized total populations (all life history strategies) in a large portion (75%) of the population's range, and b) the production of anadromous trout from resident forms. These findings led them to conclude that the southwest Washington/Columbia River distinct population unit of coastal cutthroat trout was not in danger of becoming endangered in the foreseeable future and did not meet the definition of a threatened species.

General Distribution and Life Histories

Coastal cutthroat are widely distributed throughout Washington west of the Cascade mountain crest. Anadromous forms are generally found in streams in lower elevation and lower gradient waters downstream of barriers to upstream migration. They are present in tributaries to the Strait of Juan de Fuca, Puget Sound, and Hood Canal, in coastal streams, and in tributaries of the lower Columbia River as well as in the estuary and nearshore habitats associated with those systems.

Coastal cutthroat have a diverse range of life history forms. Several "potamodromous", or freshwater, life history strategies have been described. Fluvial, or riverine, forms migrate shorter distances within streams and rivers, utilizing larger rivers for accelerated growth. Adfluvial, or lacustrine, forms migrate into lakes to feed and grow after spawning. Resident, non-migratory forms tend to spend their lives in a small area of headwater streams. A number of sources have described the "bewildering diversity" (e.g., Johnson et al. 1999) in size and age at migration, timing of migrations, age at maturity, and frequency of repeat spawning of coastal cutthroat trout in Washington (Trotter 1997; Blakley et al. 2000).

Anadromous, or "sea-run" cutthroat, spawn in small streams and the juveniles undergo smoltification to adapt to life in haline environments. Cutthroat trout populations that exhibit migration to marine waters are commonly referred to as anadromous, as are Pacific salmon. Technically, however, unlike Pacific salmon coastal cutthroat trout and some other species that enter the marine environment may be more properly termed amphidromous. Unlike strict anadromy, amphidromous individuals often return seasonally to freshwater as subadults, sometimes for several years, before returning to spawn (Wilson 1997). Nonetheless, this paper will use the term anadromous to refer to the component of the population that migrates from freshwater habitats to estuarine or marine waters for a period of time.

Johnston (1982) identified two adult return strategies for the anadromous form, termed "early-" and "late-returning". Early-returning cutthroat runs tend to peak in large streams in September and October. The later-returning form typically returns in December and January to small streams draining directly into marine waters. Spawning normally occurs from December through May depending on the stock; spawning in northern Puget Sound tributaries tends to peak later than in other areas.

Out-migration of cutthroat smolts is similar to that of wild steelhead smolts (Serl and Morrill 2004). Those species consistently have been the first migrants to reach the Cowlitz Falls project in late April or early May, reaching the 50% passage date in mid-May.

Michael (1983) concluded that migration from above a barrier to migration in Snow Creek, Clallam County was genetically lethal to the above-barrier population. Migrants from above-barrier populations are lost to that population, as they can not return to ascend above the barrier. Their contribution to below-barrier populations is unknown.

WDFW has been conducting some further research into the relationship between anadromous and resident cutthroat. On the Cowlitz River, Tacoma Power discontinued trapping downstream migrant salmonids at Riffe Lake after dams were built in the early 1970s, and anadromy was no longer possible in the upper Cowlitz River basin. Data from migrant traps at Cowlitz Falls show that from 1992-95 no adults were released upstream, yet cutthroat smolts were captured in downstream traps as soon as the Cowlitz Falls Fish Facility began operating in 1996 (Serl and Morrill 2004). Smolt tagging data since 1997 has revealed that these migrating juveniles produced adult returns. An analysis of the microchemistry of otoliths of returning adult cutthroat comparing strontium/calcium ratios determined that the fish did migrate to salt water and returned as adults (Volk 1997). Based on these results it is clear that some resident cutthroat populations can and do contribute to the anadromous population. Cutthroat smolts were counted at WDFW out-migrant traps at Lucia Falls on the East Fork Lewis River, which is considered to be a barrier to all anadromous salmonids but steelhead. Consequently, these smolts are believed to be offspring of resident coastal cutthroat (Rawding and VanderPloeg 2001).

Potential Factors Affecting Stock Status

No single factor that may affect stock status operates independently of others. An increase or decrease in cutthroat population size results from an interaction of habitat conditions, harvest management, hatchery operations, and the pressures of inter-species competition and predation.

Habitat.—The diversity of life-history, behavior, and distribution of coastal cutthroat in Washington State exposes the species to a wide variety of natural and perturbed habitats. Habitat alterations exert dynamic pressures on populations of cutthroat, as well as on associated species. Impacts to habitats that adversely affect a sympatric species may benefit the population of cutthroat.

Shoreline modification is known to degrade nearshore habitat. Thom et al. (1994) report that approximately one-third of all saltwater shorelines in Washington State have some of kind of shoreline modification structure, such as a bulkhead. Although relatively few changes have been made to the outer coast of Washington, significant anthropogenic changes to Puget Sound have occurred. The large river deltas in Puget Sound are some of the most extensively modified areas (Bortleson et al. 1980). Commencement Bay and Elliott Bay were once highly productive estuarine deltas, but are now heavily urbanized (Puget Sound Action Team 2002, 2004).

In Washington, estuary habitat losses have been caused by the cumulative effects of agriculture, logging, mining, dams, grazing, urbanization, industry, exotic species, and aquaculture (Canning and Stevens 1990; Simenstad and Thom 1992; Johnson et al. 1999). By the 1990s, cumulative area loss of Washington coastal tidal wetlands was 42%, of Puget Sound estuaries was 71%, and of Puget Sound eelgrass was 70% (Simenstad and Thom 1992)

The Northwest Power and Conservation Council (2001) reported extensive losses of habitat in the lower Columbia River and Estuary as a result of dredging, filling, diking, and channelization. From 1870 to 1970, 20,000 acres of tidal swamps (with woody vegetation; 78% of estuary littoral area), 10,000 acres of tidal marshes (with non-woody vegetation), and 3,000 acres of tidal flats had been lost. The original extent of tidal marsh and swamp in the estuary has been reduced by more than half (LCREP 1999). Thomas (1983) reported the most significant losses to the estuary were in “swamps and marshes” and in “deep and medium depth water”.

Good et al. (1998) documented the extensive alteration of freshwater riparian areas due to forestry, agricultural, residential, industrial, and other uses and subsequent declines in the water quality and biological integrity of their adjacent waterways. Logging results in direct impacts to cutthroat habitats from sedimentation, changes in composition of spawning gravels, loss of riparian cover, and stream temperature elevation (Cedarholm et al. 1978; Martin et al. 1981). Rosenfeld et al. (2000) found that disproportionate use of small streams by cutthroat indicates that protection of small stream habitat is particularly important for long-term conservation of coastal cutthroat populations.

Changes in fish populations accompany urbanization or intense agricultural land use. The most significant and documented change in the fish community of urban streams is from coho salmon dominance to cutthroat trout dominance. Lucchetti and Fuerstenberg (1993) and Scott et al. (1986) documented reductions in the percentage of coho relative to cutthroat in a number of urban streams. In healthy streams, juvenile coho account for two to 10 times the number of cutthroat fry. As urbanization proceeds, juvenile and adult resident cutthroat become more dominant and eventually surpass coho both in total numbers and biomass. This change in species composition has been attributed to the reliance of juvenile coho on stable channels with complex habitat created by large woody debris. These habitat conditions are less common in urban streams.

As a watershed becomes urbanized, the proportion of impervious surface in the watershed increases. Thus, hydrographs of urbanized streams peak more quickly than in natural streams and even fairly mild rain events cause redd-scouring flows. The impact on fall spawning coho salmon is greater than on spring spawning cutthroat. This release from competition with coho allows the cutthroat to utilize the productivity of these streams to produce larger numbers of cutthroat than would normally be found in less urbanized streams. Serl (1999) investigated the effects of increased urbanization in Lake Washington tributaries. He found that the total density, length, and biomass density (g/m^2) of cutthroat increased with increasing percent total impervious area.

Species interactions.—The interactions between multiple species in the aquatic environment reflect a dynamic process. The relationship between coho salmon and cutthroat trout has been described by a number of authors (Perkins 1982; Steward 1983; Scott et al. 1986; Lucchetti and Fuerstenberg 1993; Sabo 1995; Rosenfeld et al. 2000). Urbanization appears to alter the relationship between juvenile coho and cutthroat trout. In these studies, coho tended to dominate in undeveloped streams, whereas cutthroat were more tolerant of conditions found in urbanized streams.

Predation by cutthroat on other species is well documented, and coastal cutthroat are effective predators on other fishes (Beauchamp et al. 1995; Vamosi and Schluter 2002; Wydoski and Whitney 2003; Jaquet 2004). Suspended materials limit the underwater visual range of fish, which may either reduce the ability of prey species to detect predators or may act as a protective cover (Gregory and Levings 1996). Gregory and Levings (1998) reported that during their seaward migration in the Fraser River system, age 0 Pacific salmon were less likely to encounter and be consumed by piscivorous cutthroat in turbid water than in clear water.

The response by cutthroat to natural and anthropogenic variability in sympatric populations of coho salmon, steelhead, and other salmonids must be viewed in the context of ecosystem dynamics. The NMFS Biological Review Team identified hybridization with *O. mykiss* as a potential risk to coastal cutthroat (Johnson et al. 1999). The team discussed the importance to risk evaluations of being able to distinguish historical natural levels of *O. clarkii clarkii* × *O. mykiss* hybridization from levels of present-day hybridization, and recognized the difficulty in evaluating those risks due to the lack of historical information. Cutthroat trout are known to hybridize with *O. mykiss* in anadromous zones of Puget Sound and other western Washington streams (Baker et al. 2002; Marshall et al. 2004). Young et al. (2001) reported that their findings were consistent with the hypothesis that introgression between anadromous populations of coastal rainbow and coastal cutthroat trout is limited by an environment-dependent reduction in hybrid fitness.

Harvest.—Leider (1997) summarized the history of recreational fishing for coastal cutthroat trout in Washington State. As human populations have increased, stock health and angling success for cutthroat have declined, and harvest regulations have become more restrictive. Cutthroat trout are not targeted in commercial fisheries and bycatch in commercial gillnet fisheries is minimal because of the large mesh size of gillnets relative to the size of cutthroat trout (NMFS 2003).

Current sport harvest regulations have been designed to increase the likelihood that smaller fish escape the fishery, so that rearing juveniles and migrating smolts are protected, and a majority of adult females are able to spawn at least once before being subjected to harvest (Washington Department of Game 1984). The statewide general fishing season for streams, rivers, and beaver ponds (1 June through 31 October) provides protection to outmigrating juvenile cutthroat. Size and bag limits (two trout, at least 8 inches [20 cm] in length, may be retained) provide protection from harvest to juvenile and young adult resident cutthroat. In streams where anadromous populations and fisheries coincide, general regulations allow a daily harvest of two fish, with a 14-inch (36-cm) minimum size. Where cutthroat are encountered in marine waters, catch-and-release fishing is mandated.

In tributaries to the Hood Canal and Willapa Bay, and in most major lower Columbia River tributaries, catch-and-release regulations are imposed on the recreational trout fishery. In the lower Columbia River below Bonneville Dam, and in the Cowlitz River from the mouth to Mayfield Dam, the fishery is targeted upon returns of hatchery-origin coastal cutthroat. Regulations require the release of wild cutthroat, and allow the retention of trout greater than 12 inches (30 cm) in length that have had their adipose fins removed.

Hatchery.—The sole remaining hatchery production of sea-run coastal cutthroat occurs at the Cowlitz Trout Hatchery, located at river kilometer 66 on the Cowlitz River. The sea-run cutthroat program began when the hatchery was completed in 1967, with release of fish beginning in the spring of 1968. Recent annual release levels reached 277,000 smolts (Table 1). Up to 100,000 fry and fingerling plants were previously made in the Tilton River and several tributaries. After 2002 these plants were discontinued as the new 35-year Cowlitz Federal Energy Regulatory Commission (FERC) re-licensing agreement #2016 (July 18, 2003), and the Cowlitz River Fisheries and Hatchery Management Plan (August 2004) emphasized recovery of upper river wild, anadromous salmonids above the dams.

The current release goal of 160,000 smolts downstream of the dams is designed to contribute to a meaningful harvest for sport fisheries. The program goal is to achieve an average 4.71% smolt-to-adult survival that includes harvest plus return of up to 5,000 fish at current production levels (WDFW 2005). Hatchery juveniles are raised to smolt-size (4.0 fish/lb [8.8 fish/kg]) and released from the hatchery at a time that fosters rapid migration downstream. Program fish are checked for health and signs of smolt fitness close to release time.

The cutthroat trout hatchery program at the Cowlitz Trout Hatchery will be converted to an Integrated Type program, defined by the Hatchery Scientific Review Group (HSRG) as a program to demographically increase the abundance of fish while retaining the genetic adaptation and fitness of a natural population (HSRG et al. 2004). Tacoma Power (2004) proposed that the long-term objective of this program would be to produce 50,000 smolts to meet conservation and self-sustaining run goals.

Currently, wild adult cutthroat arriving at the Cowlitz Salmon Hatchery are transported above hydropower dams to

TABLE 1.—Cowlitz sea-run cutthroat trout rack returns and percent return.

Release year	Smolts planted	Hatchery returns from release	Percent return to rack	Assumed total return[a]
1990	69,203	1,964	2.66	3,928
1991	106,316	2,404	2.69	4,808
1992	109,645	683	0.52	1,366
1993	96,220	1,279	1.18	2,558
1994	92,381	2,232	2.06	4,464
1995	98,865	3,581	3.53	7,162
1996	82,803	812	1.00	1,624
1997	110,127	1,233	1.11	2,466
1998	140,484	5,763	4.10	11,526
1999	130,800	6,122	4.68	12,244
2000	204,572	11,434	5.59	22,864
2001	228,780	7,583	3.31	15,166
2002	277,662	21,977	0.79	43,954
2003	154,005	9,690	5.80	19,300
2004	96,940	20,733[b]	21.4	41,546

[a] Rack returns are thought to represent 50% of total return, thus average percent survival is estimated to be 4.71% (Tipping and Harmon 2001).
[b] Total for 2004 only includes 1-salt returns.

Lake Mayfield and Lake Scanewa to spawn naturally. Wild cutthroat smolts produced from above the dams are collected at Mayfield Dam and Cowlitz Falls Fish Collection Facilities, transported downstream to the Cowlitz Salmon Hatchery stress reduction ponds, and released during the spring outmigration period.

The hatchery cutthroat program was proposed for termination upon achieving the self-sustaining run size of 500 adults under the Cowlitz Fish Hatchery and Management Plan (Tacoma Power 2004), although WDFW proposed a more modest reduction to 100,000 smolts to sustain the popular and economically significant recreational fishery (WDFW 2005). A final determination on the specifics of this program has not been made.

Status and Trends

The Salmonid Stock Inventory (Blakley et al. 2000) defined a stock complex as healthy if it was experiencing production levels consistent with its available habitat and within the natural variations in survival for the stock complex. A depressed stock complex was one whose production is below expected levels based on available habitat and natural variations in survival rates, but above the level where permanent damage to the stock complex is likely. Critical status was for those stock complexes experiencing production levels that are so low that permanent damage to the stock complex is likely or has already occurred. A stock complex was defined as unknown when there was insufficient quantitative information to rate its status.

Data sufficient to determine the status of coastal cutthroat are available for few populations in the state of Washington. Of the 40 stock complexes identified in the SaSI, one was rated as healthy. Seven of the 11 stocks in the lower Columbia River region were characterized as depressed, based on a decline in the Columbia River and tributary recreational catch estimates during salmon-and-steelhead-directed fisheries from 1975 to 1995; on low escapements at the Toutle River fish collection facility and the Toutle, Beaver Creek, and Elochomon fish hatcheries; and on declines in fish trap counts at Abernathy Creek, Mayfield Dam on the Cowlitz River, and the Kalama River. The decline in the Toutle River stock was also attributed to habitat destruction following the eruption of Mount St. Helens in 1980. The remaining 32 stocks had insufficient trend information to assess the current stock status.

Most information on the presence or abundance of cutthroat is a consequence of ancillary data resulting from collection of data on other species, mainly salmon and steelhead. These data are available from creel censuses, upstream and downstream migrant trapping programs, and electrofishing surveys. The limitations of this approach are that the sampling being conducted may or may not correspond to the life history characteristics of coastal cutthroat. Those data should therefore be viewed as indices to coastal cutthroat abundance and status. The following information summarizes the known status and distribution of coastal cutthroat in Washington.

Puget Sound.—Little recent information was available relative to cutthroat population status in the major Puget Sound tributaries that would permit an assessment or revision of the status ratings provided by Blakley et al. (2000). During the WDFW SaSI process, status for anadromous cutthroat in the Puget Sound, the Strait of Juan de Fuca, and Hood Canal tributaries was unknown, with the exception of the Stillaguamish River system, where the status was identified as healthy (Blakley et al. 2000). The Puget Sound Treaty Tribes and WDFW (2004) likewise noted that cutthroat populations were healthy in the Snohomish River system. Little information was available on the status of the non-anadromous forms. Our knowledge of population abundance, trends in abundance, population dynamics, and relationships among life history forms, productivity, and status are lacking.

Several Washington streams are tributary to the Fraser River in British Columbia. Cutthroat trout are reported as ubiquitous, occurring from sea level to above 500 m in elevation, rearing in Johnson and Sumas Creeks, and spawning in Sumas Creek, Upper Johnson Creek, and tributaries of the Sumas River (Puget Sound Energy 2002). Coastal cutthroat trout have been described as a "Blue-listed" species by the British Columbia Ministry of the Environment in the British Columbia Provincial Vertebrate

Animal Tracking List, meaning that they are considered to be a taxon of "special concern" in British Columbia (Cannings and Ptolemy 1998) due to characteristics that make them particularly sensitive to human activities or natural events.

Mueller et al. (1999) found that cutthroat trout were ubiquitous throughout Whatcom Lake during sampling for warmwater fish species in the late summer of 1998. Low catch rates for cutthroat during their survey were attributed to seasonal influences and gear-related biases. Long-term records of cutthroat trout spawning activity around Lake Whatcom from 1985-1994 suggested declines in this species (Jim Johnston, WDFW, personal communication). The native cutthroat trout spawning population of Lake Whatcom decreased markedly from 1987 to 1999, ostensibly the result of urbanization, timber practices, and other anthropogenic influences (Mueller et al. 2001).

The status of coastal cutthroat in the Skagit River basin was classified as unknown, as healthy in the Stillaguamish River, and as unknown but may be healthy in the Snohomish River drainage (Blakley et al. 2000). Little recent quantitative information is available to modify those determinations.

Coastal cutthroat trout are found throughout the Lake Washington basin in both potamodromous and anadromous life history forms, although the proportion of the adfluvial form appears to be increasing while fewer anadromous cutthroat are migrating through the Ballard shipping locks (J. Serl, WDFW, personal communication). Cutthroat in this lake have apparently increased in numbers since Eggers et al. (1978) reviewed the Lake Washington fish community and found the species to be a minor component of the lake community. Currently, they prey heavily on zooplankton, threespine stickleback *Gasterosteus aculeatus* and introduced longfin smelt *Spirinchus thaleichthys* which appear to somewhat buffer cutthroat predation on juvenile sockeye salmon *Oncorhynchus nerka* (Nowak et al. 2004). Status of cutthroat trout in the Sammamish River basin has not been determined, yet populations appear to have increased in recent years (King County SWMD 1993). Cutthroat are reported to be numerous in Issaquah Creek (US Army Corps of Engineers 2003a).

In recent years, resident cutthroat trout have increased in abundance throughout the Lake Washington watershed (Paron and Nelson 2001). Widespread urbanization around Lake Washington has created marginal conditions, and cutthroat trout are able to use these habitats more successfully than other trout and salmon (Scott et al. 1986). In areas where habitat is in good condition and cutthroat trout are sympatric with other salmonids, cutthroat trout appear to take a subdominant role (Johnson et al. 1999). Apparent cutthroat trout population increases in the Lake Washington basin may reflect increased use and availability of marginal habitats, from which other salmonid species have disappeared. Seiler et al. (2003) reported production estimates from Issaquah Creek, which indicate a very large cutthroat population exists in that stream.

Anadromous coastal cutthroat have not been documented in the Cedar River watershed above the Landsburg Diversion Dam, although resident forms are present in high numbers in the watershed below the Lower Cedar Falls (NMFS 2002). It is not known what proportion of the population downstream of the Landsburg Diversion Dam is the anadromous form. Although migrant passage evidently occurs through the Ballard Locks, there are no records indicating that coastal cutthroat trout currently use the fish ladder at the locks. The presence of large cutthroat trout observed in the Cedar River downstream of the Landsburg Diversion Dam suggests that some fish may have an anadromous or potentially adfluvial life history. Resident cutthroat are widely distributed in the Taylor Creek drainage and tributaries to the Cedar River downstream of Cedar Falls. No cutthroat trout have been observed within the Masonry Pool or Chester Morse Lake and its tributary streams, suggesting that the original natural barrier to anadromous fish passage at Cedar Falls historically controlled their distribution in the watershed.

Coastal cutthroat are distributed throughout western south Puget Sound streams, although their status is unknown. We have no current quantitative data on abundance or survival with which to assess status. Hunter (1980) rated anadromous cutthroat status in many of the tributaries in this region, based on habitat quality. Within more southerly waters the following systems were ranked as good: Sherwood, Campbell, Malaney, Deer, Cranberry, Kennedy, McLane, and Woodland creeks, and Deschutes River. Those identified as fair included Goldsborough, Skookum, and Schneider creeks. Only Perry Creek received a low rating, while Mill Creek was rated very good.

The anadromous life history form is expected to be found in most of the above listed systems, but presence and distribution in freshwater may be quite seasonal because of summer and fall low flows. The resident forms of this stock complex are present in virtually all perennial streams flowing directly into western South Puget Sound.

It is expected that these fish are late entry, based upon the relative size of the streams. The fluvial form probably inhabits all of the medium sized streams, and the adfluvial form may be present in as many as 12 lakes within the range of this stock complex. Anadromous spawnings are unknown but are thought to be similar to the North Puget Sound Tributaries Complex, which is January through March (Blakley et al. 2000).

The trapping of out-migrant cutthroat has occurred since 1978 at Big Beef Creek, a tributary to east-central Hood Canal. Since 1978, it appears that the production of cutthroat in this stream has generally increased (Figure 1).

Bernthal and Rot (2001) reported the widespread presence of cutthroat trout in several streams in Hood Canal and the eastern Strait of Juan de Fuca, but did not provide estimates of population size or status. Haring (1999) reported cutthroat presence in a number of western Strait of Juan de Fuca streams, and noted problems with impassable culverts, erosion, elevated water temperatures, and other habitat degradation in streams near Port Angeles. At Snow and Salmon Creeks, western Strait of Juan de Fuca tributaries, the late entry stock is present (Michael 1989).

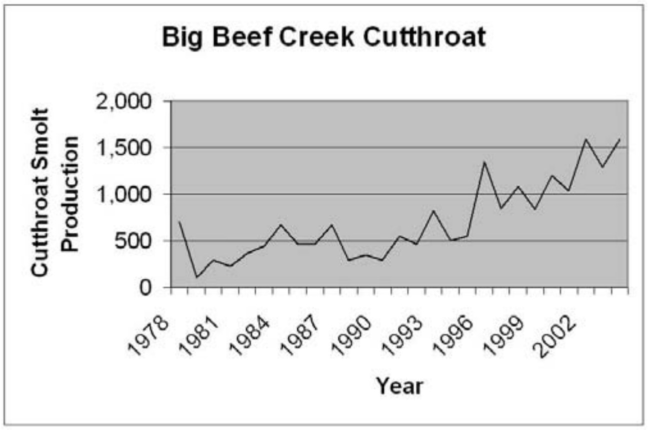

FIGURE 1.—Estimated production of coastal cutthroat trout smolts in Big Beef Creek, Kitsap County, Washington (Hood Canal) from 1978 to 2004. (D. Seiler, WDFW, unpublished data).

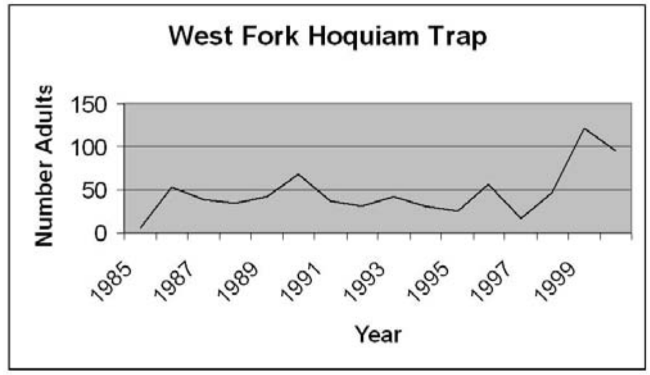

FIGURE 2.—Number of wild adult cutthroat captured at West Hoquiam River trap, 1985-2000. Data from Quinault Indian Nation Department of Natural Resources.

Washington coast.—Blakley et al. (2000) had insufficient information to rate stock complex status for the coastal cutthroat populations in the Washington coastal tributaries. The southwestern cutthroat populations are composed of cutthroat stocks from Willapa Bay and Grays Harbor. Hunter (2001) collected data on juvenile cutthroat abundance and distribution throughout the southwestern portion of the range, and concluded cutthroat are widely distributed and abundant.

Adult abundance information reported by NMFS (Johnson et al. 1999) showed increasing trends for eight of 10 populations examined. Sport fishing data for this same region show an increase of both catch per unit effort and size during the same period. Adult trap information from the West Fork Hoquiam River from 1985-2000 indicates stable adult abundance with indications of increasing trends based on the last two years that had the highest counts on record (Figure 2).

Perhaps the best indication of the status of adult cutthroat in southwestern Washington is the increasing trends of repeat spawners in the population. These trends were seen in the both Grays Harbor (West Fork Hoquiam trap) and Willapa bay stocks (Hunter 2001). Indications are that all forms of coastal cutthroat in the southwest coastal region of Washington are abundant and healthy.

Limited information is available for the production of juvenile cutthroat trout in the southwestern Washington coastal streams. The WDFW downstream migrant trap at Bingham Creek, a tributary of the East Fork Satsop River in the Grays Harbor watershed, has been operated since 1982. Figure 3 displays the estimated production of cutthroat smolts from Bingham Creek. The data indicate that the production of cutthroat in this small stream is relatively stable, although somewhat cyclical.

Examination of the existing data led WDFW to conclude that the southwest Washington coastal cutthroat are one of the healthiest cutthroat populations in the state (Fuller 2001). Adult abundance, juvenile production, and the distribution of both the resident and anadromous forms are at levels at or above other distinct populations segments.

Based on surveys conducted by Weyerhaeuser Corporation and the Quinault Indian Nation in the West Branch Hoquiam River, it is believed that coastal cutthroat trout are abundant and widespread in Chehalis River/Grays Harbor (Blakley et al. 2000). Cutthroat status remains unknown in the upper Chehalis River basin (US Army Corps of Engineers 2003a).

Lower Columbia River.—Southwest Washington / Lower Columbia River cutthroat trout were proposed as threatened in April 1999 (U.S. Office of the Federal Register 1999). The U.S. Fish and Wildlife Service and NOAA Fisheries expressed concern about the severe habitat degradation resulting in extremely low population sizes of anadromous coastal cutthroat trout in lower Columbia River streams, indicated by low incidental catches of coastal cutthroat trout in salmon and steelhead recreational fisheries, and by low trap counts in a number of tributaries throughout the region.

The SaSI process identified native, wild cutthroat stock

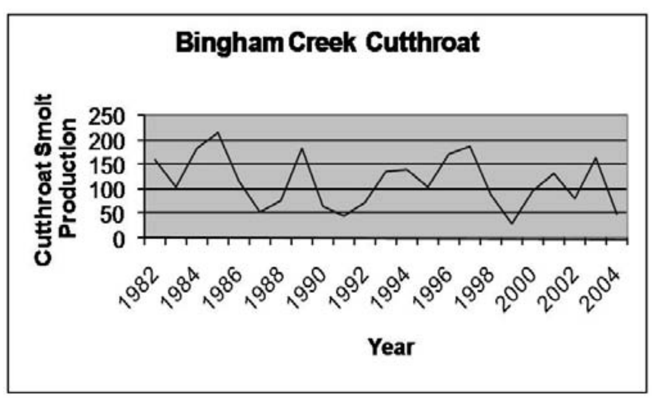

FIGURE 3.—Estimated production of coastal cutthroat trout smolts in Bingham Creek, Grays Harbor County, Washington from 1982 to 2004. (D. Seiler, WDFW, unpublished data).

complexes as depressed in several lower Columbia River tributaries. A stock complex was identified as depressed when its production was below expected levels based on available habitat and natural variations in survival rates, but above the level where permanent damage to the stock complex was likely (Blakley et al. 2000). These stocks included cutthroat in the Grays, Elochoman, Cowlitz, Coweeman, Toutle, and Kalama rivers, and Abernathy, Germany, Mill, Coal, and Skamokawa creeks. Insufficient trend information was available to assess status of anadromous stocks in the Lewis and Washougal rivers, Salmon Creek, and small tributaries from the Lewis River to Bonneville Dam. Resident forms of cutthroat are found throughout these watersheds (Wade 2002).

In their review of coastal cutthroat trout, the Northwest Power Planning Council (2004) states that anadromous, fluvial, and resident life history forms distribute themselves throughout lower Columbia tributary watersheds. They reported that freshwater forms are well distributed with relatively high abundance, in comparison to anadromous forms in the same streams.

Creel surveys continue to be directed towards salmon and steelhead fisheries, and do not measure sea-run cutthroat effort separately. It has been noted that angler effort in traditional cutthroat waters and anglers utilizing traditional sea-run cutthroat gear in creel-surveyed waters has declined greatly (Rawding 2001). This shift in effort, coinciding with regulations prohibiting the retention of wild cutthroat in an increasing number of lower Columbia River tributaries, results in harvest trend data being a poor indicator of overall stock status (Fuller 2001).

Status determination of Columbia River coastal cutthroat stocks through the use of adult cutthroat trap captures from structures designed for salmon and steelhead does not represent an accurate picture of cutthroat numbers in this population. Trap count numbers for the majority of sea-run cutthroat adults in the region should only be considered relative index numbers. In general, adult sea-run cutthroat trapping does occur, but the traps used have bar spacing designed to hold adult salmon and steelhead, therefore, smaller cutthroat and resident trout easily escape. In addition, sea-run cutthroat have been observed bypassing fish ladders and jumping falls on Lower Columbia streams (Rawding 2001).

While the Columbia River adult cutthroat populations estimates have declined from previous years, distribution of juvenile populations, and estimates of outmigrating smolts indicate that cutthroat are found in all areas with cutthroat habitat and in numbers within the range of other healthy populations with mixed species (Fuller 2001).

Field investigations targeted at juvenile cutthroat in the Columbia River tributaries were conducted between June and October of 2000 and 2001 (Mongillo and Hallock 2001). Results from these investigations at 156 sampling sites showed that coastal cutthroat were widely distributed throughout the Columbia River region both above and below anadromous zones and in areas they were projected to be found. As expected, cutthroat were not seen above Bonneville Dam on the Washington side, with the exception of Spring Creek, a tributary to the White Salmon River. These investigations also showed that relative abundance, expressed as cutthroat per square meter, and the percent of streams with cutthroat were similar to other systems that were found not warranted for listing.

A juvenile trap study was conducted on three independent drainages to the lower Columbia River (Seiler and Peterson 2001). Juvenile traps were set in Germany, Mill, and Abernathy creeks during the spring outmigration of 2001. For these three streams, the total outmigration estimate was approximately 22,000 coho salmon and 20,000 steelhead, while the cutthroat estimate was approximately 1,600 smolts. The coho-to-cutthroat ratios in this study are some of the lowest observed in systems with abundant coho juveniles (13.7:1). Based on the size of the drainage and the number of competing species, both coho and steelhead, cutthroat production in these streams are better than expected.

The lack of effective upstream and downstream passage through two reservoirs and dams below Cowlitz Falls effectively eliminated anadromous production in the upper watershed in the 1960s. The completion of the Surface Collection System and Fish Facilities at the Cowlitz Falls Dam in 1996 marked the beginning of a unique opportunity to restore anadromous salmonids to an estimated 240 linear miles (386 km) of historically productive habitat in the upper Cowlitz and Cispus watersheds. Estimated production of cutthroat smolts resulting from juvenile catches at the facility are displayed in Figure 4 (Serl and Morrill 2004, 2005). This monitoring has documented cutthroat smolts originating from existing natural populations in the watershed above the Cowlitz Falls Dam since 1997. Elsewhere in this drainage, Wade (2000) identified a "healthy" population of resident cutthroat trout in Winston Creek, in the Mayfield/Tilton subbasin.

A fish collection facility was constructed on the North Fork Toutle River about a quarter mile (400 m) above the confluence with the Green River so adults can be trucked above the sediment retention structure (B. Glaser, WDFW, personal communication). Catches at the trap are displayed

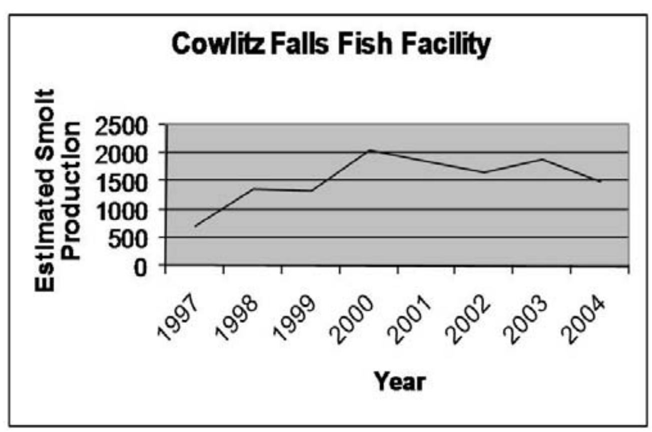

FIGURE 4.—Estimated production of cutthroat trout from Cowlitz Falls fish collection facility data 1997-2004.

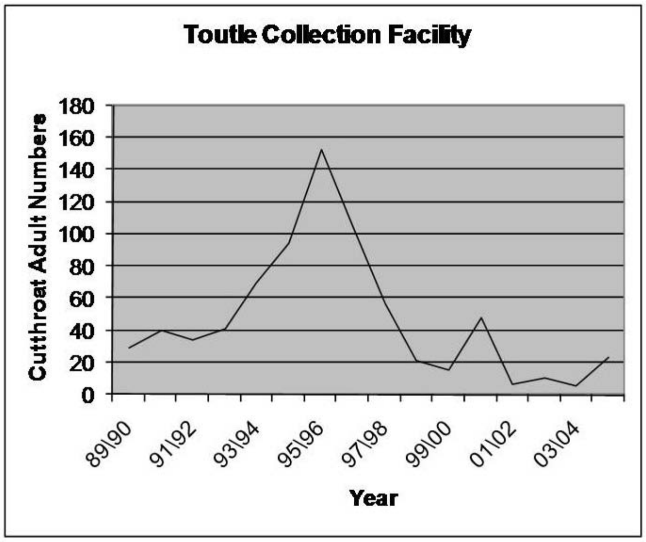

FIGURE 5.—Adult cutthroat trout trapped at the Toutle Collection Facility, 1989-2004.

in Figure 5. The trap is old and consistently fills with sediment. Considerable maintenance is required to ensure that it is working properly, and the trap may not be effectively trapping cutthroat. The North Fork Toutle River trap was considered unreliable for determining trend in cutthroat trout population size due to continued failure of the Fish Collection Facility leading to closures coinciding with the upstream migration of anadromous cutthroat trout (Fuller 2001; Rawding 2001).

Data for adult coastal cutthroat trout trapped at the falls on the Kalama River are displayed in Figure 6. The trap spacing allows small coastal cutthroat trout to pass undetected, so the numbers are considered to be an index of abundance (P.L. Hulett and C. Wagemann, WDFW Kalama Research, personal communication).

In 1998, a rotary screw trap on the Kalama River, calibrated for steelhead production, estimated sea-run cutthroat numbers at 2,153 (± 1,453 95% C.I.) smolts. This trap and other smolt traps calibrated for sea-run cutthroat

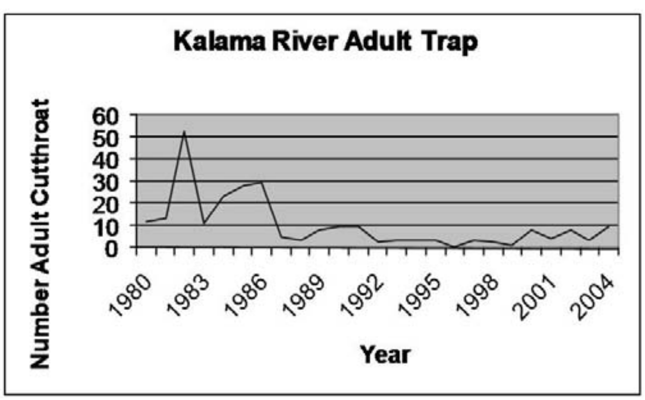

FIGURE 6.—Adult cutthroat trout counts at Kalama River upstream migrant trap, 1980-2004.

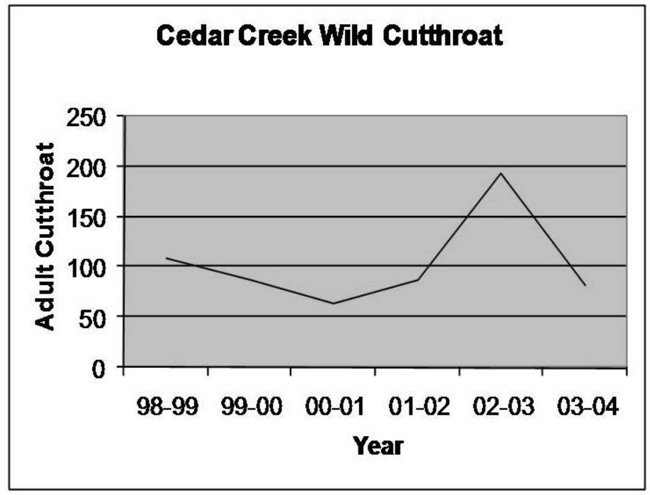

FIGURE 7.—Adult cutthroat trout trapped at the Cedar Creek trap, 1998-2004.

trap efficiencies are being tested and historical sea-run cutthroat smolt estimates from the region are being reanalyzed. Further validation of the assumptions made concerning trap efficiencies and additional data proofing are being undertaken. The estimates that have been developed to date suggest anadromous sea-run cutthroat smolt production and out-migration are robust from this tributary (Rawding 2001).

Cedar Creek is a third order tributary to the Lewis River and located in Clark County, Washington. In 1998, the WDFW installed an adult trap in the Cedar Creek fishway at river kilometer 4.0 to monitor adult steelhead escapement. Later that year the adult monitoring program was expanded to include other species, including sea-run cutthroat trout. In March 1998, a rotary screw was installed to estimate steelhead, coho salmon, and sea-run cutthroat smolt production in this watershed. Upstream migrant data are presented for cutthroat at the Cedar Creek trap (Figure 7); cutthroat smolt data were expanded to an estimate of out-migration size for the rotary trap from 2001-2004 (Figure 8) (S. VanderPloeg, WDFW, personal communication). The estimates that have been developed to date strongly suggest anadromous sea-run cutthroat smolt production and out-migration are robust from these tributaries (Rawding 2001).

Byrne et al. (2002) reported anadromous cutthroat in the Washougal River and its tributaries up to Dougan Falls, with resident forms found throughout the watershed. Stock status was unknown due to insufficient data, but habitat conditions are generally poor.

The small Columbia River tributaries between the Lewis River and Bonneville Dam contain coastal cutthroat trout. Blakley et al. (2000) identified populations in nine streams, but were unable to describe population status due to insufficient information on the stocks.

The Wind River may have historically supported small populations of cutthroat. Data on run sizes and specific spawning locations are not available. Spawning would likely have been limited to the mainstem of the Wind River below Shipherd Falls and possibly portions of the Little

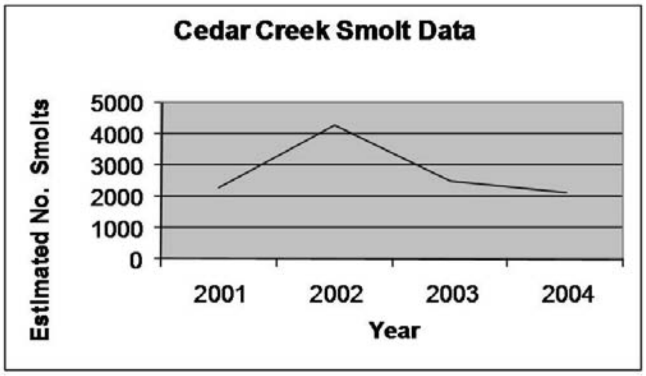

FIGURE 8.—Total cutthroat trout smolt migration estimated from collections at Cedar Creek rotary trap, 2001-2004.

White Salmon River. Cutthroat may still exist in the lower river, but straying from other systems may also account for their presence in the Wind (Washington Conservation Commission 1999).

Rawding (2000) noted that it was likely that anadromous cutthroat historically used the White Salmon River below the Condit Dam, but were believed to be extirpated. Resident cutthroat are found in the waters above Condit Dam.

Connolly et al. (2002) collected information on coastal cutthroat in Columbia River tributaries between Bonneville and The Dalles dams by interviewing professional fish biologists and reviewing published and unpublished reports. They found that the distribution of coastal cutthroat trout above Bonneville Dam is poorly documented and the current monitoring efforts are insufficient to allow determination of population status. Jewett Creek, near the towns of White Salmon and Bingen, appears to be the easternmost tributary on the Washington side of the Columbia River with a documented coastal cutthroat population.

Resident cutthroat were recorded in McCreedy and Summit creeks, tributaries to the Klickitat River, during census work in the 1980s (Sharp et al. 2000). In the late 1990s, known locations of resident cutthroat were reinvestigated with no cutthroat trout observed. Coastal cutthroat were generally reported in the lower watershed below the confluence of the Little Klickitat River.

Separation of Distinct Populations

Johnson et al. (1999) considered a number of possible configurations for evolutionarily significant units (ESUs) of cutthroat populations, and concluded that the available information supported a scenario with six ESUs. The proposed ESU designations included populations in the Puget Sound, Olympic Peninsula, southwestern Washington/Columbia River, Upper Willamette River, Oregon Coast, and Southern Oregon/California Coasts.

The ESU proposed for the southwestern Washington/Columbia River consisted of coastal cutthroat trout populations in southwestern Washington and the Columbia River, excluding the Willamette River above Willamette Falls. Baker (2000) analyzed genetic data from 19 cutthroat populations from the Washington coast and Columbia River tributaries. He concluded the cutthroat within the proposed southwestern Washington/lower Columbia River population segment might instead be separated into two populations segments based on genetic, spatial, and behavioral differences between cutthroat in southwestern Washington (i.e., Grays Harbor and Willapa Bay) and in the Columbia River. He also found that coastal cutthroat from the Washougal and White rivers were distinct from lower Columbia River populations.

Because the genetic data were not conclusive, Rawding (2001) compared populations of wild anadromous cutthroat in the Columbia River and on the southwest Washington coast as to length of fish, age at return, salt water residence time, and length at age. The differences in freshwater age structure, saltwater age structure, length, and length at age all suggest that Columbia River and southwestern Washington anadromous cutthroat trout utilize different environments, and that these are different groups.

Cutthroat Harvest Management

The biological objectives of current fishing regulations in Washington State are to 1) provide protection for juvenile and out-migrating smolts, and 2) to allow a majority of adult female cutthroat trout to spawn at least once prior to being available for harvest. Fisheries managers have implemented seasonal closures, minimum-size and daily creel limits, and catch-and-release regulations to achieve these objectives.

Resident, juvenile, and smolting cutthroat are protected under the statewide general fishing season closure from November through May, annually. In small streams, a daily creel limit is applied, allowing anglers 2 fish with a minimum size of 8 inches (20 cm), 10 inches (25 cm) or 12 inches (30 cm), depending on the characteristics of the population. Populations in anadromous waters are protected under a daily creel limit that allows the harvest of two fish over 14 inches (35 cm).

In the Cowlitz River, the sole waters where hatchery-origin anadromous cutthroat trout are stocked, and in the Columbia River below Bonneville Dam, regulations restrict anglers to the harvest of fin-clipped hatchery fish only; all wild (unmarked) cutthroat trout must be immediately released.

In 1998 the Washington Fish and Wildlife Commission adopted catch-and-release rules for cutthroat in all Washington marine waters. Catch-and-release regulations for cutthroat trout are also in effect for most Hood Canal, Willapa Bay, and lower Columbia River tributaries.

Discussion

Leider (1997) noted that "confident assessment of the status of coastal cutthroat trout in most areas of the state is limited at this time." The situation has changed little in the ensuing years, because resources are not available to survey and assess the populations, or to compile and analyze existing data. Most of the coastal cutthroat stock complexes in the 2000 SaSI were identified as unknown, as there simply was insufficient information to rate them (Blakley et al. 2000). Many of these are historically small populations, which may be especially vulnerable to negative impacts. I reiterate their conclusion that there is a pressing need to collect more information on them.

The available monitoring information suggests that cutthroat are widespread and ubiquitous, and that all life history strategies are represented within suitable habitat. At the upper limits of the range of the coastal cutthroat in the Columbia River, there has been an apparent population decline, potentially due to habitat degradation, impediments to fish passage, and historical harvest management.

The paucity of data available on the demographics of most cutthroat populations necessitates a conservative approach to the management of the species. The angling regulations currently in place in Washington State are designed to provide recreational angling opportunity on healthy, self-sustaining populations of cutthroat that have contributed to the replenishment of the stock. These regulations appear to accomplish the goals of providing recreational opportunity while providing adequate protection to the stock complexes. A management plan has been developed for the limited production of sea-run cutthroat in the Cowlitz River drainage to mitigate for the recreational fishery impacted by the building of the dams on that system, and to conserve the wild populations in the lower Columbia River tributaries.

We have a limited understanding of the dynamics of cutthroat populations relative to freshwater habitats, saltwater productivity, interactions with sympatric species, and responses to anthropogenic influences. Likewise, we are just beginning to understand the factors and conditions that influence anadromy or residency within a given population of cutthroat trout.

The interests of this unique subspecies of cutthroat trout will best be served by managers and biologists developing a better understanding of its life history, genetics, population dynamics, and habitat. Education of the public, anglers, and agencies on the biological and management requirements of the species will aid in the development of initiatives and approaches to manage and conserve coastal cutthroat and the species associated with them.

Acknowledgments

I am indebted to the WDFW field biologists who have maintained data files on coastal cutthroat, a species for which very modest resources have been made available. The preparation of this report would have been impossible without their efforts, analyses, and insight. Dave Seiler, John Serl, and Bryce Glaser provided their expertise on coastal cutthroat, and their data sets for upstream and downstream migrant counts. This paper was greatly improved by the comments and edits of Bruce Baker, Ann Blakley, Bob Gibbons, Molly Hallock, Keith Keown, J. Hal Michael, Larry Phillips, John Serl, and Jim Uehara (WDFW).

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The Status of Coastal Cutthroat Trout in British Columbia

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Abstract.—Coastal cutthroat trout are an important component of British Columbia's freshwater fauna and have a wide distribution in low-lying coastal areas of the province. Few cutthroat systems, however, are routinely monitored in a systematic fashion and the status of many individual populations remains largely unknown. A recent status review for the federal Committee on the Status of Endangered Wildlife in Canada suggests that cumulative development pressures and anthropogenic influence have left many cutthroat populations susceptible to local extirpation. As in other areas to the south, habitat degradation, overharvesting, and negative interactions with introduced fishes have all contributed to declines. The largest impediments to conservation in the province remain the lack of adequate habitat protection, unconstrained land and water use, and an under appreciation of the importance of small streams to trout conservation. While the majority of cutthroat populations in British Columbia are likely stable, those located in the densely populated Georgia Basin appear to be particularly at risk of extirpation and are deserving of additional conservation measures.

Introduction

Coastal cutthroat trout *Oncorhynchus clarkii clarkii* (CCT) are a unique and important component of British Columbia's freshwater fish fauna. As one of the first salmonids to recolonize western Canada in the wake of retreating glaciers, CCT are often the only native trout throughout much of their range and play an important role in structuring many north temperate aquatic ecosystems (McPhail and Carveth 1992). Their small size at maturity allows them to penetrate smaller streams than most other salmonids, where they may make significant contributions to the growth of riparian vegetation and forests in terms of nutrient recovery (*sensu* Willson and Halupka 1995). Populations show a remarkable diversity in phenotypic traits and life history characteristics in British Columbia; fluvial, adfluvial, and resident forms are common (often within the same population) and anadromous forms exist along the coast where access to the sea is available. While historically a widespread species, CCT have shown dramatic global declines in the number and distribution of populations. Protected areas do exist in British Columbia but are often small and do not necessarily encompass all the habitats required by the various life history forms within an area (particularly migratory forms). It is apparent that in the absence of more rigorous protection, required habitat will continue to be degraded and populations increasingly fragmented. While the majority of populations in Canada are likely stable, it is apparent that cumulative development pressures and the anthropogenic manipulation of aquatic ecosystems have left many populations of CCT (particularly in the Georgia Depression) at risk for local extirpation.

General Distribution and Tentative Management Units

In British Columbia, CCT inhabit low elevation lakes and rivers along much of the coast, including streams in the Fraser River basin, on Vancouver Island, and in parts of the Queen Charlotte Islands. As in other areas, inland penetration is generally less than 150 km, although CCT were thought to have ascended the Fraser River system as far as the Nahatlatch River above Boston Bar (~220 river km inland) and the Thompson River as far as Ashcroft, British Columbia (~300 km inland). In the Skeena River, they were reported to be found to the divide at Morrison Lake (>400 km inland) and in the Stikine River up to Telegraph Creek (~160 km inland; Carl et al. 1967). While still found throughout much of this historic range, it is apparent that CCT have becoming increasingly displaced from their preferred small stream habitat associated with low gradient valley bottoms (areas which often serve as focal points for human development). Widespread logging, urbanization, and other forms of resource extraction in these areas have directly contributed to population declines and local extirpations throughout the province (Slaney et al. 1996; Precision Identification Biological Consultants 1998; Reid et al. 1999; Costello and Rubidge 2005).

While agricultural development and urban sprawl has eliminated much of their former habitat in the area, ~840 gazetted streams in the Georgia Basin are believed to contain at least some CCT (BC FISS 2003). These include several sloughs and backwaters along the lower Fraser River mainstem, as well as several of its major tributaries (Pitt, Stave, Harrison, and Chilliwack rivers and their associated lakes). Coastal cutthroat trout are present throughout the Sunshine Coast and are likely present in the lower tributaries of several large systems along the south coast mainland, including the Squamish, Homathko, Southgate, Brem, Quatam, and Toba rivers (Hatfield Consultants 2001). Lake populations east of the Powell River area, however, are augmented by hatchery production as are many stream populations in the region. They are present along much of the east and west coasts of Vancouver Island, particularly in lowland areas such as the Comox and Cowichan valleys, the Sooke basin west of Victoria, and along the Strait of Juan de Fuca. Resident and lacustrine forms are common throughout the Fraser Basin while anadromous forms exist in most areas with access to saltwater. Fluvial and adfluvial life history forms are perhaps the least characterized, but are likely present in the larger river systems.

Fine-scaled distribution data for CCT is generally lacking outside of southwestern British Columbia, but CCT are known to be present in ~110 gazetted streams along the central coast and ~425 systems on North Coast and Queen Charlotte Islands (BC FISS 2003). In the Bella Coola River, anadromous CCT are present in several low-gradient streams and wetlands in the lower valley. The distribution of freshwater components remain undescribed, but resident and possibly anadromous CCT are known to be present in some relatively high gradient, boulder-cobble streams nearer the Bella Coola River headwaters (Burt and Horchik 1998). A myriad of smaller coastal systems associated with the Skeena-Nass river system (many of which are headed) undoubtedly provide suitable conditions for CCT. Synoptic surveys are often lacking but most known production occurs in large lakes (e.g., Lakelse and Kitwanga lakes; Whatley 1984). Coastal cutthroat trout are present in the lower reaches of the Stikine and other rivers in the Transboundary area. On the nearby Queen Charlotte Islands, resident and anadromous CCT are found in many systems, particularly throughout the north-eastern lowlands. There is evidence that the area may have served as an important refuge for CCT and several others species during the last round of glacial advance (O'Reilly et al. 1993; Soltis et al. 1997; Costello et al. 2001). Genetic and biogeographic evidence suggest that CCT populations from ~350 gazetted systems on the west coast of Vancouver (roughly north of Barkley Sound) show stronger affinities to these coastal populations than to Georgia Basin populations and likely belong to an "Outer Coast" population (see below).

While CCT span at least four regional management areas in British Columbia, no formal conservation units have yet been defined for the subspecies as they have in the United States. A recent status review (Costello and Rubidge 2005) for the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) proposes two tentative designatable units for consideration under Canada's *Species at Risk Act* (SARA 2005). The two units coincide with the unique biogeographic "ecoprovinces" inhabited by the subspecies in British Columbia:

(1) Georgia Depression (Georgia Basin) population – includes populations in large basin containing the Strait of Georgia and Puget Sound, encompassing eastern Vancouver Island and the Strait of Juan de Fuca, the Strait of Georgia and Gulf Islands, and the lower British Columbia mainland from roughly Powell River to Vancouver. This ecoprovince is predominantly a semi-enclosed estuarine environment, strongly affected by freshwater discharge from larger systems like the Cowichan, Squamish, and Fraser rivers.

(2) Coast and Mountains (Outer Coast) population – includes populations in a large and diverse region including western Vancouver Island (excluding the Strait of Juan de Fuca), the Queen Charlotte Islands, and the intervening British Columbia mainland coast. Coastlines are highly subdivided and nearly all large rivers empty into deep fjord-like bays. Extreme wind and wave exposure characterize unprotected areas such as the west coast of Vancouver Island and the Queen Charlotte Islands.

The distinction is further supported by a number of identified life history and genetic differences between CCT in the two regions (reviewed by Costello and Rubidge 2005). Given the limited marine dispersal of CCT and the large, subdivided nature of the British Columbia coastline, however, it is likely that further designatable units exist within these ecoprovinces (compare for example, their geographic scale with that of Evolutionary Significant Units [ESUs] designated in the United States, Figure 1).

Further genetic and life history profiling are being conducted along the central and north coast of the province to address the information gap. Importantly, while both

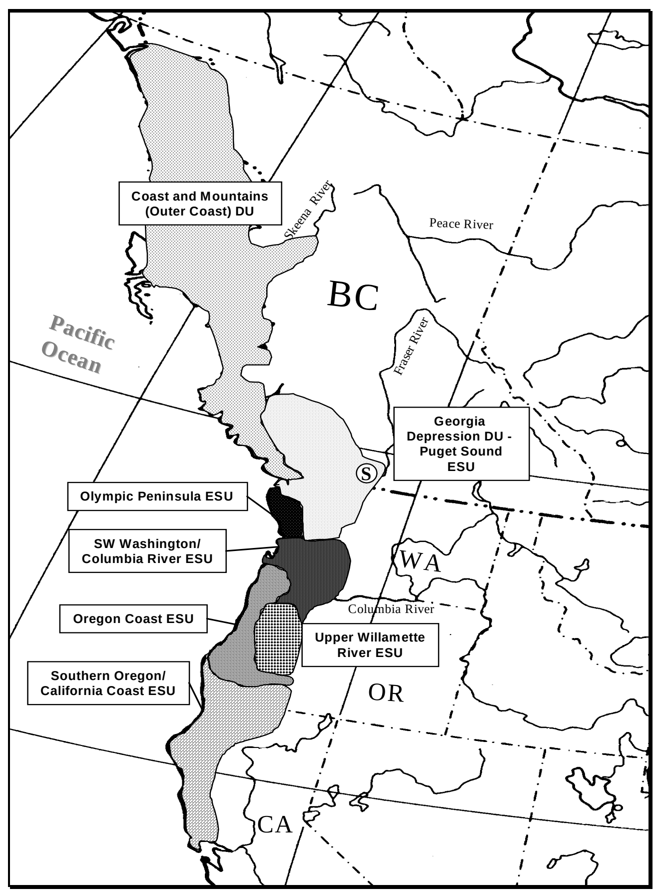

FIGURE 1.—Accepted range of CCT in North America and proposed conservation units; DU = Designatable Units under Canada's *Species at Risk Act* (SARA), ESU = Evolutionary Significant Units under the US Endangered Species Act (ESA). Marker (S) shows the location of the Salmon River discussed in the text.

units do share similar types of conservation concerns (e.g., primarily habitat loss, overharvesting), the degree of risk to populations certainly differs between the two regions. There has been an undeniable loss of CCT habitat in the Georgia Basin (Precision Identification Biological Consultants 1998; Reid et al. 1999; Slaney 2005). Further cumulative development pressures and the rapidly growing human population in the Georgia Basin suggest that many populations may be at high risk for local declines and extirpation and that immediate habitat protection may be required for several populations. A lack of sufficient data outside of the Georgia Basin means that the situation is less clear for the Coast and Mountains group. The Coast and Mountain group likely contains a mix of healthy and declining populations but further status information is required. Coastal cutthroat trout therefore appear to be "endangered" at the stock level within most of the Georgia Basin (particularly along the east coast of Vancouver Island and Lower Fraser Valley). Populations in the Coast and Mountains Group are generally considered "threatened" on the west coast of Vancouver Island and of "special concern" elsewhere.

Population Trends in British Columbia

While Pacific salmon may have spawning runs numbering in the thousands or hundreds of thousands, population sizes for CCT are typically on the order of tens to hundreds in even the largest systems (Trotter 1987, Behnke 1992). As such, CCT populations appear especially susceptible to perturbation, particularly by those factors which affect habitat quality (reviewed by Reeves et al. 1997; Rosenfeld 2001). Population productivity appears ultimately limited by the amount of juvenile rearing capacity in streams (i.e., suitable pool habitat) as juveniles require large home ranges. Given the amount of habitat loss and degradation observed in parts of British Columbia, declines are not, therefore, unexpected. Slaney et al. (1997) reported at least 15 stock extinctions at the 1995 Reedsport Symposium and suggested that at least 50 other populations were at some level of conservation risk at that time. Unfortunately, as in 1995, few CCT systems in British Columbia are routinely monitored in a systematic fashion and the status of those populations (and most others in the province) is largely unknown. The majority of CCT status information has been collected during salmon and steelhead enumerations (typically swim or fence counts uncorrected for efficiency) on systems which may not necessarily be representative of typical CCT habitat (i.e., they tend to be larger or more productive, and perhaps of more public interest than streams most often utilized by CCT). Most have been dramatically altered by human activity or have been augmented by hatchery introductions. It is therefore difficult to find natural baseline data or to even make comparisons among streams as counting methods often differ between sites (e.g., some count smolts, some count spawners). That being said, widespread habitat loss, cumulative development pressures, and similarities in available trend data suggest that CCT populations in British Columbia have not benefited from current land use practices and that several are at high risk for extirpation.

Georgia Basin populations.—Historically, CCT appear to have occupied a much wider distribution in the Georgia Basin, particularly in low gradient tributaries of the lower Fraser River. A review of 779 highly productive salmonid streams in the lower Fraser Valley found that 117 streams (15%) have been completely lost as a result of culverting, paving, draining, or filling. Another 71% were classified as critically threatened or endangered from the impacts of forest harvest, agriculture, industry, and urbanization (Precision Identification Biological Consultants 1998). The loss of CCT production associated with these lost and endangered streams is expected to be very high. Recent meta-analysis of CCT abundance in the lower Fraser River suggests that the productivity potential of intact streams in the region is high (in terms of biomass per stream unit; DeLeeuw and Stuart 1981; Ron Ptolemy, British Columbia Ministry of Water, Land, and Air Protection, personal communication). Although some aspects of development have now slowed in the valley (especially the conversion to agriculture), other aspects (e.g., urbanization) have dramatically accelerated; many estuaries have been developed, streams channelized, and marshlands filled for construction.

A similar pattern exists on the eastern coastal lowlands of Vancouver Island and the adjacent Gulf Islands. Less than 8% of that area can be considered relatively unmodified and much of that has been substantially degraded by fragmentation, development, and introduced species (Ward et al. 1998). Many streams along eastern Vancouver Island, for example, originate in private forested lands (subject to harvest) and flow through a variety of altered rural and urban environments. Nearly all suffer from reduced habitat quality (e.g., loss of pool habitat and large woody debris, excessive fines). Perhaps of more consequence, stream flows have been increasingly diverted from rivers in the area to supply commercial and residential needs. The majority show chronically low summer base flows (< 10% of mean annual discharge) and many creeks from Sooke to Campbell River now run subsurface during summer months (Reid et al. 1999; A. Costello, personal observation). Consequently, freshwater fish currently make up the single largest group of endangered plants and animals in the basin with 14 of 41 fish species in the region (34%) considered at risk for extirpation (Transboundary Georgia Basin-Puget Sound Environmental Indicators Working Group 2002).

There are a few systems in the Georgia Basin with specific trend data for CCT, however, the information has been collected by a variety of government agencies and stewardship groups and varies considerably in its scope and quality. Perhaps the most valid trend information available comes from the Salmon River, a Fraser River tributary near Fort Langley, British Columbia. Historically, the Salmon River had been a significant source for anadromous CCT production in the lower Fraser River, ranking fourth of 17 systems sampled by DeLeeuw and Stuart (1981). Importantly, the system has not been augmented by hatchery releases of CCT or steelhead (*O. mykiss*) and provides long-term trend data for both wild CCT and steelhead smolts. The Department of Fisheries and Oceans (DFO) has maintained the Salmon River system as a coho salmon (*O. kisutch*) index stream and has enumerated both salmonids and non-salmonid species there since 1998. Like other systems in the lower mainland, however, it has faced development pressures from the continually expanding human population in the valley and from ecologically damaging agricultural practices. It is currently one of the most seriously impacted groundwater areas in the Fraser Valley and its summer base flows average < 20% of mean annual discharge (Slaney 2005).

Coastal cutthroat trout population declines have been apparent on the Salmon River for some time. Creel survey information, for example, from the early 1950's (McMynn et al. 1954) and 1977-78 season (Burns 1978) suggest a number of changes associated with overharvesting and the installation of flood control pumps on the lower Fraser mainstem. McMynn et al. (1954) record a far higher percentage of larger fish than the latter survey, with some interesting age, size, and sex ratio comparisons between the two periods. Generous bag limits and less restrictive size requirements undoubtedly contributed to population decline. The legal size limit for CCT at the time was 20 cm so that by the 1977-78 creel season, it is possible that nearly 90% of the CCT captured were on their initial return from saltwater and that the majority had not yet spawned (Burns 1978). As well, pumping stations associated with Fraser River flood gates did not (and often still do not) allow for the passage of larger fish; smolts over 17cm and all kelts migrating downstream during active pumping would have experienced high mortality rates (DeLeeuw and Stuart 1981; Rosenau and Angelo 2004). Given the positive relationship between size and fecundity in CCT (e.g., Giger 1972), and the fact that most repeat spawners tend to be female, the loss of these larger fish would likely have represented a significant loss of egg deposition and productivity in the system. DeLeeuw and Stuart (1981) reports the total CCT smolt count in 1979 as 1,234 and as high as 4,070 in 1980. However, from 1998 to 2004, annual smolt yields on the Salmon River have decreased by about 65% from 1500 to 500 smolts (Figure 2). The recent decline is likely the result of poor water quality and the absence of a sufficient spawning habitat in the system. While there appears to have been an increase in CCT smolt counts from 2004 to 2005 (to ~1,150 smolts; Pat Slaney, PSlaney Aquatic Science, Ltd, personal communication), the current number of adults in the Salmon River appears to be less than 20 individuals and may be in a slow decline.

The loss of older, more fecund spawners and subsequent population decline is not specific to the Salmon River. Point counts, for example, suggest that adult numbers throughout much of the basin may be very low; maximum counts over several years have generally been <10 (Scholten 1997; Slaney 2005). It should be noted, however, that many of the systems with count data for CCT are not necessarily representative of typical CCT habitat in the region. Instead, they tend to be larger, more productive

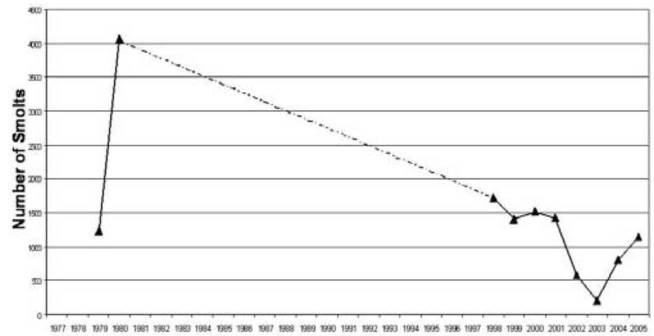

FIGURE 2.—Abundance of CCT smolts in the Salmon River, Fort Langley from 1979-2005 (Slaney 2005). Note that the stippled line indicates missing data.

streams with heightened public profiles (i.e., key regional watersheds or rivers supporting steelhead or coho fisheries). Often, they have been subject to some manner of habitat amelioration or protection targeting other salmonids. The smaller, less productive streams more typical of CCT habitat often go unaccounted for in land-use planning and may, therefore, have been impacted to an even greater degree. With the human population in the Georgia Basin expected to grow by an additional 29% by 2020 (to nearly five million people; Transboundary Georgia Basin-Puget Sound Environmental Indicators Working Group 2002), increasing development pressures are expected to further impact ecosystem processes and local populations in the region. While the lack of better trend data for individual populations limits our ability to make specific inferences, the number of endangered and extirpated populations in the basin may have increased by 15-30% in the ten years since the 1995 symposium (British Columbia Ministry of Water, Land, and Air Protection, unpublished data, 2005). Immediate habitat protection of these smaller streams is likely warranted to prevent the loss of further urban CCT populations.

Coast and Mountains populations.—While remote and less impacted than the highly populated Georgia Basin, it is apparent that there has been extensive loss of forest cover throughout the Coast and Mountains ecoprovince. Logging, is by far, the dominant resource industry in British Columbia and forest products accounted for more than half ($15 billion, or 52%) of the province's total exports in 1999 (British Columbia Stats 2001). As of 1995, nearly 75% of the original forest habitat on Vancouver Island and over 53% of British Columbia's low to mid-elevation old-growth forests had been cut (Sierra Club of Canada 2003). Several lowland valleys in the area have been developed, including the lower Bella Coola, Kitimat, and Skeena river valleys. Mining and oil exploration are increasing in the northern part of the region, particularly in the area bounded by the communities of Kitimat, Terrace, and Stewart, British Columbia. Unfortunately, little current information is available for populations in this region and meaningful status determinations are often not possible. The status of most anadromous salmonids, however, have been of concern to fisheries professionals along the north coast since the early 1980's when declines in coho salmon, steelhead, and CCT populations were first noted near urban areas. At that time, it was apparent that CCT in the southern part of region were subject to excessive harvesting pressure (Whatley 1984). Even when not directly targeted, CCT may be subject to significant bycatch mortality. It appears likely that a decline of CCT in the Bella Coola River during the 1980s and mid-1990s was a by-product of the intensive steelhead fishery on that river. When a steelhead closure was implemented in November 1995, significant increases in the number of large, mature CCT were apparent by the 1997-1998 fishing season (Ron Ptolemy, British Columbia Ministry of Water, Land, and Air Protection, personal communication, 2004).

While it is likely that the region is characterized by a mix of healthy and declining populations, those subject to habitat degradation or overharvesting are expected to show declines in the absence of further conservation measures. It should be noted that populations in this area may have originated more than one glacial refuge and may therefore be composed of different evolutionary lineages (e.g., Redenbach and Taylor 1999; McCusker et al. 2000). The large, subdivided nature of the coastline and limited marine dispersal of CCT suggests that further designatable units may exist within the Coast and Mountains ecoprovince. Further genetic and life history profiling should be conducted along the central and north coast of the province to address this information gap.

Limiting Factors and Threats

A number of factors appear to be limiting the abundance of cutthroat trout in British Columbia. While some of these occur naturally, it is clear that the most eminent and serious threats to cutthroat are of anthropogenic origin, primarily habitat loss, overharvesting, and the introduction of non-native species.

Species characteristics.—Coastal cutthroat trout possess innate biological characteristics that make them naturally susceptible to a host of limiting factors. First, the habitat requirements of the subspecies are such that populations typically inhabit coldwater streams with limited productivity. Eggs and newly hatched alevins are highly sensitive to environmental degradation (particularly the effects of sedimentation and dewatering) and factors impinging on habitat quality appear to disproportionately affect CCT populations (reviewed by Reeves et al. 1997; Rosenfeld 2001). Coastal cutthroat trout populations may be quite small and supported by a variable numbers of spawners, making them subject to stochastic events such as epizootics or rapid environmental change (e.g., drought, landslides, toxic spills). For fry and larger juveniles, competition for food and refuge (with each other and sympatric species) may be significant. Adults may be further subject to predation and negative interactions with other salmonids, particularly when those salmonids have been introduced (e.g., Reeves et al. 1997; Docker et al. 2003). The amount of pool habitat available in streams appears to limit the abundance of parr and ultimately smolt production for sea-run CCT. Many current management practices therefore endeavor to maintain minimum target densities for juveniles to achieve "habitat capacity" given assumed relationships between juvenile habitat requirements and stage-specific survivorship. The widespread generality of such relationships, however, remain uncertain as ecological data has generally been limited to only anadromous populations. Finally, while CCT can and do travel substantial distances to find suitable feeding or overwintering areas, gene flow between populations appears limited so that declining populations appear unlikely to be bolstered by immigration from nearby populations, at least over the short term (Campton and Utter 1987; Wenberg and Bentzen 2001; A. Costello, unpublished data).

Habitat loss.—Habitat loss has almost certainly been the principal factor affecting CCT populations in British Columbia. As noted, the largest losses of CCT habitat have resulted from the development of flat coastal valley bottoms and extensive logging throughout temperate rain forests. These conditions, while present throughout both designatable units, are most pressing in the Georgia Depression where human population growth and development pressure have dramatically altered aquatic ecosystems. As many as 71% of the streams in the Lower Mainland of British Columbia, for example, are now classified as critically threatened or endangered while others have been completely lost (Precision Identification Biological Consultants 1998). In most cases, these urban streams are managed exclusively for drainage capacity, with only minor regard for aquatic values. Typically, a large proportion of an urban watershed is covered and impervious to water infiltration. Peak flows can increase dramatically as precipitation is rapidly directed to streams rather than through soils, leading to increased bank scour and sediment loading in channels (e.g., Reid et al. 1999). Deposition of these sediments in pools and riffles tend to decrease surface flows under summer drought conditions leaving habitat dewatered that is typically inhabited by juvenile CCT. Urban streams also may receive influxes of harmful pollutants (e.g., paints, paint thinners and petroleum products, detergents or soaps) from storm drainages or illegal drainage connections (Slaney 2005).

Urban streams that are still relatively functional, often lack riparian cover or large woody debris and are channelized along much of their lengths. The resulting elevation of stream temperatures and lack of habitat complexity can severely impact CCT rearing and productivity (Reeves et al. 1997). Such streams readily infill with aquatic vegetation and require routine dredging to maintain circulation. Many are culverted at road and rail crossings and may not be maintained or designed to accommodate fish passage at particularly high or low flows. While the exact nature of their movements are poorly described (particularly for fluvial forms), it is apparent that CCT can and do move significant distances to find required habitat types. Coastal cutthroat trout migration is dependent on the preservation of suitable migration corridors between habitats. The dramatic decline of anadromous and fluvial populations throughout the lower Columbia River attest to the profound influence of migration barriers on that system (e.g., Nehlsen et al. 1991). The loss of larger fish and subsequent population declines in lower Fraser tributaries (such as the Salmon River) likely coincided with the installation of flood control systems on critical floodplain habitats once acting as migration routes. Not only would such barriers prevent access to seasonally available habitat, they would serve to further limit the recolonization potential of areas with declining or locally extirpated populations.

Although many of the impacts on anadromous salmonids have been historical in nature, detrimental flood control and agricultural practices continue in the Fraser Valley. The removal of native vegetation continues in areas that are ephemerally flooded; invasive dredging of salmonid-inhabited agricultural drainages and fish-killing pumping stations often continue to operate without proper bypass structures for migrating fish. Extensive use of fertilizers and excessive animal waste materials may often leach into streams and degrade summer water quality in areas historically utilized by CCT (reviewed by Rosenau and Angelo 2004). On Vancouver Island, excessive withdrawals of water have impacted the productivity of streams to such an extent that many on the eastern lowlands now run subsurface during summer months (Slaney et al. 1996; Axford 2001; Rosenau and Angelo 2003). From 1991-1999, the increase in per capita domestic water usage for several municipalities ($m^{3}\cdot d^{-1}\cdot person^{-1}$) ranged as high as 92.7% (Atlas of Canada Statistics 2003). Such large-scale changes to natural flow regimes are likely more permanent and more irrevocable than many other landscape changes as chronic dewatering affects all life history stages (Ward et al. 1998; Rosenau and Angelo 2003).

For Coast and Mountains populations, a significantly smaller proportion of habitat loss has been due to urbanization or agricultural development. Possible exceptions may be the few urbanized valleys in the region (e.g., Nass, Skeena, Bella Coola). More typically, forest harvest and associated road networks are the most common source of habitat loss. Processes such as riparian logging and the removal of large woody debris are known to adversely affect pool habitat, leading to the loss of stream complexity, bank instability, sedimentation, and the infilling of pools. Such processes reduce egg to fry survival, the availability of rearing habitat, and future production of aquatic invertebrates (reviewed by Reeves et al. 1997; Rosenfeld 2001). The small streams and tributaries utilized by CCT in coastal forests often go unaccounted for in development planning as they tend to be missing from topographic maps or aerial photos, particularly in low gradient areas with forested canopies. One study found the percentage of underestimated fish bearing stream length to range between 34-100% for individual streams on the west coast of Vancouver Island (discussed in Rosenfeld 2001). Even when identified, small fish-bearing streams often receive less protection than is required and may be improperly culverted or logged to the stream banks. In a 2001 review of 227 logging plans from forest companies working along the north and central coast of British Columbia, less than 4% provided for unlogged buffers on small fish-bearing streams flowing through logging sites (David Suzuki Foundation 2001). Similarly, two independent audits of forest industry compliance with the now repealed Forest Practices Code in British Columbia found than 11% of streams in the harvested sections studied had not been identified in logging prescriptions and received no formal protection. A further 29% of streams were systematically misclassified as fishless (when they were not) and received less protection than required (i.e., mandatory buffer zone; Rosenfeld 2001).

Habitat protection/ownership.—While several higher land-use planning processes have been initiated (see, for example, http://srmwww.gov.bc.ca/rmd/lrmp/index.htm), the protection of estuarine and freshwater salmonid habitats in British Columbia remains undervalued and limited. Various park systems and protected areas do exist in the province but “typical” CCT habitat (e.g., low-elevation areas, particularly those containing critical floodplain and nearshore habitats), are significantly underrepresented in overall conservation holdings. The fact is, many habitats are required by CCT at different life history stages; from headwater streams, to lakes and rearing areas, to main stem rivers and nearshore marine environments. Unfortunately, many of these same habitats are valuable from a human perspective and face significant development pressures. Resource managers are limited in their ability to avoid or mitigate developmental impacts where the land base is privately owned (e.g., Georgia Depression); however, the majority of CCT habitat in British Columbia lies on public land and falls under the protection of the federal government’s No Net Loss (NNL) policy for aquatic habitats (DFO 1986). Rarely, however, is the NNL commitment achieved. Several recent audits have found evidence for significant non-compliance with NNL policies in many of the watersheds studied (e.g., Harper and Quigley 2000; G3 Consulting, Ltd. 2000). A major contributing factor appears to be that the low level of monitoring and enforcement activities undertaken by senior government agencies, particularly as it pertains to site follow-up and inspection. Many fisheries professionals familiar with the subject are of the opinion that increased levels of compliance-monitoring are required to reach better performance with respect to NNL policies in western Canada. Similar problems exist with the regulation of water licensing in the province. The regulation and management of water resources in Canada is covered by a number of provincial acts and regulations for which monitoring and enforcement also appear low. Water licenses in British Columbia have often been granted without adequate water resource budgeting or scientific reasoning, leaving many streams over-allocated or approaching levels which place local fish populations at high risk for extirpation (Rosenau and Angelo 2003, 2004).

Better identification and protection of CCT habitat are essential throughout the range in British Columbia. A recent management review for CCT in the lower Fraser River (Slaney 2005) proposes that land acquisition and protection may ultimately be required to protect critical spawning and rearing habitats in the valley. Many of the identified streams are threatened by agricultural practices such as invasive dredging and riparian alterations which negatively impact rearing CCT. However, such land purchases are expensive and to date less than 15% (~700,000 ha) of the land base in the Georgia Basin has been protected. Of the 15 major watershed groups in the region, only three have greater than 20% protected area status (Transboundary Georgia Basin-Puget Sound Environmental Indicators Working Group 2002). Similarly, of the 5.9 million ha of coastal forests found in British Columbia, less than 200,000 ha (~3%) are protected (mostly on Vancouver Island; Sierra Club of Canada 2003). The apparent complacency of senior government agencies regarding habitat degradation and water use must be addressed. While the amount of habitat currently available to CCT in most areas appears adequate, its current level of protection (i.e., enforcement) is not.

Overharvesting.—Cutthroat trout are a popular sport fish in British Columbia and are harvested in several targeted fisheries: estuary-shoreline fisheries on anadromous populations; river and backwater fisheries on anadromous and river-run populations; river fisheries on migratory lake populations; and coastal lake fisheries. While increasingly restrictive fishing regulations are now in place (see http://wlapwww.gov.bc.ca/fw/fish/regulations/intro.html), angling pressure has likely been a significant factor limiting natural production of CCT in the past, particularly near urban areas (e.g., Post et al. 2002). Coastal cutthroat trout are known to be aggressive feeders at certain times of year (e.g., during outmigration following spawning events). Their propensity to rise to the surface to feed also predisposes them to highly targeted sight fishing where anglers cast to actively feeding fish. Creel surveys during the 1980s to 1990s do suggest that the overall CCT harvest on the Lower Fraser was relatively high compared to the number CCT adults produced per year; angler effort likely accounted for in excess of 100,000 angler days per year (Slaney 2005). During the same period on the North Coast, anadromous, fluvial, and resident forms of CCT near Prince Rupert and Kitimat were being overharvested to the point where populations were no longer capable of sustaining even modest fishing pressures (Whatley 1984). Less restrictive angling restrictions and the widespread use of bait during those years certainly contributed to population declines. Mortality rates associated with the deep hooking characteristic of bait angling have been estimated at up to 50% for CCT in Washington State (Mongillo 1994; Gresswell and Harding 1997), suggesting that a large number of CCT may have died even following their release.

Hatchery introductions.—In British Columbia, CCT have been generally stocked near urban centers where sport fishing demand is high. This has generally been limited to the Georgia Basin where several hatchery operations have augmented or replaced natural production on many lake and stream systems (~41% of those where Fisheries Information Summary System [FISS] management class is indicated, see Table 1). Primarily targeted towards promoting angling opportunities, stocking has not necessarily translated to increased viability for wild CCT populations in British Columbia, as the primary causes for population decline (i.e., habitat loss, overharvesting) often go unaddressed. Stocking may, in fact, often be done at the expense of native populations by leading to increased competition for food and habitat, or through the spread of parasites and disease (Krueger and May 1991; Reeves et al. 1997; Scribner et al. 2001; Docker et al. 2003). Early stocking was done with a variety of brood stock collected in Washington, Oregon, and California. More recently, attempts have been made to propagate and release locally derived populations back into their natal stream to supplement native production (e.g., Cowichan, Oyster, Salmon, Quinsam, and Qualicum rivers). Unfortunately, most current hatchery output for lake stocking (~90% from 1980-2003) is derived from brood stock collected from one source, the Taylor River on Vancouver Island (BC FISS 2003).

Widespread stocking of this type disregards the importance of locally adapted biodiversity (e.g., Taylor 1991), potentially contributing to the breakdown of population structure and decreased population fitness in wild CCT (reviewed by Rhymer and Simberloff 1996; Allendorf et al. 2001). Hatchery-reared fish are known to show abnormal patterns of migration, habitat preference, and reproductive behavior relative to their wild counterparts (Krueger and May 1991; Reeves et al. 1997; Scribner et al. 2001; Docker et al. 2003). Perhaps the most obvious example is the preponderance of residualized smolts among introduced fish (Roayl 1972). Residuals or residualized

TABLE 1.—Management class for gazetted streams containing coastal cutthroat trout in British Columbia (BC FISS 2003).

	Coastal cutthroat trout management class					
Region	Hatchery production	Augmented	Wild naturalized	Wild indigenous	Not specified	Totals
Vancouver Island	156 (21%)	19 (3%)		204 (27%)	368 (49%)	747
Lower Mainland	77 (16%)	13 (3%)	5 (1%)	171 (36%)	203 (43%)	469
Cariboo				14 (13%)	93 (87%)	107
North Coast	7 (2%)	2 (<1%)		71 (17%)	345 (74%)	425
Totals	240 (14%)	34 (2%)	5 (<1%)	460 (26%)	1009 (58%)	1748

fish do not follow normal migratory behaviors and instead remain in freshwater, competing directly with wild trout and parr for food and habitat. Many are also precocious and show abnormal spawning behavior, leading to increased levels of hybridization with sympatric species. Large numbers of residualized steelhead and CCT are now believed to be common throughout the Georgia Basin (Don McCubbing, Instream Fisheries Research, personal communication, 2003; Slaney 2005). To date, the effect on wild CCT populations has not been well characterized in British Columbia. By 1999, however, the incidence of hatchery fish among brood stock captures was about 75% in the main stem Fraser River and close to 95% in some of the smaller hatchery systems such as Alouette and Stave rivers (Slaney 2005).

The stocking of other hatchery-reared salmonids (particularly coho salmon and steelhead) is widespread in British Columbia and may be of greater concern for native CCT populations. The introduction of hatchery steelhead has been shown to lead not only to increased residualization, competition, and displacement, but also to increasing levels of interspecific hybridization (see below). The introduction of coho to CCT streams elsewhere, for example, has been shown to lead to sharp declines in CCT abundance, by up to 50% in some cases (Tripp and McCart 1983; Slaney 2005). Johnson et al. (1999) reported the majority of streams in Washington with coho fry introductions showed significant declines in both adult and juvenile CCT. The result may be one of displacement of rearing CCT fry from productive feeding habitats or due to aggressive competition (Glova 1984, 1986; Sabo and Pauley 1997). Regardless, it seems apparent that any changes to the relative abundances of species in sensitive CCT streams can potentially disrupt natural levels of competition or outstrip habitat capacity (e.g., Lichatowich and McIntyre 1987).

Hybridization.—Hybridization between CCT and steelhead have been previously identified along much of the west coast (Campton and Utter 1985; Johnson et al. 1999; Young et al. 2001; Ostberg et al. 2004). Under normal circumstances, spatial segregation on the spawning grounds or differences in the timing of spawning events appears sufficient to maintain species integrity where both are sympatric; natural hybridization appears to have been limited to streams where spawning habitat was limited or became otherwise degraded (Campton and Utter 1985; Behnke 1992). However, hybridization has been found to occur readily where the nonnative species have been introduced. In excess of one-third of all CCT pops in Washington and Oregon are now expected to contain hybrids (Johnson et al. 1999) and Spruell et al. (1998) suggested that CCT and steelhead populations no longer coexist on the Lower Columbia River without evidence of hybridization. The situation in British Columbia was believed to be less of an issue as the levels of stocking in the province have typically been much less than in the United States. Preliminary work by Costello et al. (2001), however, suggested that hybridization rates in the Georgia Basin may be as high as 20%, declining northward along the British Columbia coast (Table 2). More comprehensive studies by Docker et al. (2003) and Bettles (2004) confirm that

TABLE 2.—Select summary of CCT-steelhead hybridization assays in the province of British Columbia.

Study	Marker type	Geographic area	Number of populations	Stocking status	Inferred hybridization levels	
Costello et al. 2000	DNA sequence	Throughout range in British Columbia	60 populations; individuals believed to be CCT	Stocked and unstocked	Vancouver Island	3.8-19.4%
					Lower British Columbia Mainland	9.1%
					Central Coast	7.4%
					North Coast/ QCI	3.1-6.0%
Docker et al. 2003	Nuclear markers, mtDNA RFLP	Throughout range in British Columbia	10 sympatric populations; individuals randomly chosen	Stocked and unstocked	unstocked streams	9.9%
					stocked streams	50.6%
Bettles 2004	Nuclear markers, mtDNA RFLP	Vancouver Island	30 sympatric populations; individuals randomly chosen	Stocked and unstocked	across all sites (ranging from 0–88%; 70% of sites with >10% hybrids)	29%
A. Costello, unpublished. data	Microsats, Nuclear markers	Georgia Basin, Queen Charlotte Islands	48 populations; individuals believed to be CCT	Unstocked	Clayoquot Sound	8.4%
					Strait of Juan de Fuca	12.0%
					East Vancouver Island	8.7%
					Sunshine Coast	4.8%
					(Georgia Basin Average)	9.1%
					Queen Charlotte Islands	3.8%

hybridization in British Columbia may be far more extensive and advanced than previously believed. These authors found evidence of hybridization in the majority of sympatric trout populations examined with the effect being greater in smaller, degraded watersheds where the stocking of steelhead had occurred. Bettles (2004) found as many as 70% of the streams sampled on Vancouver Island had hybridization levels in excess of 10% and nearly half had hybridization levels in excess of 30%.

Hybridization may be prevalent even in relatively undisturbed systems. A more recent study targeting smaller systems in the province (first to third order) lacking a significant history of stocking identified hybrids in 29 of 57 populations (A. Costello, unpublished data). Unlike Bettles (2004) and similar studies, all sampled populations were expected to contain allopatric CCT populations and in those areas of natural sympatry with steelhead, every effort was made to identify and sample only CCT. The observation of hybrids in these systems, therefore, likely gauges background levels of hybridization in the region or the residual effects of straying from other stocked systems as hybrid fish are known to have altered migratory behavior (Hindar et al. 1991; Krueger and May 1991; Reeves et al. 1997; Scribner et al. 2001). The data is in agreement with similar studies which indicate that hybridization in the Georgia Basin is widespread (~9% even in unstocked systems; Table 2). The possible development of hybrid swarms in at least two streams investigated by Bettles (2004) suggest that CCT are subject to extremely rapid declines in areas where habitats are degraded and non-native fish are introduced.

This is problematic for future conservation of CCT because the production of hybrids is unidirectional; that is, all the progeny of a hybrid will essentially be hybrids (Allendorf et al. 2001). The development of hybrid swarms, therefore, present a significant threat to the persistence of native species and have been perceived as a "genomic extinction" or "extinction in progress" because the unique genotypes characteristic of the pure parental species are lost once randomly mating hybrid swarms are formed (Rhymer and Simberloff 1996). Hybridized populations, therefore, represent a unique and uncertain biological entity, both in terms of their legal definition and in terms of their ecological relevance. Neither Canada nor the United States currently has an official policy regarding the inclusion of hybrid populations under their respective endangered species legislation. The development of a workable hybrid policy and implementation program to quantify the scope and severity of the problem in British Columbia will likely be required in the near future.

Current/Future Management Initiatives

In Canada, fisheries resources are jointly managed by federal and provincial agencies. Under the federal *Fisheries Act* (http://laws.justice.gc.ca/en/F-14/), the federal government has a legislated responsibility to manage and protect Canada's fish populations. A key component of this responsibility is the protection of fish and fish habitat. To complement and enhance the level of protection and management of local fisheries, several provincial acts have been developed. In British Columbia, much of the legislation controlling the use of water is embodied in the *British Columbia Water Act* (http://www.qp.gov.bc.ca/statreg/stat/W/96483_01.htm). Unfortunately, the Act has never been able to provide for the legitimate habitat requirements of fish in terms of ensuring adequate stream flows. Often, the issuance and control of water withdrawal licenses has been conducted without proper hydrological budgeting or a scientific basis (Rosenau and Angelo 2003). Changes to the Act and the introduction of the *British Columbia Fish Protection Act* of 1997 (http://www.qp.gov.bc.ca/statreg/stat/F/97021_01.htm) were expected to provide government agencies the means to more adequately protect critical stream flows for fish populations. However, despite a plethora of provincial and federal legislation, historic problems with the over allocation of water continue to persist in British Columbia and throughout much of western Canada. Neither of the Acts have been fully implemented and the regulation of water licensing on small, "general" streams is still lacking (Rosenau and Angelo 2003; Ron Ptolemy, British Columbia Ministry of Water, Land and Air Protection, personal communication, 2004).

Coastal cutthroat trout have been previously identified as a species requiring special considerations in terms of forestry practices (e.g., Haas 1998; Porter et al. 2000). In 1995, the *Forest Practices Code of British Columbia Act* was enacted in British Columbia to enhance the level of environmental protection for lands subject to forest harvest, including ensuring adequate water flows for fish, the protection and restoration of fish habitat, and the protection of riparian habitat on private and urbanized lands. In 2003, however, the Act was effectively repealed by a new provincial government and the *Forest and Range Practices Act* was introduced. Under the new Act, government sets the objectives and desired outcomes from resource extraction, and forest companies propose strategies to meet those objectives. The Act essentially makes industry self-policing and accountable only through a rigorous government compliance and enforcement regime, which has been shown in previous studies to be poor to virtually non-existent (cited earlier). Currently, no CCT populations in British Columbia are specifically protected, although provincially, CCT are blue-listed as "vulnerable" (British Columbia Conservation Data Centre 2003).

As a popular sport fish in British Columbia, the primary level of management for CCT in the province is through sport fishing regulations. Current fishing regulations have become increasingly restrictive to protect wild spawning fish. There are now select stream closures in most areas during spawning migrations (October to May) and a mandatory release of all wild fish from streams or sloughs in the Lower Fraser valley. A province-wide single barbless hook restriction is currently in place and the use of bait may be restricted depending on the system (a complete province-wide ban on the use of bait has been proposed for the 2006-2007 season). Catch limits have also been reduced drastically from a daily limit of 20 fish in the 1970s and

1980s to between 2 and 5 fish per day depending on the area. Minimum retention size limits have been increased to 30 cm in most cases; there has been some debate, however, as to whether the minimum size limit should be increased to 35 cm to better ensure successful first spawning events (e.g., Gresswell and Harding 1997; Slaney 2005). Finally, there has been an increase in the number of stewardship programs and small stream initiatives in the province (e.g., Living Rivers Trust, Georgia Basin Steelhead Recovery Plan), although few specifically target CCT. In most cases, habitat restoration or enhancement focusing on CCT has been limited and only marginally successful (Ptolemy 1997). Instead, much effort has been placed into the development of hatchery programs for anadromous CCT. Many of the systems in the Georgia Basin, for example, are now heavily supplemented (in some cases, have been replaced) by hatchery production (Table 1).

Future management initiatives will likely need to address the chronic habitat loss affecting populations in the Georgia Basin as well as some of the outstanding gaps in our basic understanding of CCT biology in the province. Specifically, future management initiatives and research should focus on:

(1) Identification and protection of critical spawning/rearing habitats and their required stream flows (particularly in the Georgia Basin). This may ultimately require land purchases/conservancy agreements or the enabling of certain provincial regulatory powers.
(2) Development of a systematic method of quantifying trends in CCT abundance through the use of index streams and integrated adult-juvenile enumeration programs. These efforts should also include validation of current stage-specific survival models and those based on perceived habitat capacities.
(3) Quantification of habitat requirements and seasonal movement of freshwater population components as well as mixed stock structure in large rivers such as the Fraser, Bella Coola, and Skeena systems. This information will lead to better understanding of the contribution of individual populations to overall production and assist in prioritizing conservation efforts.
(4) Development of a systematic program to investigate the scope and nature of hybridization in the province as well as the influence of hatchery programs in terms of wild-hatchery stock interactions and increased levels of hybridization.

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Coastal Cutthroat Trout Symposium: Status, Management, Biology, and Conservation
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The Status and Management of Coastal Cutthroat Trout in Alaska

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Abstract.—Coastal cutthroat trout *Oncorhynchus clarkii clarkii* are a targeted species in Alaska's sport fishery and in the recently established federal subsistence fishery. Long-term stock assessment information (i.e., five or more years of data) is available for very few populations, making it difficult to assess population health or trends in abundance. Trend information is available for four lacustrine adfluvial populations and they appear to be relatively stable. Trend information is available for two sea-run populations near Juneau and both populations are declining. At Auke Creek, the number of emigrating sea-run coastal cutthroat trout is less than half the annual average from 1983–2004. At Jordan Creek, the number of emigrants has declined from over 100 fish in 2001 to only one fish in 2005. Many of the sea-run stocks in Prince William Sound were affected by the Exxon Valdez oil spill in 1989. Studies found slower growth rates in oiled versus unoiled streams, however the recovery status of these coastal cutthroat trout populations remains largely unknown. In the sport fishery, the statewide catch of coastal cutthroat trout from 1993–2003 has been highly variable, with a range of 30,825 to 75,067. Trends in catch were similar between Prince William Sound and Southeastern Alaska until 2001 when the number of anglers in Prince William Sound began to significantly increase with a corresponding increase in catch and harvest of coastal cutthroat trout. Threats posed to coastal cutthroat trout populations in Alaska include recently liberalized regulations in the federal subsistence fishery, as well as potential habitat degradation due to road construction, mines, oil spills, hydroelectric projects, and timber harvest.

Coastal cutthroat trout *Oncorhynchus clarkii clarkii* occur in streams and lakes along the coastal range throughout the Alexander Archipelago (hereafter referred to as Southeast Alaska) and Prince William Sound (Figure 1) and are the most common trout species in the region. The northern extent of the distribution of coastal cutthroat trout is bounded by Gore Point on the Kenai Peninsula (Behnke 1992). Several life history forms have been identified, including those that migrate from salt water to fresh water for winter refuge and/or spawning (typically referred to as sea-run or anadromous) as well as freshwater forms that do not enter salt water. The freshwater forms reside in either river systems (riverine), lake systems (lacustrine), or in headwater tributaries (Johnson et al. 1999). In lake systems that are below barriers to anadromous fish there may be multiple life history strategies employed. For example, Auke Lake (near Juneau) supports both sea-run and lacustrine adfluvial fish, and there appears to be plasticity between the life history strategies. Recent studies in the system showed that some sea-run fish resided in freshwater for extended periods (1-2 years) between marine forays, while other out-migrants did not return to the system to over-winter for one or more years (J. Lum, Alaska Department of Fish and Game [ADF&G], personal communication). Whether these fish from Auke Lake over-wintered in another freshwater system or remained in the marine environment is unknown.

Regulatory Management

Management of the sport fishery in Southeast Alaska.—New sport fishing regulations containing bag limits, size limits, and bait restrictions were adopted in Southeast Alaska by the Alaska Board of Fisheries (BOF) in 1994. The development and rationale for the regulations are described by Harding and Jones (2005). In most areas, anglers have a bag limit of 2 fish per day, with an 11-inch (28 cm) minimum size limit that is intended to provide protection for juvenile steelhead trout (*O. mykiss*) and sea-run coastal cutthroat trout before they emigrate to the salt water, and to protect most spawning female coastal cutthroat trout. A larger minimum size limit (14-inch [36-cm]) was adopted for areas with developed access and/or more intensive fisheries, and a maximum size limit of 22 inches (56 cm; fish greater than this size cannot be legally harvested) was also implemented to protect returning adult steelhead trout. In addition, a 10-month (November 16 through September 14) ban on fishing with bait was implemented in freshwater systems to reduce hooking mortality. The two-month period in which bait is allowed provides anglers the opportunity to use bait when adult coho salmon (*O. kisutch*) are present in fresh water. A year-round bait ban was adopted in systems where the 14-inch (36 cm) minimum size was implemented and also in systems known to have fall-run steelhead trout. The BOF also provided several exceptions to the region wide regulations, including "high-use" (14-inch [36-cm] minimum size limit), "trophy" (25-inch [64-cm] minimum size limit), "stocked lakes" and "small lakes" (9-inch [23-cm] minimum size limit), and "special lakes" (one catch-and-release-only lake and one lake with less restrictive harvest regulations).

Management of the sport fishery in Prince William Sound.—The sport fishing regulations in Prince William

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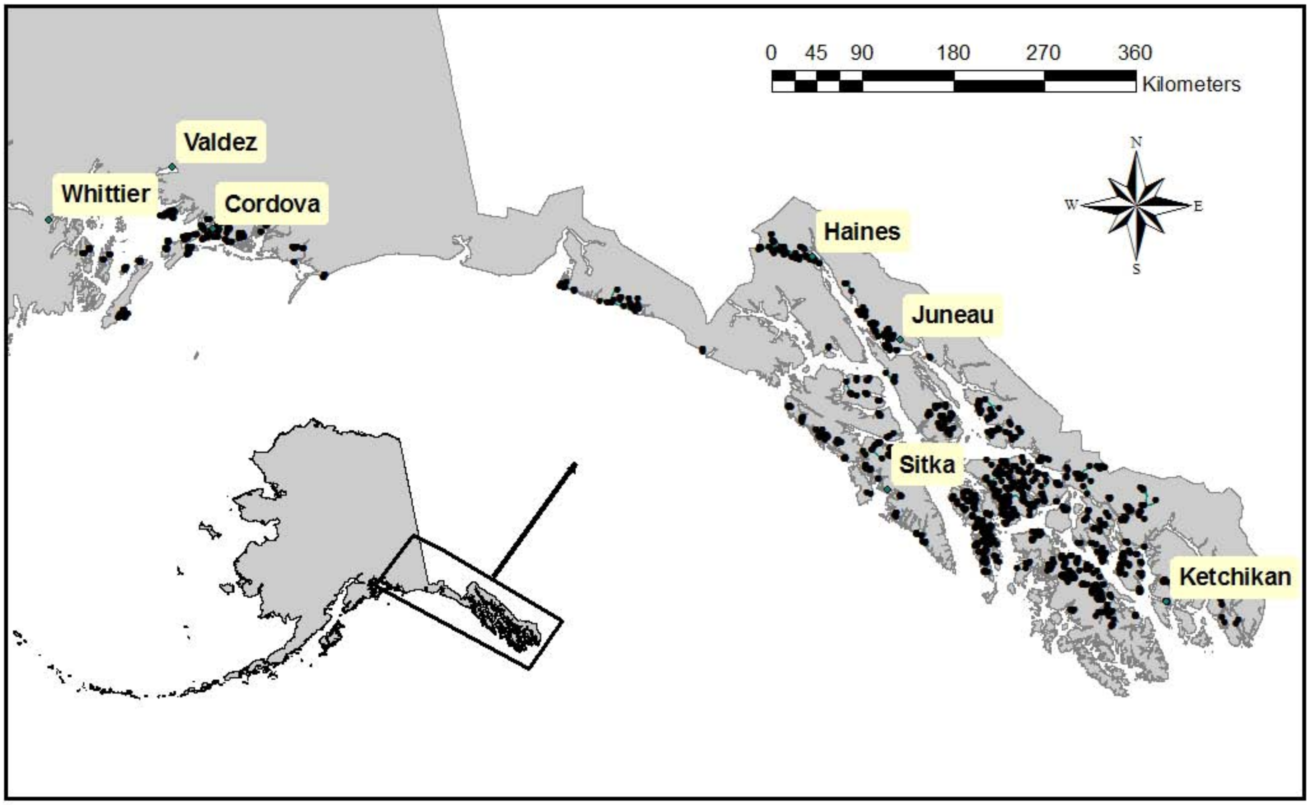

FIGURE 1.—Documented locations of coastal cutthroat trout in Alaska. Each dot represents a known location, based on the Catalog of Waters Important for the Spawning, Rearing or Migration of Anadromous Fishes and its associated Atlas, maintained by the Alaska Department of Natural Resources and the Alaska Department of Fish and Game. Because many areas have not been surveyed for coastal cutthroat trout, this map does not depict the entire distribution of coastal cutthroat trout in Alaska.

Sound consist of length restrictions, bag limits, bait restrictions, and seasonal closures around the time of spawning (April 15 to June 14). Only unbaited, artificial lures are allowed in fresh water and snagging is prohibited. In most areas, anglers have a bag limit of 2 fish per day, only one of which may be over 20 inches (51 cm) in length. The BOF has also provided exceptions to the general rules, including the establishment of the Copper River Special Management Area for Trout in 1999 (Figure 2). This management plan designates waters in the Copper River area as catch-and-release only, and was adopted based on concerns over the effects of proposed road development. The BOF was concerned that the proposed road would cross over 250 streams and rivers (48 of which were known to contain anadromous fish) and would have adverse impacts on the pristine coastal cutthroat trout fisheries. The BOF also established areas with more liberal harvest opportunities, including the Cordova road system, where the daily harvest limit is five coastal cutthroat trout per day (only one of which may be longer than 10 inches [25 cm]).

Federal subsistence management in Southeast Alaska.—In December 2000, the Federal Subsistence Board (FSB) allowed expanded harvest opportunity for cutthroat and rainbow trout under the terms of a federal subsistence permit in Baranof, Florence, Mirror, and Virginia lakes and in Hassselborg Lake and River. The FSB established a daily bag limit of six trout, between 11 and 22 inches (28 and 56 cm; slot limit) and only rod and reel without bait may be used to harvest trout. The regulations for subsistence fishing for trout were modified by the FSB in 2005 to include all freshwater systems in Southeast Alaska, although specific systems may be restricted on the permit. The 2005 regulations allow for the harvest of 6 trout per day with no size restrictions (unless special restrictions apply). Thus the regulations for the sport fishery are considerably more restrictive than the subsistence fishery. One extreme example is Turner Lake, where anglers in the sport fishery are restricted to catch-and-release fishing for coastal cutthroat trout, whereas there are no special restrictions in the subsistence fishery (i.e., regional harvest limit of 6 trout per day with no size restrictions).

Federal subsistence management in Prince William Sound.—In 2005, the FSB formalized the federal subsistence fishery for trout in Prince William Sound, requiring subsistence anglers to obtain a federal subsistence fishing permit for the harvest of trout in fresh water. The general harvest limits for trout are 5 trout per year, with a household limit of 30 trout, although stipulations on the permit provide exceptions or restrictions for certain areas, seasons, or gear types.

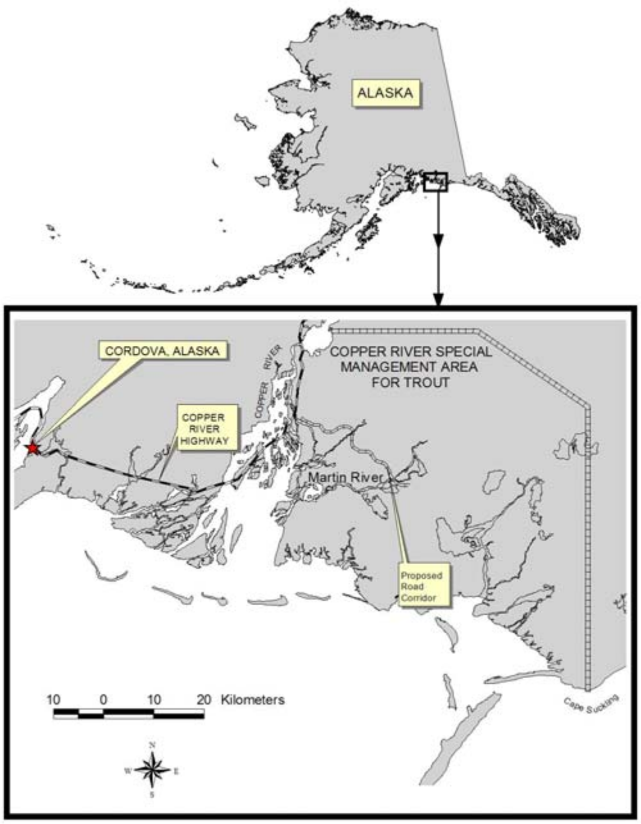

FIGURE 2.—The Copper River Special Management Area for trout in Prince William Sound, Alaska.

Harvest and Catch Information

Since 1977, the ADF&G has conducted a statewide mail survey to estimate harvest and catch (since 1990 only) in the sport fishery (e.g., Walker et al. 2003). In Southeast Alaska, there were noticeable differences in the harvest and catch rates for coastal cutthroat trout before and after the 1994 regulatory change taken by the BOF. As expected, harvests of coastal cutthroat trout in the sport fishery declined sharply in 1994 (Figure 3), though harvest had been steadily declining since 1980. Average annual harvest estimates following the regulatory change (1994-2003) were 66% less than harvests prior (1989-1993).

In the sport fishery, the statewide catch of coastal cutthroat trout from 1993–2003 has been highly variable, with estimates ranging from 30,825 to 75,067. Trends in catch were similar between Prince William Sound and Southeast Alaska until 2001 when the number of anglers in Prince William Sound began to significantly increase with a corresponding increase in catch and harvest of coastal cutthroat trout (Figures 3 and 4). The increase in angler effort in Prince William Sound may be attributed in part to the opening of the Anton Anderson Memorial Tunnel in 2000, which connects the port city of Whittier in Prince William Sound to the Seward Highway. In the first summer of operation (June–September 2000), approximately 243,000 people used the tunnel, and usage has increased to about 450,000 visitors in the summer (May–September) of 2004 (G. Burton, Alaska Department of Transportation and Public Facilities, unpublished data).

In the Southeast Alaska federal subsistence fishery, the reported harvest of trout (cutthroat or rainbow trout) has been very low (0 fish in 2002–2003, 25 fish in 2004; R. Larson, United States Forest Service [USFS], personal communication). No harvest estimates are available for Prince William Sound, as 2005 was the first year of the formalized federal subsistence fishery; however harvest is expected to be low (T. Joyce, USFS, personal communication).

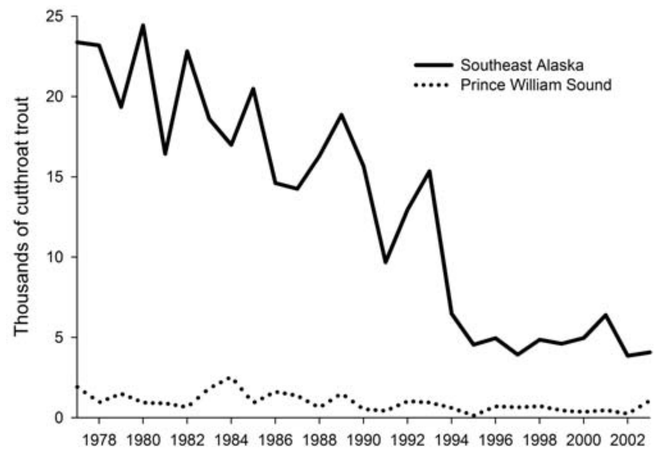

FIGURE 3.—The estimated harvest of coastal cutthroat trout in Alaska, 1977–2003, based on annual mail surveys conducted by the Alaska Department of Fish and Game (e.g., Walker et al. 2003).

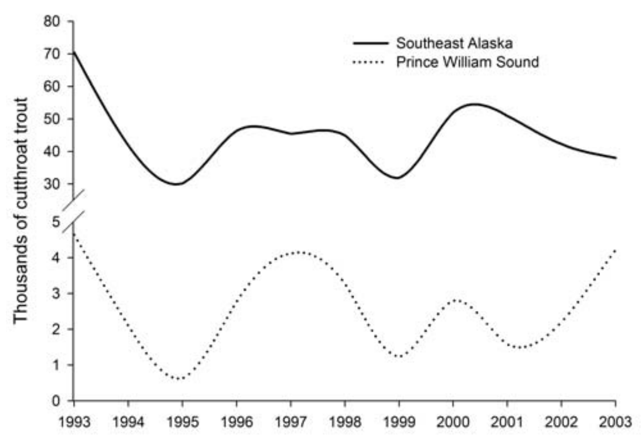

FIGURE 4.—The estimated catch of coastal cutthroat trout in Alaska, 1993–2003, based on annual mail surveys conducted by the Alaska Department of Fish and Game (e.g., Walker et al. 2003).

Population Trends

Information on population trends exists for very few riverine or lacustrine systems in Alaska. Short term studies (1–2 years) have been conducted on several populations (Table 1), however their limited duration does not allow for assessment of trends in abundance. Investigation of coastal cutthroat trout populations in Prince William Sound showed that growth rates were reduced in streams impacted by the Exxon Valdez oil spill (Hepler et al. 1996); however the long-term recovery status of the impacted streams remains largely unknown.

Trends in abundance are available for only four populations with lacustrine-adfluvial coastal cutthroat trout: Turner Lake, Baranof Lake, Florence Lake, and Auke Lake. In general, these populations appear to be relatively stable (Figures 5 and 6). Turner Lake was closed to the retention of coastal cutthroat trout in 1991 because of a perceived depression in abundance related to over harvest (Harding and Jones 2005). Despite 14 years of catch-and-release management regulations, the population does not appear to be increasing (Figure 5).

The abundance of sea-run coastal cutthroat trout has been estimated by weir studies in 13 systems; however long-term data (≥5 years) are available only for Auke and Jordan Creeks near Juneau. The number of wild coastal cutthroat trout emigrating from Auke Creek generally increased from 1983 through 1996, at which point the

TABLE 1.—Abundance estimates for short term studies of lacustrine adfluvial populations of coastal cutthroat trout in Alaska (* indicates that the confidence interval was estimated by multiplying the standard error by 1.96).

Lake	Year	Estimate	95% confidence interval	Reference
Alexander	1995	2,180	939-2,180*	ADF&G (unpublished data)
Harvey	1979	669	not available	Jones (1982)
Hasselborg	1991	10,839	7,754-13,924*	Laker (1994)
Jims	1981	2,785	2,511-3,126	Jones (1981)
Eva	1995	2,154	1,617-2,691*	Yanusz and Schmidt (1996)
Eva	1996	1,487	578-2,396*	Schmidt et al. (1998)
Little Lake Eva	1993	380	325-435*	Schmidt (1994)
Lower Leask	1988	327	54-991	Hubbart and Bingham (1989)
Lower Wolf	1987	196	125-287	Hubbart and Bingham (1989)
Margaret	1996	1,709	1,179-2,239	McCurdy and Bryant (1997)
McKinney	1996	3,756	3,172-4,340*	Harding et al. (1999a)
Mirror	1985	5,633	5,118-6,263	ADF&G (unpublished data)
Neck	1998	2,742	2,266-3,218*	Harding et al. (1999b)
Shelter	1982	2,718	2,326-3,011	ADF&G (unpublished data)
Sitkoh	1997	1,260	827-1,693*	Brookover et al. (1999)
Sitkoh	1997	1,481	967-1,995*	Brookover et al. (1999)
Upper Wolf	1993	1,233	1,012-1,454*	Schmidt (1994)
Virginia	1979	5,631	4,710-6,998	Jones (1982)
Virginia	1996	3,620	2,807-4,433*	Freeman et al. (1998)
Young	1994	1,562	1,199-1,925*	Harding (1995)

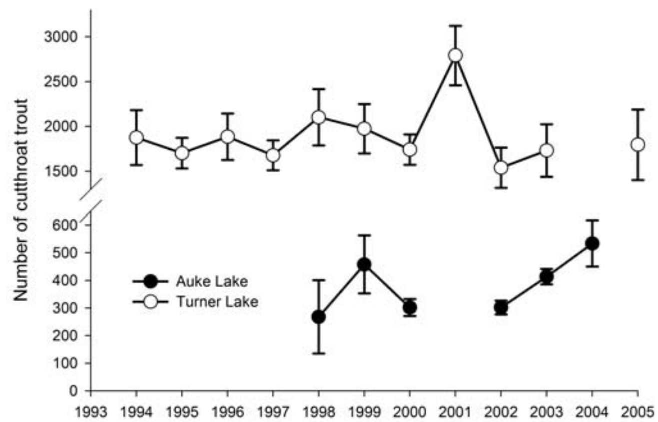

FIGURE 5.—The estimated abundance of coastal cutthroat trout in Turner and Auke Lakes, Alaska. Estimates for Auke Lake obtained by Lum et al. (2002) and by J. Lum (ADF&G, personal communication) and for Turner Lake by ADF&G (unpublished data). Vertical bars depict the standard error of the estimate.

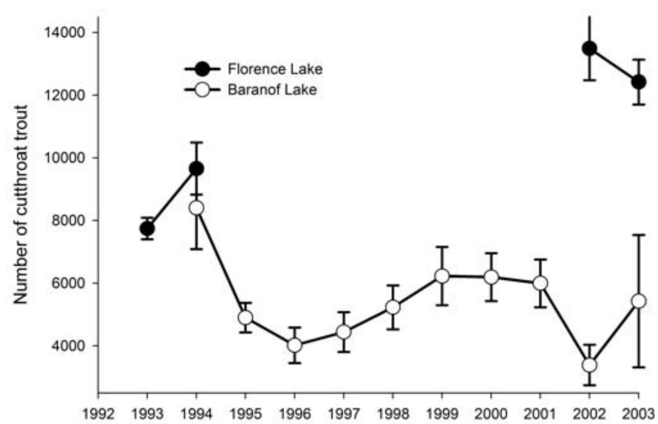

FIGURE 6.—The estimated abundance of coastal cutthroat trout in Baranof and Florence Lakes, Alaska. Estimates for Baranof Lake are from ADF&G (unpublished data), and for Florence Lake by Rosenkranz et al. (1999) and by ADF&G unpublished data. Vertical bars depict the standard error of the estimate.

number of emigrants began to significantly decline (Figure 7). The low number of emigrants in the early to mid-1980s may have been caused by over harvest in the sport fishery (S. G. Taylor, National Marine Fisheries Service, personal communication); however the cause of the recent decline is unknown. The impacts of urbanization and environmental changes (e.g., warm water temperatures) are potential factors (J. Lum, ADF&G, personal communication).

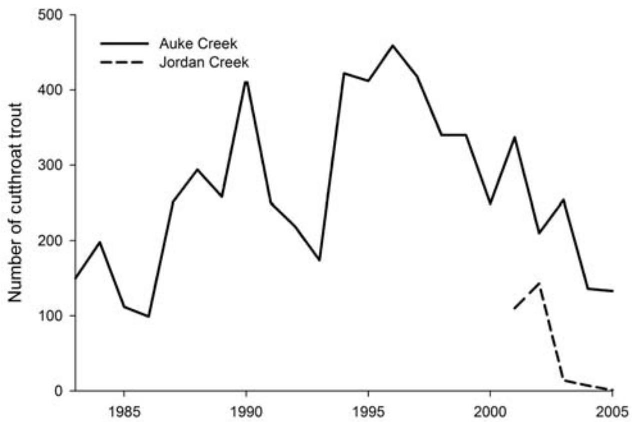

FIGURE 7.—The number of wild sea-run coastal cutthroat trout emigrating from Auke and Jordan creeks, 1983–2005, from Taylor and Lum (2005) and ADF&G unpublished data.

Jordan Creek is listed as a Section 303(d) impaired water body by the Alaska Department of Environmental Conservation for non-attainment of sediment, debris, and dissolved oxygen standards. The number of sea-run coastal cutthroat trout has rapidly declined to near elimination since monitoring began in 2000 (Figure 7). Possible causes of the decline include low flow or dewatering events, warm water temperatures, pollution, and handling or weir effects. Acute mortality events involving several hundred coho salmon smolts have been observed in late spring (May–June) of 2003–2005. The mortality events were similar in that they occurred during the first significant rainfall following a week or more of generally dry weather and associated low stream flows. Analysis of water samples collected during a mortality event in 2004 revealed the presence of acetone in the water (ADF&G unpublished data).

Other systems with multi-year weir studies are Sitkoh Creek on Chichagof Island and Eva Creek on Baranof Island. At Sitkoh Creek the number of sea-run cutthroat emigrants ranged from 1,442 in 1996 to 4,588 in 2003 (Table 2). At Eva Creek the number of coastal cutthroat trout emigrating in 1995 (n = 2,556) was nearly twice the annual counts from the early 1960s (Yanusz and Schmidt 1996). However, there can be significant inter-annual variability in the number of emigrating coastal cutthroat trout (e.g., at Sitkoh Creek there were 50% more emigrants in 2004 than in 2005, Table 2), which suggests that assessment of temporal trends in abundance may not be robust when few annual estimates are available.

TABLE 2.—Counts of emigrating sea-run coastal cutthroat trout in Alaska from short-term projects or long-term (five or more years) studies conducted prior to 1995.

System	Year	Estimate	Reference
Boswell	1990	1,366	Hepler et al. (1996)
Boswell	1991	1,685	Hepler et al. (1996)
Chilkat	1990	987	Ericksen and Marshall (1991)
Dredge	2002	174	ADF&G (unpublished data)
Dredge	2004	136	ADF&G (unpublished data)
Duck Creek	2002	1	ADF&G (unpublished data)
Duck Creek	2003	0	ADF&G (unpublished data)
Duck Creek	2004	12	ADF&G (unpublished data)
Duck Creek	2005	0	ADF&G (unpublished data)
Eshamey	1990	206	Hepler et al. (1996)
Eshamey	1991	211	Hepler et al. (1996)
Eva	1962	1,594	ADF&G (unpublished data)
Eva	1963	1,210	ADF&G (unpublished data)
Eva	1964	1,233	Armstrong (1971)
Eva	1965	2,562	Armstrong (1971)
Eva	1995	2,562	Yanusz and Schmidt (1996)
Green	1990	9	Hepler et al. (1996)
Green	1991	12	Hepler et al. (1996)
Kook	1994	345	ADF&G (unpublished data)
Kook	1995	564	ADF&G (unpublished data)
Makaka	1990	835	Hepler et al. (1996)
Makaka	1991	3,154	Hepler et al. (1996)
Petersburg	1971	202	Jones (1976)
Petersburg	1972	837	Jones (1976)
Petersburg	1973	501	Jones (1976)
Petersburg	1974	584	Jones (1976)
Petersburg	1975	691	Jones (1976)
Rocky	1990	25	Hepler et al. (1996)
Rocky	1991	0	Hepler et al. (1996)
Sitkoh	1996	1,442	Yanusz (1997)
Sitkoh	2003	4,588	ADF&G (unpublished data)
Sitkoh	2004	4,095	ADF&G (unpublished data)
Sitkoh	2005	2,736	ADF&G (unpublished data)
Windfall	1997	661	Jones and Harding (1998)

Discussion

Status summary.—Out of the thousands of coastal cutthroat trout populations in Southeast Alaska (Harding and Jones 2005), long-term (or multi-year) stock assessment information is available for very few populations, making it difficult to assess population health or trends in abundance. Trend information is available for four lacustrine adfluvial populations and they appear to be relatively stable. Trend information is available for two sea-run populations near Juneau and both populations are declining. At Auke Creek, the number of emigrating sea-run cutthroat is less than half the annual average from 1983–2004. At Jordan Creek, the number of emigrants has declined from over 100 fish in 2001 to only one fish in 2005. The cause of these declines is unknown, although similar trends in abundance have been observed in the Auke Creek Dolly Varden *Salvelinus malma* population (Taylor and Lum 2005). We recommend that resource managers investigate and work to remediate the causes for these declines. Fishery research projects should be thoroughly evaluated to ensure that handling or weir effects are not contributing to the decline. These projects should consider implementing video technology to allow for unrestricted movement of coastal cutthroat trout and to eliminate handling procedures.

Sport fishery concerns.—The remoteness of many coastal cutthroat trout populations makes enforcement of sport fishing regulations difficult. A recent mail survey of people who reserved U.S. Forest Service recreational cabins in Southeast Alaska suggests that compliance with regulations may be low in some areas (Harding et al. 2005). For example, at Turner Lake, where retention of coastal cutthroat trout is prohibited, 244 coastal cutthroat trout were estimated to have been harvested in 2002 (Harding et al. 2005). To improve compliance, managers should consider ways to improve public awareness of sport fishing regulations and the rationale behind them. Fishery managers should also collaborate with enforcement agencies to ensure that areas with conservation concerns have sufficient presence by enforcement personnel.

Prince William Sound has become more accessible to anglers with the construction of the tunnel to Whittier in 2000, and effort and catch of coastal cutthroat trout in the sport fishery has increased substantially in the last five years. The Alaska Marine Highway System has added a summer fast ferry route connecting the Prince William Sound communities of Valdez, Cordova, and Whittier. Fishery managers should be aware that the increased accessibility to these communities may lead to an increase in angler effort in some areas.

Subsistence fishery concerns.—The ADF&G expressed concern over the sustainability of the recently expanded federal subsistence fishery for coastal cutthroat trout in Southeast Alaska (T. Brookover, ADF&G, personal communication). Subsistence users are required to record, and subsequently report, the harvest of coastal cutthroat trout on their permit, however the efficacy of this reporting method is questionable. In a steelhead trout subsistence fishery on Prince of Wales Island, the Federal subsistence steelhead harvest permit and reporting system appears to be failing to record most of the steelhead harvested (Turek 2005). We recommend that managers of the subsistence fishery for coastal cutthroat trout monitor harvest levels, evaluate the effectiveness of their reporting system and compliance with regulations, and monitor the effect of the fishery on the coastal cutthroat trout populations.

Habitat concerns.—The greatest long-term threat posed to coastal cutthroat trout populations in Alaska may be habitat degradation or destruction. Rectifying the depletion of overharvested stocks (e.g., by curtailing exploitation rates) is much easier and far less expensive than restoring degraded habitat. Some of the potential causes of habitat alterations are road construction or insufficient maintenance of existing roads, mines, timber harvest, hydroelectric projects or other diversions of water, land development, and oil spills or other pollution.

The potential impacts from roads is a primary habitat concern as the Southeast Alaska Transportation Plan (Alaska Department of Transportation and Public Facilities 2004) outlines the planned development of 34 transportation and utility corridors in Southeast Alaska over the next 20 years, with the ultimate plan of having highways through all of the corridors. Road construction around Eyak Lake in the West Copper River Delta resulted in a loss of more than 40% of the historic spawning habitat for coastal cutthroat trout in the area (Hodges 1995). An example of the negative effects of inadequate road maintenance was documented by Flanders and Cariello (2000), where they examined stream crossings along 3,465 km of permanent roads in the Tongass National Forest. Their results suggest that 66% of culverts across anadromous streams (U.S. Forest Service Class I streams) and 85% of culverts crossing resident streams (U.S. Forest Service Class II streams that naturally do not support anadromous fish) are assumed to be inadequate for fish passage.

In Alaska, the *Anadromous Fish Act* (Alaska Statute 41.14.870, Alaska Legal Resource Center 2007) requires approval from the Alaska Department of Natural Resources to “construct a hydraulic project or use, divert, obstruct, pollute, or change the natural flow or bed” or “to use wheeled, tracked, or excavating equipment or log-dragging equipment in the bed” of a specified anadromous water body. For a water body to receive protection under this Act, it must be listed in the *Catalog of Waters Important for the Spawning, Rearing or Migration of Anadromous Fishes* and its associated *Atlas* (hereafter referred to as the Catalog and Atlas, respectively). The Catalog and Atlas are divided into six volumes and are revised approximately every 12 months; the volumes relevant for coastal cutthroat trout are for southeastern Alaska (e.g., Johnson and Weiss 2007a) and south central Alaska (e.g., Johnson and Weiss 2007b). Most of the streams and lakes supporting cutthroat trout in Alaska, especially small or remote systems, are likely not included in the Catalog and Atlas. The cost to update the Catalog and Atlas to include all or most of the water bodies used by anadromous coastal cutthroat trout for spawning, rearing, or migration would be prohibitively high. We recommend the development of landscape models based on geographic information systems for predicting the distribution of coastal cutthroat trout (e.g., Kruse and Hubert 1997; Porter et al. 2000). The models would allow resource managers to rapidly assess the potential impacts of development projects such as road construction, and would be a valuable tool for qualitatively evaluating coastal cutthroat trout habitat. They would also allow managers to prioritize areas for assessment, monitoring, or habitat restoration.

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PART TWO

BIOLOGY

Coastal Cutthroat Trout Symposium: Status, Management, Biology, and Conservation
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The Influence of Spawning Pacific Salmon on the Stable Isotope Composition, Feeding Behavior, and Caloric Intake of Coastal Cutthroat Trout

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Abstract.—A growing body of research has established anadromous Pacific salmon (*Oncorhynchus* spp.) as important nutrient vectors between marine and freshwater/terrestrial systems. Research must quantify species-specific use of salmon-derived nutrients to predict their response to decreasing salmon abundance. The focus of this study was to determine the extent to which coastal cutthroat trout (*O. clarkii clarkii*) utilize salmon-derived nutrients at Kennedy and Donkey Creeks in western Washington. At both study sites, after salmon began to spawn coastal cutthroat trout shifted their primary prey from invertebrates to salmon eggs. Egg feeding behavior resulted in higher caloric intakes during winter and spring for coastal cutthroat trout sampled from the anadromous reaches of both streams, compared to coastal cutthroat trout sampled above anadromous barriers. Juvenile coastal cutthroat trout from both creeks displayed increased stable isotope ratios ($\delta^{15}N$ and $\delta^{13}C$) after salmon began to spawn, reflecting their consumption of salmon-derived organic matter. The results of this study show that salmon-derived material, especially salmon eggs, are an important food source for juvenile and adult coastal cutthroat trout from fall through spring.

The role of Pacific salmon (*Oncorhynchus* spp.) in the transportation of nutrients between the marine and freshwater environments has been well documented (Cederholm et al. 1999; Gresh et al. 2000; Cederholm et al. 2000; Stockner 2003). Researchers have identified semelparous salmon as "keystone species" because they provide an important nutrient source for terrestrial wildlife (Cederholm et al. 1989; Hilderbrand et al. 1996; Cederholm et al. 2000), riparian vegetation (Bilby et al. 1996; Helfield and Naiman 2001), and aquatic organisms (Kline et al. 1990, 1993; Bilby et al. 1996; Bilby et al. 1998) during a period of low primary productivity (fall-spring).

The transfer and deposition of marine-derived nutrients to the freshwater environment is the result of the anadromous and semelparous life history traits of the five species of fall-spawning salmon native to the Pacific Northwest (Bilby et al. 2001). Since Pacific salmon accumulate more than 95% of their body mass in the marine environment (Groot and Margolis 1991), they represent a substantial allochthonous nutrient source for freshwater and riparian communities (Bilby et al. 1996).

Recent work has focused on the need to incorporate the nutrient requirements of freshwater and terrestrial systems into the development of salmon escapement goals (Michael 1998; Cederholm et al. 2000; Gresh et al. 2000; Bilby et al. 2001). Schoonmaker et al. (2003) note that the contribution of salmon-derived nutrients to the rivers of the Pacific Northwest is 13% of its historic level south of Alaska and the resulting "nutrient deficit" could be exacerbating the downward trend in salmon abundance (Gresh et al. 2000). To better understand the significance of salmon-derived nutrients to freshwater communities, the relationship between individual species and spawning salmon must be examined.

Coastal cutthroat trout (*O. clarkii clarkii*) range from the Humboldt Bay area of Northern California to Prince William Sound in Alaska, and from the Pacific Coast to the crest of the Cascade Mountain Range (Trotter 1989, 1997). Coastal cutthroat trout (hereafter used interchangeably with cutthroat trout) have an array of life history forms, which can exist in sympatry (Garrett 1998). These forms include freshwater nonmigratory (resident), freshwater migratory (potamodromous), and cutthroat trout that migrate between marine and fresh waters for spawning and/or feeding (amphidromous) (Trotter 1989; Williams et al. 1997; Garrett 1998). Most amphidromous cutthroat trout rear in freshwater for an average of 3-4 years before migrating to sea (Trotter 1989, 1997; Northcote 1997; Johnson et al. 1999), then migrate back to freshwater from August through October (early-entry) and November through March (late-entry) (WDFW 2000).

Despite being a popular game fish, coastal cutthroat trout are one of the least-studied members of the Pacific salmon, partly because they are not the target of a

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commercial fishery (Johnson et al. 1999). What information is available suggests that coastal cutthroat trout are very susceptible to habitat alterations resulting from land-management activities (Reeves et al. 1997). The long freshwater rearing phase of cutthroat trout makes them vulnerable to adverse freshwater conditions. Thus, coastal cutthroat trout have been referred to as the "canary in the coal mine" in regards to the health of freshwater systems (Reeves et al. 1997). For this reason, coastal cutthroat trout are particularly good subjects for studying the importance of salmon-derived nutrients to members of the freshwater community.

The significance of salmon material (eggs, carcass flesh, alevins/fry) use over time by coastal cutthroat trout is not yet known; however, there is evidence suggesting that cutthroat trout do feed on salmon-derived material. Bilby et al. (1996) found that the percentage of marine-derived nitrogen for older coastal cutthroat trout was as high as 44.8%, although they did not have a large enough sample size to measure the growth or condition of coastal cutthroat trout in response to coho (*O. kisutch*) carcass addition. Trotter (1989) notes that the downstream migration of cutthroat trout smolts precedes the migration of pink salmon (*O. gorbuscha*) and chum salmon (*O. keta*) juveniles, citing Johnston (1981); he theorizes that natural selection has favored this timing because it gives coastal cutthroat trout the opportunity to feed on salmon smolts in the estuary. Fresh and Schroder (1987) sampled 31 coastal cutthroat trout and found an average of three chum fry per cutthroat trout stomach in Big Beef Creek, Washington. Cartwright et al. (1998) found that coastal cutthroat trout fed heavily on sockeye (*O. nerka*) salmon fry in Margaret Lake, Alaska. Jauquet (2002) determined that coastal cutthroat trout would feed extensively on salmon eggs and chum salmon fry, when they were available in the south Puget Sound nearshore environment.

The specific objective of this study was to test the following three hypotheses:

(1) juvenile, freshwater rearing, coastal cutthroat trout exposed to spawning salmon are significantly more enriched with marine-derived nutrients compared to coastal cutthroat trout residing in the same stream but above an anadromous barrier;
(2) coastal cutthroat trout incorporate marine-derived nutrients into their tissues by directly consuming salmon carcass flesh, eggs, and alevins/fry; and
(3) coastal cutthroat trout with access to salmon carcass flesh, eggs, and alevins/fry ingest more calories during winter and spring than coastal cutthroat trout residing above an anadromous barrier.

Study Sites

Kennedy Creek flows into Totten Inlet in south Puget Sound and is located in Mason and Thurston Counties, Washington. Kennedy Creek drains approximately 53 km^2 and has a waterfall impassable to fish near river kilometer (rkm) 4.4 (Peterson and Quinn 1994). Kennedy Creek has a chum salmon run which is classified as "healthy" (WDFW and WWTIT 1993). Coastal cutthroat trout are found both above and below the waterfall barrier on Kennedy Creek. Kennedy Creek cutthroat trout belong to the Western South Sound stock complex and their status is unknown (WDFW 2000). See Table 1 for general stream characteristics and salmon abundance estimates.

Donkey Creek is a tributary of the West Fork Humptulips River, located in Grays Harbor County, Washington. Donkey Creek drains 17.27 km^2 and receives runs of Chinook (*O. tshawytscha*), chum, and coho that spawn below impassable waterfalls just beyond rkm 2.6 (Phinney et al. 1975) (Table 1). The Donkey Creek salmon runs are considered part of the Grays Harbor stock complex and are classified as "healthy" (WDFW and WWTIT 1993). Coastal cutthroat trout inhabit Donkey Creek above and below the waterfalls. Donkey Creek cutthroat trout are a component of the Humptulips coastal cutthroat trout stock complex and their stock status is unknown (WDFW 2000).

TABLE 1.—Habitat characteristics and adult salmon spawner densities during the 2001-02 season for Kennedy Creek and Donkey Creek, Washington.

Habitat characteristics	Kennedy Creek	Donkey Creek
Average bankfull width (m)	14.8	13.8
Length of anadromous zone (m)	4475	2600
Area of anadromous zone (m^2)	61755	35880
Dominant substrate	gravel	gravel and cobble
Average canopy cover (%)	48	74
Average gradient (%)	0.8	1.1
Chum salmon density in anadromous zone (number/m^2)	0.83[a]	0.02[b]
Coho salmon density in anadromous zone (number/m^2)	NA	0.01[b]
Chinook salmon density in anadromous zone (number/m^2)	NA	0.004[b]
Total salmon density in anadromous zone (number/m^2)	0.83	0.04

[a] Represents 51,393 chum spawners for the 2001 season (John Long, WDFW, personal communication).
[b] Represents 658 chum, 450 coho, and 150 Chinook spawners for the 2001-02 season (Curt Holt, WDFW, personal communication).

Methods and Materials

Sampling procedure.—Coastal cutthroat trout were sampled below waterfalls, which are barriers to upstream anadromous migration on Kennedy and Donkey Creeks throughout the summer, fall, winter, and spring of 2001-2002. The diet, isotope ratio, and caloric intake were characterized from cutthroat trout collected before anadromous salmon returned (August, September, early-October 2001); during fall salmon spawning (October and November 2001); at the peak of salmon carcass abundance in winter (December 2001 and January 2002); and again in spring (February-May 2002). Cutthroat trout were sampled from above the barriers in the non-anadromous zones of both creeks in August and December 2001, and in March 2002. The non-anadromous zones served as reference sites and the anadromous zones were the treatment sites (Table 2).

TABLE 2.—Number of coastal cutthroat trout sampled in the anadromous zones and non-anadromous zones of Kennedy and Donkey Creeks, Washington, from summer 2001 to spring 2002.

Stream	Pre-salmon spawning	Post-salmon spawning		
	Summer	*Fall*	*Winter*	*Spring*
Kennedy Creek				
anadromous zone	16	5	5	7
non-anadromous zone	12	NA[a]	12	9
Donkey Creek				
anadromous zone	10	6	8	4
non-anadromous zone	12	NA[a]	16	5

[a] High water and time limitations prevented non-anadromous zone sampling in fall.

After capture, each cutthroat trout was anesthetized, weighed to the nearest 0.1 g with a portable scale, and the fork length was measured to the nearest millimeter. Stomach contents of cutthroat trout were collected using the non-lethal lavage technique discussed by Bilby et al. (1998). The contents of each cutthroat trout's stomach were stored in 90% ethanol until analyzed. Sampled fish were then allowed to recover in a five-gallon bucket before being released.

A small number of cutthroat trout approximately 180 mm or less in length were sacrificed for stable isotope analysis. Cutthroat trout under 180 mm are assumed to be fish that have not made their first marine migration (based on length data reported by Johnson et al. 1999 and Trotter 1997). Stable isotope techniques were used to compare the proportion of marine-derived nitrogen and carbon in coastal cutthroat trout muscle tissue between fish sampled from the reference and treatment sites as well as between cutthroat trout in the treatment sites sampled before and after the fall/winter salmon runs.

Stable isotope analysis.—Stable isotope ratios for Nitrogen (N) and Carbon (C) are expressed as δ^{15}N and δ^{13}C (Peterson and Fry 1987) and are typically higher in marine systems than in terrestrial or freshwater environments (Helfield and Naiman 2001). δ^{15}N and δ^{13}C signify a level of enrichment or depletion of the heavier isotope of N or C relative to a standard (Bilby et al. 1998). The values are calculated as follows:

$$(1)\ \delta^{15}N \text{ or } \delta^{13}C \text{ ‰} = [(R_{sample} - R_{standard})/R_{standard})] \text{ X } 1000$$

where R_{sample} is the isotope ratio of the sample and the isotope ratio standards ($R_{standard}$) are air for N and Peedee Belemnite for C.

All isotope samples were sent to the University of Alaska, Fairbanks for analysis. The samples were prepared for analysis according to the method outlined in Bilby et al. (2001). Significant differences between anadromous and non-anadromous zone coastal cutthroat trout δ^{15}N and δ^{13}C values were tested using a one-tailed two sample t-test assuming unequal variances with $\alpha = 0.05$. Variances were tested for equality using a two sample F-test for variances with $\alpha = 0.05$.

Diet analysis.—The diet contents of each coastal cutthroat trout were sorted into the following categories: aquatic invertebrates, terrestrial invertebrates, unidentifiable invertebrate parts, carcass tissue, salmon eggs, whitefish (*Prosopium* spp.) eggs, unknown fish flesh, and miscellaneous material. Each category of stomach material was air-dried on a paper towel until the ethanol had fully evaporated and the towel no longer appeared moist. The material was then weighed on a pre-weighed dry towel to the nearest 0.01 g.

A diet index value (DIV), modified from a similar index used by Bilby et al. (1998), was used to compare the contribution of various food items across sampling events and sites and to correct for the influence of cutthroat trout body size. The DIV is the percent contribution of a particular food item to the total body weight of an individual coastal cutthroat trout.

(2) DIV = (Prey item air-dried weight (g))/(Total body wet weight (g) of coastal cutthroat trout (before being lavaged)) X 100

Caloric contribution of diet contents.—To assess changes in the caloric value of coastal cutthroat trout diet contents throughout the year and to correct for the influence of body size, a caloric index value (CIV) was calculated.

(3) CIV = Caloric content of food item/Coastal cutthroat trout body weight (g)

The caloric content of each food item was derived using caloric conversion values from Eastman (1996).

Results

Stable isotope analysis.—$\delta^{15}N$ and $\delta^{13}C$ values for coastal cutthroat trout, salmon carcass flesh, and chum salmon eggs collected from Kennedy Creek and Donkey Creek are presented graphically by plotting $\delta^{15}N$ values against $\delta^{13}C$ values on a Cartesian plane in Figure 1 (Kennedy Creek) and Figure 2 (Donkey Creek). $\delta^{15}N$ and $\delta^{13}C$ values of coastal cutthroat trout in the non-anadromous zones represent the background level of N and C stable isotopes derived from non-marine sources. N and C stable isotope values for salmon carcass flesh and eggs represent the source of N and C enrichment for the anadromous zones.

Coastal cutthroat trout sampled from the anadromous zone of Kennedy Creek displayed significantly higher values of $\delta^{15}N$ ($P < 0.00004$, one-tailed two sampled t-test assuming unequal variances) and $\delta^{13}C$ ($P < 0.00006$, one-tailed two sampled t-test assuming unequal variances) than coastal cutthroat trout sampled from the non-anadromous zone of Kennedy Creek (Figure 1). The elevated stable isotope values found in Kennedy Creek anadromous zone cutthroat trout indicate that salmon-derived N and C are prevalent in the system and that these nutrients are assimilated into the muscle tissue of the sampled cutthroat trout. Anadromous zone cutthroat trout collected after chum salmon spawned (January-February) exhibited higher $\delta^{15}N$ and $\delta^{13}C$ values than anadromous zone cutthroat trout sampled before the salmon run (July-August). Differences in salmon-derived nutrient sources (eggs and carcass tissue) are also apparent, with chum salmon carcasses having slightly higher $\delta^{13}C$ values and lower $\delta^{15}N$ values than chum salmon eggs.

$\delta^{15}N$ and $\delta^{13}C$ values of cutthroat trout in the anadromous zone of Donkey Creek are highly variable, ranging from low values resembling non-anadromous coastal cutthroat trout to highly enriched values similar to chum salmon eggs (Figure 2). $\delta^{15}N$ values for coastal cutthroat trout in the anadromous zone were not significantly higher than non-anadromous zone cutthroat trout ($P = 0.09$, one-tailed two sampled t-test assuming unequal variances). However, $\delta^{13}C$ levels were significantly higher for anadromous zone cutthroat trout than those residing in the non-anadromous zone ($P < 0.02$, one-tailed two sampled t-test assuming unequal variances). Two of the three pre-salmon run coastal cutthroat trout samples display isotopic levels similar to non-anadromous coastal cutthroat trout. Only one pre-salmon run coastal cutthroat trout sample is enriched with $\delta^{13}C$, but not with $\delta^{15}N$ relative to non-anadromous zone samples. Two of the three post-salmon run cutthroat trout samples are highly enriched with both $\delta^{15}N$ and $\delta^{13}C$, having values approaching salmon carcass flesh. In contrast, one of the post-salmon run cutthroat trout is not enriched with $\delta^{15}N$ and $\delta^{13}C$ relative to the non-anadromous zone samples.

The three semelparous anadromous salmonids that spawn in Donkey Creek—Chinook, coho, and chum salmon—have substantially different isotopic signatures (Figure 2) with Chinook salmon being the most enriched with $\delta^{15}N$ and $\delta^{13}C$, followed by coho then chum. Compared to chum salmon carcasses, chum salmon eggs are more enriched with $\delta^{15}N$, but less enriched with $\delta^{13}C$.

Diet analysis.—Coastal cutthroat trout from the anadromous zone of Kennedy Creek displayed a distinct change in their diet composition after chum salmon began to spawn. Before the salmon arrived, cutthroat trout fed primarily on aquatic and terrestrial invertebrates. After chum salmon began to spawn in mid-October, 16 out of 17 cutthroat trout had one or more salmon eggs in their diet. Chum salmon carcass flesh was found in the diets of 8 out of 17 cutthroat trout sampled.

Figure 3 depicts the average diet index value (DIV) of the primary food items (Equation 2) for all coastal cutthroat trout sampled from Kennedy Creek for each season. Cutthroat trout displayed strong seasonal differences in the amount and type of prey consumed. Before salmon began

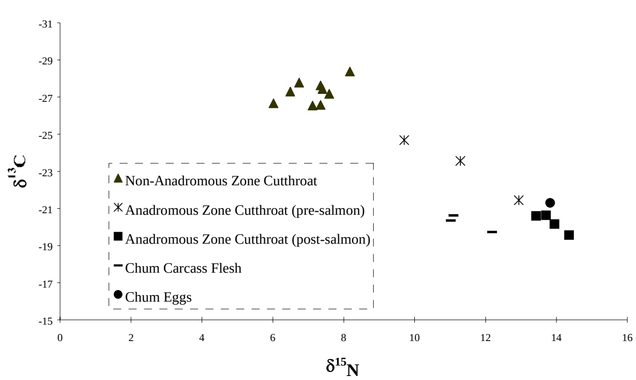

FIGURE 1.—Dual-isotope ratio plot of coastal cutthroat trout, chum salmon carcass flesh, and chum salmon eggs collected from Kennedy Creek, Washington. .

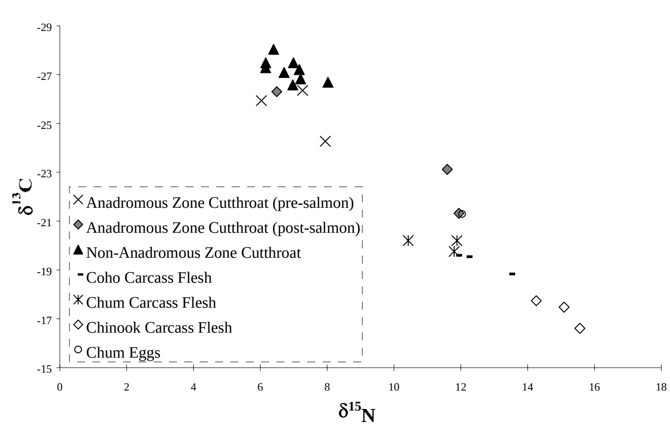

FIGURE 2.—Dual-isotope ratio plot of coastal cutthroat trout, coho carcass flesh, chum carcass flesh, Chinook carcass flesh, and chum salmon eggs collected from Donkey Creek, Washington.

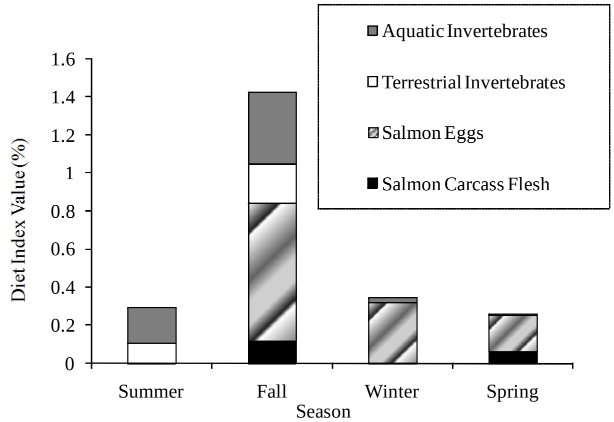

FIGURE 3.—The diet index value (DIV) of the primary prey items found in coastal cutthroat trout sampled from the anadromous zone of Kennedy Creek, Washington. All samples were averaged by prey category and season collected. See Table 2 for sample size information.

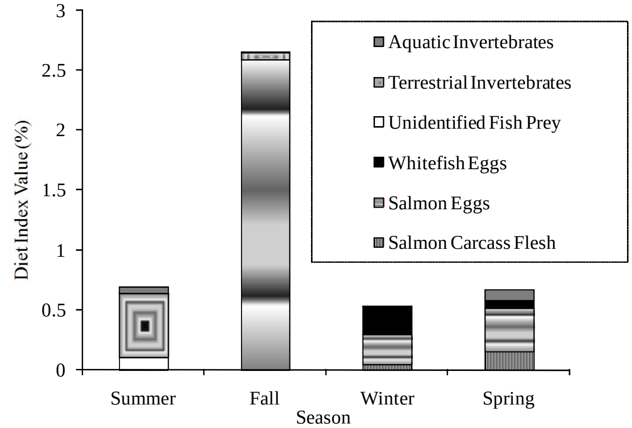

FIGURE 4.—The diet index value (DIV) of the primary prey items found in coastal cutthroat trout sampled from the anadromous zone of Donkey Creek, Washington. All samples were averaged by prey category and season collected. See Table 2 for sample size information.

to spawn, cutthroat trout prey constituted approximately 0.32% of their total body weight, with aquatic invertebrates contributing 0.20% and terrestrial invertebrates 0.12%. Cutthroat trout had a greater mass of prey items when salmon arrived in fall (DIV ~ 1.4%) than any other season, with salmon eggs constituting the majority of the mass of their prey (DIV ~ 0.73%). Salmon carcass flesh (DIV ~ 0.12%), terrestrial invertebrates (DIV ~ 0.21%), and aquatic invertebrates (DIV ~ 0.38%) also contributed to the diet mass of sampled cutthroat trout when salmon were spawning. Stomach contents from coastal cutthroat trout sampled in winter had a DIV of approximately 0.35%, with eggs (DIV ~ 0.32%) constituting the bulk of their diet. The stomach contents of cutthroat trout sampled in spring had a DIV of approximately 0.26%. Eggs remained the dominant contributor (DIV ~ 0.19%), followed by salmon carcass (DIV ~ 0.06%).

Coastal cutthroat sampled from the anadromous zone of Donkey Creek displayed a similar shift in diet composition as cutthroat trout sampled from Kennedy Creek after salmon began to spawn. Most of the cutthroat trout sampled (seven out of 10) from the anadromous zone of Donkey Creek preyed on terrestrial invertebrates before salmon began to spawn. Four out of 10 cutthroat trout sampled had aquatic invertebrates in their diets, while three out of 10 had unidentifiable fish prey. After salmon arrived in Donkey Creek, 11 out of 18 sampled cutthroat trout fed on salmon eggs and six out of 18 fed on salmon carcass flesh. Many coastal cutthroat trout also preyed on whitefish (*Prosopium* spp.) eggs. Aquatic invertebrates and terrestrial invertebrates were preyed on infrequently compared with samples collected before salmon began to spawn. Similar to the trend observed in Kennedy Creek, salmon-derived material comprised the bulk of the diet in Donkey Creek anadromous zone cutthroat trout sampled after salmon began to spawn.

When salmon began to spawn in Donkey Creek during fall, the contribution of the stomach contents to the total body weight of coastal cutthroat trout increased dramatically (Figure 4). The total average DIV (Equation 2) for all of the primary food items found in Donkey Creek anadromous zone cutthroat trout went from approximately 0.7% in the summer to approximately 2.7% (Figure 4) in the fall. Like Kennedy Creek, salmon eggs (DIV ~ 2.6%) contributed to the bulk of this increase; for example, one 287 mm, 308 g coastal cutthroat trout contained 256 salmon eggs with a wet weight of 22.46 g—this amounts to a DIV greater than 7%. The total average DIV dropped substantially from fall to winter (DIV ~ 0.53%). Salmon eggs (DIV ~ 0.25%), followed by whitefish eggs (DIV ~ 0.23%), and some salmon carcass flesh (DIV ~ 0.05%) sustained the cutthroat trout during winter. Spring total average DIV increased to near summer levels (DIV ~ 0.66%) and was composed primarily of salmon eggs (DIV ~ 0.36%), salmon carcass flesh (DIV ~ 0.15%), aquatic invertebrates (DIV ~ 0.08%), and whitefish eggs (DIV ~ 0.07%).

Caloric analysis.—The average caloric index value (CIV, Equation 3) for the entire diet of Kennedy Creek anadromous zone cutthroat trout increased measurably from summer (CIV ~ 11.2) to fall (CIV ~ 55.2), and is sustained at higher than pre-salmon levels through winter (CIV ~ 15.3) (Figure 5). The CIV returns to near summer levels in spring (CIV ~ 9.2). Salmon eggs represent the bulk of the fall (CIV ~ 32.3), winter (CIV ~ 14.2), and spring (CIV ~ 8.4) caloric intake for coastal cutthroat trout.

Figure 6 contrasts the average CIV for the primary prey items (aquatic invertebrates, terrestrial invertebrates, and unidentifiable invertebrate parts) found in the diets of Kennedy Creek non-anadromous zone coastal cutthroat trout against the average CIV for the primary prey items (aquatic and terrestrial invertebrates, salmon eggs, and salmon carcass flesh) found in the diets of anadromous zone cutthroat trout. In summer, the calories derived from invertebrates in non-anadromous zone coastal cutthroat trout (CIV ~ 52.8) are greater than the caloric intake of all food items found in anadromous zone cutthroat trout (CIV ~

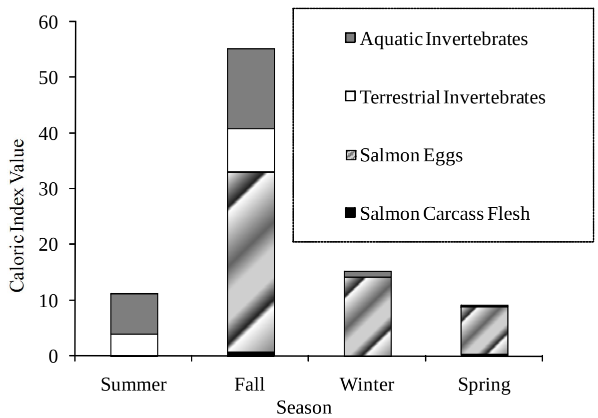

FIGURE 5.—The caloric index value (CIV) of the primary prey items consumed by coastal cutthroat trout in the anadromous zone of Kennedy Creek, Washington. All samples were averaged by prey category and season collected. See Table 2 for sample size information.

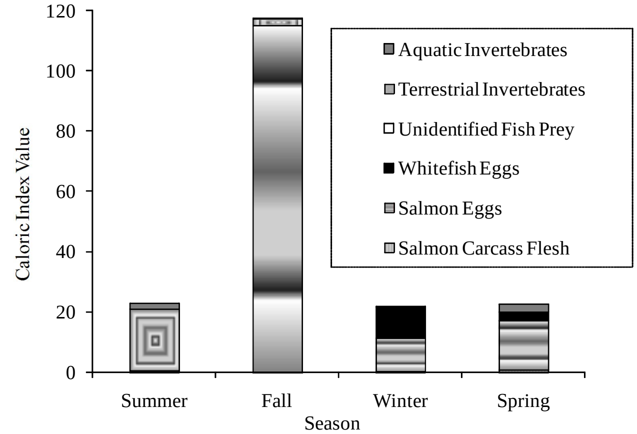

FIGURE 7.—The caloric index value (CIV) of the primary prey items consumed by coastal cutthroat trout in the anadromous zone of Donkey Creek, Washington. All samples were averaged by prey category and season collected. See Table 2 for sample size information.

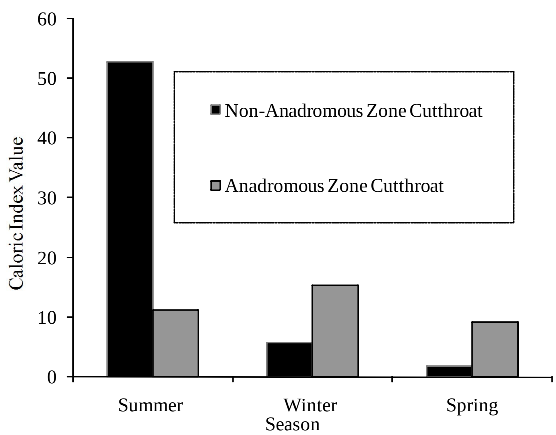

FIGURE 6.—The average total caloric index value (CIV) for the primary prey items consumed by anadromous zone and non-anadromous zone coastal cutthroat trout in Kennedy Creek, Washington. In cutthroat from the non-anadromous zone, the CIV was computed for all aquatic invertebrates, terrestrial invertebrates, and unidentifiable invertebrate parts. In anadromous zone cutthroat the CIV represents the caloric contribution of aquatic invertebrates, terrestrial invertebrates, salmon eggs, and salmon carcass flesh. A comparison could not be made for fall due to an inability to capture cutthroat in the non-anadromous zone.

11.2). This changes dramatically after cutthroat trout in the anadromous zone have access to salmon eggs, with winter and spring CIV levels higher for anadromous zone cutthroat trout prey (winter CIV $\simeq$ 15.3, spring CIV $\simeq$ 9.2) than non-anadromous zone cutthroat trout invertebrate diets (winter CIV $\simeq$ 5.7, spring CIV $\simeq$ 1.8). A comparison cannot be made for fall, due to the inability to capture coastal cutthroat trout in the non-anadromous zone.

Similar to the trend observed in the caloric intake of anadromous zone Kennedy Creek cutthroat trout, Donkey Creek cutthroat trout ingested far more calories in fall than any other season (Figure 7). The average CIV (Equation 3) increased from approximately 23.0 in summer to 117.6 in fall, with eggs contributing 115.1 to the fall total. The total average CIV was sustained at near pre-salmon spawning levels through winter (CIV $\simeq$ 22.1) and spring (CIV $\simeq$ 23.4). Salmon eggs (winter CIV $\simeq$ 11.1, spring CIV $\simeq$ 16.1) whitefish eggs (winter CIV $\simeq$ 10.4, spring CIV $\simeq$ 3.1), and salmon carcass flesh (winter CIV $\simeq$ 0.3, spring CIV $\simeq$ 1.0) represented the bulk of the coastal cutthroat trout's caloric intake during this time.

Similar to the trend observed in Kennedy Creek, there is a large disparity in the amount of calories being consumed by Donkey Creek cutthroat trout in winter and spring between the anadromous and non-anadromous zones (Figure 8). The high CIV for coastal cutthroat trout in the anadromous zone is the result of a diet composed almost exclusively of salmon and whitefish eggs. Unfortunately, fall values cannot be compared due to an inability to capture non-anadromous zone coastal cutthroat trout.

Discussion

Juvenile and adult coastal cutthroat trout in the anadromous zones of Kennedy and Donkey Creeks displayed measurable dietary and isotopic responses to the influx of salmon-derived nutrients. The results of this study corroborates the findings of other researchers that anadromous semelparous salmon provide a predictable and readily used source of nutrients for aquatic biota (Kline et al. 1990, 1993; Bilby et al. 1996; Bilby et al. 1998; Nakajima and Ito 2003). Since salmon play a disproportionately large role in the community structure of the North Pacific they are considered keystone species (Willson and Halupka 1995; Cederholm et al. 2000). As a

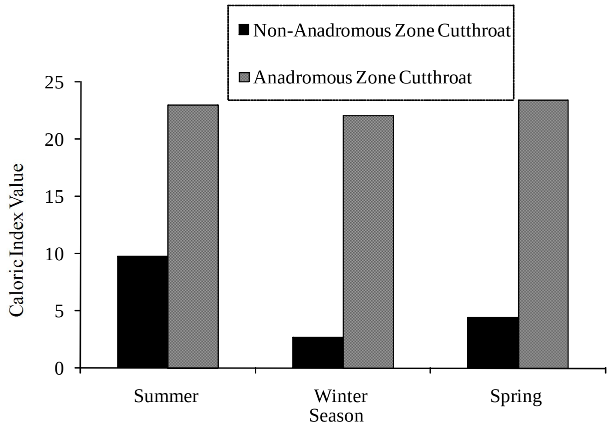

FIGURE 8.—The average total caloric index value (CIV) for the primary prey items consumed by anadromous zone and non-anadromous zone coastal cutthroat trout in Donkey Creek, Washington. In cutthroat from the non-anadromous zone, the CIV was computed for all aquatic invertebrates, terrestrial invertebrates, and unidentifiable invertebrate parts. In anadromous zone cutthroat the CIV represents the caloric contribution of aquatic invertebrates, terrestrial invertebrates, unidentifiable fish prey, whitefish eggs, salmon eggs, and salmon carcass flesh. A comparison could not be made for fall due to an inability to capture cutthroat in the non-anadromous zone.

result, managers need to formulate "ecosystem based" salmon escapement goals large enough to maintain the community structure and function within the nutrient shadow of the Pacific salmon (Cederholm et al. 2000; Murota 2003; Schoonmaker et al. 2003; Michael 1998, 2003).

A strong shift in prey preference was observed for anadromous zone juvenile and adult coastal cutthroat trout after semelparous salmon began to spawn (Figures 3 and 4). Cutthroat trout from both creeks consumed aquatic and terrestrial invertebrates almost exclusively before salmon began to spawn in fall. After salmon spawning, cutthroat trout from all size classes sampled preyed heavily on salmon eggs and some salmon carcass flesh from fall through early spring. The observed feeding preference for salmon eggs by coastal cutthroat trout in this study is similar to findings for juvenile coho and steelhead (Bilby et al. 1998), rainbow trout (Eastman 1996, Kline et al. 1990), char (Eastman 1996), and for coastal cutthroat trout in the Puget Sound nearshore environment (Jauquet 2002).

The consumption of salmon-derived material by juvenile (<180mm) coastal cutthroat trout from both Kennedy and Donkey Creeks resulted in increased stable isotope values following salmon spawning (Figures 1 and 2). Post-salmon spawning stable isotope values for Kennedy Creek coastal cutthroat trout are greater than values reported by Kline et al. (1990) for rainbow trout (*O. mykiss*) sampled during the peak nutrient loading by high-density pink salmon (*O. gorbuscha*) in Sashin Creek, Alaska. (Table 3). Donkey Creek coastal cutthroat trout post-salmon spawning isotope values are less than those from Kennedy Creek and the values reported by Kline et al. (1990), but similar to those reported by Bilby et al. (1996) for age 1 and age 2 coastal cutthroat trout in Grizzly Creek, Washington (Table 3). These data support the findings by Bilby et al. (2001) that a positive relationship exists between salmon spawner density and stable isotope values of stream dwelling fishes.

Two out of the three coastal cutthroat trout sampled after salmon began to spawn in Donkey Creek displayed elevated stable isotope values relative to the control population (Figure 2), as predicted from the observed feeding preference for salmon-derived material. However, one of the samples was not enriched relative to the control (Figure 2) despite having a diet composed primarily of salmon eggs at the time of capture. The stable isotope composition of a sampled coastal cutthroat trout's muscle tissue is a measure of the ingested and assimilated diet, representing both the long- and short-term feeding history of the trout (Peterson and Fry 1987). Since Donkey Creek is a tributary to the Humptulips River, it is conceivable that the juvenile coastal cutthroat trout may have recently migrated into Donkey Creek for feeding and/or refuge so its isotopic signature reflects a history of foraging in areas with variable levels of salmonid nutrient loading. In a similar study by

TABLE 3.—Mean Nitrogen ($\delta^{15}N$) and Carbon ($\delta^{13}C$) stable isotope ratio values for cutthroat and rainbow trout at various levels of adult salmon abundance. The numbers of fish sampled are in parentheses.

Reference	Location and year	Species	Salmon spawner abundance estimate (adults/1000m)	$\delta^{15}N$	$\delta^{13}C$
Kline et al. 1990	Sashin Creek, Alaska. 1985	rainbow trout	25,000 pink salmon	12.8 (10)	-22.3 (10)
Bilby et al. 1996	Grizzly Creek, Washington. 1992	Age 1 and 2 cutthroat trout	475 coho salmon	10.8 (6)	-24.0 (5)
This study	Kennedy Creek, Washington. 2002	Age 1 and 2 cutthroat trout	11,484 chum salmon	13.9 (4)	-20.2 (4)
This study	Donkey Creek, Washington. 2002	Age 1 and 2 cutthroat trout	484 chum, coho, and Chinook salmon	10.0 (3)	-23.4 (3)

Bilby et al. (1998), researchers observed an increased density of juvenile coho and steelhead in small streams after salmon carcasses were added. Future studies should assess the relationship between juvenile coastal cutthroat trout migrations and salmon-derived nutrient availability in large lotic systems.

Juvenile cutthroat trout rearing in Kennedy Creek are limited to migrations within the main stem and a small tributary, Fiscus Creek. Chum salmon spawn in high density throughout the anadromous reach (Table 1), so the influx of salmon-derived nutrients overlaps almost completely with coastal cutthroat trout rearing habitat (excluding small off-channel habitat features). The Kennedy Creek coastal cutthroat trout's pre-salmon spawning stable isotope values may indicate a history of feeding on salmon eggs and carcass material from the previous chum salmon run and/or are the result of salmon-derived nutrients being cycled continuously through the system, enriching biota at various trophic levels. Previous research has shown that three primary pathways exist for the cycling of nutrients through a stream's trophic web: 1) autotrophic uptake of inorganic nutrients after mineralization then trophic transfer; 2) microfaunal uptake of dissolved organic nutrients released by carcasses; and 3) direct consumption of eggs, carcasses, and fry (Cederholm et al. 1999). Although this study documented direct consumption of eggs and, to a lesser extent, salmon carcass flesh by juvenile and adult coastal cutthroat trout, it is likely that salmon-derived nutrient enrichment occurs through a combination of pathways.

On several occasions in Kennedy Creek and Donkey Creek adult coastal cutthroat trout were captured while they were on their redds (these fish were processed and released swiftly and carefully). In every instance, the diet of the adult fish contained salmon eggs. In Donkey Creek, a pair of coastal cutthroat trout was observed spawning in sympatry with a pair of coho. The cutthroat trout made feeding forays into the coho's spawning territory when the female coho would dig, although no gamete release by either pair of salmonids was observed. After observing this behavior for approximately 1 hr, the cutthroat trout were captured with hook and line. The diet contents of the male, 260 mm, and female, 249 mm, cutthroat trout contained freshly ingested eggs. It is reasonable to assume that the coho were superimposing their redd on a pre-existing egg pocket and releasing the eggs as they excavated. These findings contrast with the supposition by Giger (1972) that adult coastal cutthroat trout in the Alsea River, Oregon stopped feeding during their spawning run.

Coastal cutthroat trout with access to salmon eggs throughout the coldest time of year have an energetic advantage over cutthroat trout exposed to the same environmental conditions but in habitat not accessible to adult salmon. Terrestrial and aquatic invertebrate prey provided high calorie diets for coastal cutthroat trout in summer, especially in the non-anadromous zone of Kennedy Creek. However, invertebrate prey was scarce in the diets of coastal cutthroat trout from all zones during the winter and spring sampling events. Coastal cutthroat trout sampled from the anadromous zones of both Kennedy and Donkey Creeks displayed higher caloric index values during winter and spring than cutthroat trout sampled from the non-anadromous zones of both creeks because they were able to shift their diet from insects to salmon and, in the case of Donkey Creek, whitefish eggs (Figures 6 and 8). A high calorie diet composed of salmon and whitefish eggs translates into more energy available for growth and/or reproduction.

The relationship between calories ingested and physiological processes can be expressed using the following formula from Moyle and Cech (1996):

$$I = M + G + E \tag{4}$$

where I is the ingested food energy (measured in calories), M is metabolism, G is growth (both in somatic and reproductive tissue), and E is energy excreted. Metabolism can include calories expended for movement, digestion, and body repair and maintenance (Moyle and Cech 1996). Based on this formula, cutthroat trout that ingest calorie rich eggs have a proportionately greater amount of energy available to expend on growth and metabolic activity, which may ultimately increase their likelihood of survival and/or reproductive success.

The most profound benefit of salmon-derived nutrients for coastal cutthroat trout may accrue to the offspring of adult female coastal cutthroat trout, who have increased growth as a result of feeding on salmon-derived material as rearing juveniles and adult spawners in freshwater and, in some cases, during marine foraging (Jauquet 2002). Fecundity is positively correlated with size in adult coastal cutthroat trout, with the largest females capable of producing more eggs of larger size, therefore increasing their chance of producing more and larger offspring (Trotter 1997). These large alevins have size-dependent growth and survival advantages (Trotter 1997 citing Sargent et al. 1987, 1988). Clearly, opportunities for research exist in the study of juvenile and adult coastal cutthroat trout survival and reproductive success in relation to salmon nutrient abundance.

This study has shown that robust runs of Pacific salmon benefit coastal cutthroat trout by providing coastal cutthroat trout with a seasonally dependable source of nutrients, primarily in the form of eggs. While this study focused specifically on coastal cutthroat trout, it is important to note that many other organisms take advantage of the nutrient subsidy provided by spawning salmon. Recently, salmon recovery activities have sought to mitigate for a loss in salmon-derived nutrients through artificial fertilization (Ashley and Stockner 2003; Sterling and Ashley 2003) and carcass supplementation (Michael 2003). While these measures may increase the productivity of freshwater systems, they do not substitute for the natural supply of material and nutrients provided by wild salmon.

Recent estimates put the abundance of Pacific salmon eggs, fry, smolt, ocean-going adult, and escapement biomass south of Alaska (excluding hatchery fish) at 32%, 21%, 20%, 31%, and 13%, respectively, of historical levels (Schoonmaker et al. 2003). Nutrient supplementation with carcasses and fertilizer fails to alleviate the loss of food provided to numerous organisms throughout the various life history phases of wild salmon. For instance, carcass supplementation does not ensure a steady supply of high-energy eggs to the system. Eggs become available to predators and scavengers as a direct consequence of the spawning act of wild salmon and the resulting burial of eggs, superimposition of redds, and/or excavation of eggs by high flows.

Fisheries managers must recognize the role of wild Pacific salmon as keystone species for the entire North Pacific and set escapement goals that provide for long-term ecosystem structure and function. As noted by Schoonmaker et al. (2003), "Sustained production for harvest is no longer a sufficient measure of salmon managers' performance." In turn, restoration biologists should seek to eliminate artificial barriers to salmon migration to ensure that the nutrients from wild salmon can penetrate the entire historical anadromous area of a given basin. According to the Washington State Governor's Salmon Recovery Office, there are an estimated 2,400-4,000 road culverts and other structures blocking 3,000-4,500 miles (4,828-7,242 km) of habitat in Washington State (GSRO 2000). Ensuring salmon access to historical habitat will benefit both wild salmon populations and the biota dependent on them for sustenance.

Acknowledgements

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Dedicated to the late Jeff Cederholm, "Wild Salmon Forever."

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Effects of Landscape Pattern on the Distribution of Coastal Cutthroat Trout in Headwater Catchments in Western Oregon

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Extended abstract.—To evaluate landscape influences on the distribution and relative abundance of coastal cutthroat trout, we conducted spatially continuous surveys of stream habitat and trout abundance in forty randomly selected watersheds (500-1000 ha) in the Cascades, Coast Range, and Klamath Mountains ecoregions of western Oregon. Our investigation of coastal cutthroat trout populations across a broad range of headwater environments revealed that landscape patterns, including topography, geology, stream network structure, annual precipitation, and forest cover type, were associated with the distribution and scale of variation of trout abundance within watersheds. Understanding influences of landscape pattern on the distribution of coastal cutthroat trout is critical in the Pacific Northwest where resource managers must consider potential effects of forest management on aquatic ecosystems.

Headwater catchments were randomly selected from a known population of coastal cutthroat trout streams in western Oregon. Because a database with locations of isolated, potamodromous populations of coastal cutthroat trout did not exist, a sampling frame of isolated watersheds meeting this criterion had to be developed (Gresswell et al. 2004). After the sampling frame of watersheds was established, isolated watersheds with coastal cutthroat trout were stratified by ecoregion and erosion potential based on dominant bedrock lithology (i.e., sedimentary and igneous). A stratified random sample of 40 watersheds was selected with proportional allocation in each stratum (Figure 1).

The extent of fish-bearing stream in each watershed was sampled for aquatic habitat and coastal cutthroat trout distribution (Gresswell et al. 2006). The surveys were conducted during the summer months over a three-year period (1999-2001). Physical variables that describe habitat unit size (e.g., length, depth, and width), substrate size class, channel type, valley segment type, and woody debris were estimated or measured for all sampled habitat units. The relative abundance of coastal cutthroat trout in all pools and cascades was assessed by single-pass removal using

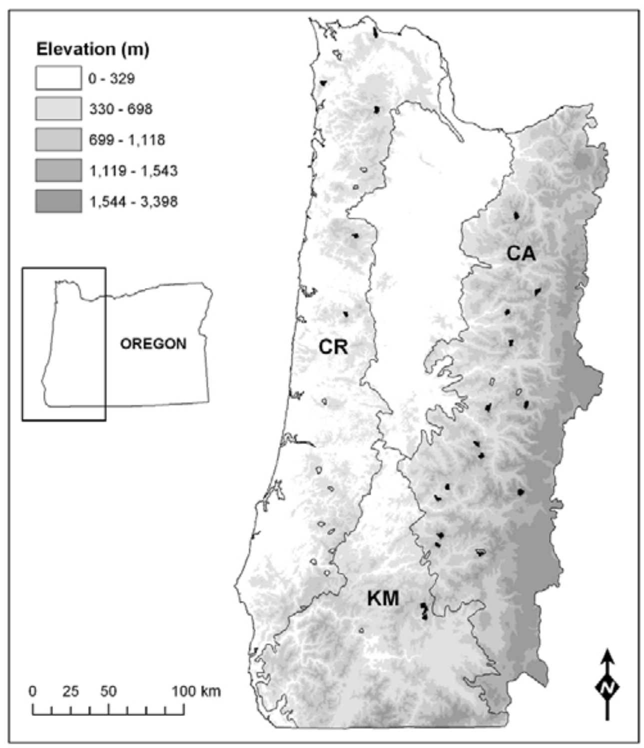

FIGURE 1.—Locations of 40 randomly selected catchments with isolated coastal cutthroat populations in the Coast Range (CR), Klamath Mountains (KM), and Cascades (CA) ecoregions of western Oregon (Gresswell et al. 2004).

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electrofishing to collect fish (Bateman et al. 2005).

Semivariograms were used to determine the spatial scale at which landscape characteristics were associated with fish distribution within watersheds (Ganio et al. 2005). Patterns of spatial variability in coastal cutthroat trout abundance were evaluated by comparing variograms among watersheds. Characteristics of the variogram, including the shape and the distance over which fish abundance was autocorrelated, were compared among watersheds with respect to landscape characteristics such as erosion potential, geology, ecoregion, and watershed characteristics (elevation, slope, and drainage density).

The spatial extent of fish distribution in each study basin was calculated in kilometers and normalized by watershed area (km^2). This variable, representing the length of stream occupied by coastal cutthroat trout, was compared among watersheds to identify broad-scale physiographic and climatic patterns that influence coastal cutthroat trout distribution. Multiple linear regression was used to identify a set of models that predicted fish distribution based on landscape explanatory variables derived from spatial data layers (climate, topography, and land use).

Spatial scaling of coastal cutthroat trout distribution was correlated with landscape characteristics. Multiple regression analysis indicated that patch size (determined from semivariograms) of coastal cutthroat trout distribution was positively associated ($r^2 = 0.78$, $P < 0.05$) with erosion susceptibility, the average distance between tributary junctions, and the maximum distance separating any two channel units within the surveyed portion of the stream network. We are currently investigating how this model can be used to predict the spatial scale of variation in coastal cutthroat trout distribution that is necessary for sampling and monitoring populations in headwater streams.

Regression models were used to investigate the spatial extent of coastal cutthroat trout distribution. Results suggest pronounced differences among watersheds and ecoregions (Figure 2), and channel slope, annual precipitation, and forest vegetation type were the primary landscape variables associated with observed differences. The biological responses of coastal cutthroat trout to changes in channel morphology, forest vegetation, prey availability, and physical constraints to movement are highly context dependent both spatially and temporally (Latterell et al. 2003). Therefore, caution should be exercised in drawing conclusions about causal relationships between coastal cutthroat trout distribution and management practices.

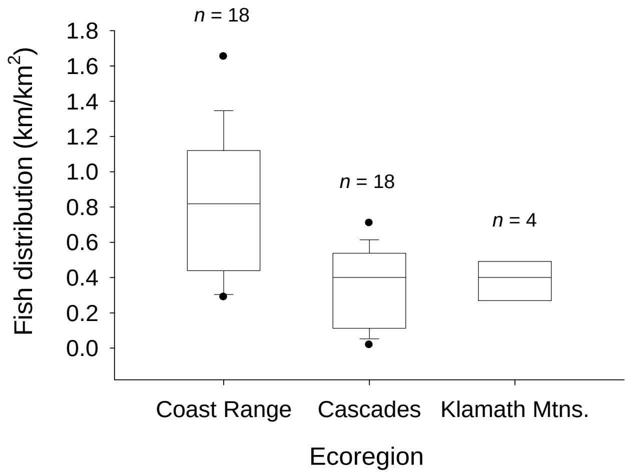

FIGURE 2.—Variability in the spatial extent of coastal cutthroat trout distribution among watersheds in ecoregions of western Oregon. Upper and lower boundaries of the box indicate 25th and 75th percentiles, whiskers indicate 10th and 90th percentiles, the midline marks the median, and the solid circles are outliers. The number of sampled watersheds per ecoregion is indicated above each box.

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This work would not be possible without the hard work and dedication of the field crew, including T. Guy, J. Wofford, S. Hendricks, J. Dhundale, T. Dietrich, K. Hood, S. Lampson, D. Leer, C. Lorion, C. Oyler, and N. Romero. This project was produced through the Cooperative Forest Ecosystem Research Program, with funding provided by the USGS Forest and Rangeland Ecosystem Science Center and the Oregon Department of Forestry.

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The Role of Barriers in the Abundance and Persistence of Coastal Cutthroat Trout in the Columbia River Gorge

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Extended Abstract.—We investigated the role of fish barriers for coastal cutthroat trout *Oncorhynchus clarkii clarkii* populations in streams within the Columbia River Gorge of the Pacific Northwest. We designed a study to test if cutthroat trout populations exhibited higher abundance when allopatric than when sympatric with rainbow trout (*O. mykiss*).

Our sampling was limited to 10 third order or smaller streams within the Columbia River basin between Bonneville and The Dalles dams in 2002-2003. This 73-km section of the river lies within the Columbia River Gorge where the river cuts through the Cascade Mountain range. Seven of the streams were within the Hood River watershed, two streams were within the White Salmon watershed, and one stream flowed directly into the Columbia River. We identified three classes of trout distributions in the 10 streams for our study: 1) those in which cutthroat trout were allopatric above and below a barrier (n = 4), 2) those in which cutthroat trout were allopatric above the barrier but sympatric with rainbow trout below the barrier (n = 3), and 3) those in which cutthroat trout and rainbow trout were sympatric above and below the barrier (n = 3).

We sampled two sections of each stream system, one section above a barrier and one section below the same barrier. These 20 sections of streams ranged from 79-812 m, but most (n = 17) were within +/- 25 m of being 100 m in length. We used backpack electrofishers to sample the fish. Cutthroat trout and *O. mykiss* (which we refer to as "rainbow trout", but included steelhead) were the dominant salmonids encountered in these streams. The only other salmonid species encountered included a single brook trout *Salvelinus fontinalis* in the lower section of stream I) and some (n = 14) age 0 Chinook salmon *O. tshawytscha* and coho salmon *O. kisutch* in the lower section of stream J.

Patterns in abundance expressed by age 1 and older cutthroat trout and rainbow trout were evident among the three classes of streams sampled (Figure 1). In streams that supported cutthroat trout as the only salmonid above and below a barrier (streams A-D), abundance was higher below the barrier in three out of four of the streams. In the three streams where allopatric populations of cutthroat trout occurred above the barrier and rainbow trout were part of the assemblage below the barrier (streams E-G), all streams had a decrease in abundance of cutthroat trout below the barrier. In the three streams with sympatric populations of cutthroat trout and rainbow trout above and below the barriers (streams H-J), the below barrier populations had either a greater increase or lesser decrease in abundance of rainbow trout relative to cutthroat trout.

The pattern of abundance observed suggests that isolated cutthroat trout populations are vulnerable to actions that introduce or promote rainbow trout, such as through hatchery fish introductions and passage improvement projects. On the other hand, isolation has been shown to increase the extirpation risk of coastal cutthroat trout (Wofford et al. 2005) and some interior cutthroat trout species (Dunham et al. 1997; Kruse et al. 2001; Novinger and Rahel 2003) through loss of genetic variability, habitat fragmentation, and catastrophic events. While removal of artificial migration barriers has become a common strategy in watershed restoration plans throughout the range of

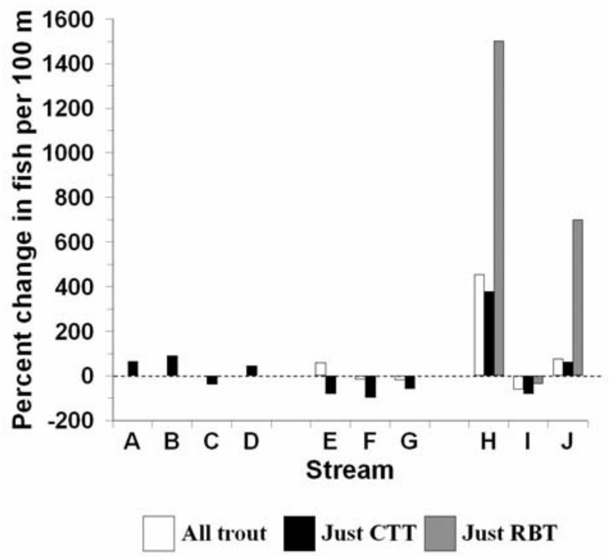

FIGURE 1.—Percent change in number of salmonids per 100 m when comparing counts below barriers to counts above barriers in 10 Columbia Gorge streams. Streams A-D had an allopatric population of cutthroat trout above and below the barriers. Streams E-G had an allopatric population of cutthroat trout above the barrier, but rainbow trout were part of the assemblage below the barrier. Streams H-J had sympatric populations of cutthroat trout and rainbow trout both above and below the barriers.

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coastal cutthroat trout, human-assisted isolation has been implemented as a conservation strategy for interior subspecies of cutthroat trout (Thompson and Rahel 1998; Kruse et al. 2001; Novinger and Rahel 2003). Before barrier removal projects are implemented to improve upstream passage and connectivity for fish, stream restoration planners should consider the potential for decreasing coastal cutthroat trout populations, especially in areas where introduced rainbow trout exist downstream.

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Emigration Rates of Coastal Cutthroat Trout in Headwater Catchments of Western Oregon

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Extended Abstract.—Coastal cutthroat trout are commonly found throughout western Oregon, but information on fluvial life history strategies has most often been collected from the portions of streams where anadromous salmonids are present. A number of different behaviors have been documented for coastal cutthroat trout in these areas, but much less is known about coastal cutthroat trout that reside in small headwater streams, where they are often the only salmonid present. These populations can be viewed as two groups: those isolated physically by an impassable barrier to upstream movement, and those isolated by behavioral mechanisms (i.e., migratory fish that have access but do not move upstream).

Here we assess downstream movement of coastal cutthroat trout across a gradient of stream channel connectivity in three catchments (858 to1,270 ha) located in the Umpqua River basin of western Oregon. Camp Creek is located upstream from a natural barrier to upstream fish movement, and cutthroat trout was the only salmonid present. Coastal cutthroat trout are behaviorally isolated in the headwaters of North and South Fork Hinkle Creek but occurred sympatrically with steelhead in the lower portions of both catchments.

Fish movement was assessed using 23 mm, half-duplex passive integrated transponder (PIT) tags and a network of fixed-station antennae (Zydlewski et al. 2001) located at the stream-segment (Frissell et al. 1986) scale (Figure 1). The entire fish-bearing portion of each catchment was subjected to single-pass electrofishing (Bateman et al. 2005) during the summer when discharge was at a minimum. All captured cutthroat trout ≥100 mm (fork length) were implanted with a PIT tag.

Because fixed-station antennae could differentiate upstream and downstream movement, it was possible to classify movement in the study catchments as local (i.e., limited spatially or temporally) or extensive (i.e., long-distance movements over extended periods). Downstream antennas were used to evaluate the relative proportion of fish detected from different portions of the study catchments; however, these antennas occurred in larger channels and detection efficiencies were correspondingly lower. Therefore, it was difficult to identify emigrants based solely on spatial criteria, and a temporal criterion was used for classification (i.e., emigrants moved downstream and did not return within 30 d).

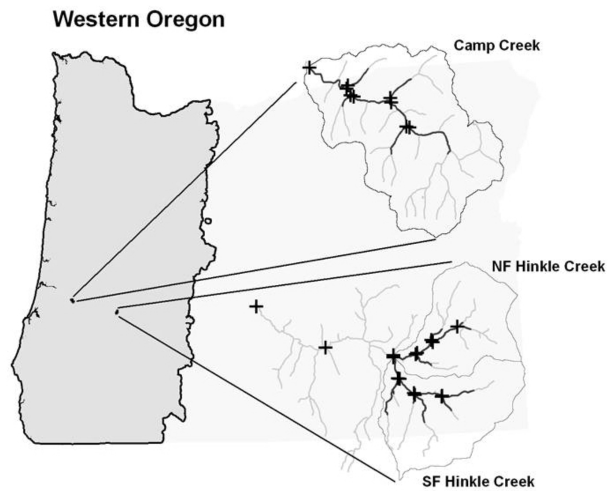

FIGURE 1.—Two fixed-station antennae are located at the junction of each fish bearing tributary and its main stem. One antenna spans the tributary while the other spans the main stem just upstream from the tributary-main stem junction. Heavy stream line corresponds to coastal cutthroat trout distribution in both watersheds. Additional antennae located downstream from the study watersheds are also depicted.

Sampling began in North Fork and South Fork of Hinkle Creek in 2002. A total of 741 coastal cutthroat trout were PIT tagged in North Fork Hinkle Creek; yearly totals were 264, 280, and 197 for years 2002, 2003, and 2004, respectively. In South Fork Hinkle Creek, 993 individuals were tagged with yearly totals of 324, 275, and 394 for 2002, 2003, and 2004, respectively. Sampling in Camp Creek began in 2003. A total of 1,127 fish received PIT tags (538 in 2003 and 589 in 2004).

In both forks of Hinkle Creek, the proportion of downstream migrants increased sharply in segments with drainage areas >450 ha (i.e., corresponding to the most downstream main stem segment in each catchment). These segments also correspond closely with the distribution of juvenile steelhead in those catchments. In Camp Creek—physically isolated by a barrier waterfall—the proportion

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(and number) of emigrants did not change in relation to catchment area (i.e., in a downstream direction). Furthermore, patterns of emigration throughout the watershed were similar to those observed in the upper main stem and tributaries in both forks of Hinkle Creek (i.e., where coastal cutthroat trout are behaviorally isolated from anadromous species). Although the ultimate fate of emigrants in this study was not determined, results suggest that the capacity of headwater populations of coastal cutthroat trout to supplement downstream amphidromous populations may be limited where they are physically or behaviorally isolated from anadromous salmonids.

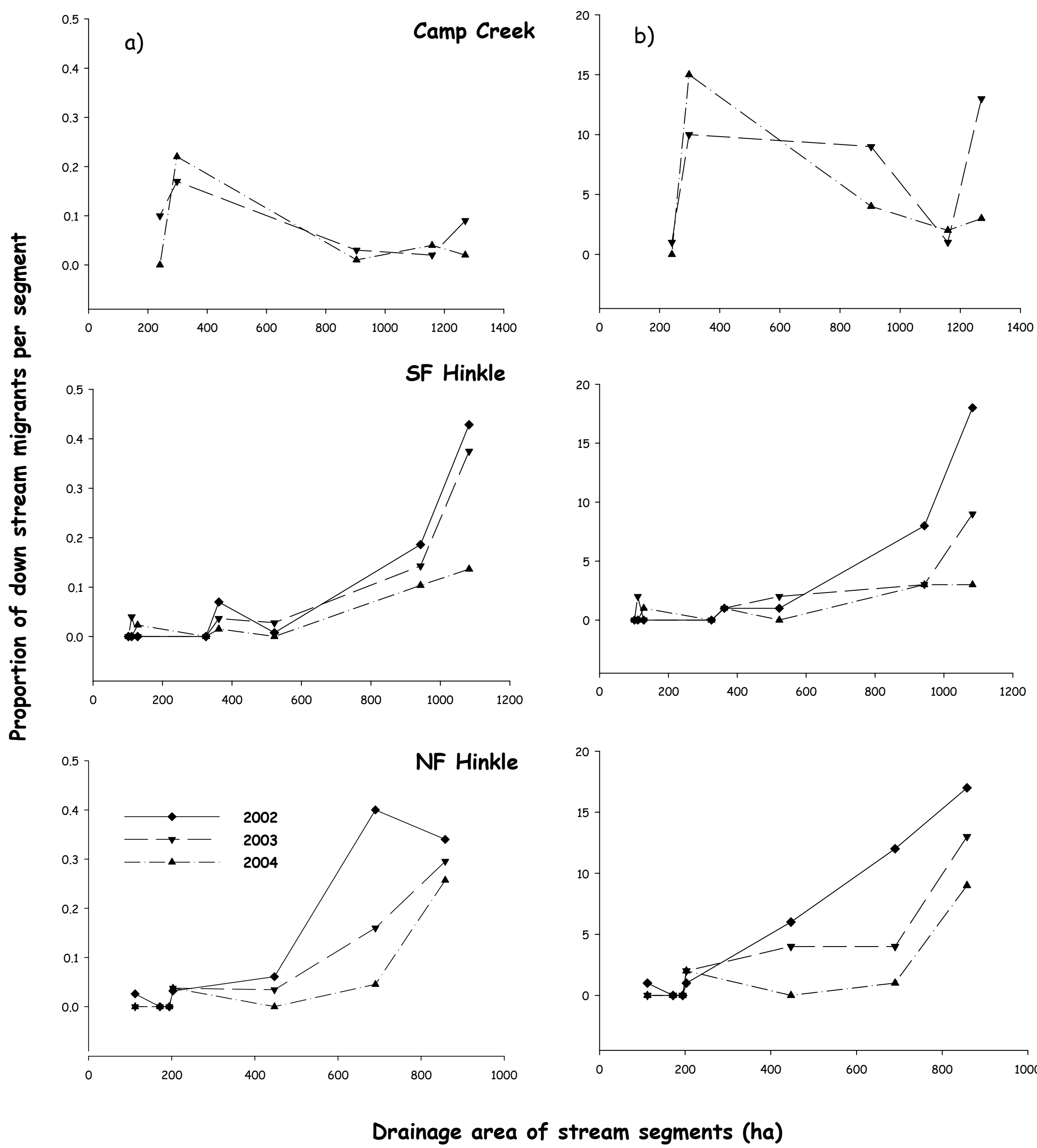

FIGURE 2.—Proportion (a) and number (b) of tagged coastal cutthroat trout classified as downstream migrants in Camp Creek, North Fork Hinkle Creek, and South Fork Hinkle Creek. Symbol location along the x-axis corresponds to the total drainage upstream from a segment pour point. In both forks of Hinkle Creek, the first four symbols correspond to the four main stem stream segments from downstream to upstream; remaining symbols correspond to the three fish-bearing tributaries in each watershed. Camp Creek has three main stem segments (progressing upstream) and two tributaries.

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Seaward Migration of Coastal Cutthroat Trout *Oncorhynchus clarkii clarkii* from Four Tributaries of the Columbia River

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Abstract.—Timing and speed of juvenile coastal cutthroat trout *Oncorhynchus clarkii clarkii* migration was investigated using both active and passive radio and acoustic telemetry in the spring of 2002 and 2003. Actively migrating cutthroat trout in Germany, Abernathy, and Mill creeks and the Chinook River (tributaries of the lower Columbia River: river km 91, 88, 87, and 6, respectively) were captured by screw trap, implanted with either a radio transmitter or acoustic pinger, and monitored. The data suggest that migrant cutthroat trout leave the tributaries and make rapid, directed movements into seawater, often within five days of entry into the main stem environment. In the spring of 2003, the telemetry effort emphasized active tracking to gather specific high resolution movement data on cutthroat trout leaving the three creeks. Directed downstream movement was correlated with outgoing tidal flows and was greatest just after dawn and dusk. Because of life history similarities, anthropogenic activities and management actions in the main stem Columbia River that influence salmon smolts are likely to affect anadromous coastal cutthroat trout smolts in a parallel fashion.

Coastal cutthroat trout *Oncorhynchus clarkii clarkii* are found on the West Coast of North America from Alaska to northern California (Behnke, 1992; Gerstung 1997; Schmidt 1997). These fish exhibit tremendous diversity in life history strategies both within a watershed and throughout their range (Armstrong 1971; Giger 1972; Jones 1978; Johnston 1982; Trotter 1989; Northcote1997). Some individuals complete their life history within their natal stream yet sympatric individuals may undertake active downstream migrations (June 1981; Johnston 1982; Northcote 1997).

There are no clear morphological distinctions between juvenile cutthroat trout that are resident or migratory (Tomasson 1978; Fuss 1982). Migratory cutthroat trout generally emigrate from natal waters at age 2 or 3 in the spring (Giger 1972; Sumner 1972; Trotter 1989). Age 2 migrants predominate in the lower Columbia River watershed of Oregon and Washington (Johnston 1982; Trotter 1989). Seaward migration at the juvenile stage affords periods of high growth in the ocean environment (Gross 1988). This migration also requires the development and maintenance of appropriate osmotic tolerances necessary for survival.

Migratory cutthroat trout have been characterized as weakly anadromous (Northcote 1997) and reportedly select lower salinities in the estuary (Loch and Miller 1988). While cutthroat trout have been caught offshore, conventional wisdom prescribes that migrating cutthroat trout do not venture far from the estuary if at all (Tipping 1981; Pearcy 1997). In many systems, these trout are thought to make more extensive use of the main stem river and estuary habitats (as both juveniles and adults) rather than offshore environments. Though migrating juveniles are characterized as "smolts" (Trotter 1997), it is unclear whether juveniles undergo a parr-smolt transformation process similar to those observed in other salmonids (Hoar 1976; McCormick and Saunders 1987). Shifts in migratory behavior and physiology (e.g., elevated gill Na^+,K^+-ATPase activity) associated with smolting are not well documented in coastal cutthroat trout.

Many migratory populations of coastal cutthroat trout have declined in recent years, including those of the Columbia River (Nehlsen et al. 1991; Hooton 1997; Leider 1997). Coastal cutthroat trout have been impacted by anthropogenic practices such as logging (Holtby 1987; Johnson et al. 1999) over fishing (Giger 1972; Ricker 1981; Gresswell and Harding 1997), and artificial propagation (Campton and Utter 1987; Flagg et al. 1995). In addition, coastal cutthroat trout are thought to use estuaries more extensively than other Pacific salmonids, particularly during certain stages in their life history. This may make them more vulnerable to changes in estuarine conditions than other Pacific salmonids (Giger 1972; Pearcy 1997).

The objective of this study was to determine the movement patterns of coastal cutthroat trout entering the Columbia River from four tributaries known to have migratory populations and to characterize the degree to which these fish used the main stem and estuary of the Columbia River. Additionally, gill biopsies of study fish were used to measure Na^+,K^+-ATPase activity as an indirect indicator of smolt development.

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Methods

Study area.—Cutthroat trout from four tributaries to the Columbia River, Germany Creek (river kilometer [rkm] 91), Abernathy Creek (rkm 88), Mill Creek (rkm 87) and the Chinook River (rkm 6), were studied in 2002 and 2003 using radio and acoustic telemetry (Figure 1). The Chinook River is a tidal system that is regulated by a tide gate at its confluence with the Columbia River. This system experiences salinity fluctuations from 0 ppt to full strength seawater and empties into an estuarine mixing zone. Germany, Mill, and Abernathy creeks are third order systems that experience tidal fluctuations at their confluences with the Columbia River, but do not experience salinity fluctuations.

Capture of cutthroat trout.—In 2002 and 2003, juvenile cutthroat trout were captured at the mouths of Germany, Abernathy, and Mill creeks in 1.5 m screw traps (operated by the Washington Department of Fish and Wildlife [WDFW]) and in a screw trap (2.4 m) at the mouth of the Chinook River (operated by Sea Resources, Incorporated, Chinook, Washington). In 2002, cutthroat trout implanted with radio tags were captured from May 5 through May 30, while those implanted with acoustic tags were captured from May 12 through May 21. In 2003, cutthroat trout receiving radio tags were captured from May 9 to June 25, while those receiving acoustic tags were captured from May 17 through June 11. Water temperature ranges observed during tagging are shown in Table 1.

Tagging.—Fish were held in the screw traps a maximum of 24 h prior to tagging. Cutthroat trout were anesthetized with a buffered solution of MS-222 (100 $mg \cdot l^{-1}$, $NaCO_3$ buffered 0.2 mmol $NaHCO_3$, pH = 7.0) in 4 L of water from the area of capture, then measured for length and weight. Also, a non-lethal gill biopsy taken for subsequent analysis of Na^+,K^+-ATPase activity. Two to four filaments from the first gill arch on the left side were removed with iris scissors above the septum (which avoids major vascularization) and handled as described below. Fish were then implanted with an acoustic (Vemco V8SC-6L-R256 coded pingers; 26 mm x 9 mm diameter; 3.1 g; 69 kHz, 20-60 sec pulse rate; estimated minimum tag life of 68 d) or radio (Lotek Nano-tags NTC-4-2S; 1.65 g; 148-150 MHz; 3 sec pulse rate; estimated minimum life of 25 d) tag.

Fish larger than 37 g were selected for implantation of acoustic tags (this excluded less than 10% of collected fish). The skin on the ventral surface was swabbed with Betadine (10% povidone-iodine) and an incision made in the peritoneal wall with a sterilized scalpel tip. The tag was inserted through the incision which was then closed with three sutures (Coated Vicryl 5-0 braided absorbable suture) and swabbed with Betadine. Typically the wound heals within 7-10 d (depending on temperature) and sutures dissolve within 10-14 d (Zydlewski, unpublished data).

Fish greater than 30 g were selected for radio tagging (excluding only a few fish). Radio tags were inserted into the peritoneal cavity in the same fashion as acoustic tags

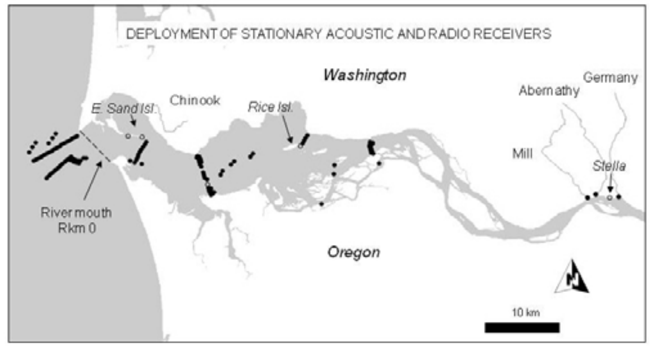

FIGURE 1.—Deployment of stationary acoustic (solid circle) and radio receivers (open circle) in the Columbia River in 2003. The four tributaries studied (Germany Creek, Mill Creek, Abernathy Creek, and Chinook River) are indicated.

TABLE 1.—Mean fork lengths (cm), weights (g), and condition factors (100 • g • cm^{-3}) of coastal cutthroat trout implanted with acoustic and radio tags in 2002 and 2003. Values are presented ± 1SD. There are no statistical differences between groups. Ranges of water temperatures at collections for each tag type within each year are given.

Year	Tag type	River (n)	Length (cm)	Weight (g)	CF (100 •g •cm^{-3})
2002	Acoustic	GERM (1)	20.4	72.2	0.85
	(9-11 °C)	ABER (12)	19.2±1.4	62.0±15.7	0.86±0.04
		MILL (10)	18.7±1.3	55.5±12.5	0.83±0.04
		CHIN (26)	20.0±2.7	72.8±33.3	0.86±0.06
	Radio	GERM (21)	18.8±1.5	60.6±15.8	0.89±0.06
	(7-12 °C)	ABER (32)	18.8±2.1	61.4±22.3	0.89±0.06
		MILL (43)	18.4±1.4	53.7±13.2	0.85±0.06
2003	Acoustic	GERM (15)	17.9±0.9	48.4±7.1	0.84±0.05
	(7-15 °C)	ABER (9)	18.4±1.0	56.8±12.3	0.91±0.08
		MILL (15)	19.4±1.6	66.6±16.9	0.90±0.09
	Radio	GERM (8)	18.5±1.6	56.1±13.5	0.87±0.06
	(13-18 °C)	ABER (4)	17.3±1.2	43.4±10.1	0.83±0.05
		MILL (10)	18.5±1.2	56.8±13.0	0.85±0.07
		ALL (206)	18.8+1.8	59.4+19.6	0.87+0.06

except for accommodation of an external antenna which was threaded through the body cavity with a sterile 18 gauge, 20 cm long deflected septum needle. The needle was then pushed through the lateral wall of the cavity approximately 1 cm anterior to the anus on the right side. The area around the antenna exit was swabbed with Betadine and the initial incision closed with two sutures. Cutthroat trout receiving either tag were allowed to recover for 10-15 min prior to release downstream of the trapping sites (within 50 m) at the closest area away from rapid flow.

Radio tracking.—In 2002 and 2003, movements of tagged fish were monitored passively via five stationary radio telemetry locations. The locations of the receivers (Lotek SRX-400 receiver/dataloggers; as indicated on Figure 1 for 2003) varied slightly between years; however areas of coverage were consistent. Receivers were located at Stella (Washington), Rice Island, and East Sand Island, and Astoria Bridge. These units were equipped with yagi antenna oriented towards the main channel of the Columbia River and were downloaded multiple times through the study. Observations were considered to be duplicates if occurring at the same point within a 10 min interval. The time of duplicate observations were averaged for analysis.

In both 2002 and 2003, active tracking was performed by both boat (minor component in 2002) and automobile. The areas of initial capture and release were generally checked at 24 h intervals to determine if individuals remained near the tag and release site. In 2003, greater emphasis was put on active tracking by boat. Subsequent to tagging, an individual observed leaving the tributary was generally tracked until it could not be relocated. Location of tagged fish was determined using two boat-mounted yagi antennas and a hand-held yagi antenna with Lotek SRX-400 receivers. Tests with drones verified the ability to confidently localize tag positions to within 50 m. Twenty-four hour-a-day tracking was accomplished in two shifts, changing approximately at 0600 and 1800 Pacific Time

Acoustic tracking.—In 2002 and 2003, movements of acoustic-tagged cutthroat trout were monitored passively via stationary acoustic receivers. The locations of the receivers (Vemco VR2) are indicated on Figure 1 (for 2003). As with the radio telemetry receiver locations, deployment of the acoustic receiver array varied slightly between 2002 and 2003 though areas of coverage were consistent between years with 50-60 receivers deployed at any one time. Because these units were moored using a buoy and anchor system, positions changed within year as well as when units were retrieved and redeployed. Receivers were deployed near the surface as described in Clements et al. (2005). Notable differences between 2002 and 2003 were the deployment of three receivers near Sand and East Sand Islands to cover movements of fish from the Chinook River in 2002 (not shown in Figure 1) and the addition of three receivers deployed in the mouths of Germany, Abernathy, and Mill creeks in 2003. As with radio telemetry data (above), observations were considered to be duplicate if occurring at the same point within a 10 min interval. The time of duplicate observations were averaged for analysis.

There was no active tracking of acoustic tagged fish in 2002, but in 2003 efforts were made to track by boat using a directional towed receiver (Vemco VR 28). This effort was largely unsuccessful due to boat equipment failure, producing a single track. The tracking protocol was the same as that described for active radio tracking above.

Gill Na^+,K^+-ATPase activity determination.—Gill Na^+,K^+-ATPase activity was determined using the microplate method described by McCormick (1993) as validated for cutthroat trout (Zydlewski, unpublished). Briefly, gill tissue was removed and immersed in 100 µL of ice cold SEI buffer (150 mM sucrose, 10 mM EDTA, 50 mM imidazole; pH = 7.3) and stored at -80 °C. Gill samples were thawed immediately prior to assay and homogenized in 200 µL of 0.1 % sodium deoxycholate in SEI buffer. The homogenate was centrifuged to remove insoluble material. Specific activity of Na^+,K^+-ATPase was determined in duplicate by measuring ATPase activity with and without 0.5 M ouabain in a solution containing 4 U/mL lactate dehydrogenase, 5 U/mL pyruvate kinase, 2.8 mM phosphoenolpyruvate, 0.7 mM adenosine triphosphate (ATP), 0.22 mM nicotinamide adenine dinucleotide (reduced)(NADH), 50 mM imidizole, 45 mM NaCl, 2.5 mM $MgCl_2$, 10 mM KCl; pH = 7.5. Kinetic analysis of ATP hydrolysis was measured at 25 °C by monitoring [NADH] at 340 nm using a 96-well plate reader. Protein concentration of the gill homogenate was determined in triplicate using the bicinchoninic acid (BCA) method (Smith et al. 1985; BCA Protein kit, Pierce, Rockford, IL, USA) using bovine serum albumen as standard. Activity of gill Na^+,K^+-ATPase is expressed as µmol ADP • mg protein^{-1} • h^{-1}.

Statistics and calculations.—Significance of statistical analysis is reported at the $p < 0.05$ level. Two-way ANOVA was used to analyze length, weight, condition factor (Table 1), and gill Na^+,K^+-ATPase activity (Table 2) using year and tributary (Germany, Mill, and Abernathy creeks) as factors. Significance of factors or of interactions was followed by analysis within each factor. One-way ANOVAs were used for comparison within each year where significance was found. An inclusive one-way ANOVA was also run for all groups to include unbalanced groups. In all analyses, significance with a one-way ANOVA was followed by a Tukey's post-hoc test. Intervals about a mean are reported as ± one standard error (SE) or standard deviation (SD) as indicated.

Calculation of time to reach the Columbia River mouth (Table 2) was based on first observation of a tagged individual at or downstream of river kilometer 20 (this was the lowest point in the system where radio tags could be reliably detected due to salinity). Two speed calculations are shown using initial time from release after tagging and last observation of tagged individual at (or upstream) of rkm 85, respectively (to allow for variation in recovery from tagging and resumption of migration). Significance within these data using Kruskal-Wallis (using either tributary or year as factors) was followed by Mann-Whitney U tests for multiple comparisons. Individual values of gill Na^+,K^+-

TABLE 2.—Mean gill Na^+,K^+-ATPase ± 1 SE (expressed as µmol ADP • mg protein^{-1} • h^{-1}) and median speed of tagged cutthroat trout from of time of tagging and time of departure from tagging area, respectively, to first detection at rkm 20 or lower. There are no statistical differences between mean gill Na^+,K^+-ATPase activities. Significance between medians for 2002 and 2003 by Mann-Whitney *U* test is indicated by "*".

Year	Source	Gill Na^+, K^+-ATPase (:ADP • mg prot^{-1} • h^{-1})	Days to reach Columbia River mouth			
			From tagging		From departure	
			Medium	Range	Medium	Range
2002	GERM	3.4 ± 0.18 (17)	6.1	2.3 – 18.9 (8)	5.6	1.7 – 17.8 (8)
	ABER	3.7 ± 0.25 (32)	9.4	2.2 – 31.8 (20)	6.1	1.0 – 31.8 (20)
	MILL	3.5 ± 0.21 (52)	5.8	2.2 – 27.7 (23)	5.5	1.0 – 27.7 (23)
	CHIN	3.7 ± 0.38 (23)	na	na	na	na
	ALL	*3.6 ± 0.13 (124)*	*6.6*	*2.2 – 31.8 (51)*	*5.5*	*1.0 – 31.8 (51)*
2003	GERM	2.8 ± 0.24 (22)	6.2	1.1 – 37.1 (8)	2.4	1.0 – 33.9 (8)
	ABER	3.5 ± 0.53 (14)	4.5	2.0 – 7.0 (6)	3.9	2.0 – 6.7 (6)
	MILL	3.5 ± 0.30 (23)	3.5	2.3 – 25.0 (10)	3.2	2.0 – 25.0 (10)
	ALL	*3.2 ± 0.19 (59)*	*4.3*	*1.1 – 37.1 (24)*	*3.2*	*1.0 – 33.9 (24)*

ATPase were compared with individual speed to reach the river mouth using a linear regression.

To consider patterns of directed movement in the context of tidal and diel cycle, observations from active radio tracking in 2003 were analyzed. Of those individuals, only those that had tracks that lasted more than 48 h and met the criteria described below were considered. "Directed movement" is defined as a movement parallel to the Columbia River shipping channel (as demarked by the US Coast Guard buoy system), with downstream movements being defined as positive and upstream movements being defined as negative.

Speeds for these analyses were calculated from position data collected at intervals of less than one hour, but greater than 10 min. Exclusion of observations at intervals less that 10 min was necessary to prevent erroneously high speed calculations based on fluctuations in Global Positioning System (GPS) position measurements. Speeds greater than 11 km/h were rejected as this represented the greatest directly observed speed during tracking efforts. Time used in calculations described below was an average of the two observed positions.

Tidal reference was determined using tidal predictions of National Oceanic and Atmospheric Administration (NOAA) from Skamokawa, Washington (rkm 54, 46° 16 N 123° 27 W) which represented an approximate midpoint in the range of observations from rkm 20 to rkm 91. Tides can differ through this reach by approximately 2 h based on data from Astoria (-1 h, rkm 20; 46° 12 N 123° 46 W) and Stella, Washington (+1 h, rkm 91, 46° 11' N 123° 7' W). Data were not interpolated for the fish location. Based on tidal predictions, a tidal cycle was defined as a continuum from 0 to 1, with 0 defined as high tide and 0.5 defined as low tide (regardless of whether the cycle represented a spring or neep tide).

Similarly, data for the diel cycle experienced by moving fish was based on prediction for Skamokawa, Washington. To consider diel cycles under a changing day length, the photoperiod was defined to a range of values between 0 and 1, with sunrise being 0 and 0.5 being defined as sunset. Because the photoperiod was changing (14.2 h light on May 1 to 15.4 h on June 30) when tracking occurred, the absolute time assigned to a value of "0" and "0.5" changed through the season but continued to represent sunrise and sunset.

For both tidal and diel representations, calculated directed speeds of a fish were assigned values in the tidal or diel cycle continuum. (For example a fish assigned 0.1 and 0.3 for diel and tidal cycles respectively would have been observed in the early morning on an outgoing tide). Individuals that did not have more than ten values in each of ten bins were excluded from analysis. For each individual and each bin the 25th, 50th, and 75th percentiles were calculated. Averages of these values for all fish are presented in Figure 2. Differences in averages of the 50th percentile were analyzed via one-way ANOVA (using tidal or diel bins as a grouping variable). Significance with one-way ANOVA analysis was followed by a Tukey's post-hoc test.

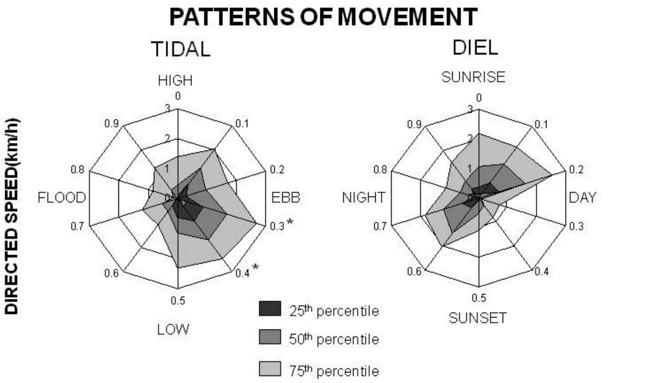

FIGURE 2.—Downstream movement patterns of coastal cutthroat trout implanted with radio tags in 2003 and actively tracked by boat. The radial graphs represent movements with relation to tidal cycle and diel cycle. For tidal cycle "0" is defined as high tide, 0.5 as low tide. For diel cycle "0" is defined as sunrise and "0.5" as sunset. Each polygon represents the average percentile (25^{th}, 50^{th}, and 75^{th}) of 12 fish for which there was adequate data. (See materials and methods). Asterisks indicate significance between 50^{th} percentile and lowest values.

Results

Downstream movement.—In 2002, 96 cutthroat trout were tagged with radio transmitters and released in Germany, Abernathy, and Mill creeks. From these fish, 91 tracks were collected and 5 fish were not observed after release. A total of 31,223 observations were made with 433 active and 30,790 passive observations. In 2003, 22 cutthroat trout were tagged with radio transmitters and released in Germany, Abernathy, and Mill creeks. From these fish, 17 tracks were collected and 5 fish were not observed after release. Some 9,072 observations were recorded—3,234 active and 5,838 passive.

In both years, the majority of fish displayed directed downstream movement (55/91 in 2002 and 17/22 in 2003; Figure 3). No fish was observed moving more that 3 km upstream after entry into the main stem of the Columbia River. Of those fish displaying downstream movement, the vast majority were subsequently observed at rkm 20 or lower in the system (49/55 in 2002 and 13/17 in 2003).

In 2002, 49 cutthroat trout were tagged with acoustic transmitters, 23 from Germany, Abernathy, and Mill creeks and 26 from the Chinook River. From these fish, 7,189 passive observations were collected and 32 tracks were collected. Seventeen fish were not observed after release. In 2003, 39 cutthroat trout were tagged with acoustic transmitters in Germany, Abernathy, and Mill creeks. From these fish, 13,022 observations were made, 280 during active tracking and 12,742 passive observations. Seven fish were not observed after release.

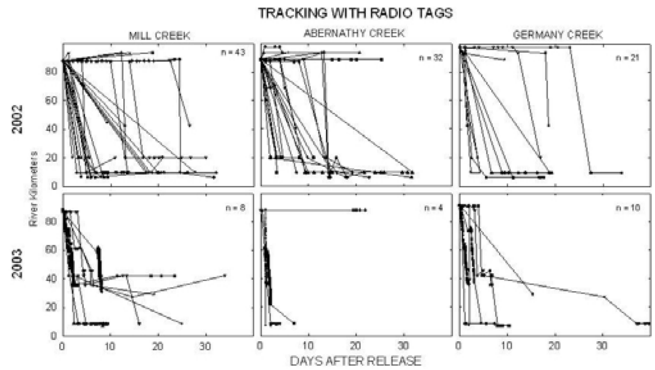

FIGURE 3.—Downstream movement data for coastal cutthroat trout implanted with radio tags in the mouths of up-river tributaries (Germany, Abernathy, and Mill creeks) of the Columbia River. The number of trout tagged for each tributary and year is indicated in the upper right corners of the graphs.

As with the radio telemetry, the acoustic tracks in 2002 and 2003 demonstrated rapid and directed downstream movement from Germany, Abernathy, and Mill creeks towards the mouth of the Columbia River (17/23 in 2002 and 12/39 in 2003; Figure 4). More than half of the fish observed to move downstream were observed at or in the ocean (rkm 0; 10/17 in 2002 and 7/12 in 2003). Similarly, in the Chinook River (2002) cutthroat trout rapidly moved downstream (14/26) and left the Columbia River (13/14; Figure 5).

For cutthroat trout leaving Germany, Abernathy, and Mill creeks in 2002, individuals took a median of 6.6 d to reach the mouth of the Columbia River from the time of tagging and a median of 5.5 d once movement had been initiated. In 2003, downstream movement was more rapid, moving to the mouth at median times of 4.3 and 3.2 d (p =

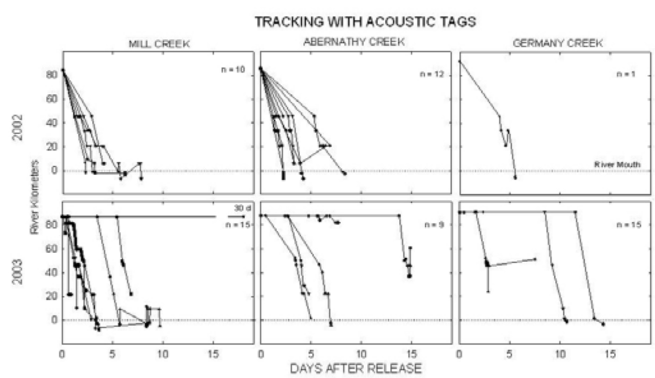

FIGURE 4.—Downstream movement data for coastal cutthroat trout implanted with acoustic tags in the mouths of upriver tributaries (Germany, Abernathy, and Mill creeks) of the Columbia River. The mouth of the Columbia River (rkm 0) is indicated with a dotted horizontal line. The number of trout tagged for each tributary and year is indicated in the upper right corners of the graphs.

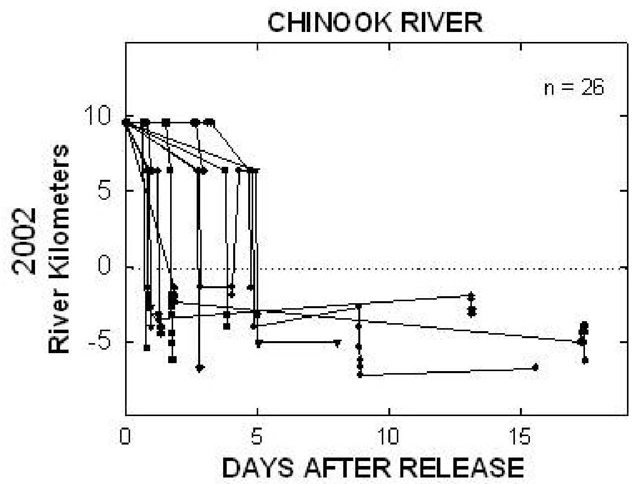

FIGURE 5.—Downstream movement data for coastal cutthroat trout implanted with acoustic tags in the mouth of the Chinook River. The mouth of the Columbia River (rkm 0) is indicated with a dotted horizontal line. The number of trout tagged for each tributary and year is indicated in the upper right corners of the graphs.

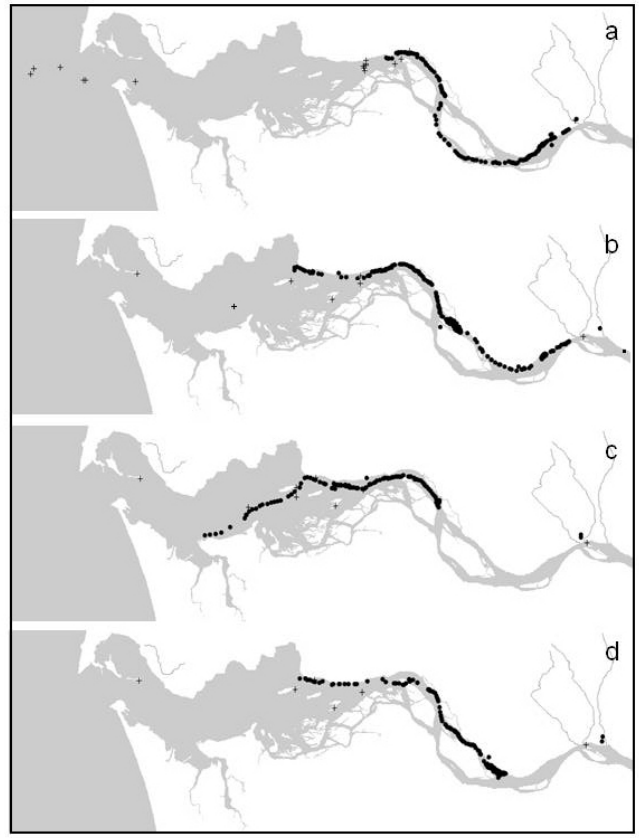

FIGURE 6.—Detailed tracks of cutthroat trout implanted with acoustic (a) and radio (b,c, d) tags in 2003. These representative tracks show both active and passive data ("•" and "+", respectively).

0.07 and p = 0.01, respectively). Several individuals did not initiate movement for as long as 23 d, followed by directed downstream movement.

Maps depicting the active tracks of four cutthroat trout are shown in Figure 6. Individual tracks lasted up to 6 d. Cutthroat trout were observed traveling at rates greater than 10 km/h. Conversely, tracks of fish were at times punctuated with long lulls in activity, often associated with changes in the tidal cycle. Cutthroat often traveled near shore; however several individuals were observed crossing the shipping channel, but also traveling in the channel for multiple hours.

Gill Na^+,K^+-ATPase activity from cutthroat trout did not differ between years or tributaries (Table 2). Average activities in 2002 and 2003 were 3.6 and 3.2 µmol ADP • mg protein^{-1} • h^{-1}, respectively. Gill Na^+,K^+-ATPase activity was positively correlated with the time it took successful individuals to reach the mouth of the Columbia River, but the relationship was extremely weak (R^2 = 0.01, p = 0.002, n = 64). When cutthroat trout that delayed the initiation of movement by 10 or more days are excluded, the relationship is marginally strengthened (R^2 = 0.09, p = 0.0005, n = 44).

Downstream movement patterns indicate an association of migration with tidal cycle and suggest an influence of diel cycle (Figure 2). These data represent the 12 fish that had sufficient observations to fit the criteria described above (see Materials and Methods) with a median of 137 observations (range 126-1561). Averages of these percentiles are represented in the figure. Tidal cycle influenced directed downstream speed (one-way ANOVA; p = 0.006); cutthroat trout exhibited greater rates of movement concurrent with the ebb tide and less directional movement during the flood tide. There was a marginally significant effect of diel cycle on downstream speed (one-way ANOVA, p = 0.06), though no paired comparisons were significant. The data suggest greater movements just after sunrise and after sunset independent of tidal cycle.

Lengths, weights, and condition factors of tagged fish did not differ between tributaries or between years (Table 1). Average condition factor for all groups was 0.91 or less. The timing of tagging differed between years, May 5 to May 30 (mean of May 13) for 2002; May 9 to June 25 (mean of June 3) for 2003.

Discussion

Cutthroat trout tagged with both radio and acoustic tags in this study displayed directed downstream movement towards the ocean consistent with smolting behavior (Figures 3, 4, 5). Fish traveling from Mill, Abernathy, and Germany creeks to the mouth of the Columbia River exhibited travel speeds of 6.6 and 4.3 d from time of tagging and resumption of migration, respectively (Table 2). Many individuals traveled the distance in 1-2 d. Speeds were consistent with the movements of cutthroat trout tagged with passive integrated transponder (PIT) tags in these creeks and "recaptured" in the lower Columbia River (Zydlewski, unpublished data) using a PIT trawl (Ledgerwood et al. 2004). These speeds are also similar to those observed in other anadromous salmonid smolts in the Columbia River and other rivers (Schreck et al. 2002).

The calculated speeds of movement from the time of departure of the tagging area to the mouth of the Columbia River differed between 2002 and 2003 (Table 2). In 2003, travel speed of migrants was nearly two-fold lower than that observed in 2002. A possible explanation for this difference is the timing of tagging differed between years. In 2002 migrants were tagged from May 5 to May 30 while in 2003 migrants were tagged from May 9 through to June 25. Based on flow data from the Columbia River (USGS data) fish in 2003 were tagged during a period of moderately higher flows than those in 2002. In addition to annual variations in river flow conditions, migrants experienced higher river temperatures in 2003, perhaps influencing migratory behaviors.

While most observations indicate a pattern of directed seaward migration, there are a number of fish for which there is either no data subsequent to tagging or only observations at or near the point of release. These fish could have lost their tag, not been detected by the receivers, not displayed migratory behavior, or been mortalities. Tagging is unlikely to be a direct cause of mortality. Immediate and delayed tagging mortality was rare (<1 %) in controlled tagging studies (Zydlewski, unpublished data). Likewise, tag loss is rare during the life of the tag. However, it can be assumed that surgical tagging is likely to affect short term performance (e.g. swimming speed; Adams, 1998) and may contribute to vulnerability to predation. While acoustic tags cannot be located out of water, six radio tags were recovered on the islands of the lower Columbia River (Rice and East Sand Islands; Figure 1), which harbor nesting colonies of Caspian terns *Sterna caspia* and double crested cormorants *Phalacrocorax auritus*. The birds inhabiting these colonies are known to impact salmonid smolt numbers in the Columbia River (Collis et al. 2001).

A minority of tagged fish may have not been migrating seaward when tagged; their capture could simply have been a result of local movements. For a small number of fish, the last observation was in the creek where they were tagged. In several cases, the fact that the fish was alive subsequent to remaining near the tag site was confirmed with electrofishing (one fish in 2003) and recapture of tagged fish in the rotary screw trap (four recaptures in 2002). In at least five cases, tagged fish entering the Columbia River traveled into the mouths of the neighboring creeks; two of the five were eventually observed at the mouth of the Columbia River. The possibility remains, however, that tagged fish were active migrants that ceased migratory behavior, possibly as a result of tagging.

Data from acoustic telemetry suggests that fish tagged in Mill, Abernathy, and Germany creeks and reaching the mouth of the Columbia River tended to exit the river mouth and move into the plume (Figure 4 and Figure 6a). At least three individuals were observed remaining in the area of the river mouth for 3-5 d before their last observation, apparently moving with the tide. This pattern appears to be consistent with the behaviors of juveniles exiting the Chinook River (rkm 6; Figure 5).

Once exiting the mouth of the Columbia River, the evidence suggests that the migrants leave the area of the river plume in the vicinity of the ocean array receivers. One tagged fish (from Abernathy Creek) was observed to have left the immediate area of the Columbia River mouth and traveled 65 km south in two weeks, near the Nehalem River mouth on the Oregon coast (where an unrelated acoustic tracking study was underway). This movement is consistent with observations that coastal cutthroat trout do not venture far offshore. Tipping (1981) surmised that coastal cutthroat trout from the Cowlitz River may not go far from the estuary of the Columbia River. Similarly the highest numbers of coastal cutthroat trout are caught from 10-45 km from the coast of Oregon and Washington (Johnston 1982). A relatively short sojourn to sea before retuning in the fall has been hypothesized to result in relatively high survival of returns (some 40% higher than other salmonids; Giger 1972).

The observed directed seaward movement described here differs from some observations where juvenile cutthroat trout evidently make greater use of the estuaries (Tomasson 1978; Trotter 1997; Lisa Krentz, Oregon Department of Fish and Wildlife, unpublished data). Variation in observed life history strategies among rivers should not be surprising. Migratory patterns for coastal cutthroat trout have been described as diverse, with both sea-run and river run (potamodromous) migratory behaviors being observed (Trotter 1997). However, the relative uniformity of seaward movements subsequent to entry into the main stem of the Columbia River (and the apparent absence of potamodromy) was unanticipated. It may be the case that rapid and directed downstream movement seaward may be the most advantageous migratory strategy in this and other large river systems. "Typical waters" supporting anadromous coastal cutthroat trout are generally small streams with low flow (Johnston 1982) possibly limiting competition from larger salmonids for spawning habitat (Pearcy 1990). Exploitation of the lower reaches of these small systems may therefore afford greater rearing opportunities.

The possibility that this somewhat uniform migratory pattern is a recent condition cannot be cast aside. Life history diversity of cutthroat trout may have declined in the Columbia River due to changes in the hydrograph. The impacts of hydropower on upriver salmonid stocks are understandably linked to passage (Deriso et al. 1996; Deriso 2001). In the lower Columbia River, however, regulated flow has resulted in a shift in the amplitude and timing of high flow events (PNRC 1978). This shift in hydrological character influences main stem flows, plume structure, salinity profiles, tidal range, and productivity (Bottom 2001). The shift in invertebrate community has likely altered the growth opportunities of juvenile salmonids that linger in the estuary (including cutthroat trout). It should be noted that this pattern of limited main stem Columbia River usage may be specific to the juvenile life history stage. Returning anadromous adults to the system have been observed to use the main stem river more extensively (Mike Hudson, U.S. Fish and Wildlife Service, unpublished data).

Migrating juvenile cutthroat trout tracked by boat in this study often traveled near shore; however several juveniles were observed not only crossing the shipping channel (e.g., Figure 6a and 6c) but also traveling in the channel for several hours. This observation was unanticipated as an avoidance of open waters has been suggested (Jones 1976). Entry into the channel was often associated with the presence of formations (natural or human) that intersected with the flow of the water (e.g., pile dikes).

Downstream movements of coastal cutthroat trout were greatest on an outgoing tide (Figure 2). Patterns of tidal transport have been reported for many species (deVeen 1978; Locke 1997) including juveniles of spring Chinook, fall Chinook and steelhead trout in the Columbia River and estuary (Moore et al. 1998; Shreck et al. 2005). Trout using tidal currents to aid migration gain obvious energetic and navigation advantages. Observations in this study also suggest that downstream movement is greatest in the hours just after sunrise and just after sunset. While this data is limited, it is not unreasonable to hypothesize that downstream migratory behavior of cutthroat trout would be influenced by diel cycle as has been observed in other salmonids (Carlsen et al. 2004; Emmett 2004)

Smolting salmonids develop seawater tolerance coincident with migration as part of a complex developmental shift, the parr-smolt transformation. There is some correlation between gill Na^+,K^+-ATPase activity and the parr-smolt transformation in salmonids (Hoar 1976; McCormick and Saunders 1987; Hoar 1988), however we have insufficient data to do more than speculate as to the developmental state of the fish studied. Average gill Na^+,K^+-ATPase activity values (3.6 and 3.2 μmol ADP • mg protein^{-1} • h^{-1} for 2002 and 2003 respectively) are nearly two-fold higher than activities measured in coastal cutthroat trout captured in November 2002 (Zydlewski, unpublished data) but are lower than those measures in many smolt species (McCormick and Saunders 1987). It is reasonable to conclude from similar enzyme activities among streams and time that those fish tagged were of roughly similar developmental stage. While gill Na^+,K^+-ATPase activity should be viewed as an indirect indicator of smolting, it should not be viewed as a surrogate for more detailed physiological work including seawater challenges. There is some suggestion that gill Na^+,K^+-ATPase activity is related to downstream migration speed. As both metrics (behavior and Na^+,K^+-ATPase activity) are extremely variable, the relationship is understandably weak.

Based on these data, juvenile coastal cutthroat trout studied in these four tributaries to the Columbia River exhibited behavioral patterns that are consistent with those observed in other salmonid species. Juveniles leaving tributaries of the main stem Columbia River move in a rapid and directed fashion seaward. There was no indication that these fish displayed a potamodromous life history or lingered in the estuary (as is observed in some other systems). Because of these similarities, anthropogenic activities and management actions in the main stem Columbia River that influence salmon smolts are likely to affect anadromous coastal cutthroat trout smolts in a parallel fashion. It is important to note, however, that other life history stages may use the main stem and estuary habitat of the Columbia River more extensively.

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Coastal Cutthroat Trout Symposium: Status, Management, Biology, and Conservation
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Adult Coastal Cutthroat Trout Movement and Habitat Use in the Lower Columbia River

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Extended Abstract.—Coastal cutthroat trout *Oncorhynchus clarkii clarkii* were tracked in 2004 and 2005 to assess adult movement and habitat use in the lower Columbia River basin. The objective was to describe adult coastal cutthroat trout movement patterns and duration of time spent in the lower Columbia River main stem and estuary, proximity to the shipping channel, and potential causes of mortality. The impetus of this project was the channel deepening project in the lower Columbia River and how it may affect this species. A better understanding of adult coastal cutthroat trout behavior, spatially and temporally, in this habitat will help guide management decisions that may affect this species.

Coastal cutthroat trout kelts were collected from Mill Creek, Washington (river km [rkm] 87) in February 2004, and from Mill Creek, Abernathy Creek (rkm 88), and Germany Creek (rkm 91), Washington in February and March 2005 (Figure 1). A total of 44 captured individuals were implanted with 360 day radio tags and tracking was conducted via automobile and boat through September 2005 between Longview, Washington and Astoria, Oregon (Figure 1). In 2004, tracking occurred three times a week from February through November, and then at least once a week until February 2005. Beginning in February 2005, tracking occurred every day until late May, and then continued through September at least once every other week

Adult coastal cutthroat trout that left tributaries (n = 30) occupied the lower Columbia River main channel, side channels, backwaters, and other tributaries. These individuals remained in the lower Columbia River from 1-60 d before mortality or migrating toward the river mouth. Main stem movement appears to be influenced by the tidal cycle and that movement may occur within the main channel and/or side channels. However, all fish that initially moved upstream eventually turned and headed downstream if not a mortality. Coastal cutthroat trout tagged in Mill Creek that utilized multiple tributaries (n = 5) were observed in Abernathy Creek (Washington), Green Creek (Oregon), and the Clatskanie River (Oregon) and occupied those tributaries for 1-34 d (Figure 1). Thirteen fish made one to five moves across the shipping channel during the period of tracking, comprising 36.9% of the observed moves exhibited by these individuals. Suspected or confirmed mortalities (n = 26) through the duration of the study were of unknown cause or via avian or marine mammal

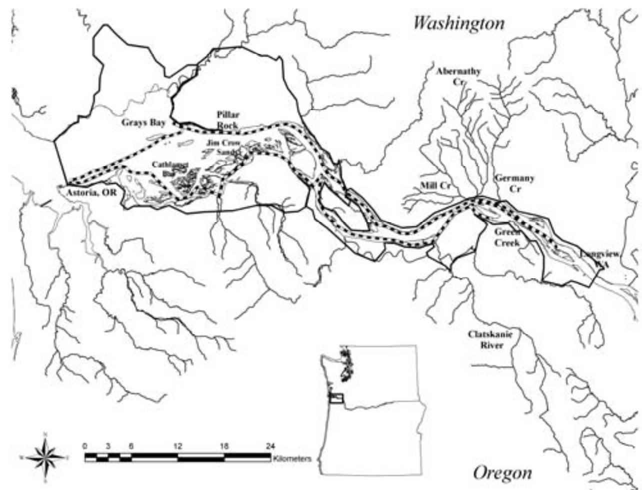

FIGURE 1.—Locations of tributaries sampled and routes followed for active telemetry. The dashed inner loop represents the path followed during boat tracking. The solid outer loop represents the path followed during car tracking.

predation, and resulted in a cumulative mortality rate of 59.1%.

While there is limited information available on migratory coastal cutthroat trout movement, patterns seen in the Lower Columbia River have been seen in other parts of the species range and on different scales (Jones and Seifert 1997; L. Krentz, Oregon Department of Fish and Wildlife, unpublished data). However, Jones and Seifert (1997) did not detect coastal cutthroat trout crossing larger open waterways. Tagged adults in this study regularly moved from one side of the river to the other across the shipping channel. In some places, this equates to 3-5 km from the Oregon shoreline to the Washington shoreline. Overall movement was large with cumulative movements over 90 km when fish moved from the tributaries to the mouth of the lower Columbia River. However, movement was generally not sustained. Factors affecting sustained movement included tidal cycle, structures that provided temporary cover (e.g., pilings), use of additional tributaries, and predation. Avian and marine mammal predation may present a threat to coastal cutthroat trout in the lower Columbia River. Colonies of Caspian terns and double crested cormorants are known to significantly impact salmonid numbers in the Columbia River (Collis et al. 2001). It is estimated that the tern population consumes approximately 11.2% of out-migrating salmonid smolts that survive to the estuary, but reliable estimates on adult and

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juvenile coastal cutthroat trout predation rates are not available due to a lack of monitoring efforts.

This data and associated studies (Johnson et al. 2008; Zydlewski et al. 2008) demonstrate that multiple life stages and age classes of coastal cutthroat trout may be found in the lower Columbia River main stem and estuary throughout the year. Therefore, management activities should be timed to minimize impacts to coastal cutthroat trout. Furthermore, these activities should consider impacts on habitat, both in stream supporting coastal cutthroat trout and out-of-stream supporting potential predators.

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Habitat Utilization and Seasonal Movements of Radio-Tagged Copper River Delta Coastal Cutthroat Trout

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Abstract.—I used radio telemetry to track movements of 27 adult coastal cutthroat trout on the North Gulf Coast/Copper River Delta, Alaska. Sixteen upstream-migrating spawners and four downstream-migrating spawners were tagged as they passed the Eighteen Mile Creek weir in the spring. Seven fish caught by hook-and-line in the fall were tagged and followed to overwintering areas. Tracking of individual fish (272-489 mm fork length) ranged from 6-343 days. Freshwater habitats were utilized in all seasons with residence in overwintering refuge habitats lasting up to six months. Spawning locations varied from low gradient, broad river reaches near the mouth to narrow (<1 m width) to ephemeral headwater streams 4.8 km upstream. Large migratory females (320 mm, 283 mm fork length) spawned in headwater streams with "resident-sized" males (100-130 mm fork length). After spawning, upstream-migrating spawners remained in Eighteen Mile Creek for the summer, out-migrated to adjacent freshwater drainages, or out-migrated to the estuary. Stream residence for kelts leaving the system ranged from 3-28 d. Downstream-migrating spawners out-migrated 1.6-5.6 km to adjacent drainages. Four fish tracked to the estuary in spring were subsequently tracked to freshwater habitats in August, suggesting a behavior of summering in saltwater. In late summer and fall, fish were tracked to lakes and ponds where they overwintered and remained until April. Movements and habitats used by these coastal cutthroat trout suggest the presence of both potomodromous and anadromous behavior.

The Copper River Delta is the largest wetland on the Pacific Coast of North America. It is a low-lying alluvial outwash floodplain that empties into the North Gulf Coast of Alaska, east of Cordova, Alaska (Figure 1). The 139-km wide delta, which receives approximately 380 cm of rainfall annually, is a complex ecosystem comprised of pristine and diverse aquatic habitats including ponds, lakes, braided streams, and tidally influenced sloughs. Large populations of sockeye salmon, coho salmon, Dolly Varden char, and coastal cutthroat trout are present, along with numerous bird and mammal species.

Aquatic habitats on the delta are generally intact, but future development activities on the delta including logging, road building, mining, and offshore oil drilling have raised concerns of adverse effects to aquatic species. Outside of the delta, coastal cutthroat trout have been impacted by anthropogenic practices such as logging (Holtby 1987; Johnson et al. 1999) and over-harvest (Giger 1972; Ricker 1981; Gresswell and Harding 1997), and declines in cutthroat trout numbers throughout the species' range have been reported (DeShazo 1980; Griffith 1986). Damage to stocks in the nearby Prince William Sound from the Exxon Valdez oil spill has already been documented (Hepler et al. 1996).

The majority of fisheries studies conducted on the delta have focused on coho and sockeye salmon, primarily because these fish are important commercial and sport fishery species. The life history of the coastal cutthroat trout is arguably the most complex of the Pacific salmonids (Northcote 1997), but limited research has been conducted on delta stocks of cutthroat trout. Little is known about spawning times, seasonal migrations, and critical habitats utilized by Copper River Delta coastal cutthroat trout, providing incomplete information on which to base management decisions. Studying movement patterns can identify which portions of a stream are most critical for maintenance of a population (Rieman and Dunham 2000). The evaluation of habitat use of coastal cutthroat trout through all life history stages should increase understanding of potential impacts from anthropogenic activity (Hudson et al. 2002).

To fulfill the objective of enhancing our knowledge of coastal cutthroat trout adult life history, I radio-tagged 27 coastal cutthroat trout and tracked them over a three-year period spanning 1994-1996. Fish were tracked through the entire calendar year to gather seasonal behavior information, migration times, and habitat utilization.

Study Area

Sample sites were located in three stream systems in the western Copper River Delta: Eighteen Mile Creek, Goose Meadows Creek, and Alaganik Slough (Figure 1). Eighteen Mile Creek is a fourth-order coastal floodplain river with a catchment area of approximately 150 km^2 and 21 km of stream channels. Mean stream surface gradient was 1%. Mean discharge was estimated at 7.0 $m^3 \cdot s^{-1}$ and mean wetted width was approximately 9 m during mean summer flow. The substrate was dominated by alluvial gravels and cobbles. Goose Meadows was similar in size and other physical characteristics. Eighteen Mile and Goose Meadow creeks enter Alaganik Slough at river kilometer (rkm) 13.7 and 14.3, respectively. Alaganik Slough is a lake outlet

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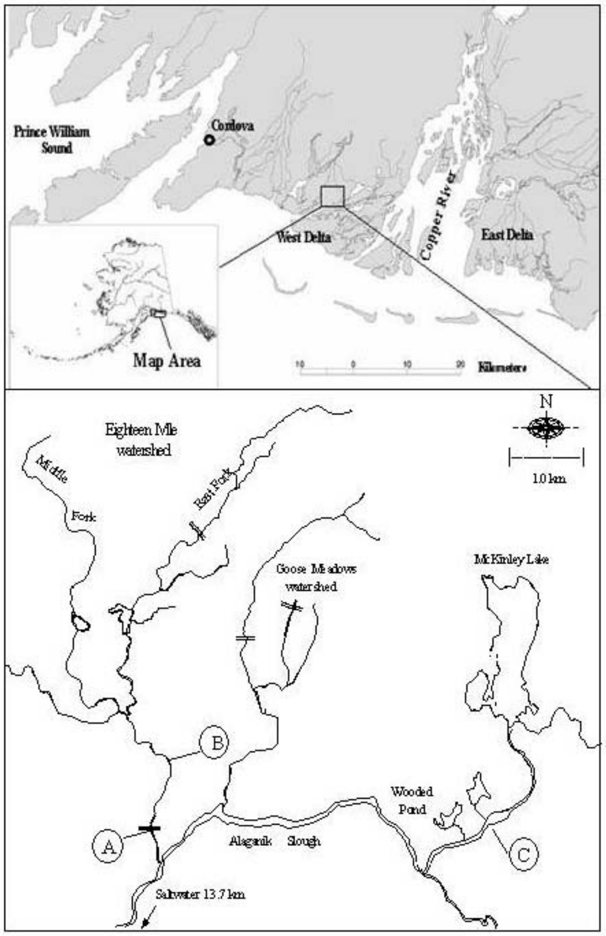

FIGURE 1.—Location of the study area and capture locations in Eighteen Mile Creek and Alaganik Slough (A = Eighteen Mile weir, B = Eighteen Mile Creek, C = Alaganik Slough). Double-line bars indicate fish passage barriers.

river that drains McKinley Lake and numerous tributary slough channels that branch off from the Copper River. In addition to Eighteen Mile and Goose Meadows creeks, Alaganik Slough also drains several smaller, unnamed watersheds. McKinley Lake is one of the largest lakes on the Copper River Delta with a surface area of 114 ha, a maximum depth of 11 m and a mean depth of 5.1 m. Numerous ponds and small lakes are located within the study area. Pond sizes range from 324 to 4,298 m^2, with maximum depths between 1.0 and 1.8 m. Riparian habitats are dominated by Sitka alder *Alnus sinuata* and willow *Salix* spp., with sweet gale *Myrica gale*, western hemlock *Tsuga heterophylla*, and Sitka spruce *Picea sitchensis* present to a lesser degree.

In addition to coastal cutthroat trout *Oncorhynchus clarkii clarkii*, sockeye salmon *Oncorhynchus nerka*, coho salmon *Oncorhynchus kisutch*, Dolly Varden char *Salvelinus malma*, three-spined stickleback *Gasterosteus aculeatus*, slimy sculpin *Cottus cognatus*, and eulachon *Thaleichthys pacificus* were present within the study area.

Methods

A total of 27 coastal cutthroat trout were captured and implanted with radio transmitters. Four fish were tagged in 1994, seven fish were tagged in 1995, and 16 fish were tagged in 1996. Captures were made at a 27.4 m long, two-way fish weir on Eighteen Mile Creek (n = 20), or by hook-and-line in Eighteen Mile Creek (n = 4) and Alaganik Slough (n = 3) watersheds (Figure 1).

The Eighteen Mile weir was constructed approximately 0.8 km above the stream's mouth during early spring after ice-out, typically during the first two weeks of April. The weir was operated until the number of fish passing upstream or downstream declined to when 5-7 d passed without capturing a cutthroat trout. Dates of operation were 31 March–8 July 1994; 7 April–13 July 1995; 18 April–7 July 1996. The weir was "fish tight" for all dates except for 19–24 May 1994, and 7-9 May 1995, when storms caused high flows to breach the weir.

Upon capture fish were anesthetized in a buffered solution of tricaine methanesulfonate (MS-222), measured (mm, fork length [FL]), and weighed (g). The direction of migration (upstream or downstream) was recorded for fish captured at the weir. Fish captured during the spring spawning season were checked for sexual maturity and ripeness (indicated by production of milt or eggs upon gentle external massage). Fish over 250 mm long were tagged with esophageal radio transmitters (Advanced Telemetry Systems, Isanti, Minnesota. Tags were inserted through the mouth and into the stomach using a plastic straw-sized tube. Radio transmitters had external whip antennas weighing 5-8 g. For 25 of the tagged fish, the "2% rule" (Winter 1983) of transmitter weight to body weight was used. Fish were held for 24 h and checked for tag regurgitation or handling injury before being released at the site of capture.

In 1994, radio transmitters were programmed to transmit 12 h/d. Transmitter life ranged from 90-120 d. During 1994, because radio tags were anticipated to expire quickly, most tags were pulled from fish that returned downstream to the Eighteen Mile weir. In 1995 and 1996, tags with variable duty cycles were used to prolong battery life. These radio tags were programmed to transmit 4-6 h/d and transmitted every day during the spring, 1-4 d during the summer and fall, and one week per month during winter. Maximum life for these tags was 12-13 months, although tag life varied considerably. Radio tags transmitted signals through freshwater, but not through saltwater.

Radio-tagged fish were located from the ground with a hand-held, two- or three-element Yagi antenna. Attempts to relocate fish began 24 h after release using foot, car, and/or airboat surveys. The frequency of surveys varied by season and weather conditions. During the spring spawning migration surveys were conducted daily. Attempts to relocate fish were made on a weekly basis during summer and fall. During the summer, aerial surveys were conducted from 1-7 d per week to determine the timing of post-spawning, seaward migrations of anadromous fish. Weekly flights were made throughout the late summer and early fall to determine timing of reentry of anadromous fish into freshwater. During the winter, surveys were made one to two times per month.

During ground surveys, fish locations were determined to the nearest meter using triangulation methods and recorded on aerial photographs (1 cm = 1 km). Distances between fish locations were measured using a map wheel. Unless directly observed, the date of an event such as entry from freshwater into saltwater was interpreted as the average date between contacts (Swanberg 1997).

Results

At initial capture, radio-tagged fish lengths averaged 364 mm (SD 45 mm; range 272-489 mm) and weights averaged 498 g (SD 219 g; range 188-1197 g) (Table 1). Of the 27 radio-tagged fish, three experienced tag failure, one regurgitated its tag, and one was depredated before any movement data could be collected (Table 1). Of the remaining 22 fish, 19 were tracked during the spring spawning period, 11 were tracked to summer post-spawning locations, and five were tracked through the fall and winter to overwintering habitats.

Spring immigration into Eighteen Mile Creek.—Coastal cutthroat trout that were implanted with radio tags entered Eighteen Mile Creek from 21 April to 14 June (Table 1; Figure 1). Numbers of adult and juvenile cutthroat trout immigrating into the creek past the weir each spring from 1993-1997 ranged from 29-126 fish (Table 2). Within Eighteen Mile Creek, total upstream distances traveled by radio-tagged fish averaged 3.1 km (SD 1.3 km; range 1.2–4.8 km) and occurred at an average rate of 0.5 km/d. Radio-tagged fish were tracked to their highest point in their migration and their spawning locations 1-19 d after passing through the weir (Figures 2 and 3). Most radio-tagged fish (n = 10) moved directly to spawning habitats and did not pause or meander while searching for spawning areas. Four fish showed exceptions to this pattern, spending from 4-13 d in large pools associated with beaver dams before moving to their spawning locations (fish 2, 10, 16, 23; Figures 2 and 3). No downstream movement was observed prior to spawning.

Once the fish reached their spawning location, they stayed within a 100-m reach during the spawning period, which typically lasted 1-3 d (Figures 2 and 3). Spawning locations were distributed throughout Eighteen Mile Creek, but were most concentrated in the upper reaches of the East Fork (Figure 4) where stream widths were <1 m and depths were ≤15 cm.

Spawning behavior of five radio-tagged fish (fish 4, 5, 10, 11, and 12; Table 1) was observed. These fish were females ranging from 283-363 mm in length that paired with smaller males ranging from 100-130 mm in length. Females constructed redds in the tailouts of pools while dominant males defended territories around the redds from other males of similar length.

Spring emigration from Eighteen Mile Creek.—Numbers of juvenile and adult cutthroat trout emigrating past the weir each spring from 1993-1997 ranged from 93-240 fish (Table 2). Of the tagged adults leaving Eighteen Mile Creek, there were two forms: kelts that had entered and spawned in Eighteen Mile Creek (n = 3; fish 9, 16, and 21; Table 1) and spawners that were leaving Eighteen Mile Creek to spawn elsewhere (n = 4; fish 17, 18, 19, and 20; Table 1). None of the four tagged spawners had previously passed upstream through the weir during the spring, suggesting that they had overwintered within the Eighteen Mile Creek watershed. Two of these fish spawned at locations outside of Eighteen Mile Creek (Figure 4). Spawning locations for the other two fish were not determined.

TABLE 1.—Coastal cutthroat trout radio tagged in Eighteen Mile Creek and Alaganik Slough, Alaska. Capture locations refer to locations in Figure 1.

Fish #	Capture location	Study dates[a]	Study period (d)	Fork length (mm)	Weight (g)
1	A	9 Jun 1996–9 Sep 96	93	373	484
2	A	30 May 1996–29 Aug 96	91	375	455
3	A	2 Jun 1995–29 Aug 95	79	359	
4	A	11 May 1995–11 Jul 95	61	283	199
5	A	24 Apr 1994–27 Sep 94[b]	150	363	454
6	B	28 Sep 1995–17 May 96	232	397	628
7	B	28 Sep 1995–6 Sep 96	343	361	539
8	C	23 Oct 1995–17 May 96	207	390	615
9	A	17 May 1996–26 Nov 96	193	343	349
10	A	9 May 1996–27 May 96	19	345	403
11	A	11 May 1994–30 May 94	20	320	319
12	A	27 April 1994– 3 May 94	8	359	442
13	A	14 Jun 1994–22 Jun 94	9	337	380
14	B	9 Sep 1996–[d]	1	362	509
15	A	1 May 1996–5 May 96	4	357	412
16	A	28 Apr 1995–14 May 95	17	369	
17	A	21 Apr 1996–5 May 96	15	381	541
18	A	10 May 1996–27 Aug 96	109	272	188
19	A	30 Apr 1996–24 Oct 96	244	360	442
20	A	25 May 1996–4 Jun 96	10	405	508
21	A	17 May 1996–21 Oct 96	166	489	1197
22	A	25 May 1996–2 Aug 96	69	462	1046
23	A	20 Apr 1996–18 May 96	29	392	566
24	A	19 Apr 1996–[c]	1	335	
25	C	20 Oct 1995–[d]	1	340	364
26	C	23 Oct 1995–[e]	1	317	270
27	B	11 Sep 1996–[d]	1	393	642

[a] From implantation of transmitter to final radio contact.
[b] No signal detected after 16 June. Fish was recaptured at location of last contact by hook and line on 27 September. The tag was still implanted in the fish but was no longer transmitting.
[c] Fish depredated by mink before any data were collected.
[d] No signal was received after release due to apparent radio failure.
[e] Fish regurgitated tag before any data were collected.

TABLE 2.—Numbers of coastal cutthroat trout passing the Eighteen Mile Creek weir during spring 1993-1997. Range of fork lengths for upstream migrants was 110-520 mm. Range of fork lengths for downstream migrants was 100-560 mm.

Migration direction	1993	1994	1995	1996	1997
Upstream	126	73	29	98	65
Downstream	240	93	160	191	100

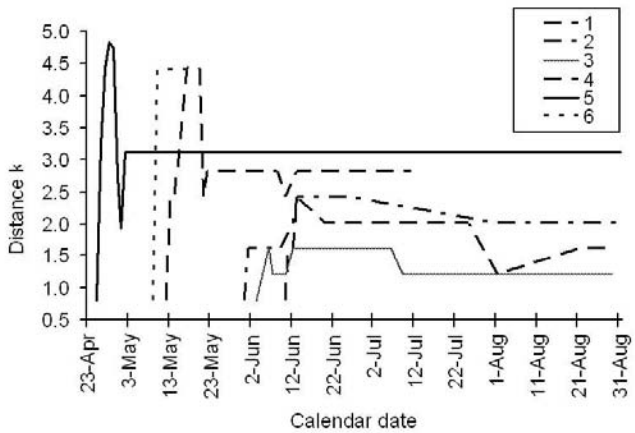

Figure 2.—Distances moved by calendar date for radio-tagged coastal cutthroat trout remaining in Eighteen Mile Creek after spawning. Values on the y-axis indicate distances moved upstream of the mouth of Eighteen Mile Creek. The weir location was at 0.8 km.

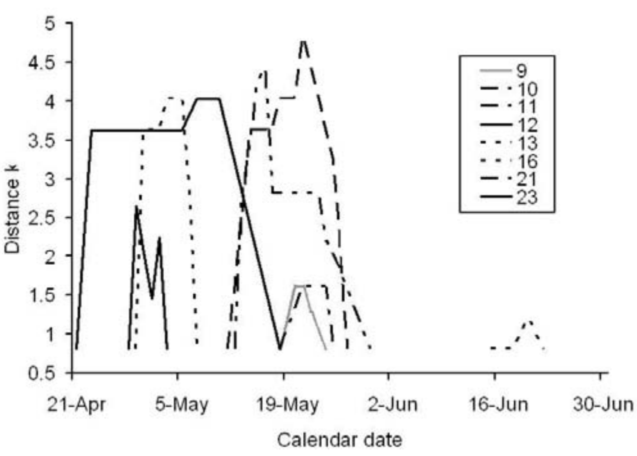

FIGURE 3.—Distances moved by calendar date for radio-tagged coastal cutthroat trout returning to the Eighteen Mile Creek weir. Values on the y-axis indicate distances moved upstream of the mouth of Eighteen Mile Creek. The weir location was at 0.8 km.

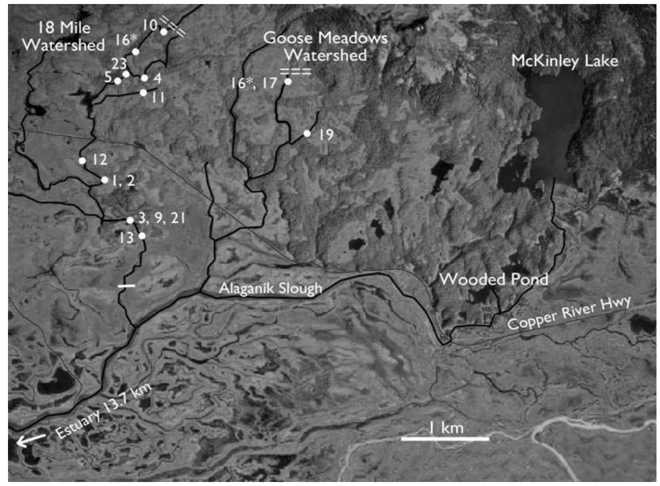

FIGURE 4.—Spawning locations (circles) of radio-tagged coastal cutthroat trout. Double-line bars indicate fish passage barriers. Single-line solid bar indicates the Eighteen Mile Creek weir site. Numbers correspond to fish in Table 1. For fish 16 (*) spawning occurred either in Eighteen Mile Creek or Goose Meadows.

Movements of fish leaving Eighteen Mile Creek fit into two patterns: fish that moved to adjacent freshwater systems, presumably for spawning or feeding, and fish that emigrated directly to saltwater (Figures 5 and 6).

Summer post-spawning habitat residence.—Spring immigrants displayed two post-spawning movement patterns: 1) fish that returned to the weir and exited the system after spawning, and 2) fish that stayed above the weir and remained in Eighteen Mile Creek after spawning. Surveys through the summer post-spawning period ranged from 6-252 d after spawning.

Five tagged fish (fish 1, 2, 3, 4, and 5) remained in Eighteen Mile Creek throughout the summer, moving to habitats located an average of 0.9 km (SD 0.7 km; range 0–1.6 km) downstream from their spawning locations (Figures 2, 6, and 7). Post-spawning movements of fish remaining in Eighteen Mile Creek were less direct than prespawning movements, consisting of short upstream and downstream movements between periods with no change in location (Figure 2). Periodic summer movements occurred between large pools associated with beaver dams.

Eight tagged fish (fish 9, 10, 11, 12, 13, 16, 21, and 23) returned to the weir between 3 May and 22 June after spending an average of 13 d (SD 7.8 d; range 6–28 d) in Eighteen Mile Creek (Table 3, Figure 3). Fish returning to the weir exhibited signs of spawning, such as abraded caudal fins and vacuous abdomens, and lost an average of 70 g of their pre-spawning body weight (n = 6; SD 0.04 g; range 30–175 g; Table 3). The number of days spent in Eighteen Mile Creek was weakly and negatively correlated with the timing of entry into the stream (Pearson correlation, r = -0.46).

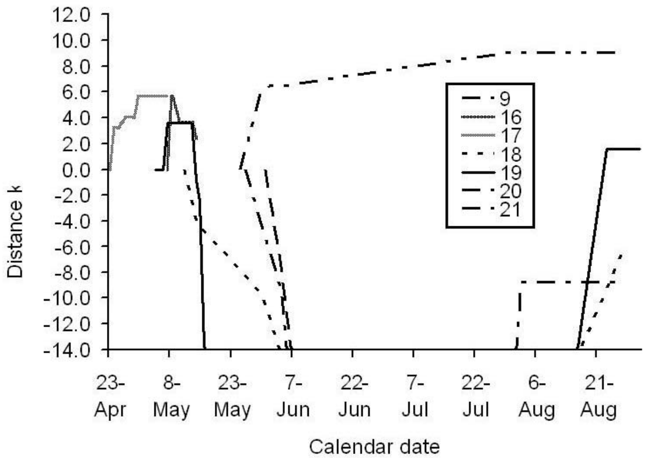

FIGURE 5.—Distances moved by calendar date for radio-tagged coastal cutthroat trout emigrating from Eighteen Mile Creek. Tagged fish leaving Eighteen Mile Creek consisted of both kelts that had entered and spawned in Eighteen Mile Creek (n = 3) and spawners that were leaving Eighteen Mile Creek to spawn elsewhere (n = 4). Values on the y-axis indicate distances moved upstream (positive values) and downstream (negative values) from the mouth of Eighteen Mile Creek. The Gulf of Alaska was located 13.7 km below the mouth of Eighteen Mile Creek.

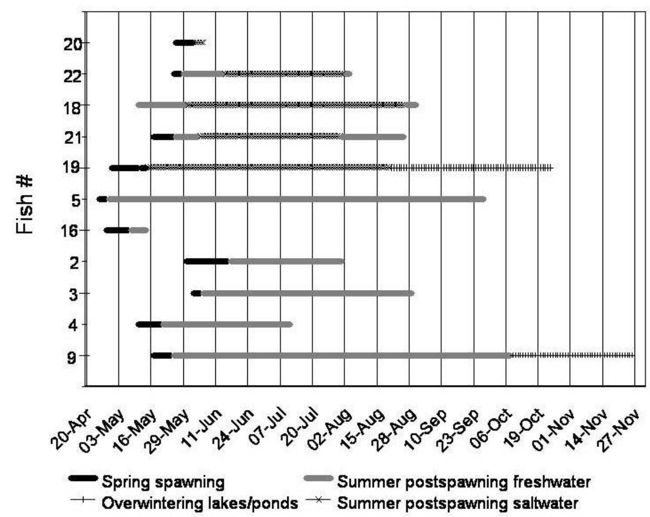

FIGURE 7.—Summer trophic, post-spawning habitat residence times for 11 tagged fish. After leaving Eighteen Mile Creek, fish migrated to either freshwater (n = 6) or saltwater (n = 5) for the summer. Two fish were tracked to overwintering lakes and ponds by late summer/early fall.

Eighteen Mile Creek post-spawning movements of emigrating fish back to the weir were generally direct and occurred at a rate of 0.6 km/d (SD 0.46 km/d; range 0.2–1.6 km/d). Except for fish 11 and 12, all fish were found further downstream on each subsequent post-spawning contact (Figure 3).

Fish length was not significantly different between fish remaining in Eighteen Mile Creek and fish returning to the weir (*t*-test, P > 0.05). Fish length was not significantly different between fish migrating to saltwater and fish that stayed in freshwater after spawning (*t*-test, P > 0.05). The length of fish tagged in the spring was not significantly different from fish tagged in the fall (*t*-test, P > 0.05).

Migrations to winter habitats.—Of five fish tracked to winter habitats, two fish were originally tagged during the spring at the weir (fish 9 and 19; Table 1, Figure 7), two fish were tagged during the fall in Eighteen Mile Creek (fish 6 and 7; Table 1, Figure 8), and one fish was tagged during the fall in Alaganik Slough (fish 8; Table 1, Figure 8). All five fish moved from lotic to lentic habitats (Figure 6).

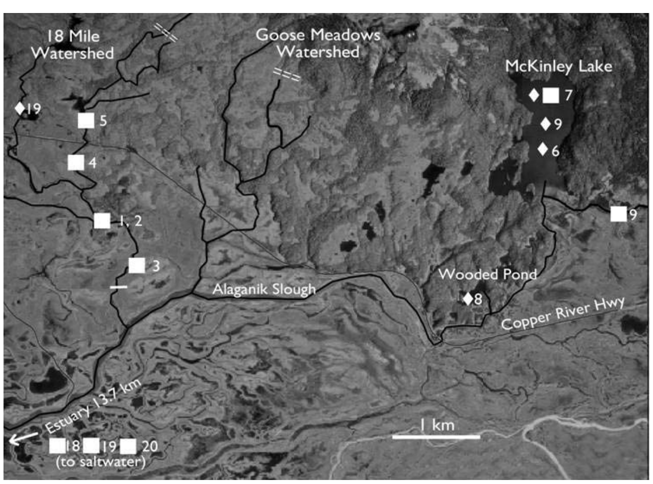

FIGURE 6.—Summer locations (squares) and winter locations (diamonds) of radio-tagged coastal cutthroat trout. Double-line bars indicate fish passage barriers. Single solid bar indicates the Eighteen Mile Creek weir site. Numbers correspond to fish in Table 1.

TABLE 3.—Length, pre-spawning and post-spawning weight, and timing of radio-tagged coastal cutthroat trout returning to a weir in Eighteen Mile Creek, Alaska.

Fish number	Fork length (mm)	Pre-spawning weight (g)	Post-spawning weight (g)	Date of return	Days above weir
9	343	349	302	24 May	6
10	345	403	359	26 May	17
11	320	319	283	30 May	19
12	359	442	355	3 May	7
13	337	380	350	22 Jun	8
16	369	>500		7 May	9
21	489	1197	1022	25 May	8
23	392	566		18 May	28

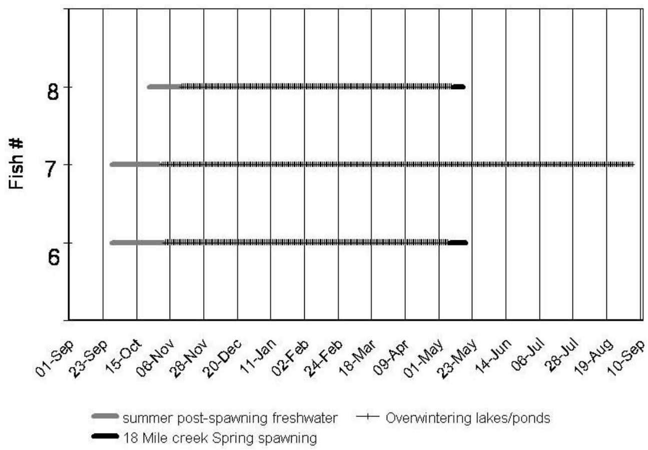

FIGURE 8.—Overwintering habitat residence times of three tagged fish. Fish moved to overwintering lakes and ponds beginning in November. Two fish migrated back to Eighteen Mile Creek by May of the following spring, presumably to spawn. One fish remained in the lake through the following spring and summer before loss of tag signal.

Fish tagged during the fall moved an average of 6.8 km (SD 4.85 km, range 1.2–9.6 km) from their capture location to winter habitat (Table 1; Figure 6). Entry time into winter habitats was variable and ranged from late-August to late-November. Residence time in winter habitats was also variable. One fish (fish 7) entered McKinley Lake in late-October and remained there through the following spring and summer. Two fish (fish 6 and 8) remained in McKinley Lake until the following May when they out-migrated back to Eighteen Mile Creek to spawn. One fish (fish 8) depredated by mink was ripe with eggs.

Other tagged fish.—Two fish that were tagged at the weir while immigrating to Eighteen Mile Creek during the spring (fish 15 and 22; Table 1) were accidentally released below the weir. Neither fish attempted to move back upstream through the weir and their subsequent movements were tracked to habitats outside Eighteen Mile Creek.

Discussion

Based on tracking results, I found indications of coastal cutthroat trout spawning on the Copper River Delta beginning as early as mid-April and lasting until late June. Residence in post-spawning summer feeding habitats occurred from mid-April to early October and lasted up to 5.5 months. Migrations into overwintering habitats began in mid-August and lasted until early October. Overwintering in lake and pond habitats lasted up to six months.

I saw variable stream residence times in Eighteen Mile Creek, suggesting variable post-spawning, trophic behavioral preferences. Five fish left in 9 d or less, 3 fish left from 17-28 d after entering, and 5 fish did not leave the stream and were tracked remaining in the stream up to 150 d before surveys ended due to tag failure.

Data from two tagged fish showed post-spawning residence in main stem river habitats rather than first and second order streams during the summer. Residence in the main stem rivers ranged from 3-4.5 months. Fish underwent migrations from their spring spawning streams to trophic habitats in main stem rivers.

Residence time in overwintering habitats was variable. Tracking data showed residence time in overwintering habitats of up to six months before fish moved back out and returned to spawning streams in the spring. One fish that had entered refuge habitat (McKinley Lake) in the fall remained there through the following spring and summer before tracking surveys ended due to tag loss.

I saw a mix of aquatic habitats on the Delta (streams, rivers, ponds, and lakes) used as trophic habitats during the summer. Streams used for spawning were also used for trophic, post-spawning phases.

I observed overwintering in ponds and lakes but was not able to determine if fish were overwintering in saltwater. Where ponds and lakes were used as overwintering habitat, it appeared that the primary requirement for fish using these habitats was sufficient water depths to avoid freeze-out during the winter. Beaver ponds with shallow depths were used only during summer, but I saw no overwintering of fish in these ponds. Refuge habitats were not used exclusively for overwintering and in some instances lakes were used year-round for both refuge and trophic habitat

My tracking data suggest that fish may not always undertake annual spawning migrations. Fish 7, caught in Eighteen Mile Creek in September 1995, did not return to Eighteen Mile Creek the following spring or summer and instead remained in McKinley Lake for the following spring and summer. This fish remained in this habitat for 10 months before the tag expired. For this fish, McKinley Lake provided winter, spring, and summer habitat.

I saw evidence of fidelity to specific locations. Fish 6, caught in Eighteen Mile Creek in September, migrated to McKinley Lake where it resided through the winter for a period of six months. The following May, this fish left the lake and returned to Eighteen Mile Creek, an absence of nine months. Fish 19, tagged leaving Eighteen Mile Creek in April 30, returned to the creek by August 21, almost four months later. Another tagged fish (fish 20) leaving Eighteen Mile Creek in spring had two fin-clip marks used during previous studies at the weir indicating that this fish had returned to Eighteen Mile creek at least three years in a row.

The results of this study provide some insight into the migratory behavior and seasonal habitat usage of coastal cutthroat trout on the Copper River Delta. Despite close proximity to saltwater, not all cutthroat trout on the Delta underwent anadromous migrations and some migratory fish remained in freshwater throughout the year. These results suggest the presence of a potamodromous behavior form sympatric with resident and anadromous forms on the Delta.

Copper River Delta aquatic habitats appear to be diverse and productive enough to satisfy multiple seasonal habitat requirements for multiple behavioral forms. From a management perspective, it is reasonable to assume that more than one behavioral type may occupy the same habitat during different seasons, or that multiple behavioral forms may be present in the same habitat at the same time.

Because these Delta habitats are apparently able to support multiple life history forms, conservation of these areas are crucial to sustaining Copper River Delta cutthroat trout populations. The preservation of connectivity among these habitats is critical for fish undertaking seasonal migrations. Main stem rivers are important for not only feeding habitats in the summer but as migratory corridors as well. Fragmentation in streams causes declines in fish populations by interrupting movements to and from critical sites that fish must reach to complete their life history (Schlosser 1995). Road culverts on the delta that present barriers to migration may affect multiple seasonal life history phases for multiple behavioral types.

Some studies of fish movement have shown evidence that larger fish move longer distances (Clapp et al. 1990; Young 1994; Schrank and Rahel 2004). It has been suggested that fish move downstream after spawning because of greater growth potential in higher order stream reaches, including the opportunity to become piscivorous (Clapp et al. 1990; Behnke 1992; Bunnell et al. 1998).

This study did not reveal any trends to suggest that larger sized fish migrate longer distances. I saw no size differences between fish that remained in Eighteen Mile Creek after spawning and those that left for either saltwater or freshwater summer habitats. I saw that both the largest and smallest fish tagged in this study displayed anadromous behavior and migrated to the estuary. However, the results may be biased because of the small sample size and the non-random method for selecting fish to be tagged.

In their study of Bonneville cutthroat trout, Schrank and Rahel (2004) observed that characterization of salmonids movements during one season will not necessarily allow movement patterns during other seasons to be predicted. In this study, I saw fish that chose not to undertake spawning migrations each year and as a result spent summer residence in different locations during different years.

Dunning et al. (1992) and Schlosser (1995) have suggested that the extent of migratory behavior within a population appears to depend on the degree of habitat complementation that exists in a drainage. If all the habitats fish need to complete their life history are in close proximity, then movement will be minimal. However, if spawning, feeding, and overwintering habitats are located far apart, then movement distances will be high.

In this study, I saw a continuum of spatial movements to seasonal habitats ranging from short migrations within close proximity to spawning grounds to more extensive movements across multiple stream drainages or to saltwater. Some studies have suggested that fish may be moving to find increased space, better physical habitat, or more tolerable thermal regimes (Kahler et al. 2001; Roni and Quinn 2001; Schrank et al. 2002).

Determining why movement occurs will offer more insight into which habitats are critical for population persistence (Schrank and Rahel 2004**).** It is difficult to postulate the reasons for the varied and diverse post-spawning movements observed. Habitats utilized in this study were prolific and diverse, ranging from small beaver ponds to large lakes, from lower order streams to main stem rivers, and from freshwater to saltwater. It appears that there is no shortage of suitable habitat on the Delta, and artificial barriers are few to none. Water is of high quality as impacts generally leading to adverse water temperature effects, such water diversions or habitat fragmentation, are absent here. The relatively low numbers of cutthroat trout censused at the weir suggest that intraspecific competition would not be a limiting factor. However, there are high numbers of coho salmon and Dolly Varden char sympatric in these streams and interspecific competition with these populations may occur.

Migrations to overwintering refuge habitats were quite extensive. Suitable overwintering habitat consists of water bodies with sufficient depth to avoid freezeout. On the Delta, these habitats are fewer in number and more widely dispersed than the shallower ponds and beaver dams that were used during summer.

There has been much research on the importance of headwater streams for salmonids (Kawaguchi and Nakano 2001; Wipfli and Gregovich 2002; England and Rosemond 2004). This study showed use of small headwater streams by large migratory fish. Large migratory females were tracked to surface-runoff fed headwater streams 1 m wide, where they spawned with smaller resident-sized males. This observation clearly demonstrates the importance of headwater streams for providing multi-seasonal critical habitats for multiple behavioral types. Because many of these headwater streams have small bankfull widths and shallow incision, they may not be recognized as providing critical habitat. Even small, localized disturbances such as trail building may result in adverse affects at the local scale. Landscape-scale disturbances such as logging, road building, or development activities could have adverse impacts to multiple fish populations across multiple drainages.

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Coastal Cutthroat Trout Symposium: Status, Management, Biology, and Conservation
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Coastal Cutthroat Trout Ecohydrology and Habitat Use in Irely Creek, Washington

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Extended abstract.—Coastal cutthroat trout *Oncorhynchus clarkii clarkii* are native (adfluvial) in the Irely Creek watershed of the upper Quinault River drainage, which is protected as Olympic National Park. The coastal cutthroat trout coexist with anadromous coho salmon (*O. kisutch*, the dominant fish), two resident fishes, and several amphibian species. During 2001-2002, cutthroat redds and fry were abundant in the main stem (Figure 1), such that we had adequate data (including also 2003 substratum results) to formulate microhabitat suitability curves for spawners and assess the incubation period before fry emergence (roughly two months).

The results for spawning depth preference (optimum = 0.6-0.89 ft [0.18-0.27 m], good = 0.2-0.59 ft [0.06-0.18 m]) and velocity preferences (optimum = 0.8-1.09 fps [0.24-0.33 mps], good = 0.5-1.59 fps [0.15-0.48 mps]) were similar to spawning resident trout species. Those results suggest that cutthroat trout require lower stream flows than salmon or steelhead (*O. mykiss*) for reproduction, supported by 1) our observations that cutthroat spawned at lower flows than coho salmon and 2) predictions based on PHABSIM studies elsewhere in western Washington (Caldwell et al. 2004; Beecher et al. 2006).

In contrast, cutthroat trout substratum preferences for spawning were more similar to those of anadromous than resident Pacific-salmonid spawners. Cutthroat found large gravel to small cobble optimal, small gravel good, and muddy and boulder/bedrock particles completely unsuitable for spawning. Because we employed dominant/subdominant substratum coding to handle sand-caused bimodality, we found weighted geometric, rather than arithmetic, means to be more realistic for estimating habitat suitability (by using geometric means, we avoided predicting nonzero suitability over beds with high amounts of extreme particles—fine and/or large rock—that weren't spawned over). Nevertheless, given our observed use of some fine-bedded habitat for spawning in other glacial-fed rivers of Washington state, the average value of the weighted geometric and arithmetic means may best predict salmonid redd locations. This implies that cutthroat and other salmonid spawners select dominant or subdominant substratum types with some interdependence, but without complete compensation if one particle size is unsuitable. Our observations demonstrate that large (sandy) fines are less harmful than small (muddy) fines for salmonid spawning and incubation. Thus, a fines criteria to assess human impacts should be standardized to these two particle-size ranges.

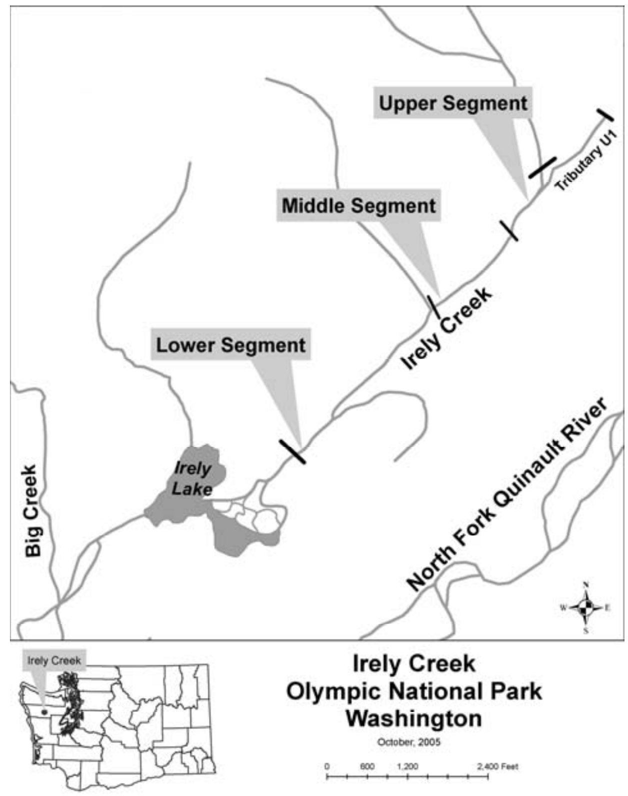

FIGURE 1.—Map of the Irely Creek study area, upstream from Irely Lake. Note that Big Creek (shown) is a tributary of the main stem Quinault River well below where the North and East forks come together. There were three study segments in the main stem, as well as one upper tributary (U1) where cutthroat spawning occurred, the surveyed area being delineated by wider lines and segment boundaries by thinner lines. The lower main stem limit of sampling was above the backwater zone caused by beaver dam and lake inundation effects. The upper main stem and U1 limits of sampling were bounded at points where significant hydraulic drops occurred.

Our hydraulic and substratum preference data are being used to assess in stream flow needs in smaller western

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Washington streams having varying levels of riparian disturbance.

In contrast to 2001-2002, cutthroat trout redds were an order of magnitude rarer during 2003-2006, except for a partial resurgence during 2005. This observation corresponds with the summer droughts of 2002-2003, when Irely Lake dried out completely, and 2005, when the lake was nearly dry (potentially causing water-quality and/or predation problems), as contrasted with the non-drought ("normal") year of 2004 that nevertheless showed severe main stem flood scour during winter. In 2006 a summer drought again fully dried out Irely Lake, and further depletion of the cutthroat trout population is expected. But extirpation has not occurred to date, given the consistent presence of cutthroat fry in a headwater tributary, as well as the regular presence of juveniles in the main stem. Despite possible competition with coho salmon, Irely Creek cutthroat often schooled with coho as fry and likely benefited from coho carcass-derived nutrients.

Despite their higher spawning flow needs, coho salmon were less vulnerable to pond dry out than cutthroat trout because the former rear in the perennially flowing creek and because spawners can access the creek during winter when flows are relatively high. Supporting this theory, the winter drought of 2005 corresponded with the lowest level of coho carcass/adult counts (taken at the end of spawning season) between 2002 and 2007. Additionally, sparse spawning may have occurred during the winter drought 2001, based on early-March carcass observations.

Coho salmon persist in Irely Creek because the salmon's in- and out-migration timing corresponds to the colder, high-flow season for which downstream water (Irely Lake, the lake outlet, and the middle Big Creek main stem) is present. During periods of drought, cutthroat trout have lost their primary adult-rearing habitat in Irely Lake, which formerly provided good cutthroat catches for gillnet sampling (J. Meyer, Olympic National Park, unpublished data) and catch-and-release fishing by ourselves and others (Shorett 1996; Wood 2000). Hence, drought timing will impact run timing (if not abundance) of coho differently than it will impact cutthroat escapement. Thus, climatic and flow variability are likely affecting both species in Irely Creek despite its pristine nature.

Finally, we found noticeably later spawn timing (mid-late March to mid-early May, with a peak in early April and sub-peak in late April) than previously reported for migratory cutthroat trout in the Raft/Quinault River area (i.e., January through March) (Blakley et al. 2000). This difference in timing highlights the need for site-specific biophysical data, given thermal differences between streams, even adjacent ones (Vadas 2006).

Acknowledgments

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Factors Influencing the Distribution of Coastal Cutthroat Trout in a Cascade Mountain Stream

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Extended Abstract.—Aquatic ecologists working in small streams are challenged with the task of identifying stream habitats, the spatial distribution and temporal persistence (i.e., rate of change) of habitat, and the timing and manner in which habitats are used by stream fishes. Because temporal variation of stream habitats and the mobility of stream fishes complicate species abundance-habitat association models (Van Horne 1983), the identification of high quality aquatic habitats is often problematic. In an attempt to assess habitat quality of a stream network in western Oregon, we evaluated the persistence of abundance patterns and habitat associations of coastal cutthroat trout *Oncorhynchus clarkii clarkii* by monitoring stream sections of high and low relative abundance for 13 months. Simultaneous habitat evaluations provided insight into factors affecting distribution patterns in main stem and tributary streams.

The South Fork of Hinkle Creek is located in the Umpqua River basin at the foothills of the Cascade Mountains in southwestern Oregon. The 1,100 ha watershed is dominated by 40-year-old, second-growth conifer forest. Mean annual discharge is approximately 0.20 m^3/s, and mean active channel width is about 4 m. Fish species include steelhead *Oncorhynchus mykiss*, sculpin (*Cottus* spp.), and potamodromous coastal cutthroat trout.

A continuous electrofishing census of fish in the watershed (Bateman et. al 2005; Gresswell et al. 2006) was used to identify 13 main stem and 6 tributary stream sections of high and low relative abundance. Stream sections ranged from 30 m to 320 m long and consisted of multiple channel units (i.e., pool, riffle, and cascade). A total of 320 coastal cutthroat trout (mean fork length = 122 mm; range = 100-190 mm) were implanted with 23-mm half-duplex passive integrated transponder (PIT) tags. Thirty-one stationary PIT-tag antennas were installed at the upstream and downstream boundaries of stream sections to monitor changes in relative fish abundance and individual fish movements continuously throughout the study. Bimonthly surveys using portable PIT-tag antennas were conducted to relocate fish at the channel unit scale. Canopy cover, shrub cover, stream gradient, discrete channel units, maximum depth, pool spacing, active channel width, boulder abundance, large wood abundance, and cobble embededness were quantified in each section (Moore 1997) and monitored throughout the study period.

Differences in the number of fish between high and low abundance sections at the time of initial tagging were statistically significant (one-sided *t*-test, $P < 0.01$) in both main stem and tributaries. Differences in relative abundance of PIT-tagged coastal cutthroat trout between high and low abundance sections remained statistically significant (repeated-measure ANOVA, $F_{1, 91} = 11.62$, $P < 0.01$) in the main stem throughout the study. In contrast, abundance of PIT-tagged coastal cutthroat trout in high abundance sections in the tributary decreased, and differences in the number of fish between high and low abundance section were not statistically significant by the end of the study (repeated-measure ANOVA, $F_{1, 42} = 2.57$, $P = 0.18$; Figure 1).

Results from the bimonthly surveys suggested that the number of fish moving among main-stem study sections was less than among tributary study sections. The mean percentage of fish moving among main stem sections was 37% and 60% for high and low abundance sections, respectively. The mean percentage of fish moving among tributary sections was 55% for high abundance sections and 65% for low abundance sections. In the main stem, high-

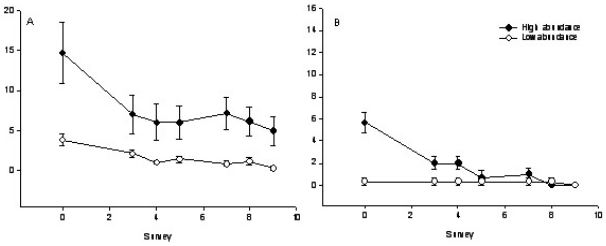

FIGURE 1.— Bimonthly mean PIT-tagged coastal cutthroat trout abundances in high (black points) and low (white points) relative abundance sections in main stem (A) and tributary (B) streams in the South Fork Hinkle Creek watershed, from August 2003 to June 2004. Vertical lines indicate the standard error of the mean.

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abundance sections maintained high abundance, and abundance in low sections remained low, but different individual fish were detected in sections over time (Figure 2).

In August 2003 more boulders were found in high abundance sections (87) of the main stem than low abundance sections (32), and the differences were statistically significant (repeated-measures ANOVA: P = 0.03). A simple linear regression model with boulders as the predictor variable explained most of the observed variation in relative trout abundance in main stem study sections (r^2 = 0.86; P < 0.05). During the August 2004 electrofishing survey, the number of boulders accounted for 92% of the variation in mainstem trout abundance (r^2 = 0.92; P < 0.05).

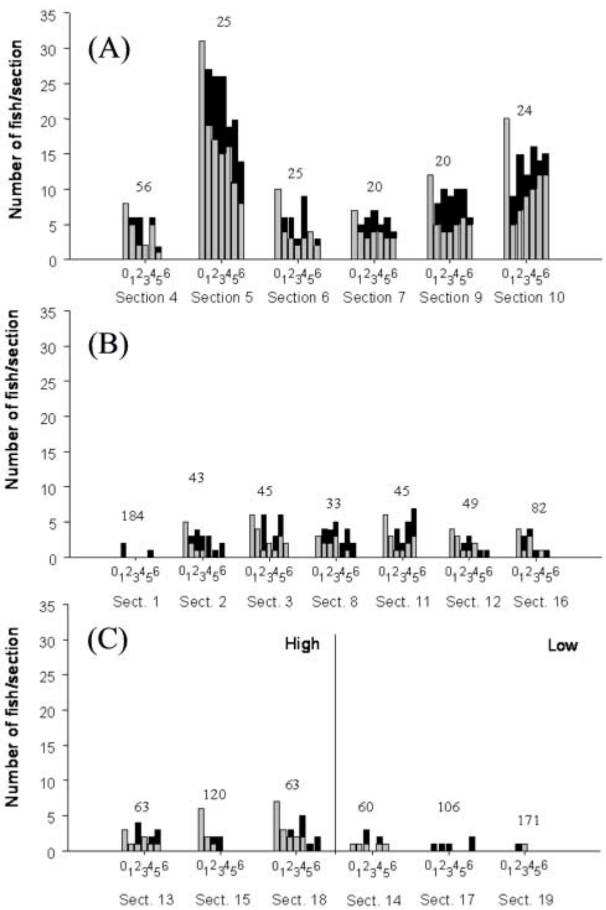

FIGURE 2.— Time series of bimonthly mobile PIT-tag antenna censuses in main stem high (A), low (B), and tributary (C) abundance sections, South Fork Hinkle Creek. Gray bars indicate fish that were present during the previous survey. Black bars are number of new fish moving into that section. Numbers above bars are coefficients of variation for total fish detected in each section. Numbers 0-6 indicate the initial electrofishing and subsequent mobile PIT-tag antenna surveys.

In this study, habitat selection at the multiple channel-unit scale was not random and appeared to be influenced by the presence of physical habitat provided by boulders. These observations provide important implications for sampling and monitoring of trout populations in small streams. Recognition that the spatial pattern and temporal persistence associated with specific habitat types (at a variety of spatial scales) can affect local population size, persistence of populations, and behavior of individual trout may assist resource managers challenged with monitoring trout population dynamics, setting angling regulations, and regulating land management in headwater ecosystems.

Acknowledgements

The U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center provided extensive field support for sampling, equipment installation, and equipment maintenance. Funding for this project was provided by the U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, and the Watershed Research Cooperative (Oregon State University, Department of Forest Engineering), Oregon State Department of Forestry, and Roseburg Forest Products; the latter provided access to the study site. The use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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Biomass Benchmarks for Coastal Cutthroat Trout *Oncorhynchus clarkii clarkii*: Can Ecoregions be Used as a Place-based Standard for Abundance?

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Extended Abstract.—Coastal cutthroat trout (CCT) appear to be the most threatened native trout species in British Columbia, yet our understanding of cutthroat ecology and population assessment ability remains inadequate. The factors most influencing population size and productivity, patterns of regional abundance, and population dynamics are poorly understood at this time. Current conservation initiatives are, therefore, often proceeding without quantitative benchmarks for determining health and conservation status, particularly at the regional level.

It is generally accepted that freshwater salmonid production must be limited to a certain stream-specific level due to the territorial behavior of fish, together with the finite space available to each life stage at various scales: the mesohabitat (e.g., riffles, pools), reach, and watershed level. Because fish abundance collected at any given time or place may be below capacity due to insufficient recruitment to saturate habitat or lack of suitable habitat at a particular site, it is difficult to infer potential capacity for a stream based on a small sample size or when habitats are degraded. A goal of this paper is to develop and describe a method for assessing maximum stream capacity at the mesohabitat scale using retrospective data.

Methods

The protocol for determining maximum or reference density-size or biomass using population self-thinning rules is simple. However, it draws on much structured information and is affected by data quality, patterns of CCT incidence, partitioning total sample site biomass into various ages and species, aggregating biomass for overlapping size classes of CCT with rainbow and/or char, stream and habitat factors, and water chemistry. The underlying hypothesis is that there is a correlation between water chemistry and invertebrate prey production used by cutthroat trout (i.e., a bottom-up effect). There is also an expectation that water chemistry varies in a systematic way between ecoregions as consequence of differences in climate, rainfall, runoff, vegetation, and geology. I expect capacity to rear salmonids will also vary at this large landscape scale in a predictable way.

Specifically, the review attempts to:

(1) Examine fish population density-size information for all sample streams in the Province where coastal cutthroat trout had been captured, were known to be properly identified, and where standard stream inventory methods were followed. Surveys that were multi-season and multi-year duration were favored for the sake of variability in recruitment, fish growth, and in environmental conditions.
(2) Select and annotate density estimates derived from single mesohabitats versus reaches (combination of mesohabitats).
(3) Generate Allen Plots from organized data in an Excel spreadsheet.
(4) Exclude sample streams from the analysis but not from the database in which only shallow mesohabitats were sampled (riffles). This reduces a systematic and negative bias since parr abundance would be much lower than the maximum. Samples from streams that had zero flow and lack of hydraulic diversity were also excluded.
(5) Estimate the elevation in each Allen Plot (biomass envelope curve) using the 95th percentile estimator while assuming the density variance at age or high scatter below the curve results from habitat suitability differences over a broad range in mesohabitats sampled. The scatter may also relate to variable recruitment or loss of fish though emigration. The highest single or average of 95th percentile biomass per stream or group of streams (if sample size was small) was reported per "stream". The life-history stage(s) with the highest biomass was flagged as the driver for the biomass envelope curve.
(6) Locate sample streams according to EcoProvince, EcoRegion, and EcoSection as described by the British Columbia Ministry of the Environment (http://srmwww.gov.bc.ca/ecology/ecoregions/).
(7) Acquire both hydrometric and water quality data for each study stream. Water chemistry results were specific to summer baseflows. Note any special attributes such as presence of salmon spawners or known nutrient enrichment.
(8) Describe and model landscape unit patterns of cutthroat biomass throughout the province.

Results

Sample size and extent of electrofishing

All sample CCT streams were located in the Humid Temperate EcoDomain. Most sampling has been conducted in the South Coast of the Province, which is largely found in the Georgia Depression EcoProvince. In all, 21 of the 25 possible ecosections that contain cutthroat were represented. There were four ecosections that were not sampled: Outer Fiordland, Queen Charlotte Lowlands, Windward Queen

TABLE 1.—Least squares means table. Means shown are for 1-way Anova. Std Error derived using a pooled estimate of error variance.

Level	Number	Mean	Standard error	Lower 95%	Upper 95%
Central Interior	8	2.69275	0.10169	2.4920	2.8935
Coast & Mountains	86	2.33493	0.03101	2.2737	2.3961
Georgia Depression	81	2.64992	0.03196	2.5868	2.7130
Southern Interior	2	2.41026	0.20338	2.0089	2.8117
Sub-Boreal Interior	2	2.21756	0.20338	1.8161	2.6190

Charlotte Mountains, and the Boundary Ranges. There were three ecosections from the Central and Sub-boreal Interior EcoProvinces that contained native cutthroat. These watersheds included small (< 5 m wide) tributaries to the Morice, Bulkley, and Suskwa rivers.

A grand total of 213 streams or local groups of streams were sampled in this study: 88 from Vancouver Island, 86 from the Lower Mainland region, and 39 from Cariboo-Skeena regions. The total number of electrofished sites was 3,144, which produced 8,297 x-y or density-size coordinates in the 213 Allen Plots. All fish were collected using shore-based electrofishing and under ideal conditions for total removal. Many more electrofishing surveys were available; however they were excluded due to incompleteness. Biomass patterns across the landscape using EcoSection resolution There were significant differences (1-way NOVA ratio = 14, $p < 0.0001$, Table 1) in CCT biomass at the EcoProvince level with a geo-mean of 447 g/unit in the Georgia Depression and 216 g/unit in the Coast and Mountains. The 95% confidence interval (CI) for each mean was mean(×÷1.16) using a pooled estimate of error variance. A "unit" of habitat equates to 100 m^2. The trend in biomass within the Georgia Depression was high in the South Gulf Islands (610), Nanaimo Lowlands (598), and Fraser Lowlands (582) ecosections to moderately high biomass in the Georgia Lowlands (398) to lower biomass in the higher unit runoff and higher elevation Leeward Island Mountains (251) (Figure 1). The 95% CI were about 1.2 ×÷ geometric mean where ecosection sample size was adequate ($n > 15$). While biomass was generally low (216) in the Coast and Mountains EcoProvince, exceptional biomass was found in Eastern Pacific Ranges and Kitimat Ranges, each with mean biomass of 376 to 249 g/unit, respectively. Using all biomass data, the adjusted R^2 improved progressively from 22% to 27% to 44% in the summary of model fit, for EcoProvince, EcoRegion, and EcoSection, respectively.

Conclusions

Coastal cutthroat trout abundance varies consistently across the landscape according to ecoregions. Thus, ecoregions can be used as a convenient place-based standard as it already has in stream classifications elsewhere (Harding and Winterbourne 1997). I caution its use, as it is intended to be employed as a realistic predictor of the upper limit to population density of juvenile CCT in streams from the ratio of maximum biomass into mean size (g) at age. It should be used in concert with habitat models that scale maximum density according to mesohabitat weightings.

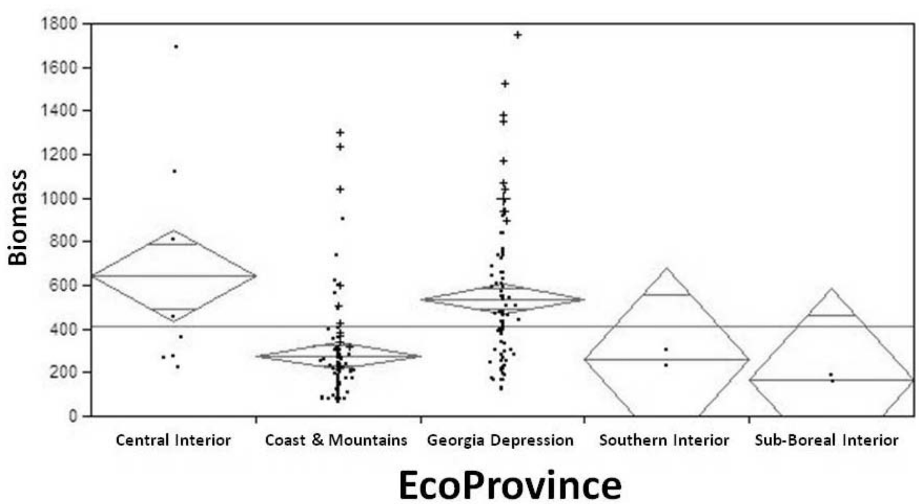

FIGURE 1.—Least squares means and 95% CI (biomass per age or size class in g/100 m^2) for all EcoProvinces that were analyzed in this study. Jitter scatterplot shows all stream cases with enriched in blue and "normal" in red.

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Errors in Visual Identifications of Juvenile Steelhead, Coastal Cutthroat Trout, and Their Hybrids

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Extended Abstract.—Steelhead *Oncorhynchus mykiss* are listed under the U.S. Endangered Species Act (ESA) across much of California and the Pacific Northwest. Juvenile-based population estimates (e.g., Hankin and Reeves 1988) have often been used for discerning trends of ESA-listed salmonids, but this approach is confounded where steelhead are sympatric with coastal cutthroat trout *O. clarkii clarkii*. Juvenile steelhead and cutthroat trout are difficult to distinguish from each other because they are closely related and morphologically similar (Williams 2004). Furthermore, hybridization between the two species is common and produces viable F1 offspring (Bettles 2004; Baumsteiger et al. 2005). Thus, in sympatric settings with all three genotypes present, the estimated proportion of steelhead is likely to be biased (Baumsteiger et al. 2005).

This study sought to better understand the sources of steelhead-cutthroat field classification errors by evaluating genetic data, morphometric, and qualitative phenotypic traits of juvenile trout (n = 761) sampled from two coastal streams in northern California.

Methods

We used a modified Hankin and Reeves (1988) approach to sample the majority of anadromous fish-accessible habitats in two study streams: McGarvey Creek, a third order tributary to the Lower Klamath River, California; and Freshwater Creek, a fourth order tributary to Humboldt Bay, California. Every sampled trout was assigned to one of three visual classifications (steelhead, unknown trout, or cutthroat trout) and a presumptive age class (0 or 1) based on size. Qualitative descriptions of maxillary extension and cutthroat-like slash intensity and morphometric measurements were recorded. We collected tissue samples from a systematic subsample of captured trout to determine those individuals' true genotypes (Baker et al. 2002).

Error rates were discerned by correlating genotype and field classification for each fish. Standardized morphometric relationships were calculated for each age class and genotype in each stream. Two qualitative indexes and three morphometric relationships were used as predictor variables to develop competitive decision tree type models. Error rates for competing models were compared with visual identification error rates.

Results and Discussion

Genotyping revealed that 75% (n = 299) of trout sampled from McGarvey Creek were homozygous for cutthroat trout alleles, 15% (n = 60 fish) were heterozygous for at least one locus (hybrids), and 10% (n = 40 fish) were homozygous for steelhead alleles. For the Freshwater Creek sample, 38% of individuals were homozygous for steelhead (n = 139), 41% were homozygous for cutthroat trout alleles (n= 148), and 21% were heterozygous for at least one locus (n = 75).

Field classification error rates ranged between 8.6% for age 1 trout (n = 152) in McGarvey Creek to 38.4% for age 0 trout (n = 168) in Freshwater Creek, and varied overall by age class and location (Table 1). In both streams visual identifications of age 1 trout were more accurate than for age 0 fish (Table 1).

Specific phenotype-based models demonstrated lower error rates versus actual visual classifications for age 0 fish (maxillary extension) in each location, and for age 1 trout (slash intensity) in Freshwater Creek (Table 1). None of the candidate models, however, significantly outperformed any of the visual classifications—the maximum improvement in accuracy offered by any one model was approximately 8%.

Visual classification error rates were considerably lower for each species and age class in the McGarvey Creek

TABLE 1.—Comparison of error rates for phenotype-based decision tree models versus field classifications of juvenile steelhead, cutthroat, and their hybrids by age class, McGarvey Creek and Freshwater Creek, California, 2003. FL= fork length.

Age	Sample size (n trout)	Decision tree model specifications	Error rate Model	Error rate Visual
McGarvey Creek				
0	247	maxillary extension	20.2%	27.1%
1	152	slash	29.6%	8.6%
1	152	maxillary extension	23.0%	8.6%
1	152	slash maxillary extension maxillary length/head length maxillary length/FL head length/FL	10.5%	8.6%
Freshwater Creek				
0	168	maxillary extension	30.4%	38.4%
1	188	slash	23.4%	23.4%
1	188	slash maxillary extension	24.5%	23.4%
1	188	slash maxillary extension maxillary length/head length maxillary length/FL head length/FL	19.1%	23.4%

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versus Freshwater Creek samples. The relative proportion of steelhead and cutthroat trout in each stream, however, may provide a partial explanation for this pattern. Juvenile cutthroat trout are much more abundant than steelhead in McGarvey Creek and, as such, steelhead appear quite distinct when encountered. In contrast, the higher error rates seen in Freshwater Creek may reflect the inability of field technicians to discern the species when they are present in closer to equal numbers and there is broad overlap of phenotypic characters used to distinguish the species.

In most cases the phenotype-based models had no theoretical chance to outperform the visual classifications because each morphometric relationship had overlapping 95% confidence intervals between genotypes at each study location. Our results corroborated findings by Baumsteiger et al. (2005) that visual classifications are imperfect, and that a substantial fraction of juvenile trout in each sympatric setting are potentially hybrids (15% in McGarvey Creek and 21% in Freshwater Creek).

This blend of genotypes (and overlapping phenotypes) demonstrates the need for accompanying genetic analysis if unbiased population estimation is required for either parent species. Genetic samples that are collected with equal inclusion probabilities can allow estimation of the true species proportions by using the genotypes of sampled trout to calibrate the first phase sample of visual identifications (Hankin et al., in press).

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Estimating Abundance of Juvenile Steelhead in the Presence of Coastal Cutthroat Trout and Steelhead-Cutthroat Hybrids: A Two-Phase Approach

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Extended Abstract.—In northern California, steelhead *Oncorhynchus mykiss* are listed as endangered. Monitoring of steelhead populations is complex because juvenile steelhead are difficult to visually distinguish from sympatric coastal cutthroat trout *Oncorhynchus clarkii clarkii* and their hybrids. We propose an estimation scheme whereby biased visual identifications of fish can be adjusted by known genetic identifications, thereby allowing an essentially unbiased estimate of the abundance of juvenile steelhead. First, a modified Hankin and Reeves (1988) survey is used to estimate the total abundance of juvenile "trout" (a combined category including coastal cutthroat, their hybrids, and steelhead). Second, all fish collected by electrofishing are visually classified as coastal cutthroat trout, hybrids (or unknown), or steelhead, and a second phase subsample of these same fish are subjected to genetic analyses which allow determinations of true species categories. This second two-phase survey uses a two-phase ratio estimator to produce an approximately unbiased estimate of the proportion of steelhead. Total abundance of steelhead is then estimated as the product of the estimated total number of "trout" and the estimated proportion of steelhead among all "trout" (Hankin and Mohr, in press).

In summer and fall of 2000, 2002, 2003, and 2004 we collected fin clips from samples (100 < n < 350) of juvenile "trout" from six small coastal streams in northern California (Baumsteiger et al. 2005; H. Voight, Humboldt State University, unpublished). Experienced fishery biologists visually classified all collected fish as steelhead, unknown (hybrids?), or as cutthroat. Seven nuclear DNA loci that exhibit fixed species-specific differences between steelhead and coastal cutthroat trout were used to identify pure steelhead, pure coastal cutthroat trout, and their hybrids (Baker and Moran 2002). Individuals that were homozygous at all seven loci for the steelhead alleles were judged to be pure steelhead.

We constructed cross-classification tables of visual and genetic identifications of our field data to calculate empirical values of two conditional classification probabilities (Gordis 2000) that are key to use of our proposed estimation scheme: 1) *sensitivity*—the probability that a true steelhead is visually classified as a steelhead, and 2) *specificity*—the probability that a true "non-steelhead" (hybrid or coastal cutthroat trout) is visually classified as a "non-steelhead. Note that the complements of these classification probabilities have important statistical interpretations: *(1 – sensitivity)* = probability of a "false negative", whereas *(1 – specificity)* = probability of a "false positive".

We used Monte Carlo simulation methods and analytical approximations of sampling variance to determine the relationships between the performance (expected value, sampling variance, and mean square error) of our two-phase estimator of the proportion of steelhead and the underlying errors of visual identification, measured via sensitivity and specificity. These analyses assumed that the genetic identifications were error free.

Our field-based calculated values of sensitivity ranged from 0.55 to 0.98 and averaged about 0.83. Calculated specificities ranged from 0.62 to 1.00 and averaged about 0.93. Classification errors were greater for large (>85 mm fork length) juveniles in 2000, but in other years classification errors were greater for small (<85 mm) juveniles. Assuming, conservatively, that the cost per fish of genetic classification is 20 times the cost of a quick visual classification, the average sensitivities and specificities that we calculated imply that our proposed two-phase ratio estimator would have lower sampling variance than an equal cost survey based exclusively on use of genetic methods. This conclusion holds as long as the proportion of steelhead ranged from 0.15 to 0.90. For larger or smaller proportions of steelhead, the two-phase approach may still be advantageous, but only if sensitivities and specifies are larger than the average values from our field samples and/or if the relative costs per fish are substantially greater than 20.

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Status, Habitat Relations, and Interspecific Species Associations of Coastal Cutthroat Trout in Two Managed Tributaries to the Smith River, California

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The Smith River located in Del Norte County is one of the few remaining undammed coastal rivers in California, designated and protected as such in 1986 through the Wild and Scenic Rivers Act. Its surrounding watershed is considered critical refuge for declining native fish; natural runs of Chinook salmon *Oncorhynchus tshawytscha*, coho salmon *O. kisutch*, chum salmon *O. keta*, steelhead *O. mykiss irideus*, and coastal cutthroat trout *O. clarkii clarkii* can be found in many of its tributaries.

Mill Creek is a productive anadromous fish-bearing tributary of the Smith River that originates in reforested land south of the Smith River and runs through several miles of protected redwood groves before meeting the Smith approximately 23 river kilometers from the Pacific Ocean. Long-term fisheries monitoring was initiated in Mill Creek in 1994. The fisheries program includes annual estimations of adult spawner escapement, smolt salmonid outmigration, and summertime abundance dive counts.

The study area includes two anadromous tributaries to the main stem Mill Creek, known as the West Branch and East Fork of Mill Creek. The West Branch and East Fork watersheds vary in size (2,882 ha and 4,263 ha, respectively), however both tributaries offer similar lengths of anadromous habitat (10,660 m and 11,799 m, respectively) (Howard and McLeod 2005). The Mill Creek watershed is steep and ranges from 60-731 m above sea level. Mean annual rainfall ranges from 152-380 cm and mean monthly temperatures range from 9-16 °C. Lower reaches of Mill Creek are broad, flat valley bottoms with large amounts of stable sediment in terraces located above the active channel (Madej et al. 1986). Stream morphologies in the study area vary from colluvial, boulder-cascade, step-pool, and bedrock channels in the upper basin positions to forced pool-riffle and plane-bed alluvial channels in the lower basin areas (Stillwater Sciences 2003).

The coastal cutthroat trout is considered a master in solving the problems of living in many diverse environments. The cutthroat displays one of the most diverse and flexible life histories of any of the Pacific salmonids (Johnson et al. 1999). Cutthroat trout utilize a variety of life history strategies to occupy a variety of ecosystems in most coastal and headwater tributaries. Cutthroat trout morphology in the Mill Creek watershed, given their coastal proximity to the Pacific Ocean and lack of anadromous barriers low in the watershed, can be characterized as representing both anadromous and fluvial life histories. Annually, during outmigration trapping (February through July), adult cutthroat can be best described as anadromous (adults appearing with small, well disbursed spotting and silvered), ranging in size from 170-420+ mm. In addition, similarly sized adult cutthroat that are captured during this same period have larger spots and less silver coloration. These individuals are most likely a part of a fluvial life history. Cutthroat ranging from 96-138 mm that generally show no parr marks and take on the appearance of a small adult fish are thought to be smolts of the species. Small spots, relative to body size, and overall coverage are still very much visible on the smolting cutthroat, completely covering the smolt unlike their steelhead and coho salmon cousins within the watershed. A resident life history stage is also present in the watershed, and usually is only observed during large storm events that may flush them downstream into outmigration traps. These resident cutthroats lack the size and appearance of the anadromous life history, displaying a very colorful, mottled spot pattern, with background colors typically appearing silver with purple to bluish sheens.

Although these two tributaries have similar lengths of anadromy, there is clearly a difference in the way riparian areas were harvested, including adjacent upslope areas which contributed large woody debris (LWD). Large woody debris recruitment, which operates on a longer time scale and provides critical fish habitat, can be degraded by riparian harvest (Hall and Lantz 1969; Hall et al. 1987; Murphy and Koski 1989; Bilby and Ward 1991). Methods of harvest, timing of harvest, stream cleaning, and limited regulation adjacent to riparian areas has affected both tributaries, but in different ways, resulting in low wood recruitment and subsequent pool formation over the last several decades. However, as seen in stream data there is a significant difference between the two tributaries when comparing pool frequency and depth (Figure 1) and pool composition (Figure 2). Data collected shows that both pool depth and frequency are significantly higher in the West Branch than the East Fork Mill Creek (V. Ozaki, Redwood National and State Parks, personal communication).

Logging has occurred in the Mill Creek watershed since 1908. Timber harvest first occurred in the West Branch of Mill Creek over a period of 14 years, and was later initiated in the East Fork of Mill Creek in 1954. Different LWD levels exist in the two tributaries because riparian area harvest methods changed between when the West Branch was harvested (1908-1922), and when the East Fork was harvested (1954-1989). Delayed entry into the East Fork of Mill Creek was the result of many factors, including World War II, the limited value for redwood lumber, new land acquisitions, and timber management techniques of the era. Timing of harvest entry into the West Branch versus the East Fork of Mill Creek was separated by several decades.

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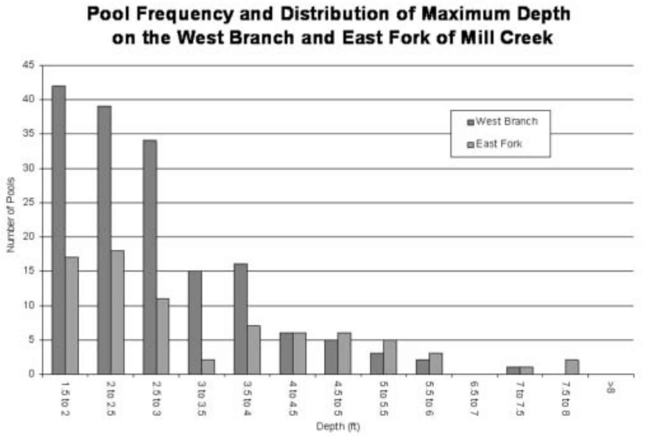

FIGURE 1.—Pool frequency and distribution of maximum depth on the West Branch and East Fork of Mill Creek.

To the best of our knowledge, the majority of harvest occurring in the West Branch Mill Creek took place adjacent to anadromous reaches, both affecting LWD recruitment and riparian composition between 1908 and 1922. Harvest removal techniques included the use of rail cars, steam donkeys, and horse and oxen. These were fairly "dirty" techniques, which left a lot of standing timber and low value trees and avoided salvaging logging or removal of low value instream LWD. Headwater portions of the West Branch Mill Creek, including some areas potentially suitable to anadromous species that specialize in confined, higher velocity channels, where not entered until after 1954, which coincided with the first entries into the East Fork Mill Creek. Areas harvested adjacent to riparian habitat on the West Branch after 1954 were logged with long lines and cable machines. In addition, a large portion of the anadromous section of West Branch was secured in the early 1930s as part of a California State Park land acquisition, subsequently eliminating any threat of timber harvest.

The East Fork Mill Creek was left largely untouched until 1954. Limited logging occurred prior to 1954 on the lower portions of the East Fork; however those areas adjacent to anadromous reaches where not heavily logged until after the purchase of the tributary by Stimson Lumber Company in 1945. Logging ceased in 1999 in both the West Branch and East Fork of Mill Creek due to the sale and transfer of ownership from Stimson Lumber Company to California State Parks (completed in 2001).

Forest practice rules within California governing the logging and removal of vegetation within riparian zones were not effective until 1989 (R. Cox, retired General Manager Stimson Lumber Company, California, personal communication), when enforcement and increased standards limited access and harvest within these areas. Before 1989, logging adjacent to stream zones often included the complete removal of hardwoods and conifers, and often involved large wood removal from within the stream channel, a process known as "stream cleaning".

The observed differences in pool frequency and composition are most likely a relic of harvest history (i.e., time of entry, harvest level, stream cleaning, and type of harvest), which may also account for observed biological differences seen in the two tributaries. Increased salmonid production post-harvest followed by a decrease in productivity has been observed in many Pacific Northwest streams as salmonid populations respond to riparian logging (Murphy and Hall 1981; Hawkins et al. 1983; Bission and Sundell 1984; Murphy et al. 1986; Beschta et al. 1987; Gregory et al. 1987; Bilby and Bission 1992).

Overall, cumulative coastal cutthroat trout smolt production over the last 11 years has not varied much within the two tributaries, with cutthroat smolt production within the West Branch totaling 15,546 versus 15,071 in the East Fork (Figure 3). This lack of variation has not been observed for the other overwintering species that occur in the system, coho salmon and steelhead. Both species have shown a twofold increase in overall smolt production during 11 years of trapping, with the West Branch producing significantly higher smolt output than the East Fork (Figure 3). Although West Branch production is slightly higher

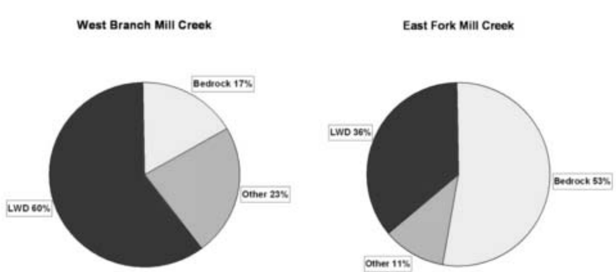

FIGURE 2.—Pool composition on the West Branch and East Fork Mill Creek.

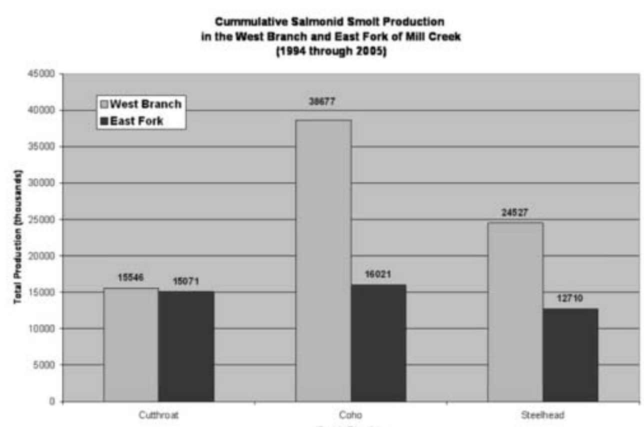

FIGURE 3.—Cumulative smolt production estimates for the West Branch and East Fork of Mill Creek (1994 through 2005).

than the East Fork, cumulative cutthroat trout production appears to be the same for both tributaries.

Looking specifically at the East Fork, cumulative steelhead smolt production is lower than coastal cutthroat trout production (Figure 3). Only coho salmon appear to have a slightly higher number than steelhead and cutthroat. Instream habitat quality in the East Fork may be a factor contributing to the observed densities among freshwater life histories of these three species. As seen in Figure 2, pool habitat specifically created by large wood is half that of the West Branch, which most likely contributes to the decreased production among all three species in the East Fork. However pool habitat does not appear to be a factor affecting the smolt production in the West Branch, which may be more dependent on interspecific competition. It is also a possible that a significant portion of the anadromous and fluvial population merely redistribute during a given season, depending on habitat availability and density dependent competition. Since cutthroat trout are considered one of the least aggressive of the salmonid species, when they can be pushed to marginal habitat by more aggressive coho salmon and steelhead (Trotter 1989). Woody debris, boulders, and other complex habitat features provide cutthroat shelter from their aggressive coho and steelhead relatives. Such refuge may not be available with increasing coho densities as observed within the last several years of outmigrant trapping on the West Branch and East Fork (Howard and McLeod 2005).

It appears interspecific competition among species has played a role in West Branch Mill Creek, where coho salmon are the more dominate species. Interactions between coho and coastal cutthroat trout have potentially reduced or kept anadromous cutthroat numbers to a minimum within the watershed; however it is unclear if coho, the more aggressive of these salmonids, have caused redispersal of anadromous populations. During spring outmigration trapping, a significant number of pre-smolting cutthroats (cutthroats not taking on the appearance of smoltification, although similar in size) are captured in May and June (Howard and McLeod 2005). These populations were not sampled for mark-recapture estimates. Although these captured pre-smolt numbers were comparable in size to captured smolt numbers, population estimates were not conducted due to concerns with recapture probabilities.

Unlike coho salmon and steelhead, coastal cutthroat trout smolt production within the West Branch and the East Fork has been very similar over the last 11 years of monitoring (Figure 3). Interestingly, the cumulative cutthroat smolt production is almost identical within both tributaries and different than the variable production experienced by the other salmonids. The difference in observed smolt production levels between the two tributaries may indicate limited habitat availability in the East Fork and more stable, potentially further recovered habitat in the West Branch. However, density dependent competition, rather than habitat availability may contribute more to the observed numbers of smolts in the West Branch.

Populations of salmonids native to the two tributaries underwent habitat disturbance through anthropogenic activities during different time periods. Differences in harvest history, harvest method, and time of entry within the two tributaries reflect the observed variation in both pool frequency and LWD created habitat types. These differences may correlate to observed population size of salmonids within the watershed, and their subsequent cumulative production levels. Riparian logging can alter chemical, biological, and physical processes and features that shape stream ecosystems and in turn determine population densities and community structure of salmonids (Gregory et al. 1987; Reeves et al. 1993). Because these processes and habitat features operate at different time scales, the recovery of fish populations following riparian logging represents an integrated response to multiple habitat attributes that change through time (Gregory et al. 1987). It appears, however, that cutthroat trout utilizing Mill Creek and its tributaries for rearing and reproduction are able to take advantage of various ranges and qualities of habitat, and maintain relatively stable populations that are cable of replacing themselves.

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Demographics of Coastal Cutthroat Trout *Oncorhynchus clarkii clarkii* in Prairie Creek, California

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Abstract.—The southern distribution of coastal cutthroat trout *Oncorhynchus clarkii clarkii* terminates in northern California. Coastal cutthroat trout have received less attention in this region than they have further north and less is known of their ecology and abundance. We monitored population abundance in and gathered basic biological data from fish in three coastal streams in northern California during 2000-2004. Density ranged from 107-983 fish/ha during the period and varied among streams and years, although strong temporal trends were not apparent. Density was greater in pool and run habitats than in riffle habitats. Density was correlated with abundance of juvenile coho salmon, *O. kisutch*, in pool habitats, but not in run or riffle habitats. The size of 1,220 coastal cutthroat trout measured during the period ranged from 50-269 mm. Size of fish sampled differed among streams, years, and habitat types. Condition of coastal cutthroat trout also did not differ among streams or between seasons, but did differ among years. Our principal finding was that coastal cutthroat trout population abundance in northern California streams sampled appears stable, although abundance varies with habitat condition.

Coastal cutthroat trout *Oncorhynchus clarkii clarkii* occupy coastal streams in northwestern California extending from the Eel River, the southern limit of distribution, to the Oregon border. Their distribution at the southern end of the range is limited to a narrow band only about 8 km inland, but this inland distribution widens to about 48 km along the California-Oregon border (Gerstung 1997). Coastal cutthroat trout have been found in 182 streams and occupy about two-thirds of stream habitat within this limited area, although their population density is typically low (Gerstung 1997). The limited distribution and low population density of coastal cutthroat trout in California has contributed to the general lack of information on their ecology and status within the state. However, the National Park Service has compiled long-term monitoring data for the Redwood Creek Estuary that includes coastal cutthroat trout (Anderson 1997). Most of the coastal cutthroat trout found in this estuary are migrants from the Prairie Creek watershed.

Much recent research on coastal cutthroat trout has focused on life history variation within the species and hybridization with steelhead, *O. mykiss* (Williams 2004). Life history variations, ranging from stream residency to potadromy and anadromy (Trotter 1997), complicate assessment of population status. The apparent propensity of coastal cutthroat trout to hybridize with steelhead further complicates investigations of their biology (Williams 2004).

Our objective in this study was to provide a base of information on the population status of coastal cutthroat trout inhabiting three northern California coastal streams. Toward that end, we present information on population density, distribution within stream reaches, and size of coastal cutthroat trout gathered over a five-year period.

Study Area

The Prairie Creek watershed lies within the Northern California coastal zone in Redwood National and State Parks, Humboldt County, California (Figure 1). Prairie Creek is a coastal stream that drains into Redwood Creek less than 5 km above the latter stream's confluence with the Pacific Ocean. The majority of the Prairie Creek basin is underlain by shallow marine and alluvial sedimentary rocks. The lower portion of the basin consists of shallow marine sands, whereas upper portions consist of coarse alluvial sequences (Cashman et al. 1995). Annual air temperatures are moderated by proximity to the Pacific Ocean, and average 11 °C. Mean annual precipitation is 172 cm, and occurs almost entirely as rain during November through April. Discharge is low in summer and high in winter. The Prairie Creek watershed is forested with old growth redwood *Sequoia sempervirens* and Sitka spruce *Picea sitchensis* mixed with western hemlock *Tsuga heterophylla*, bay laurel *Umbellularia californica*, big leaf maple *Acer macrophyllum*, and red alder *Alnus rubra*. Study areas included the upper 6 km of Prairie Creek, and the lower 2 km in Boyes and Streelow creeks, which are tributaries to Prairie Creek.

The three streams were selected for study because they are in the same watershed, but have different land use histories. The portion of Prairie Creek studied is a fourth order stream draining an area of 34.4 km^2 that is primarily an old growth redwood forest. Mean annual discharge is 1.49 m^3/s, gradient is 0.0032 m/m, and stream substrate consists of well sorted cobbles and gravels. Streelow Creek is a third order stream draining an area 5.7 km^2 that was logged of redwood timber during the 1950s. Forest cover in

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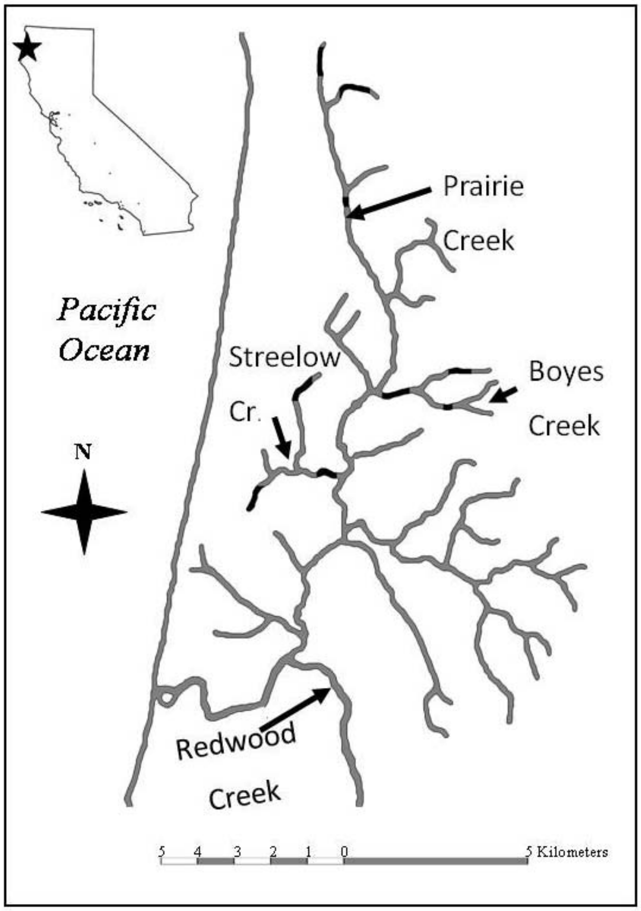

FIGURE 1.—Map of the Prairie Creek watershed, Humboldt County, California.

this watershed now consists of second growth redwood mixed with red alder. Mean annual discharge is 0.25 m^3/s, gradient is 0.0040 m/m, and stream substrate consists of small cobble mixed with sand. Boyes Creek is a third order stream draining an 4.4 km^2 area containing predominantly second growth redwood mixed with red alder, big leaf maple, bay laurel, and western hemlock. Boyes Creek is considered impaired by fine sediment introduced by a road construction failure in 1989, as well as past logging practices and unstable hill slopes. The streambed consists of cobbles, often embedded within fine sediments and silts. Other fish species present in these streams include coho salmon *O. kisutch,* Chinook salmon *O. tshawytscha,* steelhead, threespine stickleback *Gasterosteus aculeatus*, prickly sculpin *Cottus asper*, coastrange sculpin *C. aleuticus*, Pacific lamprey *Lampetra tridentata*, Pacific brook lamprey *L. pacifica,* and Sacramento sucker *Catostomus occidentalis.*

Methods

We estimated population abundance of coastal cutthroat trout in sections of each of the three streams during July and October 2000 through 2003, and in July 2004. Areas sampled each year in Streelow and Boyes creeks extended from their confluence with Prairie Creek upstream to near the first barrier to migration, 2.1-2.3 km. The area sampled in Prairie Creek consisted up a 6 km reach terminating about 2.0 km downstream of the first barrier to migration.

We used a modified Hankin and Reeves (1988) method to estimate abundance of cutthroat trout during all years. In July of each year we measured the total area of shallow pool, deep pool (>1.1 m deep), run, and riffle habitats within each stream study reach. We used an adaptive sequential independent sampling (ASIS) scheme to randomly assign habitats for first phase fish sampling (Brakensiek 2002). The ASIS scheme results in approximately equal probabilities of inclusion for all habitat units, with a reduction in variation among sample sizes. Number of habitat units randomly selected for sampling averaged 39 in Boyes Creek, 29 in Streelow Creek, and 95 in Prairie Creek over all years.

We used two sampling techniques in the three streams. Sampling in Prairie Creek involved single pass diver observations in the habitats randomly selected. Single pass diver observations consisted of two divers moving slowly upstream parallel to one another and recording fish observed. We calibrated diver observation efficiency in randomly selected habitats using the method of bounded counts. We used the number of juvenile coho salmon observed during the first pass to determine the method of calibration sampling. When 20 or fewer coho salmon were observed in a habitat unit during the first phase diver observation, calibration sampling involved three additional single pass diver observations. Calibration dives were repeated immediately after the first phase observation. If more than 20 coho salmon were observed, three to five pass depletion electrofishing was used to calibrate diver observations. Habitat units selected for depletion electrofishing were blocked on the upstream and downstream ends with 6 mm mesh netting, then sampled with two backpack electroshockers. Boyes and Streelow creeks contained smaller habitat units than Prairie Creek that were difficult to dive without disturbing fish. Therefore, we sampled all randomly selected units in Boyes and Streelow creeks using depletion electrofishing. We considered a habitat unit depleted when 20% or fewer coho salmon were captured during a sampling pass, relative to the previous pass. We believe that our use of coho salmon density to determine habitat unit calibration methods and electrofishing depletion did not bias results for coastal cutthroat trout. Density of coho salmon in these streams was about ten times greater than density of coastal cutthroat trout and data indicated that sampling almost always depleted trout before salmon.

We recorded size from a subsample of coastal cutthroat trout from each stream each year. Size was recorded from fish captured during electrofishing; we did not attempt to classify size of fish during diver observations. We measured fork length (FL, nearest mm) on a measuring board and weight (nearest 0.01 g) using a portable electronic balance. We calculated Fulton's condition of fish as

$$\left(\frac{w}{l^3}\right)\cdot 10{,}000$$

where *w* = weight (g) and *l* = fork length (mm) (Ricker 1975). We multiplied Fulton's condition factor by 10,000 to make expressed results more understandable. Due to potential hybridization with steelhead in these streams (Neillands 2001), we identified fish less than 80 mm FL as coastal cutthroat trout only if the maxillary extended beyond the posterior margin of the eye and red or orange coloring was present on the inner edge of the lower jaw.

We estimated coastal cutthroat trout density, size, condition, and distribution. A mixed-model ANOVA was used to assess differences in density (number/m^2) and size (log[FL]) among streams, years, seasons (July and October), and habitat types. We used a logarithmic transformation of fork length data to approximate normality in analyses. Interaction terms in the analysis of density data were significant, so in place of the mixed-model, we used one-way ANOVA to analyze for differences among or between each of the independent variables. We used linear regression to analyze patterns of cutthroat trout density and size within the sample reaches. We expressed location as percent distance upstream within the study reach, since linear distance sampled in each stream varied. Throughout our analyses, we used an α of 0.05 to determine significance and all analyses were conducted using SYSTAT v 10.0 (SYSTAT Software Incorporated, Chicago, Illinois).

Results

Habitat characteristics varied among the three streams. In Prairie Creek pool, run, and riffle habitats were present in roughly equal proportions, but pools covered 48.5% of the total habitat area (Table 1). Mean maximum pool depth in Prairie Creek was 0.81 m and mean area of all habitats was 77.6 m^2. In Streelow Creek, pools were the most frequent habitat type encountered and covered 49.6% of the total habitat area. Mean maximum pool depth in Streelow Creek was 0.70 m and mean area of all habitats was 37.4 m^2. In Boyes Creek, riffles were the most frequent habitat type encountered and covered 44.4% of the total habitat area. Mean maximum pool depth in Streelow Creek was 0.45 m and mean area of all habitats was 28.0 m^2.

Density of coastal cutthroat trout differed among streams, years, seasons, and habitat types. Density was greater (df = 2, F = 147.13, $p < 0.0001$) in Streelow Creek than in either Boyes Creek or Prairie Creek (Tables 2, 3, and 4). Among years, density in 2004 (614/ha) was greater (df = 4, F = 9.28, $p < 0.0001$) than other years, while density in 2000 (444/ha) and 2001 (383/ha) was greater than density in 2002 (315/ha) and 2003 (248/ha). Total density was greater in July than in October in all three streams (df = 1, F = 22.56, $p < 0.0001$). This seasonal pattern was, however, not consistent among all habitats. In each stream, densities in run habitats during October were greater than in July during two to three years. Among habitats, density was greater (df = 2, F = 4.51, $p < 0.0111$) in runs (408/ha) and pools (378/ha) than in riffles (268/ha).

Density of coastal cutthroat trout was unrelated to position in the stream, but related to potential prey in some habitats. The relationship between density and location in the stream as measured by percentage of distance upstream within the study reach was not significant (df = 1, f = 0.0671, p = 0.7968) and appeared to explain none of the variation in density (r^2 = 0.00). Density was positively correlated with density of juvenile coho salmon in pool habitats (df = 1, f = 20.16, p = 0.0001, r^2 = 0.424) and also in run habitats (df = 1, f = 3.86, p = 0.0606, r^2 = 0.099), though the relationship in run habitats was not significant. Density in riffle habitats was not correlated with density of coho salmon (df = 1, f = 0.006, p = 0.9391, r^2 = 0.000).

Size of coastal cutthroat trout varied little, although differences were often significant. Coastal cutthroat trout were largest in Streelow Creek (mean FL = 115.4 mm), while in Prairie Creek average FL was 110.6 mm and in Boyes Creek it was 104.5 mm. However, differences among streams were not significant. (df = 2, f = 0.799, p = 0.450). Both Steelow and Prairie creeks contained low numbers of fish greater than 200 mm FL, but the largest fish

TABLE 1.—Average number of habitats (n), total habitat area (ha), and percent habitat area available in three northern California creeks sampled during 2000–2004. Standard errors are in parenthesis.

Location	Pool	Run	Riffle	Total
Prairie Creek n	127 (9.8)	117 (16.2)	153 (9.8)	397 (27.2)
area (ha)	1.245 (0.101)	0.643 (0.065)	0.677 (0.035)	2.565 (0.147)
area (%)	49	25	26	100
Streelow Creek n	76 (8.8)	58 (6.1)	49 (4.0)	183 (11.8)
area (ha)	0.363 (0.037)	0.241 (0.018)	0.128 (0.015)	0.732 (0.038)
area (%)	50	33	17	100
Boyes Creek n	59 (7.2)	65 (8.0)	91 (8.6)	215 (17.6)
area (ha)	0.154 (0.021)	0.166 (0.034)	0.256 (0.012)	0.576 (0.045)
area (%)	27	29	44	100

TABLE 2.—Estimated population density (number/ha) of coastal cutthroat trout in different habitat types of Prairie Creek and total density.

Year	Month	Pool	Standard error	Run	Standard error	Riffle	Standard error	Sum	Standard error
2000	July	240.4	35.9	256.3	34.8	200.7	89.1	233.0	31.8
	Oct.	74.7	27.5	107.7	9.2	239.7	94.1	130.9	30.1
2001	July	119.2	34.6	274.7	74.3	520.4	164.8	242.9	43.4
	Oct.	64.8	19.5	44.1	6.3	39.1	23.3	153.9	11.6
2002	July	89.1	38.9	104.7	20.6	319.0	141.5	157.6	43.9
	Oct.	79.3	6.5	165.9	29.8	97.5	65.7	106.6	20.2
2003	July	130.1	32.0	163.5	8.2	565.9	228.8	239.2	54.7
	Oct.	75.2	15.9	182.0	28.2	64.2	49.5	102.5	15.8
2004	July	245.4	52.7	467.9	169.5	87.4	47.9	234.6	43.7

TABLE 3.—Estimated population density (number/ha) of coastal cutthroat trout in different habitat types of Streelow Creek and total density.

Year	Month	Pool	Standard error	Run	Standard error	Riffle	Standard error	Sum	Standard error
2000	July	759.5	218.8	1,210.2	107.9	266.7	71.8	789.3	121.7
	Oct.	792.1	210.1	1,043.3	186.4	762.0	133.0	855.2	126.2
2001	July	1,020.3	570.9	1,188.7	171.7	465.9	233.0	983.8	242.4
	Oct.	697.4	427.0	1,541.3	290.7	220.5	113.6	953.1	209.0
2002	July	1,063.2	192.9	614.7	130.9	394.4	121.6	774.2	101.6
	Oct.	782.6	216.5	727.9	184.9	258.0	85.8	657.8	118.4
2003	July	537.2	133.2	518.1	106.5	444.9	121.3	521.7	88.4
	Oct.	403.4	92.3	269.9	107.0	89.5	82.1	332.2	64.6
2004	July	619.5	138.1	595.1	136.4	523.6	364.1	708.0	102.3

TABLE 4.—Estimated population density (number/ha) of coastal cutthroat trout in different habitat types of Boyes Creek and total density.

Year	Month	Pool	Standard error	Run	Standard error	Riffle	Standard error	Sum	Standard error
2000	July	678.3	201.6	801.5	167.1	213.2	75.0	564.5	87.9
	Oct.	651.7	223.5	922.8	171.7	193.4	52.9	597.9	90.8
2001	July	1,278.6	402.4	852.6	222.1	80.6	56.9	653.2	142.1
	Oct.	781.2	319.5	625.2	191.8	13.6	18.5	409.0	112.9
2002	July	1,488.0	202.3	695.2	139.9	562.8	12.6	714.0	66.1
	Oct.	1,211.5	238.1	751.3	180.9	196.3	70.0	526.6	86.4
2003	July	996.3	272.3	505.6	66.9	118.1	28.0	377.7	47.9
	Oct.	1212.9	414.6	535.3	130.1	39.3	19.3	378.8	75.5
2004	July	651.2	309.2	1412.7	254.7	45.8	34.1	529.0	114.4

collected in Boyes Creek was 181 mm FL (Figure 2). Mean size of cutthroat trout ranged from 104.4-114.4 mm FL annually. Differences in size among years were significant (df = 4, f = 3.287, p = 0.0109), with size being greater in 2002, 2003, and 2004 than in 2000 and 2001. Size of fish collected in July (mean FL = 113.6 mm) were only slightly larger than those in October (mean FL = 107.8 mm), but differences between seasons were significant (df = 1, f =

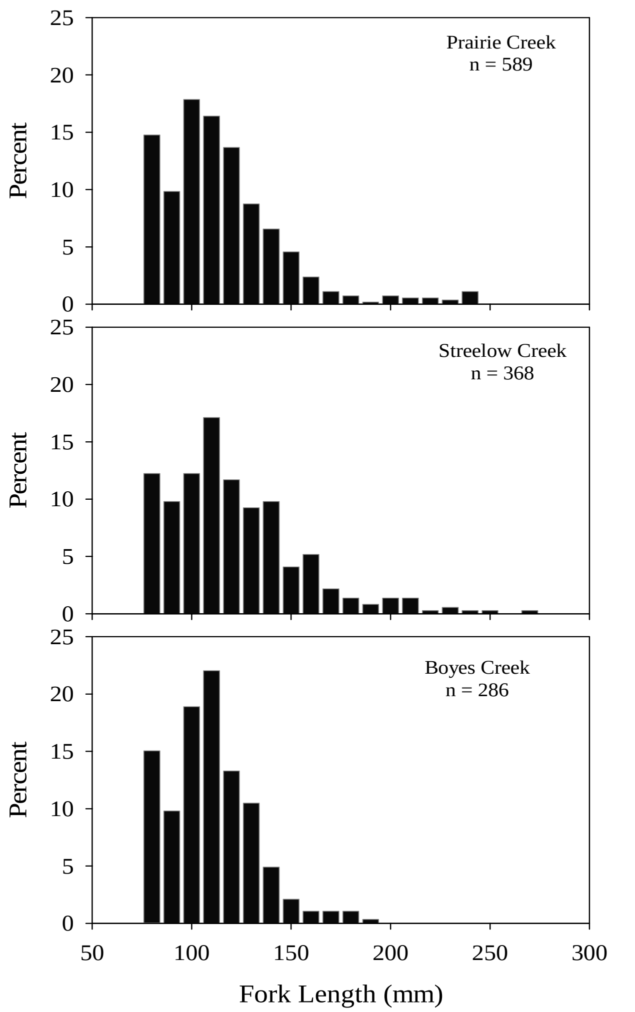

FIGURE 2.—Size-frequency distribution of coastal cutthroat trout from three northern California streams during 2000-2004.

6.071, p = 0.0139). Coastal cutthroat trout in pools were larger (mean FL = 114.4, range 58-269) than in runs (mean FL = 104.3, range 51-236) or riffles (mean FL = 81.0, range 50-137). Differences in size among habitats were significant (df = 2, f = 41.168, p < 0.0001).

Condition of coastal cutthroat trout appeared to vary little. Indeed, condition among streams ranged from 0.1083–0.1119 and was not significantly different (df = 2, f = 0.082, p = 0.9214). Among years, condition did differ (df = 4, f = 7.184, p < 0.0001), ranging from 0.1085 in 2000 to 0.1138 in 2001. Fish were heavier in 2001 and 2004 than in other years. Condition of fish was also greater in July (0.1120) than in October (0.1077) (df = 1, f = 47.902, p < 0.0001). Finally, we found no difference in condition of coastal cutthroat trout in different habitats (df = 2, f = 0.066, p = 0.7968).

Discussion

Our principal finding was that population density of coastal cutthroat trout appeared to be relatively stable over five years in the three northern California streams we studied. Average population density during 2000-2004 ranged from 731 fish/ha in Streelow Creek to 178 fish/ha in Prairie Creek. Population density of coastal cutthroat trout we report are consistent with densities reported from other streams in California (Mitchell 1988, Justice 2007) and Oregon (Reeves et al. 1993), but lower than in British Columbia (Rosenfeld et al. 2000).

We found the greatest population density of coastal cutthroat trout in Streelow Creek, a stream we considered recovering from past disturbance. Population density in this stream, whose watershed had been logged during the period 1950-1960, was about three times that of Prairie Creek, a stream that is considered relatively undisturbed. Although this finding is inconsistent with the relationship between coastal cutthroat trout density and logging history reported by Reeves et al. (1993), we consider Streelow Creek to be in recovery and the time that has elapsed since disturbance may be sufficient to allow fish population recovery. Furthermore, habitat features common in Streelow Creek likely also favored coastal cutthroat trout. It is a relatively small stream, mean width 3.3 m, with a relatively high proportion of deeper pools offering deep, low velocity habitat, and high density of large woody debris (LWD). Rosenfeld et al. (2000) found that cutthroat trout density was negatively related to stream width and that cutthroat were most abundant in small streams. Streelow Creek is intermediate in size between Prairie Creek (mean width 3.9 m) and Boyes Creek (mean width 2.6 m). Rosenfeld et al. (2000) also found a negative relationship between coastal cutthroat trout density and percent of an area in pool habitat. However, density of coastal cutthroat trout in tributaries of the Smith River, California, were greatest in deeper (0.4-1.0 m deep) habitats with water current velocities of less than 30 cm/s (Mitchell 1988). Positive associations of larger coastal cutthroat trout have been reported from British Columbia (Rosenfeld et al. 2000) and California (Harvey et al. 1999). Volume of LWD in Streelow Creek is less than in Prairie Creek, with both these streams having much greater volumes of LWD than Boyes Creek. Thus, it appears that the combination of stream size and habitat conditions in Streelow Creek favor coastal cutthroat trout.

Differences we found in density of coastal cutthroat trout among streams could be influenced by sampling techniques. We sampled Prairie Creek, the largest stream, using diver observations calibrated by both multiple passes by divers and depletion electrofishing of selected habitat units while sampling of the other two streams was accomplished using only electrofishing. These different techniques could result in different levels of precision due to 1) observers inability to separate steelhead from coastal cutthroat trout, or 2) their ability to see fish varying among habitats. However, standard errors we calculated for all three streams were comparable. In fact, the average standard error for total population density during the five years examined was 18% in each stream. Therefore, we attribute differences in population abundance among streams to differences in stream size (Rosenfeld et al. 2000) and differences in habitats among streams.

We also found that population density of coastal cutthroat trout were greater in Boyes Creek, a stream we consider impaired from sediment inputs, than in Prairie Creek, a stream we consider undisturbed. The reason for this disparity is not obvious. However, we suggest it may be more a function of stream size and fish behavior than habitat condition. Habitat area available for colonization in Boyes Creek is roughly one-third the area available in Prairie Creek and individual habitat units are twice as large as in Boyes Creek. If coastal cutthroat trout exhibit territoriality or are susceptible to aggression by other species, few fish may successfully colonize a single habitat unit and this would effectively "inflate" density in smaller streams.

Our finding that population density of coastal cutthroat trout was greater in pool and run habitats than in riffle habitats is also consistent with previous reports. Mitchell (1988) reported that riffle habitats in Smith River tributaries were occupied primarily by age 0 cutthroat trout, whereas larger, older fish were more common in pools and runs.

We also found that population density varied with season, and was generally greater in summer than fall, but not consistently. We suggest here that seasonal differences in population density are likely a function of movement. We collected one apparently potadromous individual that had been marked in the Redwood Creek Estuary (David Anderson, Redwood National Park, personal communication). We did not measure movement and cannot be sure of the extent of potadromy in coastal cutthroat trout inhabiting these streams, however, previous studies suggest this life history pattern is not uncommon (Trotter 1997). The presence of potadromous individuals could explain why we occasionally observed increased population density in fall relative to summer. Although we have observed anadromous coastal cutthroat trout spawning in Prairie and Streelow creeks, we do not believe anadromy contributed to seasonal density differences we observed. The mouth of Redwood Creek is closed by lateral drift of sand during most years, and opens after fall rains, typically in November. Our sampling was, therefore, completed before anadromous individuals could have entered tributaries.

We found that the size of coastal cutthroat trout we collected differed, but not always as we anticipated. Size did not differ among streams, but did differ among years, seasons, and habitat types. We were somewhat surprised that size did not vary among streams, given the range in population density we found among streams and the lack of fish greater than 200 mm FL in Boyes Creek. However, we could find nothing in the literature relating size to density in coastal cutthroat trout populations. Furthermore, fish greater than 200 mm FL made up a small portion of the total fish we measured and likely did not greatly influence statistical results. Size of the fish we sampled suggests the populations are comprised primarily of either residents or pre-smolting anadromous or potadromous individuals (Hooton 1997; Trotter 1997). A small sample of nine coastal cutthroat trout from Prairie Creek in 1951 (DeWitt 1954) offers some size at age data for comparison. DeWitt reported back calculated size at age as; 0 = 43-81 mm, 1 = 97-124 mm, 2 = 152-191 mm, 3 = 208-226 mm, 4 = 282 mm, and 5 = 340 mm. Thus, these limited data suggest fish we sampled were primarily age 1 and 2. We also found that coastal cutthroat trout occupying pool habitats were larger than those occupying run or riffle habitats. This finding is consistent with the observations of Mitchell (1988) that small coastal cutthroat trout in Smith River tributaries occupied primarily riffle habitat, while larger fish were more often found in slower, deeper habitats.

We found that condition of coastal cutthroat trout we sampled did not vary among streams or habitats. However, we found that condition was greater in 2001 and 2004 than during other years. Oddly, population density in all streams during both of these years was either high or moderate. Bates and McKeown (2003) found no differences in condition of age 1 wild and hatchery coastal cutthroat in Wilson Creek, British Columbia, although they found that wild fish grew larger than hatchery fish. These authors did, however, find seasonal differences in condition of age 0 coastal cutthroat trout produced from different hatchery paternal combinations. We suggest that food in these streams is likely not limiting growth of coastal cutthroat trout. Lastly, we found that condition during summer was greater than condition during winter. Although comparative data are lacking, we suggest this could be result of movement by potadromous individuals into tributary streams in fall.

The data we present here serve as a base for coastal cutthroat trout density and size distribution in coastal streams of northern California having different disturbance histories. We found a greater density of coastal cutthroat trout in a stream recovering from logging disturbance 50-60 years ago than in a relatively undisturbed and recently disturbed stream. This finding may be a response to dynamic habitat conditions within the watershed (Reeves et al. 1995) or it may simply reflect a preference by coastal cutthroat trout for smaller streams (Rosenfeld et al. 2000). In either case, we suggest the populations we studied are currently relatively stable, as suggested by Gerstung (1997). Furthermore, the size distribution of these populations suggests each is comprised of residents, anadromous individuals of pre-smolt age, or a mixture of both.

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Utility of Scales to Estimate Age and Growth Characteristics of Coastal Cutthroat Trout in Isolated Headwater Streams of Western Oregon

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Extended Abstract.—Although scales have been used to estimate age and growth characteristics of coastal cutthroat trout *Oncorhynchus clarkii clarkii* throughout their range, previous age and growth studies have focused on anadromous life history forms of coastal cutthroat trout. In fact, there is little quantitative information on the age and growth of potamodromous populations, especially headwater forms (Trotter 1989). An ongoing study focused on distribution of coastal cutthroat trout in small stream networks (500-1000 ha) in western Oregon (Gresswell et al. 2006) provided an excellent opportunity to expand current knowledge of age and growth characteristics of this cutthroat trout subspecies. A sample of 40 watersheds was selected randomly from a population of 269 headwater watersheds (500-5,800 ha) located above barriers to upstream fish movement and where coastal cutthroat trout are the only salmonine fish species (Gresswell et al. 2006). Specific objectives were: 1) to demonstrate coastal cutthroat trout in headwater streams can be reliably aged by the scale method, and 2) to provide preliminary information concerning age and growth for this subspecies in headwater streams across western Oregon.

Coastal cutthroat trout were collected using single-pass electrofishing, and scale samples were collected for up to10 fish per 10-mm length group (e.g., 90–99 mm) for 37 watersheds. Estimation of coastal cutthroat trout age followed criteria described by Jearld (1983), and lengths at annulus formation were estimated by back calculation using the direct-proportion method. To reduce the influence of size selective mortality (i.e., Lee's phenomenon; Gutreuter 1987), only the last full year of growth before capture was estimated for each fish. The number of circuli to the first annulus was recorded and used to investigate potential lack of first-year annulus (Lentsch and Griffith 1987).

Age was validated for 234 coastal cutthroat trout (length range = 60-175 mm) from two streams where individuals were marked and later recaptured. Almost all of the scales (97% and 94% of fish from the two streams) formed the expected number of annuli between capture events. Reader precision and bias was estimated for mark-recapture fish (n = 234), known age brood stock from two hatcheries (n = 350), and samples collected from the 37 study watersheds (n = 4,250). Coefficient of variation ranged from 4.8-8.3% for all of the readings. Differences in the calculated lengths at age from the three independent readings were not statistically significant.

Missing first-year annuli were not observed for populations of headwater coastal cutthroat trout in western Oregon. The mean number of circuli to the first annulus for individual populations ranged from four to seven (Table 1). Scales with more than eight circuli to the first annulus were common, but there was a strong relationship between the number of circuli to first annulus and elevation ($r^2 = 0.85$); counts were higher in lower elevation streams with longer growing seasons.

Our data suggest that coastal cutthroat trout in populations from headwater streams of western Oregon grow fast but do not live long. Three of the populations (14%) exhibited a maximum age of 3 years, but the majority had a maximum age of 4 (65%) or 5 years (22%). Mean relative growth rates for the last full year of growth generally decreased with age and size (Figure 1a). The mean relative growth rates by age group averaged from 0.64 mm/mm/year (age 1) to 0.18 mm/mm/year (age 4). Mean relative growth rates by 10-mm length groups showed a similar degrease in growth rates, with a mean relative growth rate between 0.71 mm/mm/year (60-mm size group) and 0.15 mm/mm/year (170-mm size group; Figure 1b).

Using scales to estimate age and growth characteristics is a common method for age determination because collection and preparation are relatively easy and sampling is non-lethal. Validation and reader precision and bias assessment are critical, and these additional steps are important for all methods of age determination. Estimating the number of degree-days from egg deposition until the end of the growing season is valuable for determining the probability of occurrence of a first-year annulus. Our data suggest that scales provide reliable estimates of age and growth for headwater populations of coastal cutthroat trout in western Oregon.

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TABLE 1.—Scale characteristics for age-1 and older coastal cutthroat trout in western Oregon. Standard error (SE) given in parentheses.

Stream name	Mean focus radius distance (mm)	Mean scale radius distance (mm)	Mean number of circuli to 1st annulus	% of fish with 8 or more circuli to 1st annulus
Augusta Creek	0.06 (0.01)	0.39 (0.09)	6.4 (0.8)	9
Barney Creek	0.07 (0.01)	0.41 (0.14)	5.5 (1.0)	2
Brice Creek	0.06 (0.01)	0.32 (0.07)	6.2 (0.9)	6
Bridge Forty Creek	0.06 (0.01)	0.39 (0.09)	6.2 (0.8)	6
Camp Creek	0.06 (0.01)	0.37 (0.09)	6.4 (0.8)	2
Canyon Creek	0.06 (0.01)	0.44 (0.10)	5.3 (0.8)	7
Cavitt Creek	0.06 (0.01)	0.39 (0.09)	6.4 (0.8)	7
Coffee Creek	0.06 (0.01)	0.37 (0.10)	6.1 (0.8)	3
Dead Horse Creek	0.06 (0.01)	0.45 (0.07	6.3 (0.9)	2
Drowned Out Creek	0.06 (0.01)	0.44 (0.12)	5.1 (0.9)	3
E.F. Laying Creek	0.06 (0.01)	0.39 (0.09)	6.3 (0.9)	10
E.F. Millicoma Creek	0.06 (0.01)	0.36 (0.09)	6.3 (1.0)	3
Glenn Creek	0.06 (0.01)	0.40 (0.11)	6.3 (1.2)	1
Hardy Creek	0.06 (0.01)	0.35 (0.08)	5.5 (0.9)	8
Hunt Creek	0.07 (0.01)	0.43 (0.11)	6.4 (0.8)	2
Little Stratton Creek	0.06 (0.01)	0.40 (0.09)	6.5 (0.8)	4
Lukens Creek	0.05 (0.02)	0.35 (0.16)	6.1 (0.8)	7
Miller Creek	0.06 (0.01)	0.40 (0.11)	5.4 (0.9)	3
Moose Creek	0.07 (0.01)	0.41 (0.10)	6.0 (1.0)	4
Muletail Creek	0.06 (0.01)	0.41 (0.11)	6.3 (1.1)	2
Nevergo Creek	0.07 (0.01)	0.39 (0.08)	5.3 (0.9)	6
N.F. Ecola Creek	0.06 (0.01)	0.42 (0.11)	6.3 (1.3)	3
N.F.E.F. Rock Creek	0.07 (0.02)	0.39 (0.12)	4.5 (0.8)	5
R.F. Salt Creek	0.06 (0.01)	0.43 (0.09)	7.1 (0.8)	4
Rock Creek (Coquille)	0.06 (0.01)	0.50 (0.12)	5.9 (0.9)	5
Rock Creek (Rouge)	0.06 (0.01)	0.43 (0.11)	6.8 (1.1)	5
Rock Creek (Youngs)	0.07 (0.01)	0.42 (0.14)	5.3 (1.0)	2
Salt Creek	0.06 (0.01)	0.43 (0.08)	7.2 (0.7)	7
S.F. Buckeye	0.06 (0.01)	0.41 (0.09)	6.0 (0.9)	8
Slater Creek	0.06 (0.01)	0.42 (0.09)	6.2 (1.0)	2
Slide Creek	0.06 (0.01)	0.42 (0.07)	6.2 (1.2)	1
Sweet Creek	0.07 (0.01)	0.48 (0.14)	6.3 (1.0)	2
Tucca Creek	0.07 (0.02)	0.37 (0.09)	5.4 (0.8)	2
Tumblebug Creek	0.06 (0.01)	0.38 (0.09)	5.7 (0.9)	11
W.F. Brummit Creek	0.06 (0.01)	0.43 (0.13)	6.0 (0.8)	3
W.F. Deer Creek	0.06 (0.01)	0.42 (0.10)	6.2 (0.8)	3
Wolf Creek	0.06 (0.02)	0.40 (0.09)	6.1 (0.9)	2

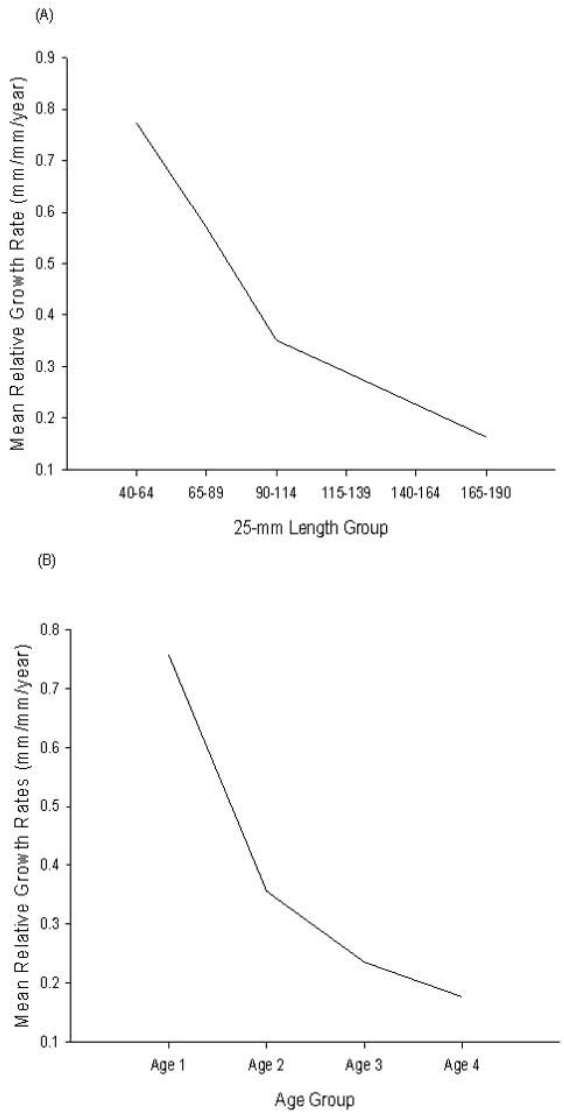

FIGURE 1.—Mean relative growth rates for 4,250 coastal cutthroat trout from 37 isolated headwater watersheds in western Oregon, 1999-2001. (A) Mean relative growth by 10-mm length group. (B) Mean relative growth rates by age group (1-4).

Acknowledgments

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Geographic Variation in Genetic and Meristic Characters of Coastal Cutthroat Trout

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Extended Abstract.—Understanding how populations within a species interact across various geographic and temporal scales is fundamental to developing appropriate conservation strategies. We examined the geographic variation in genetic and meristic characters of coastal cutthroat trout *Oncorhynchus clarkii clarkii* based on approximately 1,400 fish sampled from 54 populations spanning their distributional range (northern California to Prince William Sound, Alaska) to provide a glimpse of how populations have been structured by landscape processes.

Coastal cutthroat trout exhibited extensive variation across their range in the meristic characters examined. There were no latitudinal clines detected for any meristic characters, and little geographic concordance in meristic characters was observed. However, populations at the southern end of the range exhibited phenetic affinity despite significant meristic differences within this regional area. Juvenile fish with intermediate phenotypes consistent with those expected from decedents of coastal cutthroat trout and steelhead (*O. mykiss*) hybridization were detected.

Analysis of genetic population structure based on 30 enzyme encoding loci revealed that the primary genetic structure of coastal cutthroat trout populations occurred at the individual stream level. There was genetic affinity among populations at a regional scale, with geographic concordance of populations in the northern and southern portions of the range and little geographic concordance in genetic structure from populations in the central portion of the range.

Our genetic and meristic survey of coastal cutthroat trout populations across their range found many diverse local populations with inter-regional differences in the distribution of that diversity across the landscape. These data suggest that compared to other species of Pacific salmon and trout, coastal cutthroat trout are characterized by more diverse local populations that act in a more independent, isolated nature. The observation of unique meristic characteristics of southern populations at the periphery of the range is consistent with observations of other species at the margins of their distribution and suggests that these populations may warrant special consideration in conservation planning.

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Management Implications

Persistence of a population or group of populations is dependent on their ability to adapt or track changes in the environment through time. Such adaptation requires that individuals be able to move across the landscape, which depends on the availability of suitable habitat features at various spatial and temporal scales. Our snap-shot of population structure across the range of coastal cutthroat trout provides a glimpse of past landscape dynamics since the current population structure is a reflection of dispersal and isolation that have occurred over a range of time scales. The landscape within the range of coastal cutthroat trout is dynamic in space and time ranging from the geologic processes of glaciation and volcanism that have shaped a large portion of the area (McPhail and Lindsey 1986) to other events such as fire and flood that have shaped the landscape at smaller temporal (10^1 - 10^2 years) and spatial scales (watersheds and basins) (Benda 1994). These various disturbances create a shifting mosaic of abiotic and biotic conditions (Reeves et al. 1995).

Variations in habitat at spatial and temporal scales will be reflected in any snapshot of population structure. Regardless of the mechanisms that might have been in play that resulted in the localized nature of the population structure we found (e.g., low dispersal rates, founder effects), the implications are that localized extinctions may be more difficult to overcome by coastal cutthroat trout than for other species of Pacific salmonids. The opportunity for movement across the landscape during various portions of its life cycle is critical for the survival of a local population. Opportunities for individuals to move among populations (i.e., stray) are critical for recolonization following local extinctions, which appears to be especially relevant for coastal cutthroat trout given the local population structure we found.

In summary, understanding the historical and current spatial structuring of populations is useful for conservation and management of coastal cutthroat trout. Management and long-term conservation plans are likely to depend on protection of distinct populations (Lesica and Allendorf 1995), particularly peripheral populations in marginal habitats that may contain high adaptive significance to the species as a whole (Scudder 1989). For coastal cutthroat trout, the unique meristic characteristics of populations in the southern extent of the range suggest that these populations may be essential to conserve the range of diversity in the subspecies. But as this study has shown, assuming similar population structure across regions would be inappropriate. Range-wide conservation planning must account for differences in landscape dynamics and local population response.

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Genetic Variation and Geographic Structure of Coastal Cutthroat Trout *Oncorhynchus clarkii clarkii* at the Northern Extent of Their Range, Prince William Sound, Alaska

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Extended Abstract.—Species at the edge of their distribution range may reflect patterns of extinction and recolonization that are consistent with metapopulation dynamics. At the northern extent of species ranges genetic diversity may be reduced relative to populations from more southern locations. Molecular genetics can be used to examine these populations and extract clues to their structure. In this study we examine the genetic structure of coastal cutthroat trout *Oncorhynchus clarkii clarkii* at the northern extent of their distributional range in Prince William Sound (PWS), Alaska. Landscape features of PWS create a unique opportunity to examine trout populations in a dynamic environment. First, the region was glaciated during the last glacial maxima 8-12 thousand years before present (Calkin 1988), and it is thought that trout colonized the region from populations that persisted in southern refuges. Second, within PWS glaciers have been advancing and retreating within the past 150-350 years (Cooper 1942). Finally, as in other locations throughout their range, resident coastal cutthroat trout reside above barriers and amphidromous trout reside below waterfall barriers.

In this study we examined the genetic structure of populations within PWS using two genetic methods, mitochondrial DNA (mtDNA) and microsatellite DNA. We focused on three questions using these different methods. The unique inheritance pattern of mtDNA constrains the passing of genes from generation to generation; however it mutates rapidly and is an effective tool for examining differences among lineages. Here, we use mtDNA to compare genetic diversity of PWS trout populations with populations from more southern locations. Microsatellite DNA, tandem repeats in non-coding regions of nuclear DNA, is highly variable and is useful for examining genetic variation at the population and individual level. Using microsatellite DNA, we asked if amphidromous populations were panmictic with the exception of allopatric differentiation above and below waterfall barriers. We also asked if isolation by distance, where genetic differences increased with geographic differences, was structuring populations.

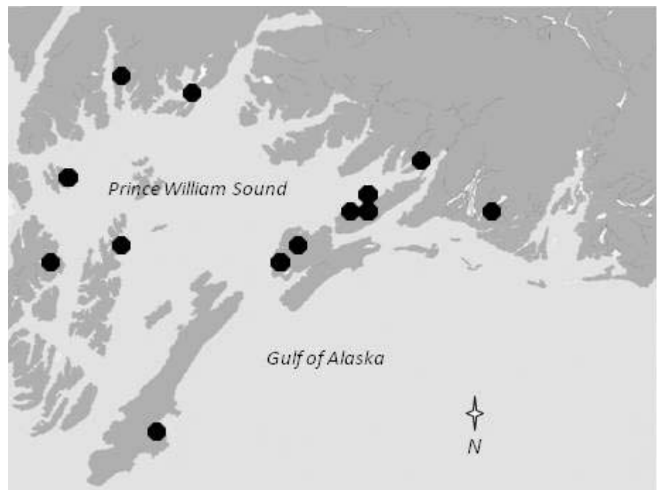

FIGURE 1.—Circles indicate sampling locations of coastal cutthroat trout collected in 1996 and 1997 in Prince William Sound, Alaska.

Methods

In 1996 and 1997 coastal cutthroat trout were collected from 13 sites in PWS including two from above waterfall barriers (Figure 1). DNA was extracted using standard methods (Sambrook et al. 1989). We examined three regions of mtDNA with 16 restricted fragment enzyme polymorphisms (RFLP's) from 80 trout subsampled from eight of the thirteen locations. The same RFLP enzyme combinations were examined in tissues from coastal cutthroat trout samples obtained in previous studies from Elk River, Oregon, Fort Lewis, Washington (Zimmerman 1995), and Vixen Inlet, Alaska (Figure 2).

To examine nuclear DNA diversity we used five microsatellite loci. We tested the hypothesis that coastal cutthroat trout from 13 locations including two above presumed waterfall barriers were panmictic. We then tested for a correlation of genetic and geographic distance in coastal cutthroat trout in PWS using isolation by distance models. We tested two models of isolation by distance. First, we used shoreline distance assuming that trout

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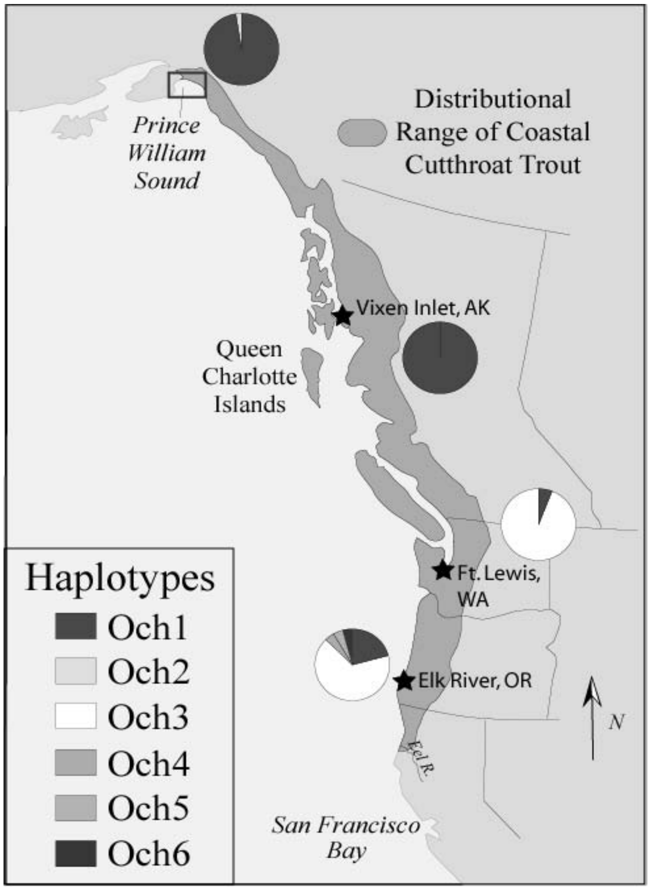

FIGURE 2.—Composite mtDNA haplotype diversity from four locations throughout the distributional range of coastal cutthroat trout.

followed shallow shorelines. Second, we tested isolation by distance using distance measures assuming trout would cross deep water channels.

Results

Seventy-eight of the 80 individuals examined with mtDNA shared the same haplotype. Two individuals had an alternate haplotype. MtDNA diversity was significantly different among the four locations throughout the range ($p < 0.05$). The trout from Elk River, the most southern location, had the highest haplotype diversity and included the two haplotypes detected in PWS.

Results from microsatellite DNA suggested that genetic diversity within PWS had a strong geographic pattern. We did not detect significant differences ($p > 0.05$) between populations above and below barriers. Instead, we found that locations in northwest PWS had significantly lower numbers of alleles and average heterozygosity than in other locations within PWS when corrected for sample size and multiple comparisons. Three populations in eastern PWS were similar to one another and no significant differences ($p > 0.05$) were detected. We also found support for isolation by distance using shoreline distance. The hypothesis that trout crossed open deep channels was not supported.

Discussion

Our study suggests that coastal cutthroat trout from PWS belong to a single mtDNA clade. While the frequencies differed greatly the haplotypes present in PWS were also present in the Elk River. These finding support the hypotheses that PWS was colonized by trout from southern refuge populations (McPhail and Lindsey 1986).

We found no evidence that genetic differences resulted from putative barriers in PWS. Likewise, mean Sr/Ca ratios in otoliths from above and below these barrier populations were not significantly different (Griswold 2002). Based on these results we suspect that these barriers were not true migration barriers.

Our microsatellite data suggests that the genetic structure of trout in PWS can be best explained by isolation by distance. Our findings suggest that trout dispersed using shorelines and did not cross large open bodies of water, which is consistent with other coastal cutthroat trout studies. Populations in the eastern sound were genetically similar and there was evidence for high levels of genetic exchange among these populations. Isolated populations in the western sound were genetically different from one another. In populations that were recently colonized (150-350 years before present) we found low genetic diversity which is consistent with processes of genetic drift due to founder effects.

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Cutts Above the Rest: Waterfall-Isolated Coastal Cutthroat Trout, Microsatellite Genetic Diversity, and Watershed-Scale Habitat Features

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Extended Abstract.—Coastal cutthroat trout *Oncorhynchus clarkii clarkii* throughout the Pacific Northwest often exist in populations above waterfalls isolated from upstream migration. Although effects of extrinsic barriers on dispersal have been shown to play a significant role in the structuring of genetic diversity, describing the relationship between landscape structure and genetic diversity remains a major challenge. In this study, we sought 1) to determine the extent of differentiation and hierarchical genetic structure among isolated coastal cutthroat trout populations in headwater streams, and 2) to assess how watershed-scale environmental factors correlate with the structuring of genetic diversity among isolated populations.

Methods

A random sample of 24 watersheds was selected for study from 269 watersheds where populations of coastal cutthroat trout were the only salmonid above natural migration barriers, and there was no record of hatchery stocking (Gresswell et al. 2004; Guy 2004; Gresswell et al. 2006). Three additional isolated populations were selected opportunistically to yield 27 sample watersheds (Figure 1). Fin tissue for genetic analysis was obtained between 1999 and 2002 from 15-96 (average 80) fish per watershed.

Population genetic parameters were assessed for 2,232 individuals (Guy 2004). Pairwise F_{st} values were calculated using permutation procedures. Isolation-by-distance (IBD) was assessed by examining correlation between genetic distance and geographic stream distance for all coastal cutthroat trout populations combined and for among population groupings (i.e., ecoregions and evolutionarily significant units or ESUs) using Mantel tests (Figure 1). Additional Mantel tests using the residuals from initially positive IBD results were performed following the approach of Hutchison and Templeton (1999). In this approach, the degree of "scatter" among IBD tests is evaluated to ascertain the relative contribution of drift and gene flow among compared groupings.

Genetic diversity (i.e., total number of alleles for all loci) and watershed-scale environmental variables thought to influence genetic structure were compared between the Coast Range and Cascade Mountain ecoregions using two sample t-tests. Environmental variables included an index of topological stream channel complexity (ratio of summed tributary lengths to the longest length of stream per watershed) and within-watershed connectivity (total number of vertical falls >1 m divided by the total number of channel units in each watershed; Guy 2004).

Results

Genetic differentiation among 27 isolated populations of coastal cutthroat trout was high (mean F_{st} = 0.33), and intrapopulation genetic diversity (mean number of alleles per locus = 5; mean He = 0.60) was moderate. There was evidence of IBD when all populations were combined, but not when populations were partitioned by ecoregion or by ESU (Figure 2). Mantel tests comparing residuals from positive initial IBD plots were significant when all populations were examined collectively as a group. Among-population IBD assessments were significant for the Cascade Mountain ecoregion but not the Coast Range ecoregion (Figure 2).

Differences in genetic diversity between the Coast Range ecoregion (mean alleles = 47) and the Cascade Mountains ecoregion (mean alleles = 30) were statistically significantly (P = 0.02). Coast Range topological stream channel complexity (0.54) and connectivity (0.02) were greater than in the Cascade Mountains (0.1, P < 0.01 and 0.04, P < 0.03 respectively).

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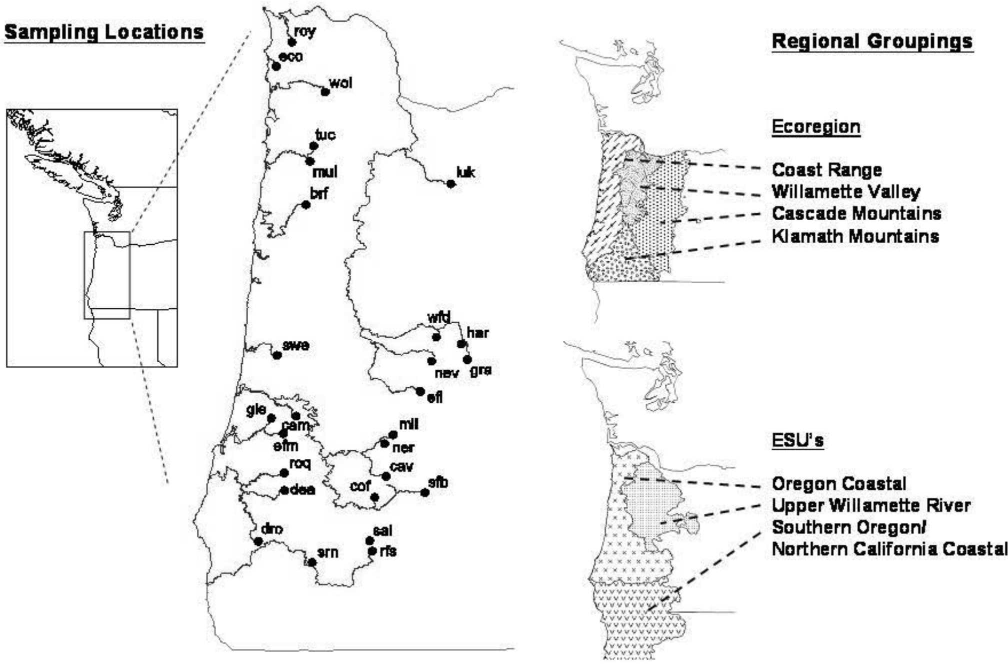

FIGURE 1.—Sampling locations, and regional groupings (Ecoregions and Ecological Significant Units [ESUs]) for coastal cutthroat trout in this study. Full stream names are given in Guy (2004).

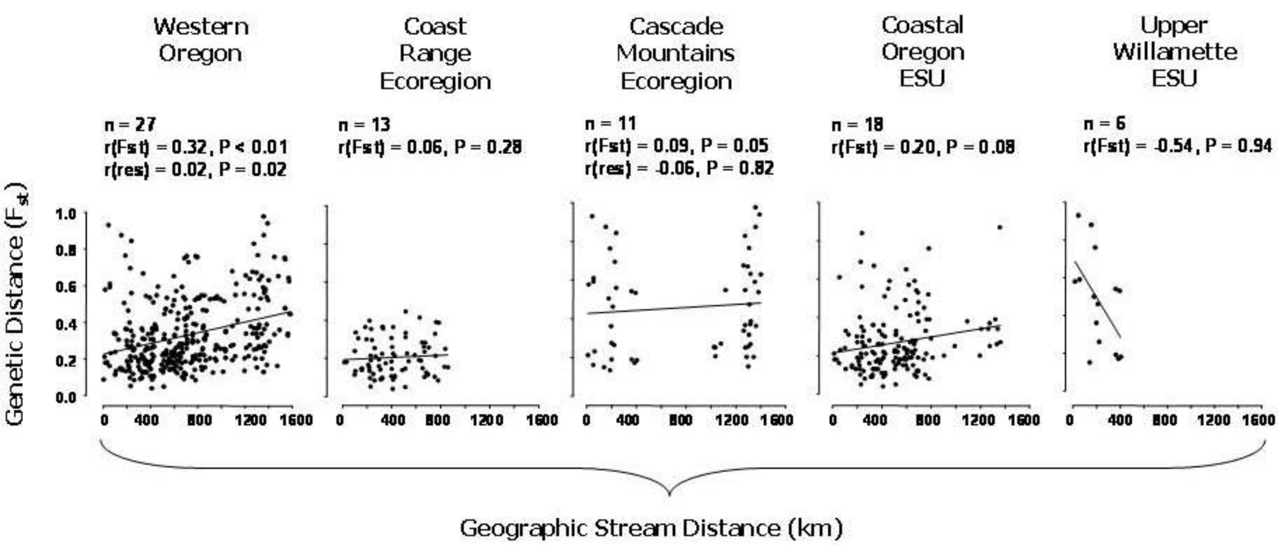

FIGURE 2.— Isolation-by-distance for coastal cutthroat trout populations that are grouped by ecoregion and Evolutionarily Significant Unit. Correlation coefficients and P-values represent the relationship between genetic distance and geographic distance, r(F_{st}), or residuals and geographic distance plots, r(res), based on Mantel tests using 1,000 permutations.

Discussion

Our results suggest that genetic patterns in the Coast Range were more strongly influenced by gene flow than in the Cascade Mountains, where drift appeared to be the dominant factor influencing genetic diversity. Watersheds in the Coast Range, an area of predominantly sedimentary geology, tended to have more complex drainage patterns and fewer within-watershed obstacles to dispersal than catchments of similar size in the primarily basalt Cascade Mountains (Guy 2004). We hypothesized that watersheds with higher complexity and within-watershed connectivity retain more genetic diversity, in spite of stochastic disturbances such as landslides and debris flows. Populations in the Coast Range are more likely to retain genetic diversity in the face of disturbances because there is a low probability that the entire population will be affected by a single disturbance event (e.g., debris flow). Cascade Mountain populations commonly exist in a single channel with many in-stream barriers to upstream dispersal. In these watersheds, a single debris flow can cause an immediate decrease in genetic diversity followed by a lasting resistance to upstream recolonization and gene flow.

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Drawing the Circles: Nested Analysis of Genetic Variation in Coastal Cutthroat Trout and the Delineation of Distinct Groups in British Columbia

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Extended Abstract—While coastal cutthroat trout (CCT) are an important component of many freshwater aquatic communities on the west coast of North America, our understanding of CCT biology remains extremely limited. The factors most influencing population size, productivity, patterns of movement, and the demographic independence of adjacent populations are not fully understood. The delineation of distinct population segments (and the factors which structure them) is an essential part of any conservation program and a clear rationale for defining distinct groups of CCT that will ultimately be required for legal protection under Canada's *Species at Risk Act (SARA)*. Current conservation initiatives in Canada may, therefore, be proceeding without a realistic understanding of what exactly constitutes a "typical" CCT population.

Methods

The process of defining distinct population segments (or "drawing the circles") synthesizes a host of disparate information, including patterns of species incidence, the distribution of unique morphologies or other traits, physiogeographic factors, and increasingly, genetic information. Concordance between different types of data can lend strong support to inferred population structure. Because the distribution of biological diversity is hierarchical in nature, this study employs a nested sampling design to target different scales of CCT diversity (Figure 1). Specifically, the ongoing project has three objectives:

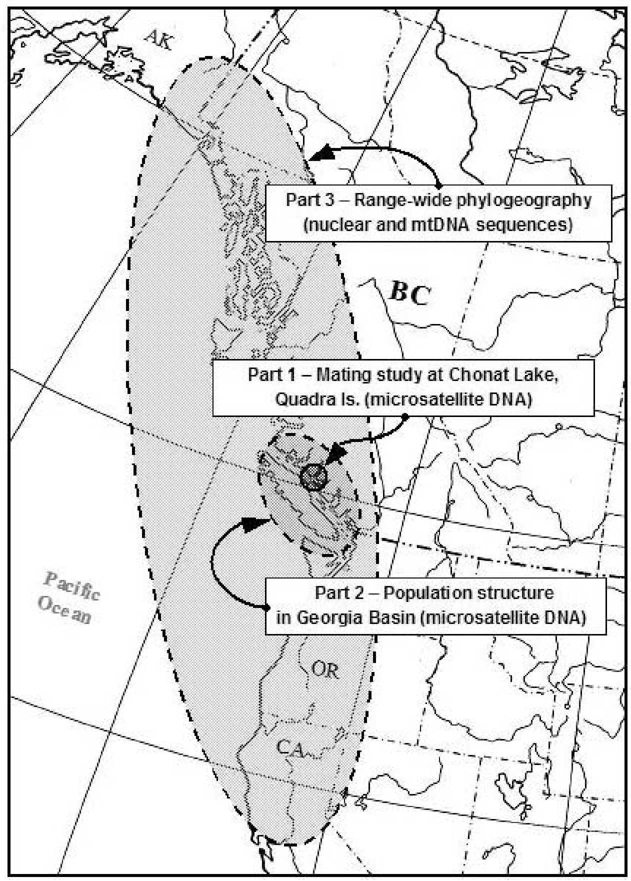

FIGURE 1.—Overview of the nested design of the study targeting coastal cutthroat trout diversity over different spatial scales.

i. Investigate a "representative" CCT population to determine the degree of annual variation in the composition and success of cutthroat spawners. This is being accomplished by means of a fish enumeration fence on a typical spawning stream and genetic parentage analysis of young-of-the-year (YOY) fry produced over several years. The location chosen for the study was Chonat Lake on Quadra Island. This simple system has one main spawning stream (Chaos Creek, <3 m wetted width and ~700 m total length) that supports a healthy population of CCT with lacustrine, anadromous, and resident components (total N ~570 ±160 based on mark-recapture, unpublished data).

ii. Generate an understanding of population structure in CCT by using genetic markers to infer patterns of isolation, migration, and gene flow between adjacent streams. While evidence from other areas suggests

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that populations may ultimately be structured at the level of individual streams (e.g., Wenberg and Bentzen 2001), limits to anadromous dispersal suggest that localized groups of populations (i.e., metapopulations) may exist in British Columbia. We are examining patterns of gene flow among 48 populations from Vancouver Island and the Lower Mainland to determine the geophysical factors which may influence anadromous movement.

iii. Describe regional patterns of CCT genetic diversity at nuclear and mitochondrial markers to delineate the distribution of evolutionary lineages in the province which could act as the primary conservation units beneath the subspecies level.

Results

i. Chonat Lake parentage study.—The number of female spawners observed at the Chonat Lake fish fence varied considerably from 57 in 2001 to just 21 in 2002. The number of males was not significantly different between years (n = 24, 23 respectively). Males generally appear to follow a lacustrine life history and may be less subject to variable ocean mortality. Many fish exhibited a pattern of up and down movement past the fish fence, some leaving the system without apparently mating (i.e., females with full complement of eggs). In contrast, no such movements were observed in year 2. Parentage analysis using microsatellite DNA confirms that the overall percentage of successful spawners was low in Year 1: just 16/24 (67%) males and 31/57 (54%) females were assigned YOY fry. A much higher percentage of spawners appear to have successfully mated in the low density year: 22/23 (96%) Year 2 males and 20/21 (95%) Year 2 females were assigned YOY offspring.

ii. Population structure in Georgia Basin.—Analysis of microsatellite DNA data suggest that all 48 populations sampled in the Georgia Basin are significantly differentiated (in terms of allele frequencies); some over very small spatial scales (<1 km, overall F_{st} = 0.245). For example, Chef, Cook, and McNaughton creeks—which essentially share a common confluence into Deep Bay on the east coast of Vancouver Island—are all genetically differentiated. At larger spatial scales, however, regional structure becomes apparent and populations form distinct groups loosely corresponding to geographic areas (e.g., Sechelt Inlet, Strait of Juan de Fuca, and Georgia Basin including the Sunshine Coast, eastern Vancouver Island, and the Gulf Islands). Interestingly, populations in Clayoquot Sound are more similar to populations in the Queen Charlotte Islands (added for comparison) than to other Vancouver Island populations (Figure 2). Similarly, Sunshine Coast populations are more similar to east Vancouver Island populations (across the Georgia Strait) than to Sechelt Inlet populations despite the greater geographic distance.

iii. Range-wide phylogeography.—Initial results from the sequencing of mitochondrial (ND1 and D-loop) and nuclear encoded DNA markers (type 2-growth hormone) suggest that the complexity of cutthroat trout phylogeography may be on par with the complexity of its ecology and life history forms (see also Williams 2004). Nuclear data suggests the existence of three primary lineages of coastal cutthroat trout, one of which is prevalent only on the Queen Charlotte Islands. Mitochondrial data suggests the existence of at least two groups of cutthroat trout: a monophyletic group and a second group of cutthroat which cluster with rainbow trout. Whether this is the result of the introgression of rainbow trout DNA into hybrid fish or a remnant of some type of ancestral polymorphism is not clear at this time (Costello et al. 2001). Again, populations on the west coast of Vancouver Island appear more similar to those on the Queen Charlotte Islands than to other Vancouver Island populations.

Discussion

Preliminary findings suggest that successful spawning populations of CCT may vary considerable from year to year and be small compared to total population sizes. The ratio of successful breeders to total population size (N_b/N) averaged just 8% at Chonat Lake, which is less than values reported for other salmonids (up to 20% in Pacific salmon; Allendorf et al. 1997). Initial results suggest that high spawner densities and competition for spawning habitats may have a particularly strong effect in CCT populations because of the limited habitat available in smaller CCT streams. It may also suggest that the amount of available spawning habitat in small CCT streams can potentially set an upper limit on the number of spawners able to reproduce in even robust populations. Conversely, a form of "genetic compensation" (where a greater proportion of available individuals contribute during low spawner densities) appears to operate in the Chonat Lake population. This type of compensatory mechanism has been observed in other salmonid species, including steelhead and sockeye salmon (e.g., Chebanov 1991).

There appears to be little geneflow between adjacent systems (<1 migrant per generation), but populations appear loosely grouped into regional clusters. For example, Sechelt Inlet, Georgia Basin, and Strait of Juan de Fuca populations cluster (likely originated from a Chehalis/Columbia refuge) and are possibly an extension of the Puget Sound evolutionarily significant unit (ESU). Populations on the west coast of Vancouver Island north of Barkley Sound show stronger affinities with the Queen Charlottes and may instead represent the southern extreme of an Outer British Columbia Coast Designatable Unit under *SARA* (Costello and Rubidge 2005). Given the large number of inlet and fjord complexes along coastal British Columbia, it is likely that the number of genetically distinct, demographically isolated population segments of CCT could be quite large. Cutthroat trout likely colonized British Columbia from more than one glacial refuge and many British Columbia populations may represent a mix of refugial races. This

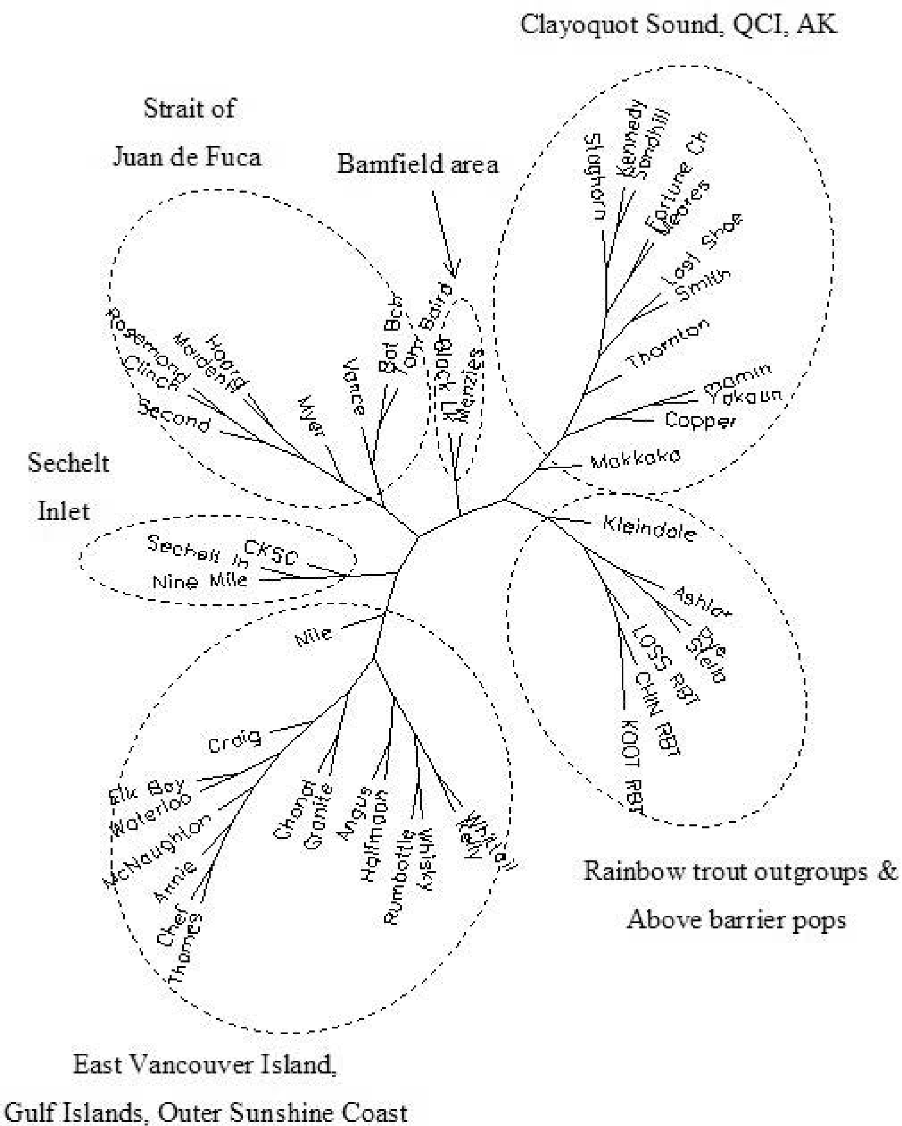

FIGURE 2.—Consensus UPGMA network of genetic relationships between cutthroat trout populations sampled in British Columbia based on Cavalli-Sforza and Edward's chord distances. Regional groupings are highlighted and hybrids have been removed prior to analysis. Note that the Chonat Lake population is located centrally within the Georgia Basin group.

would represent a significant component of the subspecific biodiversity in the province and have obvious implications for conservation and fisheries management.

Acknowledgements

I would like to acknowledge the many biologists who assisted with sample collection and technical issues during the course of this study, particularly Sue Pollard and Ted Down at the British Columbia Fisheries Science Unit in Victoria. Special thanks to Bob Devlin and the staff at the Department of Fisheries and Oceans lab in West Vancouver for their assistance in early stages of this research. Finally, thanks to Ron Ptolemy, Jim Roberts, Pat Slaney, and Rob Knight of the British Columbia Ministry of Environment and to John Wenburg and Kim Hastings of the U.S. Fish and Wildlife Service in Alaska for sharing their thoughts on cutthroat trout.

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Coastal Cutthroat Trout Symposium: Status, Management, Biology, and Conservation
Oregon Chapter, American Fisheries Society, 2008

Naturally Isolated Coastal Cutthroat Trout Populations Provide Empirical Support for the 50/500 Rule

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Extended Abstract.—Small populations face an increased risk of extinction from stochastic events and processes, but how small is small? The widely-used 50/500 rule, originally proposed in Soule and Wilcox (1980) from theoretical arguments, holds that an effective population size (N_e) of 50 is required to avoid inbreeding depression in the short term (Soule 1980), while an N_e of 500 individuals is needed to retain evolutionary potential over the longer term (Franklin 1980). Subsequent debate has produced estimates of effective minimum viable population size ranging between 500 (Franklin and Frankham 1998) and 5000 (Lynch and Lande 1998). However, empirical evaluation of the 50/500 rule has been largely unavailable, owing to the generally lengthy time it takes for the stochastic process of population extinction to play out, and because it would generally be unacceptable to allow that process to proceed to conclusion for a threatened population.

To address this deficiency, we chose to examine natural extinction processes. In southeastern Alaska, numerous small populations of resident salmonids have been isolated for hundreds of generations by isostatic rebound. These populations were founded from saltwater early in the Holocene, when the ice that covered the entire region during the Pleistocene first receded. As the land rebounded from the weight of the ice, geological discontinuities were occasionally exposed in streambeds emerging from saltwater. These became uplifted bedrock waterfalls that prevented further immigration to upstream populations, and created a widely replicated natural experiment in the long-term persistence of isolated fish populations. To determine the amount of habitat required to support long-term population persistence, we surveyed a number of such sites where populations of coastal cutthroat trout *Oncorhynchus clarkii clarkii* and Dolly Varden *Salvelinus malma* would be expected (Figure 1). From presence-absence data, we compare the estimated effective size of populations still in existence with those that have apparently been extinguished.

Each sample site consisted of the contiguous habitat that would be available to an isolated population of fish living upstream of a permanent and complete movement barrier. We defined "suitable habitat" to be all stream reaches less than 25% gradient that would have been continuously connected to saltwater prior to the start of Holocene uplift. Lakes and ponds provide a refuge from stressful environmental conditions and, at least at low elevations in southeastern Alaska, are almost universally associated with persistent fish populations regardless of the amount of attached stream habitat. Thus, in order to focus on the most limiting conditions for population persistence, streams connected to lakes were excluded from this study.

The length of available above-barrier habitat at the 124 sites we assessed varies from 200-50,100 m. The longest fishless stream we identified consists of 2,300 m of above-barrier habitat. We found isolated Dolly Varden in streams as short as 415 m long, and isolated coastal cutthroat trout

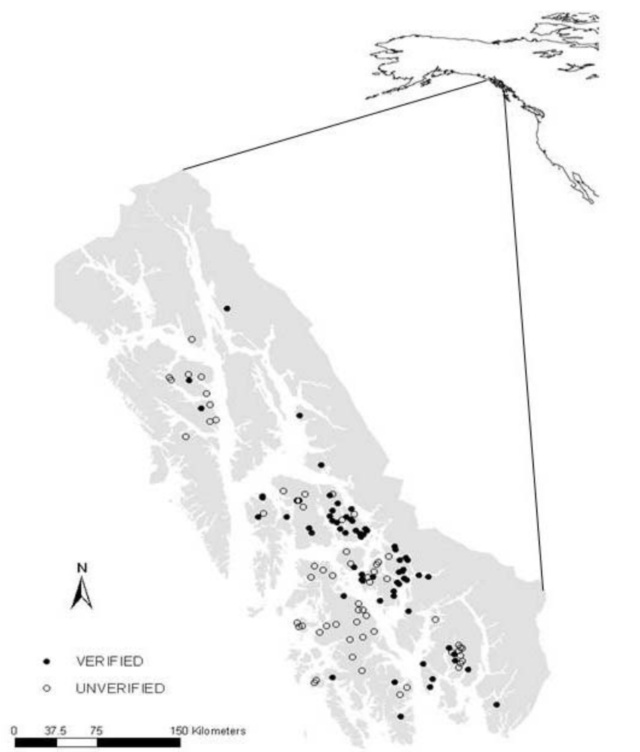

FIGURE 1.—Sites sampled for fish species presence in the Alexander Archipelago and mainland coast of southeastern Alaska (55 N-58 N). Solid circles are sites where presence or absence was conclusively established; open circles were unverified reports.

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populations in streams as short as 700 m. One or both species are generally present in streams with 2 km or more of habitat, and generally absent from streams with less than about 1.5 km of habitat. Using logistic regression, we calculate a greater than 50% likelihood of finding at least one species present in streams longer than about 1.5 km, and a 90% likelihood of finding each species present in streams over 5.5 km long.

Our results show a surprisingly accurate alignment with the predictions of the long-term ("500") portion of the rule. An effective population size (N_e) of 500 would correspond to a census population size of about 2500 adult salmonids, based on an expected N_e/N ratio of 0.2 for this taxonomic group (Allendorf and Waples 1996). A population of 2500 adult fish at the densities that we find (about 0.4 fish/m) would require approximately 6.25 km of stream habitat, a very close fit with the 5.5 km of habitat that we find are required for a 90% likelihood of persistence. Though the 50/500 rule of thumb for recommended minimum population size has a strong theoretical foundation (Soule and Wilcox 1980), empirical support for the rule has been hard to come by because of the long-term nature of the predictions. Our study is the first in which the persistence of stream-resident, headwater salmonid populations is inferred from empirical data unencumbered by complications due to extensive human alterations of the landscape. While one must always use caution when extrapolating beyond the conditions examined in an individual study, these results should bolster the confidence of those employing the 50/500 rule in settings where empirical support for its predictions is unavailable.

Acknowledgements

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PART THREE

CONSERVATION PLANNING

Coastal Cutthroat Trout Symposium: Status, Management, Biology, and Conservation
Oregon Chapter, American Fisheries Society, 2008

Review of the 2002 Withdrawal of Southwestern Washington/ Columbia River Distinct Population Segment of Coastal Cutthroat Trout

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On July 5, 2002, the U.S. Fish and Wildlife Service (USFWS) withdrew the proposed rule to list the Southwestern Washington/Columbia River Distinct Population Segment (DPS) of coastal cutthroat trout as a threatened species (USFWS 2002). At the current time, no DPS of coastal cutthroat trout has any listing status under the Endangered Species Act (ESA) (16 U.S.C.1531-1544). This paper summarizes the rationale behind the USFWS's July 5, 2002, withdrawal of the proposed rule (Withdrawal). Another paper in these proceedings (Finn et al., this volume) summarizes the activities that USFWS has undertaken to encourage, initiate, and maintain active coastal cutthroat trout research, monitoring, and conservation programs.

Listing represents the crossroads of science and law. Scientific information, applied through Federal policies to the legal requirements of the ESA, provides the basis for decisions, but does not itself answer the legal question of "Should the species be listed?" Biologists working for the Federal agencies must apply the scientific information to the legal and policy requirements, an exercise that often requires extrapolation or inference. This paper describes the regulatory process and summarizes the conclusions reached in the USFWS's decision to withdraw the proposed listing of Southwestern Washington/Columbia River DPS of coastal cutthroat trout. It represents a summary, not a complete literature review. It does not attempt to present the complete information from over 700 documents that were used in reaching the final determination. For more detailed and expansive information, see the Federal Register notice of the withdrawal (USFWS 2002).

In describing this process, we portray the legal and regulatory requirements of the ESA, the various steps in the listing and withdrawal process, and the four categories of new information leading to a decision that listing was not warranted. We provide an overview of the analysis that supported the conclusion by USFWS that listing was not warranted. We emphasize that while the Southwestern Washington/Columbia River DPS does not meet the definition of a threatened species, there are remaining threats and uncertainties that should be addressed in the future. Finally, we describe the information needs identified during this process that would allow future managers to better assess and document the condition of this species, as well as USFWS's recommendations and commitments for future management and conservation of coastal cutthroat trout.

Endangered Species Act Listing: Legal and Regulatory Requirements

The ESA, passed in 1973 and amended several times since, is a keystone Federal law designed to prevent the extinction of species. The ESA establishes a safety net for species that might otherwise fall through the cracks. The ESA is a tool of last resort to prevent species from going extinct, and not a general management tool for declining species. Its protections apply only to species that meet rigorous standards, after a thorough scientific review and public comment process.

Species can be listed under the ESA as either "Endangered" or "Threatened".—Endangered species are defined as "any species which is in danger of extinction throughout all or a significant portion of its range…" (16 U.S.C. 1532[6]). While there is no specific mention of the time frame for extinction, biologists assigned to listing determinations usually consider this definition to focus on extinction risks that are urgent and imminent (not those operating over evolutionary or geologic time frames). This definition is specific to extinction—a total loss of the species—and not just declines or local extirpations. The ESA also requires that USFWS look forward; projecting future threats and future condition of the species, and not just consider current condition or past changes. To do this, we look not only at the past impacts, but the likely future condition and threats based on the latest regulations or laws.

In recognition that waiting until a species was on the brink of extinction before listing and applying the ESA provisions was probably not the best and most effective approach, Congress created a category specific to species that were approaching endangered status, the Threatened species. A Threatened species is defined as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range." This definition does apply a time standard: foreseeable future. This term is not defined further in law or regulation and is one of the areas where there is some disagreement among even listing specialists. In the past, the "foreseeable future[s]" in listing decisions have ranged from 20 to over 100 years.

The determination of whether a species should receive Threatened or Endangered status is based, by law, solely on whether they meet the definition of threatened or endangered (16 U.S.C. 1533[b][1][A]). Congress did provide some guidance in the ESA on what causal factors or threats should be considered in determining the appropriate listing status (16 U.S.C. 1533[a][1]). These are:

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(A) the present or threatened destruction, modification, or curtailment of its habitat or range;
(B) overutilization for commercial, recreational, scientific, or educational purposes;
(C) disease or predation;
(D) the inadequacy of existing regulatory mechanisms;
(E) other natural or manmade factors affecting its continued existence.

Often, one or more of these conditions or threats may exist for a species, but unless the condition and threats to the species cause it to meet the definition of Threatened or Endangered, it does not qualify for listing under the ESA.

By law, listings must be based on the best scientific and commercial data available. Listing decisions are often preceded by a review of the status of the species conducted by the agency or contractor, and take into account any efforts being made to protect the species. To accomplish this, USFWS considers all information and evaluates its scientific validity, including the scientific validity of published work. Agency biologists review all documents, considering whether they have been previously peer-reviewed. Documents that are not peer-reviewed are given greater scrutiny. The law does not require that USFWS accept any written material at face value, nor does it allow the USFWS to delay its decision to gather new information or fill in information gaps outside the limited timeframes in the law.

Listing History: Southwestern Washington / Columbia River Coastal Cutthroat Trout

The Southwestern Washington/Columbia River DPS[2], one of six DPSs identified in the Status Review of Coastal Cutthroat Trout from Washington, Oregon, and California (Johnson et al. 1999) (Status Review), was jointly proposed for listing on April 5, 1999 (Proposal) (U.S. Office of the Federal Register 1999), by the National Marine Fisheries Service (NMFS) and USFWS. The proposed DPS consisted of coastal cutthroat trout populations in southwestern Washington (tributaries to Grays Harbor and Willipa Bay) and the Columbia River, including the Willamette River below Willamette Falls. The DPS included all anadromous, migratory, and non-migratory forms of coastal cutthroat trout.

In November 1999, the USFWS assumed sole jurisdiction of, and responsibility for, the coastal cutthroat trout under the ESA. The USFWS published a document in the Federal Register (USFWS 2000a) on April 14, 2000 extending the deadline from April 5, 2000 to October 5, 2000 for the final action on the proposed rule to list the Southwestern Washington/Columbia River DPS, and to provide a 30-day comment period. The USFWS published a document on June 2, 2000 (USFWS 2000b), reopening the public comment period and announcing a public hearing in Illwaco, Washington on June 20, 2000. On July 14, 2000, USFWS published a proposed rule in the Federal Register (USFWS 2000c) to clarify the take prohibitions for coastal cutthroat trout and provide for a 30-day public comment period. This proposed rule was necessary to answer questions USFWS had received regarding the application of the take prohibitions of section 9 of the Act to the proposed listing of the coastal cutthroat trout as threatened. The comment period was again reopened September 6, 2000 (USFWS 2000d), and a hearing was held September 21, 2000 in Aberdeen, Washington based on a request during the public comment period.

In November 2000, USFWS suspended work on the proposed listing of the coastal cutthroat trout due to budgetary limitations (USFWS 2002). On August 29, 2001 USFWS issued a press release announcing that, as part of a settlement agreement with conservation groups, USFWS would commence work on the final listing decision for the Southwestern Washington/Columbia River coastal cutthroat trout DPS (Center for Biological Diversity, et al. versus Norton, Civ. Number 01-2063 [JR] [D.D.C.]). This was followed by a 30-day comment period opening on November 23, 2001 (USFWS 2001). USFWS requested any new information related to the status and biology of the coastal cutthroat trout population in southwestern Washington and the Columbia River, any threats to the species, and any efforts being made to protect populations.

In all, five requests for additional information were published. Appropriate Federal and State agencies, county governments, scientific organizations, and other interested parties were contacted and requested to comment. During the five comment periods, a total of 127 comments were received from 96 different government agencies, organizations, or individuals, including oral testimony at the four hearings held during the process.

USFWS's Listing Team Evaluation and Finding

In taking over sole jurisdiction for the species and listing decision, USFWS assigned a team (USFWS team) of agency biologists with expertise on fisheries, salmonids, and the ESA listing process to accumulate, analyze, and thoroughly review all existing and new information. The USFWS team used the information gathered during the original Status Review (Johnson et al. 1999), as well as additional information provided during open comment periods, to evaluate the status and potential future threats faced by the species. This evaluation was used to determine whether the DPS met the definition of a Threatened species: in danger of becoming an Endangered species in the foreseeable future. For the purposes of this listing, the USFWS team considered the foreseeable future for coastal cutthroat trout to be between 20-100 years, or approximately 4-20 generations based on professional judgement.

[2] In the status review and original listing proposal developed by the National Marine Fishery Service, this segment of the population was referred to as an Evolutionary Significant Unit (ESU). The ESU label applies only to Pacific salmonids and is used in an ESA context only by NMFS. ESUs are equivalent to the Distinct Population Segment described in the ESA, therefore, we have converted all ESU references to DPS as described in the ESA (16 U.S.C. 1533[16]).

As the USFWS team gathered and evaluated new information, they discovered that the information, conditions, and threats driving the Proposal to list had changed. After detailed evaluation, analysis, and discussion, the USFWS team reached the unanimous recommendation that, based on the best available scientific information, the species no longer met the definition of a threatened species. This recommendation was passed to the agency managers for a final decision. Four categories of new or re-analyzed information indicated listing was no longer warranted: population numbers, population trend, life history plasticity, and changes in regulations or protections. These four categories of new or re-analyzed information are presented below.

Population Numbers and Trend

The Proposal expressed concerns about extremely low population size of anadromous coastal cutthroat trout, especially in the Columbia River, as evidenced by trap counts consistently below 10 fish annually for six years prior to the Proposal, as well as near-extinction of anadromous coastal cutthroat trout in two rivers. The USFWS team evaluated coastal cutthroat trout population numbers and trends by reviewing the original Status Review data as well as new information from traps and surveys in the range of the DPS. Very few long-term population data sets are available for the DPS. Much of the original and new data came from traps designed to collect information for adult salmon or steelhead, and often lacked important information such as trap efficiency and trapping effort for coastal cutthroat trout. This limited the USFWS team to evaluating indices and required careful evaluation of the consistency of the trap operation relative to coastal cutthroat trout. All the trap data came from traps within areas accessible to anadromous salmonids. Because these traps measured migrating adult fish, they generally represented only the migratory life history strategy of coastal cutthroat trout.

Because of the lack of capture efficiency information for coastal cutthroat trout at most traps, the USFWS team could not calculate, or even estimate, actual population size for those rivers. Where trap operations were consistent over time, we were able to use these values as indices of population trend. We were able to determine that trap counts in the DPS area, including specifically in tributaries to the Columbia River, were no longer as low as described in the original Proposal (based on the Status Review). Raw population numbers not corrected for trap efficiency, which were likely low estimates in many cases due to the spacing of the trap bars and timing of operations resulting in cutthroat trout moving through uncounted, ranged from 50 to 1400 anadromous adult coastal cutthroat trout annually in five of the nine traps with current information. In addition, one of the remaining traps was known to miss many of the migrating coastal cutthroat trout due to wide spacing of the trap bars. The remaining three traps continued to have low fish counts.

The Status Review pointed to very low anadromous coastal cutthroat trout populations in two systems, the Sandy and Hood Rivers in Oregon, as indicative of near extinctions of anadromous coastal cutthroat trout runs. However, the data for the Sandy River does not measure most of the river system because the trap is operated for salmon and steelhead on a small, mid-basin tributary, and does not sample lower and upper basin spawning adult coastal cutthroat trout, or mid-basin adults spawning in other tributaries. Few anadromous coastal cutthroat trout likely make it through Bonneville Dam and up to the Powerdale Dam fish collection facility on the Hood River. However, the Hood River is on the eastern-most edge of anadromous coastal cutthroat trout range, and may have naturally had lower fish run sizes. Unfortunately, past hatchery releases of coastal cutthroat trout make the long-term Hood River population and trend data sets difficult to interpret. In both the Sandy and Hood River basins, the resident coastal cutthroat trout population is considered healthy (ODFW 1998, PGE 2000). These two river systems represent about six percent of the DPS.

The State of Washington completed a two-year survey of the distribution and relative abundance of coastal cutthroat trout in southwestern Washington, which represents 75% of the DPS, including many areas within the areas accessible to anadromous salmonids. This new information provided substantially greater information on relative population numbers and distribution than available in the original Status Review. The Washington Department of Fish and Wildlife survey revealed population densities of coastal cutthroat trout in southwestern Washington comparable to or exceeding those in areas that were considered healthy and not likely to become endangered in the foreseeable future in the Status Review.

In evaluating the latest trend information, the USFWS team used a linear regression, as used in the Status Review and Proposal. To evaluate the strength of the regression results, the USFWS team calculated both p and r^2 values. The USFWS team used these values, as well as information concerning trap bias provided by the agencies collecting the information, to weight the individual data sets on strength of the analysis and quality of the information. Regression results with low p values (e.g. <0.05) and relatively high r^2 values (e.g. >0.5) were given more weight in the final decision than results with higher p values or lower r^2 values. Because of the high variation in annual trap counts for coastal cutthroat trout, the USFWS team also limited itself to longer-term data sets. A short data set of four to five years was much more likely to measure the variation over that short time frame rather than actual long-term trend.

In comparing the Status Review and Proposal information to the latest trap information and analyses, the USFWS team found that the trend for adults in the Grays Harbor tributaries had changed. Only a single trap (Bingham Creek, Chehalis River) provided a reliable, long-term data set for analysis of adult population and trend in the Grays Harbor portion of the DPS. This adult data set was not used in the risk evaluation of the Status Review, though it is listed in a table of information received after the risk evaluation was complete (Johnson et al. 1999). The latest analysis indicated that population trends were neutral to slightly increasing in annual abundance of coastal cutthroat trout. Data from the two other moderately reliable data sets on juvenile outmigration showed contradictory trends (15% decline, 10% increase).

For the Columbia River portion of the DPS, new information and re-analyses called into question the Proposal's interpretation of trend data. Only one adult trap data set provided relatively reliable statistical trends. The Kalama River trap, which is known to miss most adult coastal cutthroat trout due to trap size but is run consistently, allowing use as an index, showed a 10% annual decline in migrating adult coastal cutthroat trout in this small basin (<1.5% of DPS). The USFWS team did not have sufficient data to determine a reliable rate of recent decline in any other Columbia River tributary.

The Proposal and Status Review indicated significant declines in total angler harvest of anadromous coastal cutthroat trout in the Columbia River; however, these analyses did not take into account reduced angler effort as a result of significantly modified harvest regulations (Figure 1). Due to the lack of angler catch per unit effort data, as well as significant changes in the regulations for coastal cutthroat trout, creel census data for the lower Columbia River was not usable to index population size or detect population trends.

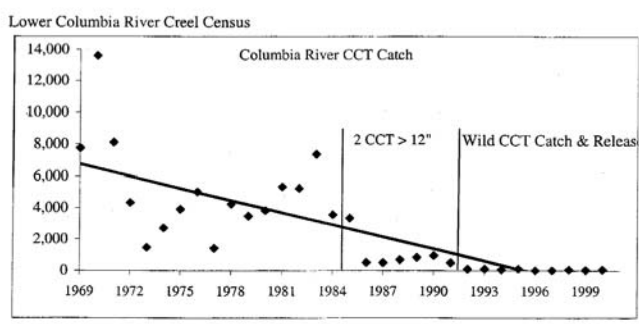

FIGURE 1. Creel census data for lower Columbia River, showing the timing of change in fishing regulations and limits for coastal cutthroat trout.

The USFWS acknowledged that the anadromous life history component of the DPS, especially in the Columbia River tributaries, is likely lower than historic levels, and may still be declining is some areas. As noted above, data sets are limited in the DPS, and many are not usable for long-term population and trend analysis. Usable population and trend data are limited to the areas accessible to anadromous salmonids. There are no data to address population trend in the resident component of the population. However, populations in a large portion of the DPS appear to remain at levels comparable to healthy populations in other areas, indicating that large scale, long-term, and continuing declines of coastal cutthroat trout may not have occurred at a landscape level in the DPS. In summary, new and re-analyzed population and trend data do not support the Status Review and Proposal conclusion that the DPS has extremely low population sizes, and the current population sizes and trends do not support a conclusion of increased risk of extinction due to small population size in the foreseeable future.

Life History Plasticity

While anadromy provides one long-term mechanism to restock large river systems if they experience catastrophic losses, resident and freshwater migratory fish also provide potential stock for recovery if any unaffected portions of the system provide refugia for these life history forms during the catastrophe. Therefore, maintaining all life history strategies may reduce long term risk to the species. The Proposal pointed out that a loss of anadromy might tend to restrict connectivity of populations, thereby increasing genetic and demographic risks. The Status Review expressed concern that a reduction in life history diversity could affect the integrity and the likelihood of this DPS's long-term persistence. The Proposal did note that the presence of well distributed freshwater forms in relatively high abundance, coupled with the possibility that freshwater forms could produce anadromous progeny, which could act to mitigate risk to anadromous forms of coastal cutthroat trout.

In the Proposal, there was limited information on whether the anadromous life history form represents a relatively discrete component of the population, or a "choice" depending on conditions and availability of ocean resources. Some new information became available to the USFWS team that was not available for the Status Review risk assessment and was not described in the Proposal suggesting that anadromous individuals are not segregated from the resident component of the population. The information used to evaluate life history included production of anadromous smolts from long-term landlocked populations, the genetic similarity of cutthroat within drainages, the irregular age of outmigration, and evidence of similar plasticity in other trout species (Jonsson and Jonsson 1993, Behnke 1997, ODFW 1998, WDFW 2001a, WDFW 2001b).

The USFWS team received additional information not available at the time of the original status review risk assessment on the potential for downstream migrants to be produced by resident coastal cutthroat trout above dams on the Cowlitz River. This area still produces a significant number of coastal cutthroat trout outmigrants over 40 years (>10 generations) since the dam was established without fish passage, and over 20 years since the single introduction of hatchery progeny from anadromous adults. There is evidence that some above-dam Cowlitz River migrants egress to the ocean and return (WDFW 2001a). Also, individual fish within a drainage above and below barriers are more closely related to each other than to individuals in other drainages, indicating interbreeding and interaction occurs between resident and anadromous fish. Given the wide distribution and relatively high abundance of resident coastal cutthroat trout throughout the DPS, and the potential ability of resident fish to produce anadromous progeny, the USFWS team concluded that the well-distributed resident forms of coastal cutthroat trout in the DPS reduce the risk of loss of the anadromous life history strategy in the foreseeable future.

Changes in Regulations and Protections

The final significant change in the threats to the coastal cutthroat trout in the DPS resulted from changes in regulations and conservation efforts. Between the Proposal and Withdrawal, two large Habitat Conservation Plans (HCPs) were completed that addressed habitat for coastal cutthroat trout on over 800,000 acres of land, resulting in some predicted long-term improvement in habitat in these areas. In addition, Washington State adopted revised Forest Practices Regulations for private lands that substantially reduce future threats on over 30% of the DPS by addressing timber harvest in and around riparian areas; road construction, use, and maintenance; and increased riparian buffer widths, reduced level of management activities within the buffers, and increasing the percentage of the stream network subject to these buffers. Federal management under the Northwest Forest Plan was also anticipated to continue to improve aquatic habitat, including coastal cutthroat trout habitat, on 27% of the DPS. As a result of new Washington regulations, HCPs, and Federal land management, at least 57% of the DPS's range is now under management and regulations that greatly reduce the rate of future habitat impacts and provide for long-term improvement of coastal cutthroat trout habitat.

Updated Five-Factor Threat Analysis

The USFWS team completed an updated five factor threat analysis as required in the listing process. Significant new habitat and watershed condition information was reviewed by the USFWS team, which indicated habitat and watershed conditions in the DPS had been significantly impacted in the last 100 years. However, even in these altered environments, coastal cutthroat trout appeared to remain extant throughout the DPS. There were no unexplained, significant "holes" in coastal cutthroat trout distribution, and these fish were reasonably abundant, even in degraded habitat conditions. The USFWS team found that angling or commercial use of coastal cutthroat trout was not a significant threat in the DPS. The USFWS team found no evidence of significant loss of wild coastal cutthroat trout to parasites, disease, or predation. Improved regulatory mechanisms with regard to forestry techniques were implemented in the southwestern Washington portion of the DPS, which were expected to result in greatly reduced rates of future adverse habitat impacts. Some low levels of hybridization with rainbow/steelhead trout were noted, but this may be a natural condition for these sympatric species. Finally, the USFWS team determined that the widespread distribution of this species over three large basins reduces the potential for losses from catastrophic events.

USFWS Team Conclusion

Based on the new information and re-analyses relative to population size and trend, life history plasticity, and new conservation efforts, and after completing a full five-factor analyses, the USFWS team reached the unanimous recommendation that the Southwestern Washington / Columbia River DPS of coastal cutthroat trout did not meet the definition of a threatened species in the foreseeable future. New and re-analyzed information indicated the coastal cutthroat trout has not reached this level of concern at this time. This recommendation was reviewed by USFWS regional and national staff and managers for consistency with USFWS policies and regulations. Listing decision authority is delegated to the Director of the USFWS. Therefore, the USFWS withdrew the Proposal to list the DPS on June 24, 2002 under signature of then Director Steve Williams. The Service is currently in litigation on this decision.

Our decision that the Southwestern Washington / Columbia River DPS of coastal cutthroat trout has not reached a level of imperilment required for listing under the ESA does not mean that that the USFWS concluded that human activity and development has had no effect on the species or its habitat, or that the species is not in need of careful management. The USFWS team identified the need for continuing and increased conservation efforts, improved monitoring efforts, and addressing several research questions to fill gaps in the knowledge for future evaluations.

Another paper presented at the Symposium (Finn et al., this volume) highlights the USFWS's commitments to encourage and assist with efforts to implement a broad-scale conservation strategy, including improved research, monitoring, and conservation efforts.

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Life History Diversity and Protection of the Southwestern Washington/Columbia River Distinct Population Segment of the Coastal Cutthroat Trout

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Based on a January, 1999 status review, the National Marine Fisheries Service (NMFS) and U.S. Fish and Wildlife Service (USFWS) jointly proposed to list the Southwestern Washington/Columbia River Distinct Population Segment (DPS) of the coastal cutthroat trout as a threatened species under the U.S. Endangered Species Act (Johnson et al. 1999; NMFS/USFWS 1999). On July 5, 2002, USFWS withdrew the proposed rule concluding that although some populations "are likely at lower-than-historic levels and probably still declining, recent changes in regulations have reduced threats," and "the latest information" indicates "relatively healthy-sized total populations (all life history strategies) in a large portion (75 percent) of the DPS's range" (USFWS 2002, pg 44862). In addition, USFWS believed that "production of anadromous trout from residents" ensures the security of anadromous populations. To evaluate these claims, we comprehensively reviewed all information cited in the status review, proposed listing, and USFWS withdrawal.

Much of the information cited in the withdrawal was also cited in the status review and proposal, indicating that the withdrawal was based as much on a reinterpretation of existing data as new information. The withdrawal and proposal differed on the importance of the anadromous portion of the population to the viability of the DPS as a whole. Both the NMFS status review and proposed rule concluded that listing was warranted based on the status of the anadromous portion of the population alone (Johnson et al. 1999, NMFS/USFWS 1999). For example, the NMFS status review concluded: "Team members concurred that the loss of any individual life history form could increase risk to the ESU [evolutionary significant unit] as a whole" (Johnson et al. 1999, pg xiv).

In withdrawing the proposed rule, however, USFWS focused much of its analysis on the DPS as a whole without considering individual life history strategies. To conclude that coastal cutthroat trout populations are "relatively healthy-sized," USFWS relied on surveys conducted by the Washington Department of Fish and Wildlife (WDFW) that did not separate anadromous and resident fish when estimating population densities (WDFW 2001). In comments on the proposed listing, WDFW strongly advocated for lumping populations from all life history strategies, stating that "the status review of these fish should be based on all forms of coastal cutthroat across the entire DPS" (WDFW 2001). USFWS extensively relied on these comments, citing them 20 times in the withdrawal (USFWS 2002).

By analyzing both resident and anadromous populations together, USFWS was able to argue that threats, which have a greater impact on anadromous populations, have a minimal impact on the DPS as a whole. In discussing the impacts of forest management, for example, USFWS concluded that "despite the long-term, widespread impacts to aquatic and riparian conditions, coastal cutthroat trout have survived in all portions of the DPS for many generations, and apparently remain at densities comparable to healthy-sized populations elsewhere" (USFWS 2002, pg 44947). Likewise, when discussing the impacts of urban and industrial development, USFWS acknowledged that urban areas "have a proportionally greater effect on the anadromous and migratory portions of the coastal cutthroat trout population." Yet USFWS ultimately minimized these impacts, concluding that urban areas "include only about three percent of the current land base in the DPS" (USFWS 2002, pg 44949).

USFWS also argued that the DPS is covered by adequate regulations by deemphasizing the anadromous population. Many resident populations occur entirely on federal lands, where they are protected by the Northwest Forest Plan and other regulations, whereas anadromous populations are dependent on estuaries and lower reaches of rivers that occur primarily on private lands and are far less likely to be protected (USFWS 2002). By employing this methodology, USFWS never analyzed the extent of threats to or protection of anadromous populations, never determined whether the viability of this portion of the DPS was in question, and did not determine whether declines within and threats to the anadromous population affect the viability of the DPS as a whole.

USFWS based its reversal of the proposed rule in large part on the fact that resident cutthroat can occasionally produce anadromous progeny (Griswold 1996; Johnson et al. 1999; WDFW 2001; USFWS 2002). The same information was available to NMFS when it conducted the status review and proposed to list the DPS, but NMFS still concluded listing was warranted for several reasons (Johnson et al. 1999; NMFS/USFWS 1999). First, smolts observed by WDFW in 1997 and 1998, as cited in WDFW 2001, come from a population above a dam and it is unclear whether these smolts were produced by purely resident fish or the descendents of anadromous fish that were trapped by construction of the dam (Johnson et al. 1999). Second, if poor habitat conditions are suppressing anadromous

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populations, any anadromous progeny produced by resident fish will face the same habitat limitations. Finally, even if smolts are produced by resident fish, this reproduction "has not resulted in demonstrably successful reestablishment of anadromous forms" (NMFS/USFWS 1999, pg 16407). In withdrawing the proposal, USFWS never addressed these issues.

NMFS's status review concluded that concern over the anadromous portion of the DPS alone warranted listing in large part because migratory fish are a source of colonists to new habitat and can rescue populations following local extirpations. The review concluded (Johnson et al. 1999, pg 145):

> *Reduced opportunities for dispersal among coastal cutthroat trout populations due to reductions in the anadromous form could cause dramatic increases in local population extinctions due to the demographic and genetic effects of isolation. If too many local populations are extirpated, the metapopulation dynamics in a region may be severely disrupted, leading to the eventual extinction of an entire ESU.*

NMFS's status review also concluded that loss of anadromous populations could "reduce the number of larger and more fecund individuals in the population," potentially "have significant effects on the population age structure, spawn timing, age and size at first reproduction, degree of iteroparity, sex ratio, spatial distribution of individuals, and mate selection," and lead to a reduction in life history variability, a measure that NMFS considered to constitute perhaps the "most reliable indicator of population resilience and ESU status" (Johnson et al. 1999, pgs 48-49).

Several recent scientific reviews have likewise concluded that maintaining all life histories in *Oncorhynchus* spp. is critical to ESU viability (SRSRP 2004; Hey et al. 2005; ISAB 2005). ISAB (2005), for example, concluded:

> *To be viable an ESU needs more than simple persistence over time; it needs to be in an ecologically and evolutionarily functional state. Evaluation of ESU viability should not only rest on the numbers of component populations or on the abundance and productivity of those individual populations, but also should be based on the integration of population dynamics within the ecosystem as a whole. This concept of ESU viability does not accommodate the loss of populations or the anadromous or resident life history form from any given ESU, because that loss would represent a loss in diversity for the ESU that would put its long-term viability at risk. This argument is based on evidence that an ESU needs to contain viable populations inhabiting a variety of different habitats, interconnected as a metapopulation, if that ESU is to fulfill the entire complement of ecological and evolutionary interactions and functions.*

In reversing the proposed listing, USFWS did not explicitly address these issues, nor explain why the concerns about viability of the anadromous population alone were not sufficient to warrant listing. These failings run counter to existing scientific consensus and potentially compromise the viability of the Southwestern Washington/Columbia River Distinct Population Segment of coastal cutthroat trout.

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U.S. Fish and Wildlife Service's Coastal Cutthroat Trout Conservation Activities and Vision

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On July 5, 2002, the U.S. Fish and Wildlife Service (Service) withdrew the proposed rule to list the Southwestern Washington/Columbia River Distinct Population Segment (DPS) of coastal cutthroat trout (USFWS 2002). In the proposed rule withdrawal, the Service expressed concern that certain populations of coastal cutthroat trout are likely below historic levels and continue to decline, and discussed the need for more and better information to make effective management decisions. The Service agreed to "continue to provide technical assistance to Federal, State, and other entities and encourage them to address the conservation needs of the coastal cutthroat trout". The Service also committed to "work with these [Federal, State, and other] agencies and entities to collect additional biological information, monitor the status of coastal cutthroat trout, and monitor the progress of conservation efforts for the DPS." Additional support of these commitments is found in the Pacific Region: Fisheries Program Strategic Plan (2004-2008), specifically in Regional Objective 3.2: "Maintain healthy, diverse, self-sustaining populations of fish and other aquatic resources and assist in preventing listings under ESA [Endangered Species Act]".

To fulfill these commitments as well as establish a broad conservation vision for coastal cutthroat trout, the Service initiated an effort to develop a range-wide coastal cutthroat trout Conservation Strategy and a Research, Monitoring, and Evaluation (RME) program. Using a simple conservation strategy model, which emphasizes a range-wide RME program, specific conservation activities, and actions to evaluate population and habitat response to those RME and conservation actions, we contacted Federal and State agencies to facilitate and financially support Conservation Strategy and RME program development and implementation. In addition, the Service has been investigating basic life history characteristics of coastal cutthroat trout in an effort to better understand movement and habitat use of the subspecies for more effective monitoring and evaluation in the future. Examples include Service funded and supported research on lower Columbia River and Salmon River basin coastal cutthroat trout life history, migration, and habitat use. Finally, we secured start-up funding and initiated planning for the 2005 Coastal Cutthroat Trout Symposium.

Our most notable conservation planning progress has been in Oregon, where the Service and Oregon Department of Fish and Wildlife (ODFW) have signed a Coastal Cutthroat Trout Memorandum of Understanding (ODFW MOU) to accomplish three products:

(1) A cooperative coastal cutthroat trout RME program, implemented under the Oregon Plan for Salmon and Watersheds and ODFW's Native Fish Conservation Policy;
(2) A coastal cutthroat trout conservation plan, developed via ODFW's Native Fish Conservation Policy; and
(3) A Conservation Agreement between the Service and ODFW to specifically identify the RME and conservation actions and responsibilities necessary to conserve coastal cutthroat trout in Oregon.

Since the MOU was initially drafted in 2003, the Service has 1) met regularly with ODFW to discuss research and monitoring needs, 2) provided technical input on ODFW's North Coast coastal cutthroat trout harvest management proposal, 3) provided technical assistance and funding for the Salmon River coastal cutthroat trout research project, and 4) met with ODFW to discuss results of ODFW's internal coastal cutthroat trout research and monitoring needs workshop.

To generate additional interest in coastal cutthroat trout conservation, the Service has financially supported and provided leadership in planning and hosting the 2005 Coastal Cutthroat Trout Symposium. We hope the 2005 Symposium will supplement information originally developed in 1995, bring research and management personnel together, and invigorate multi-state research and management actions on key biological questions and conservation opportunities.

Key uncertainties continue to exist in our understanding of both the biology and status of coastal cutthroat trout populations throughout their range, and addressing these uncertainties would be a key objective of a range-wide coastal cutthroat trout conservation strategy. An RME effort to address these uncertainties is critical to effective management and conservation of coastal cutthroat trout, to

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address threats to the species, as well as to prevent future listing of the species. The following are several key uncertainties identified during the Service's coastal cutthroat trout listing process:

- Trends in population abundance, distribution, and age structure;
- Relative contribution and expression of resident and migratory strategies within a population, including above-barrier populations;
- Identification of Distinct Population Segment boundaries;
- Influence of hatchery stocking programs; and
- Need to improve understanding of coastal cutthroat trout biology and ecology by investigating life history relations, and by determining the environmental and habitat factors associated with these life history strategies.

The Service encourages the development of collaborative conservation initiatives. Examples of such collaborative successes can be seen with other western native trout such as Bonneville cutthroat trout and Colorado River cutthroat trout. The coastal cutthroat trout would be a good candidate for such an initiative. Associated with the National Fish Habitat Initiative, funded in fiscal years 2005 and 2006 by Congress, coastal cutthroat trout have been included in the proposed Western Native Trout Initiative. This joint venture between the States and Federal land management agencies seeks to speed the implementation of conservation strategies for numerous western native trouts.

In summary, efforts to initiate broad-scale conservation and RME programs, participation in the Western Native Trout Initiative, and implementation of conservation activities under the ODFW MOU indicate the Service's commitment to coastal cutthroat trout conservation. The Service's broader vision is to assist with development of a range-wide coastal cutthroat trout conservation intitiative. The Service remains committed to assist other interested and committed entities in development and implementation of local, regional, or range-wide coastal cutthroat trout conservation strategies, and commits to support and supplement these new coastal cutthroat trout conservation efforts.

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Developing a Consistent Framework for Measuring and Reporting the Conservation Status of Coastal Cutthroat Trout

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The status of coastal cutthroat trout *Oncorhynchus clarkii clarkii* is a good indicator of management of coastal stream systems and fish communities (Williams and Nehlsen 1997). Application of integrated tools that measure and report range-wide conservation status of coastal cutthroat trout should be a regular part of our coastal management efforts. These tools should be scientifically comprehensive, easily repeatable, based on the latest status information, and readily understood by the interested public as well as scientists. To date, assessments of coastal cutthroat trout primarily have been conducted at the state and province level (Hall et al. 1997). There would be significant benefits to integrating state and provincial surveys into a range-wide, transboundary assessment. The primary benefits of a single transboundary assessment include: 1) use of a consistent analysis and reporting methodology across the entire range, 2) improved ability to perceive trends in status and threats at larger spatial scales, 3) facilitated ability for transboundary restoration, and 4) improved availability of websites and other tools to inform the public about assessment results and management consequences. We propose the Conservation Success Index (CSI), which has been developed by a team of scientists working with Trout Unlimited (TU) to measure the conservation status of salmonid fishes in North America, as an available tool to assist in a transboundary assessment.

The Conservation Success Index

Trout Unlimited began developing the CSI in 2004 as a means to measure the conservation status of coldwater fishes in North America. The intent was to develop a scientific, rigorous, and easily repeatable index that could be understood by our conservation partners and organization members. Equally important, Trout Unlimited desired a tool that would strategically inform management and restoration efforts, including those of local TU Councils and Chapters.

The CSI was developed to be broadly applicable to trout and char species or subspecies, but may have broader application for other fishes. The core of the CSI includes a 100-point framework that examines 20 indicators within the following groups to track conservation status and trend: 1) changes in range-wide condition over time, 2) population integrity, 3) habitat integrity, and 4) future security (Table 1). After analysis, each of 20 indicators is scored on a scale of one to five to facilitate public understanding of assessment results and to provide comparisons among taxa for which the CSI has been developed. The relative importance of these 20 factors will vary among fish taxa examined depending upon their life history, habitats, and limiting factors, and it is likely that a unique rule set would need to be developed among cooperators for scoring coastal cutthroat trout. The CSI also includes a process for identifying priority subwatersheds for protection, restoration, reintroduction, and monitoring efforts. The primary analysis unit for CSI is the subwatershed (6th level hydrologic units, catchments of approximately 7,900 ha in size). The following steps describe the assessment process associated with CSI. This process is similar to assessments conducted for fishes of the Interior Columbia River Basin (Lee et al. 1997) and the currently preferred method of aquatic and riparian assessments required by Regions 1 and 4 of the USDA Forest Service (K. Overton, Rocky Mountain Research Station, personal communication).

- *Step 1:* Determine historic distribution and limiting factors
- *Step 2:* Conduct workshops to assemble current condition and threat information
- *Step 3:* Spatially locate/geographic information system (GIS) current distribution, status, threats and their severity by stream segments and/or subwatersheds
- *Step 4:* Validate resulting maps with resident professional fish biologists
- *Step 5:* Score CSI
- *Step 6:* Determine priority areas for future management actions
- *Step 7:* Make findings available through scientific journals, public reports, and accessible websites
- *Step 8:* Integrate findings into management and recovery planning processes

Initial application of CSI includes an assessment of the eastern brook trout *Salvelinus fontinalis* in 17 states of the United States and is described in more detail at TU's website www.tu.org. The brook trout effort was a partnership among the Eastern Brook Trout Joint Venture (EBTJV) that included the U.S. Forest Service, U.S. Fish

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TABLE 1.—Twenty indicators analyzed to determine the Conservation Success Index. Indicators are scored from 1-5 at the subwatershed scale.

Range-wide Condition
- Percent of historic stream habitat occupied (compares historic and current habitat by stream mi/km)
- Percent of historic subbasins occupied (compares historic and current distribution by 4th level hydrologic units)
- Percent of subwatersheds occupied (compares historic and current distribution by 6th level hydrologic units)
- Percent of current habitat occupied by stream order (compares historic and current distribution by size of stream occupied)
- Percent of historic lake habitat occupied (compares historic and current distribution in lakes and wetlands)

Population Integrity
- Population density (number of adults/habitat area)
- Population extent (examines fragmentation and connectivity by geographic extent of populations)
- Genetic purity (examines hybridization and introgression from introduced salmonids, including hatchery-produced fish)
- Disease vulnerability (examines proximity and accessibility to sources of diseases and parasites)
- Life history diversity (examines the presence and extent of life history forms such as migratory and adfluvial populations)

Habitat Integrity
- Land stewardship (examines amounts of occupied habitat with conservation protective management, such as parks, wilderness, inventoried roadless, research natural area, area of critical environmental concern or other special status)
- Watershed connectivity (examines barriers, water diversions, and other sources of habitat fragmentation)
- Watershed condition (examines riparian integrity, road density, habitat complexity, deep pools, large woody debris, and other indicators of habitat quality)
- Water quality (examines temperature, dissolved oxygen, pollutants, and other water quality indicators)
- Flow regime (examines water quantity, including daily and seasonal high and low flows)

Future Security
- Land conversion (examines potential for land development based access, slope, and proximity to existing population centers)
- Introduced species (examines potential for future introductions based on access, barriers, and other watershed factors)
- Resource extraction (examines potential for future energy, mineral, or commodity extraction)
- Flow modification (examines potential for future flow modifications based on dams, diversions, groundwater withdrawal, road networks, urbanization, and land conversion)
- Climate change (examines potential vulnerability of subwatershed based on elevation change, habitat connectedness, and population size)

and Wildlife Service, U.S. Geological Survey, James Madison University, Virginia Tech University, TU, and numerous state agency partners (EBTJV 2006). A core team comprised of U.S. Forest Service/James Madison University and TU scientists gathered data from fish biologists in eastern states and mapped the status, trends, and threats to brook trout in 11,400 subwatersheds. The assessment results depict significant thresholds of persistence and remaining core areas of high integrity that will direct a range-wide strategy for the eastern brook trout in the United States and help direct restoration actions of local groups such as TU chapters.

To the extent possible, CSI will utilize existing assessment information that is comprehensive and current. The CSI will be expanded during 2005/2006 to include greenback cutthroat trout *Oncorhynchus clarkii stomias*, Bonneville cutthroat trout *O. c. utah*, westslope cutthroat trout *O. c. lewisi*, Snake River fine-spotted cutthroat (*O. c.* ssp.), and Yellowstone cutthroat trout *O. c. bouvieri*. In the case of Bonneville cutthroat trout, a comprehensive range-wide assessment was recently completed by the State of Utah (May and Albeke 2004) and forms the basis of continuing CSI work for that subspecies. For coastal cutthroat trout, we anticipate that CSI could be conducted in partnership with a variety of state, provincial, and federal agencies primarily using existing information. Completion of a comprehensive transboundary assessment for coastal cutthroat trout would improve our understanding and management of this valuable indicator species of the coastal zone.

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Trends in Inland Cutthroat Trout Conservation

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The term inland cutthroat trout refers to eight subspecies of potamodromous cutthroat trout *Oncorhynchus clarkii* that occur in the interior portions of the western United States. These subspecies include Bonneville cutthroat *O. c. utah*, Colorado River cutthroat *O. c. pleuriticus*, greenback cutthroat *O. c. stomias*, Lahontan cutthroat *O. c. henshawi*, Paiute cutthroat *O. c. seleniris*, Rio Grande cutthroat *O. c. virginalis*, westslope cutthroat *O. c. lewisi*, and Yellowstone cutthroat *O. c. bouvieri*. Historical conservation efforts for these subspecies were generally linked to actions associated with general trout management conducted by state fisheries management agencies. These management efforts had a strong utilitarian focus that often benefited introduced trouts (e.g., rainbow trout *O. mykiss*, brown trout *Salmo trutta*, and brook trout *Salvelinus fontinalis)* and other nonnative fishes that were introduced from other parts of the country or world. In many instances, cutthroat trout became victims of competition, predation, over harvest, and hybridization. Concern for the plight of the various cutthroat trout subspecies began to surface in the late 1950s and early 1960s as some fishery workers openly acknowledged the reduction of cutthroat trout numbers and distributions. For example, the Yellowfin cutthroat trout *O. clarkii macdonaldi* was judged extinct. It was believed that others, such as the Bonneville cutthroat trout, had declined so dramatically that extinction was inevitable. Toward the end of this period management programs were slowly expanding to include consideration of intrinsic values associated with cutthroat trout.

Contemporary conservation of cutthroat trout began in the early 1970s as concern for inland cutthroat trout became more popular. At this time three cutthroat trout—the Lahontan, Paiute, and greenback cutthroat trout—were listed under the Endangered Species Act, and recovery efforts were eventually initiated. Early conservation efforts for the remaining inland cutthroat trout were weakly coordinated and largely driven by personal motivation of a few dedicated individuals. More recently, conservation efforts for the unlisted cutthroat trout have become better coordinated as conservation strategies and agreements have been developed under a range-wide perspective. Administrative and jurisdictional boundaries have become less obvious, and coordination of efforts and resources has been enhanced. Interagency conservation teams, at several levels, have been formed and they are overseeing the various conservation efforts.

Although progress toward conservation of cutthroat trout is apparent, the job is incomplete. It is important that conservation of cutthroat trout include a strong administrative and organizational foundation upon which to build the conservation effort. Many biologists view these activities as complementary, but oftern unnecessary. Inventory, project implementation, and to a lesser degree, evaluations of effort effectiveness, are perceived as the highest conservation priorities; however, cutthroat trout conservation requires a strong, stable foundation to be successful over the long term. For example, it is important that conservation efforts have well-defined, clearly stated goals and objectives that reflect both range-wide and local perspectives. Participants in the conservation efforts should be asked to join the conservation effort by signing a conservation or coordination agreement that defines roles and responsibilities, highlights authorities, and provides a contractual context that binds the participants together in a common cause. Necessary actions should be identified, generally and specifically, in accordance with stated goals and objectives. Plans should be based on assessments that provide the best, most current and consistent information concerning population distribution, status, and threats to persistence. To be effective each conservation program should have an aggressive public outreach and education program that improves the understanding for those who will pass judgment on the effectiveness of the conservation activity.

An organizational framework that fosters "buy in" and makes effective use of the available workforce is another critical component of successful conservation efforts. Partitioning tasks among geographical subdivisions and the development of teams, working groups, and committees that operate under the direction of a conservation coordinator are two useful strategies that can increase productivity.

Support and acceptance of the conservation efforts associated with inland cutthroat trout are based on trust and a clear understanding of the conservation goals and objectives. To date, however, there is considerable misunderstanding among the public regarding the current conservation efforts for the inland cutthroat trout. This situation is largely attributable to a paucity of public outreach effort. To gain needed public support outreach efforts should have an emphasis equal to, or greater than, other components of the conservation program.

The success of contemporary conservation programs can be linked to the degree to which the administrative, organizational, and implementation components have been addressed and incorporated in the respective program. For each of the five subspecies being conserved principally under state leadership, there are strengths and weaknesses. Most have both range-wide and local goals and objectives associated with conservation agreements and plans. Some maintain a high level of coordination through annual meetings, but others meet less often. Although significant conservation action has occurred, most programs are not organized in a way that optimizes the available workforce in an effective and efficient fashion. Furthermore, none of the current conservation programs has active, well-coordinated outreach and education plans.

The quality of inland cutthroat trout conservation has vastly improved over the past three decades. Early efforts of a few dedicated individuals have been replaced by the efforts of many individuals working in a more coordinated and consistent manner. Inland cutthroat trout conservation is becoming institutionalized and is an integral component of most fishery management programs. The future of all inland cutthroat trout is more secure because of the coordinated programs that have been initiated and the dedication of those associated with these programs.

PART FOUR

POSTER SESSION

Effects of Wildfire on Growth of Coastal Cutthroat Trout in Headwater Streams

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Extended Abstract.—Wildfire, a largely terrestrial perturbation, is broadly recognized as an agent of disturbance and ecological change in forested biomes. Links to subsequent changes in aquatic systems have been less well documented. The majority of studies related to wildfire effects on fishes have focused on direct mortality, extirpation, recolonization, and change in relative abundance. Studies focused on the effects of post-fire conditions on ecological responses of stream fishes are lacking, although hypothetically the two are strongly connected. The influence of wildfire may be most profound in headwater streams because of the tight linkage between aquatic and terrestrial ecosystems. By observing growth of coastal cutthroat trout *Oncorhynchus clarkii clarkii*, we sought to investigate how post-fire conditions influence fish demographics in headwater streams. Specifically, we investigated the relationship between wildfire and relative growth rates of coastal cutthroat trout in headwater streams.

During the summer 2002, wildfire burned portions of two headwater catchments in the North Umpqua basin. Burn severities ranged from moderate to severe. An unburned, third catchment was selected as a control. Sampling was conducted upstream of migration barriers to anadromous fishes (i.e., waterfalls) where coastal cutthroat trout were the only species of salmonid present. During the summer of 2003, all fish-bearing streams in these catchments were surveyed using a single-pass electrofishing method. Scale samples were collected from a subset of each population for age and growth analysis. In addition, stream temperature was monitored, and riparian vegetation cover was visually estimated at the habitat-unit scale. Relative growth rates were derived from scales by back calculation of age at length.

Preliminary results from this study suggest that wildfire has affected growth of coastal cutthroat trout in these headwater streams of western Oregon. Although relative growth rate depended on the age and size of individual fish, data suggested that coastal cutthroat trout growth was affected by reduced canopy and increased water temperatures. Relative growth rates and length at last annulus formation of coastal cutthroat trout were positively related to the number of degree days during the growing season, and Pearson correlation coefficients ranged from 0.60 ($p < 0.07$) to 0.90 ($p < 0.01$), respectively. Growth rates and size of fish were not significantly correlated with relative density of fish ($p \geq 0.14$). Despite considerable changes to the physical stream environment following the wildfire, results suggest that the effects of wildfire on stream ecosystems may result in greater fish growth when temperature increases are not excessive.

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Coastal Cutthroat Trout Symposium: Status, Management, Biology, and Conservation
Oregon Chapter, American Fisheries Society, 2008

Unexpected Abundance: Coastal Cutthroat Trout *Oncorhynchus clarkii clarkii* as the Inheritors of Seattle Urban Creeks in the Declining Presence of Other Wild Salmonids

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Extended Abstract.—Since 1999 the Wild Fish Conservancy (WFC) has documented coho salmon *Oncorhynchus kisutch* dying at elevated rates prior to spawning upon return to major urban creeks in Seattle. This phenomenon, termed prespawning mortality (PSM), occurs at rates up to 100% in some Seattle watersheds surveyed. In 2002, the National Oceanic and Atmospheric Administration (NOAA) Fisheries, assisted by Seattle Public Utilities and WFC, began investigating the causal mechanism of coho PSM, focusing on stream/storm water quality and ecotoxicological assays. Notably, there is interspecific variability among Pacific salmon in the degree of susceptibility to the factors (as yet incompletely understood) causing PSM. Chum salmon *O. keta*, for instance, typically exhibit PSM rates under 10%, while sockeye *O. nerka* and Chinook *O. tshawytscha* PSM incidence is more highly variable year to year.

In contrast to that of Pacific salmon, the spawning success of Washington's native trout within urbanized watersheds has, until recently, remained largely unknown. Citizen reports of spring spawning activity in Thornton Creek in Seattle stimulated WFC spawning surveys in March and April 2001. These surveys documented numerous large coastal cutthroat trout *O. clarkii clarkii* and several unoccupied redds. Concurrent surveys of nearby Piper's Creek also revealed redds. Based on these initial findings, WFC has undertaken annual surveys of Thornton and Piper's Creeks from October through May to determine 1) numbers of spawning salmon and trout by species; 2) salmonid spawning success and PSM incidence; and 3) the temporal and spatial extents of spawning activity.

Migratory coastal cutthroat trout were found to be the predominant species of wild salmonid spawning during the winter and spring, constituting apparently self-sustaining populations in Thornton and Piper's Creeks (Figure 1). Spawning was documented as early as December 16 and as late as June 2 in weekly surveys from 2002 through 2005. Between 465 and 667 cutthroat of presumptive adfluvial life history (12-28 in [30-71 cm] fork length) spawned annually in 3.5-4.4 miles (5.6-7.1 km) of Thornton Creek surveyed, producing 86-116 redds/mi (53-72 redds/km). In the 0.52 mile (0.8 km) of Piper's Creek surveyed during 2004 and 2005, 28-48 cutthroat of probable sea-run life history (12-20 in [30-51 cm]) spawned annually (44-60 redds/mi [27-37 redds/km]). Fish distribution in both watersheds is abbreviated by barrier culverts (McMillan 2005). Peak

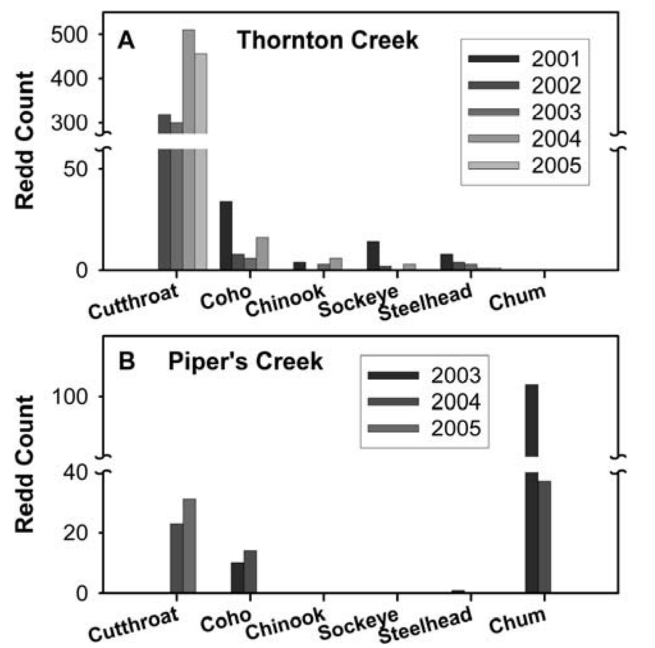

FIGURE 1.—Annual salmonid redd count totals for (A) Thornton Creek and (B) Piper's Creek. Cutthroat redds averaged 397 (SE = 52) in Thornton Creek and 27 (SE = 4) in Piper's Creek during WFC surveys. Coho and steelhead redds were observed in both systems, while Chinook and sockeye redds were only documented in Thornton. Chum redds from hatchery fish dominated in Piper's.

cutthroat redd counts on both streams were made in February and March, although the Piper's sea-run population ceased spawning more than a month earlier than Thornton's adfluvial population. Limited resident cutthroat spawning occurred throughout the season but small resident males were observed actively spawning with migratory cutthroat in both streams. A few late coho salmon returned in February at each stream. The only confirmed steelhead *O. mykiss* sightings were two carcasses at Thornton Creek, both prespawning mortalities.

The coastal cutthroat trout found in Thornton and Piper's Creeks were unexpectedly abundant. Both urban watersheds have had significant anthropogenic alterations to their ecology, and cutthroat have been noted as particularly sensitive to such environmental disturbance (Trotter 1987). Stream-dwelling salmonids, including coastal cutthroat, typically depend on macroinvertebrate prey (Keeley and Grant 1997; Wydoski and Whitney 2003), the taxonomic diversity of which is reflected in part by the Benthic Index of Biological Integrity (B-IBI). Thornton Creek had the

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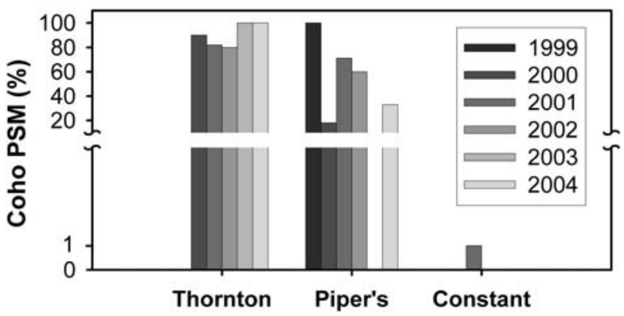

FIGURE 2.—Prespawning mortality (PSM) rates in female coho salmon within urbanized and non-urbanized Washington streams. Thornton and Piper’s Creeks in Seattle showed substantially higher rates of coho PSM (mean 75% and 47%, respectively) than did Constant Creek (1%), a relatively pristine stream within the Sauk River basin. For comparison, coastal cutthroat trout PSM rates in Seattle streams were a fraction of one percent on average.

lowest B-IBI scores (mean 11.5 on a scale of 10-50) of 45 index sites sampled in Washington’s King County (Morley 2000; Morley and Karr 2002). Piper’s Creek B-IBI scores fluctuate more annually but are also relatively low (11-23) (L. Reed, Seattle Public Utilities, personal communication). In addition, these Seattle streams are characterized by high rates of prespawning mortality in female coho salmon (Figure 2), which may preclude sufficient egg seeding for self-sustaining coho populations. The relatively large numbers of wild cutthroat observed in Thornton and Piper’s Creeks are surprising, then, in light of the streams’ low B-IBI scores and high incidence of coho PSM.

Whereas prespawning mortality in Pacific salmon may be linked to contaminants in urban stormwater runoff, cutthroat trout seem little affected by such water quality degradation, or by the compromised biological condition of Seattle’s streams. Despite the adversities, wild cutthroat appear to be the primary inheritors in the urban creeks we studied, whose conditions have proven limiting for other salmonids.

Improving our understanding of this incongruous finding awaits further study. An important area for future research is assessment of the extent of cutthroat cannibalism in both Thornton and Piper’s Creeks, and the role of abundant suckers (*Catostomus* spp.) and peamouth *Mylocheilus caurinus* as potential prey that may support self-sustaining cutthroat populations in the absence of other abundant salmonid assemblages and a diverse invertebrate community.

Acknowledgments

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Feeding Ecology of Cutthroat Trout in the Salmon River Estuary, Oregon

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Abstract.—Until recently, coastal cutthroat trout *Oncorhynchus clarkii clarkii* were thought to use estuaries primarily as a migration corridor to and from the ocean, rather than as a rearing environment. However, recent research in Oregon's Salmon River estuary has defined an extensive estuarine life history for a portion of the population. This study was designed to assess the diet of coastal cutthroat trout that reared in the Salmon River estuary during the summer 2003. Fifty-five coastal cutthroat trout, ranging in size from 130-400 mm, were collected by beach seine at three locations in the Salmon River estuary from June 18 through August 1. Stomach samples were obtained by gastric lavage and described by taxonomy, total number, and weight. Fish community composition was also recorded at each site. Coastal cutthroat trout fed actively on pelagic and benthic fishes, benthic invertebrates, and some terrestrial insects. Only 4 of 55 cutthroat trout had empty stomachs. Overall, prey availability and diet varied by site. Active selection of various prey items was noted at each location and was site specific. Chinook salmon fry were not selected for, although they were found in stomach samples.

Introduction

Coastal cutthroat trout *Oncorhynchus clarkii clarkii* have among the most complex life history patterns found in Pacific salmonids, and this complexity is exemplified by their migratory behavior (Johnston 1982; Northcote 1997; Johnson et al. 1999). All cutthroat trout are spawned in freshwater, but they exhibit a diversity of rearing patterns ranging from residency to migratory within fresh water (i.e., potamodromy) as well as migration to marine waters (i.e., anadromy). Despite these migratory tendencies, sea-run cutthroat spend most of their life in freshwater and, unlike other anadromous salmonids, migrate to marine waters to feed for only a brief period (rarely more than six months; Trotter 1997). Few, if any, overwinter in marine waters, though they may make repeated excursions during subsequent years. While the marine residence of cutthroat is brief, it remains an important life history phase influencing both growth and survival (Pearcy 1997).

The estuarine environment is of particular importance to sea-run cutthroat trout because they repeatedly migrate to and from marine water. Thus, cutthroat trout spend more time in this environment than other Pacific salmonids. In a comprehensive study of the Nestucca, Alsea, and Siuslaw estuaries, Giger (1972) concluded that although the estuary may be more important for cutthroat trout than for other salmonids, it is used as mainly a "staging ground" for passing to and from the ocean. Other publications (Loch and Miller 1988; Pearcy et al. 1990; Trotter 1997), however, suggest that estuaries likely play a larger role in coastal cutthroat trout development. A population in the Rogue River, Oregon, was found to remain in the estuary, rarely migrating to the ocean (Thomasson 1978). In a recent telemetry study in the Salmon River, Oregon, Krentz (2007) demonstrated that estuarine use by coastal cutthroat trout can be highly variable. Some trout reside in the estuary for the duration of the summer while others stay for only a few days as they pass to and from the ocean. These rearing strategies appeared to be independent of size or age.

Considering that some populations of coastal cutthroat trout use estuaries extensively, it is beneficial to understand their feeding ecology while in estuarine environments. Existing research on this subject is minimal; however, limited but conflicting data have been collected in several locations. Giger (1972a, 1972b) concluded that in the Columbia River estuary cutthroat forage when moving downstream, but their primary food resources are in the ocean. However, Johnston (1982) suggested that the movement of anadromous cutthroat through Minter Creek, Washington, may be timed to prey on migrating juvenile salmonids in the estuary. Giger (1972a, 1972b) also argued that cutthroat trout do not feed in the estuary on the return trip to the spawning grounds. However, other studies (Loch and Miller 1988; Trotter 1997) found that cutthroat trout do feed on the return trip, although perhaps not as extensively

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as on the downstream migration.

Cutthroat trout are thought to be opportunistic feeders (Pauley et al. 1989; Trotter 1997). In freshwater, cutthroat trout diet is dominated by aquatic invertebrates, although terrestrial insects, zooplankton, and fish are consumed when available (Pauley et al. 1989). Out at sea, cutthroat trout prey on a variety of invertebrates including gammarid amphipods, isopods, shrimp, juvenile crab, mysids, and euphausids. They also prey on fish such as sculpins and other small bottomfish, anchovy, stickleback, sand lance, and various species of juvenile salmonids (Loch and Miller 1988; Pauley et al. 1989; Trotter 1997). In the estuary, cutthroat trout diets have been found to include Crangon shrimp, gammarid amphipods, aquatic insects, herring, anchovies, perch, and smelt (Giger 1972b; Loch and Miller 1988; Pearcy et al. 1990). Diet changes from invertebrates to fish as the cutthroat trout move downstream through the estuary (Giger 1972b). In addition, cutthroat trout become more piscivorous as they increase in size (Pauley at al. 1989).

The ocean is thought to provide plentiful food resources for salmonids during the transition from their juvenile to adult stage, hence the advantage of an anadromous lifestyle. However, a significant portion of cutthroat trout in the Salmon River spend little or no time in the ocean and instead remain in the estuary for the entire spring and summer (Krentz 2007). This study was designed to examine the diet composition of coastal cutthroat trout residing in the Salmon River estuary during the summer months. By describing cutthroat diet and feeding ecology in this residence period, we hope to shed some light on why the cutthroat trout exhibit an estuarine life history. We also address how feeding behavior differs by cutthroat trout size and sample location (i.e., habitat and estuary position), and we consider if certain prey are selected.

Methods

Study area.—The Salmon River estuary is located on the north central Oregon coast (45° 01' N, 123° 58' W), approximately 6 km north of Lincoln City (Figure 1). The watershed drains approximately 194 km^2 and forms an 800 ha estuary that extends 6.5 km from the mouth.

We selected three sample locations in the estuary (Figure 1). Site 1, the downstream site, is characterized by eel grass beds and a fringing marsh, adjacent to a deep channel. It is located in the lower estuary, and experienced an average salinity and temperature of 30 ± 9‰ and 14 ± 4ºC, respectively, during the sampling period. Site 2 is a deep channel located at the mouth of an undisturbed marsh (Gray et al. 2002). It is located in the mid-estuary and experienced an average salinity and temperature of 12 ± 7‰ and 18 ± 2ºC, respectively. Site 3 is a deep pool at the mouth of a recently restored marsh (Gray et al. 2002) in the upper estuary. It had an average salinity of 8 ± 6‰ and temperature of 19 ± 3ºC, respectively. Based on telemetry data (Krentz 2007), these three sites represented the primary holding areas for cutthroat trout in the estuary. We collected all data between 18 June and 1 August 2003.

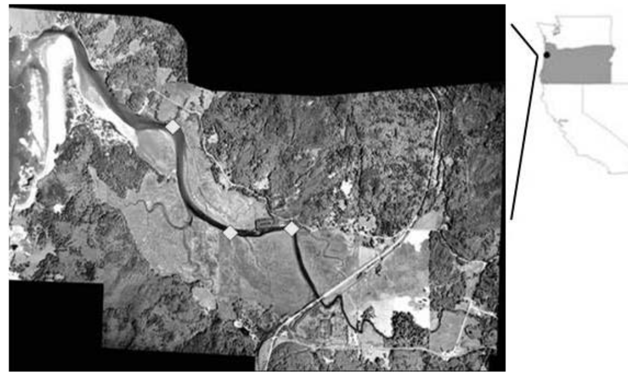

FIGURE1.—Aerial view of Salmon River estuary, located on the north-central Oregon coast approximately 6 km north of Lincoln City. Sample sites are marked by the light colored diamonds. The estuary enters the ocean to the left. Downstream site is site 1, mid-estuary site is site 2, and upstream site is site 3. Highway 101 is the white line that crosses the estuary upstream of the third site. Marsh areas are adjacent to the main channel.

Sampling methods.—The number of cutthroat sampled by site and size class is shown in Table 1. We attempted to sample 15-20 cutthroat trout from each site, and to represent each size class equally (i.e., 130-220 mm, 220-280 mm, and 280-400 mm by fork length; Table 1). Unfortunately, we were unable to sample as many cutthroat trout in the 220-280 size class, only one of which was from the upper site, site 3 (Table 1).

Table 1.—Numbers of cutthroat trout sampled by site and size class.

Site	130-219 mm	220-279 mm	280-400 mm	Subtotal
Lower (Site 1)	7	3	6	16
Mid (Site 2)	10	6	4	20
Upper (Site 3)	9	1	9	19
Subtotal	26	10	19	55

We collected cutthroat trout with a beach seine measuring 38 by 3 m (1.9 cm mesh in the wings) with a bag 3 by 1.5 m (0.6 cm mesh). Cutthroat trout were sedated with MS-222 (50 gm/L) and measured for fork length (tip of snout to caudal fork). Gastric lavage, a common technique in fish diet studies, was used to excavate stomach contents (Foster 1977; Light et al. 1983). A garden pump with soft rubber tubing (4 mm diameter) provided the water pressure to flush stomach contents on to a 500 µm sieve. We did not sacrifice any cutthroat trout because they were part of a larger study by Krentz (2007) and were thus unable to test the efficiency of the technique. However, other studies have demonstrated a very high efficiency (>90%) for trout of similar size (Foster 1977; Meehan and Miller 1978; Light et al. 1983; Gunckel 2001). Stomach contents were stored in ethanol. Other fish species caught in the net were counted and recorded for prey availability data. Additional beach seining was conducted in conjunction with ongoing studies in the Salmon River estuary by Krentz (2007) and Hering (unpublished), and these data were also used to assess prey availability.

Stomach content analysis.—Stomach contents were identified (when possible) and enumerated under dissecting scope. The number of each fish species present was counted, but we recorded only presence and absence data for invertebrate prey due to extensive disarticulation. Total and individual stomach contents were weighed to the nearest 0.1 g to provide relative weights of fish, invertebrate, and terrestrial invertebrate prey groups. Other items, such as rocks, wood, and algae, were also recorded.

Stomach content composition was calculated as percent biomass of differing prey types. A G-stat (Sokal and Rohlf 1981) was used to test for differences in prey species at each site and also among prey species found in stomach samples between sites. Ivlev's electivity index (Strauss 1979) and the log of the odds ratio (Gabriel 1978) were used to test for fish prey species selection (i.e., captured by the 0.6 cm seine mesh) by cutthroat trout. We did not test for selection of invertebrate prey because we had no relative measure of availability of aquatic or terrestrial invertebrates. Ivlev's index is scaled from -1 to +1. The log of the odds ratio is scaled from $-\infty$ to $+\infty$. Infinity is reached either when prey was eaten but not caught in the beach seine (positive), or when prey items were not eaten but were caught in beach seines (negative). For the items that were present in both net and stomachs, the values of the ratio runs from about -10 to +10. The advantage of the log of the odds ratio is that a standard error can be calculated, which allows for tests of statistical significance. Because the results of Ivlev's and the log of the odds ratio were similar, we only present the results from the later. A z-statistic was calculated to test for significance between Ivlev's and log of the odds, according to Gabriel (1978). Data on prey species available at each site, used to calculate electivity, were summarized from seine hauls most similar in time, tide, and location to the capture of each individual cutthroat.

Multivariate analyses were based on ln(x+1) transformed data using the Bray-Curtis distance measure (McCune and Grace 2002). Ordination and significance tests used Canonical Analysis of Principal Coordinates (CAP) (Anderson and Willis 2003). Partial CAP allowed the test of an explanatory (constraining) variable after partialling out (conditioning) the variation related to a covariate. All significance tests used 10,000 permutations of residuals under the full model, stratified by site when necessary (Legendre and Legendre 1998). Analyses were run using the vegan package in R, version 1.8.1 (R Development Core Team 2003).

Results

We sampled stomach contents from 55 total coastal cutthroat trout, 16 cutthroat trout from the lower estuary site, 20 from the mid-estuary site, and 19 from the upper site. Fork lengths ranged from 132-397 mm. The majority of cutthroat trout sampled, 93%, had prey in their stomachs. Of these, 73% had invertebrates, 62% had fish, and 18% had terrestrial insects in their stomachs (Table 2).

Fish and invertebrates co-occurred in 47% of cutthroat trout stomach samples. Of 25 stomach contents with identifiable fish prey, 22 (88%) of those consisted of only one species. The most common fish prey species were northern anchovy *Enaraulis mordax*, staghorn sculpin *Leptocottus armatus*, shiner perch *Cymatogaster aggregata*, and juvenile Chinook salmon *Oncorhynchus tshawytscha* (Figure 2). The most common invertebrate prey taxa were isopods (*Gnorimosphaeroma* spp.) and gammarid amphipods (*Corophium* spp. and *Eogammarus* spp.) (Figure 2). One particular fish (132 mm in length) was captured two days in a row (identified by passive integrated transponder [PIT] tag), and both times had isopods, mysids, and gammarid amphipods in its stomach. Small rocks and plant matter were also common in stomach samples. Cutthroat trout had consumed fish, invertebrate, and terrestrial invertebrate prey at all sites. However, cutthroat trout at the mid-estuary site (site 2) had a higher occurrence of benthic fishes (sculpins and gunnels) and benthic invertebrates (*Corophium* spp. and isopods) in their stomach contents than at either the upper or lower site.

TABLE 2.—Prey items identified in cutthroat stomach samples.

Prey type	Prey taxa
Pelagic Fish	Chinook salmon (*Oncorhynchus tshawytscha*) Northern anchovy (*Engraulis mordax*) Pacific herring (*Clupea harengus*) Shiner perch (*Cymatogaster aggregata*) Surf smelt (*Hypomesus pretiosus*)
Benthic Fish	Pacific staghorn sculpin (*Leptocottus armatus*) Prickly sculpin (*Cottus asper*) Saddleback gunnel (*Pholis ornata*) Flatfish spp. (family *Pleuronectidae*) Pacific sand lance (*Ammodytes hexapterus*)
Estuarine Invertebrates	Isopoda *Eogammarus* spp. *Corophium* spp. *Crangon* spp. Cirripedia Brachyura Zoea Brachyura parts Mysidae Polychaeta Nematoda
Terrestrial Invertebrates	Soldier Beetle (family *Cantharoidae*) Ladybug (genus *Coccinellidae*)

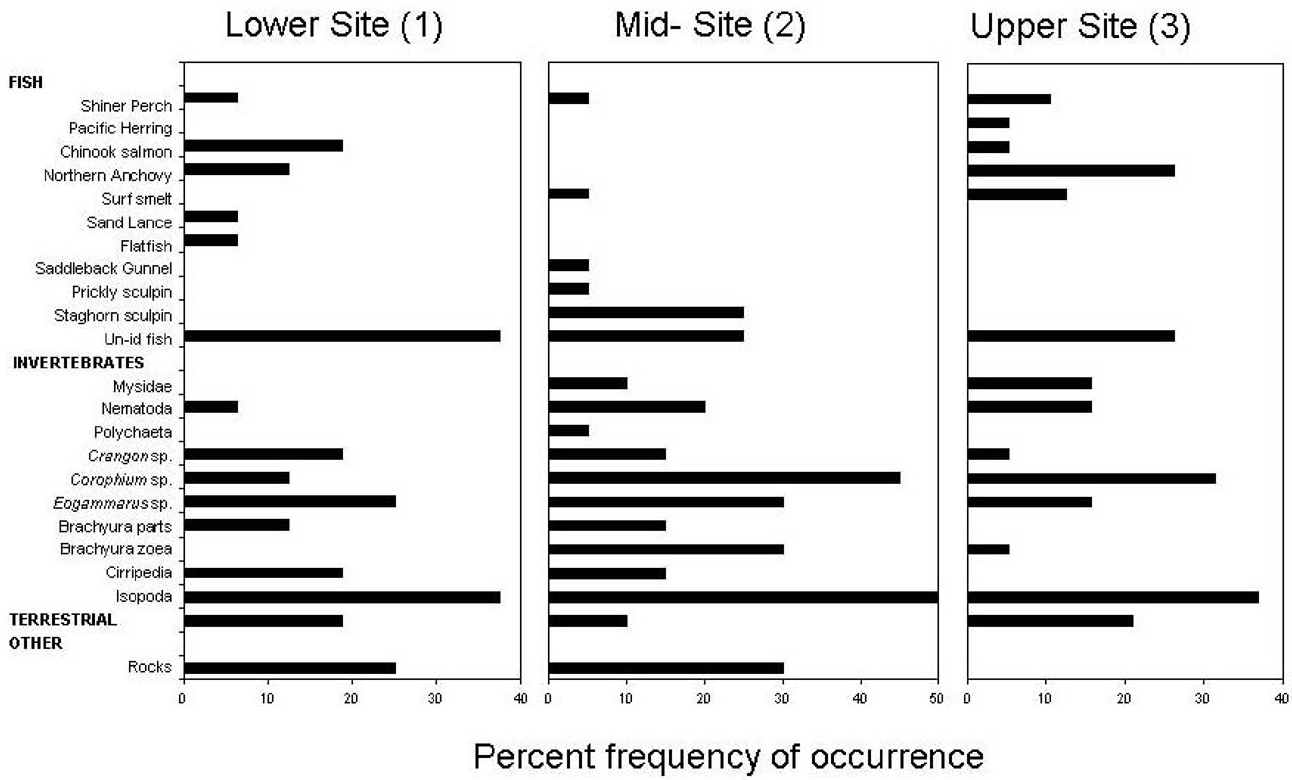

FIGURE 2.—Percentage occurrence of each prey taxa in cutthroat stomach samples by site.

Fish size was positively correlated with the amount of fish and invertebrate prey consumed, but not with the amount of terrestrial species ingested. Percent biomass of fish prey increased significantly with fork length (Spearman's ρ, $r^2 = 0.494$, $p < 0.001$). Percent biomass of invertebrates by fork length varied significantly (Spearman's ρ, $r^2 = -0.381$, $p = 0.004$). There was no significant variation in percent terrestrial biomass by fish size by regression and correlation (Spearman's ρ, $r^2 = -0.128$, $p = 0.353$). When trout were grouped into size classes (130-220 mm, 220-280 mm, 280-400 mm) cutthroat trout in the largest size class ate a significantly higher percentage of fish prey than the smallest size class; they also consumed a significantly lower percentage of invertebrate prey than fish 130-220 and 220-280 mm long (Tukey's HSD pairwise comparison: $p < 0.05$; Figure 3).

No significant relationship existed between sample site and percent biomass of fish, invertebrate, and terrestrial prey consumed (ANOVA: $f = 1.212$, $p = 0.306$; $f = 0.252$, $p = 0.779$; $f = 1.619$, $p = 0.208$, respectively; Figure 4). However, the prey species available and prey species consumed varied significantly between sites ($G_{H(28)} = 133.51$, $p < 0.001$ for prey availability, $G_{H(18)} = 47.82$, $p < 0.001$ for prey consumed; Figure 5).

The multivariate analysis identified similar significant relationships of fish prey in the diets. Cutthroat body length explained a greater amount of variation in diet composition than did salinity or date of stomach sampling when each variable was tested separately (salinity: 8.8%, date of sampling: 13.0%, length: 17.4%; $p < 0.001$). After accounting for cutthroat length, diet composition varied significantly among sites as well (conditioned: 17.4%, constrained: 19.5%; $p = 0.0035$; Figure 6). Axis 1

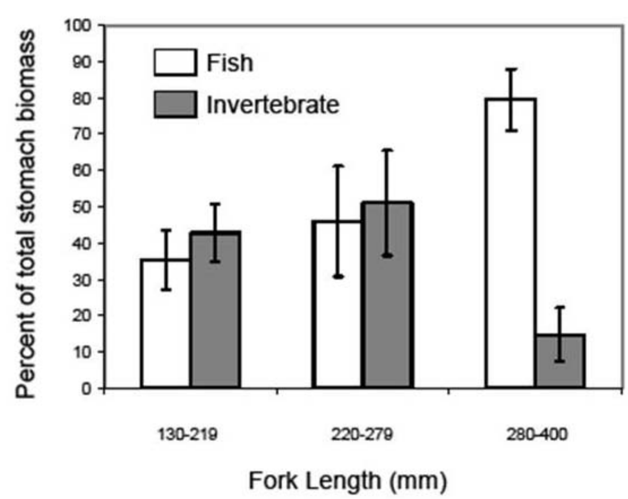

FIGURE 3.—Percent fish and invertebrate prey of total cutthroat trout stomach biomass, by size class of cutthroat trout. Error bars represent standard error.

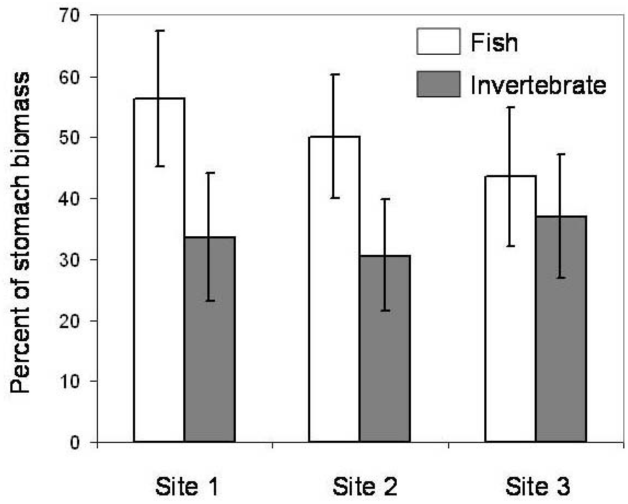

FIGURE 4.—Percent fish and invertebrate prey of total cutthroat stomach biomass, by sample site. Error bars represent standard error.

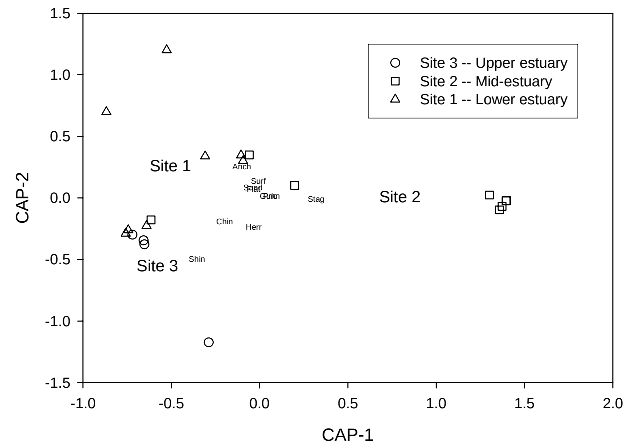

FIGURE 6.—Ordination of diet by site and piscine prey species. Site centroids shown by site labels. Diet of individual cutthroat identified by symbol according to site and prey species (identified by first four letters of common name). Prickly sculpin and saddleback gunnel overlap near the center, as do flatfish and Pacific sandlance.

explained the variation between fish diets at site 2 and sites 1 and 3. Axis 2 separated the variation in diet between sites 1 and 3. Northern anchovy and surf smelt were associated with diets at site 1, Pacific staghorn sculpin with site 2, and shiner perch, Chinook salmon, and Pacific herring with site 3.

Cutthroat trout demonstrated preference for certain fish prey (z-test on log of the odds ratio: $p < 0.001$; Table 3). The log of the odds ratio indicated that at the lower site (site 1) cutthroat trout preferentially selected anchovy, shiner perch, and surf smelt. Staghorn sculpin and surf smelt were selected at the mid-estuary site (site 2), and anchovy, Pacific herring, and juvenile shiner perch at the upper site (site 3). Juvenile Chinook salmon were abundant in beach seine catches at every site, but were not eaten proportionally to their abundance in the estuary at the mid- and upper sites. Numerous fish prey were collected by beach seine in the estuary, but not consumed by cutthroat trout. Table 3 displays the complete electivity results for fish prey, and prey availability is shown in Figure 5.

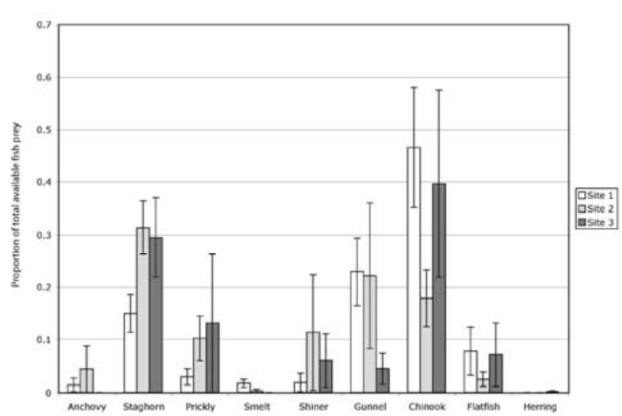

Figure 5.—Composition of available fish prey species at each site, based on seine net capture (n = 24). Error bars represent standard error.

Discussion

Smaller cutthroat trout in the estuary fed on a higher percentage biomass of invertebrate than fish prey, while the converse was true of larger cutthroat (Figure 3). This

TABLE 3.—Fish species selected for and against by cutthroat trout according to the log of the odds ratio at each site. Species were only included if present in significant numbers and consumed by cutthroat trout at one of the three sites. Negative values represent selection against and positive represents positive selection for an item. Negative infinity indicates that prey were available but not eaten, positive infinity indicates that prey were eaten but not collected by beach seine. Significant values ($p < 0.05$) are highlighted in gray. Blank cells indicate that a species was not collected by beach seine or stomach sample at a site.

Species	Lower estuary	Mid-estuary	Upper estuary
Juvenile shiner perch	+1.8	- 0.6	+3.4
Pacific herring	- ∞		+2.1
Chinook salmon	- 0.5	- ∞	-2.4
Northern anchovy	+2.9		+ ∞
Surf smelt	+2.5	+3.9	
Flatfish	- 0.2	- ∞	- ∞
Saddleback gunnel	- ∞	- 0.3	- ∞
Prickly sculpin	- ∞	+ 0.5	- ∞
Pacific staghorn sculpin	- ∞	+1.1	- ∞

increase in piscivory with size appears to be a pattern common among cutthroat (Pauley et al. 1989). Invertebrates, however, remained an important part of the diet of large fish (280-400 mm) in the estuary, comprising about 15% of their diet in terms of weight. Eleven out of the 18 fish in the largest size class which had items in their stomachs contained invertebrates. Of these eleven, two of the samples were comprised solely of invertebrate prey items.

In late July, a large school of northern anchovies moved into the upper site. Six cutthroat trout were sampled from that site during this time, all between 297 and 400 mm, and all except one had anchovies in their stomachs. Such opportunistic feeding is thought to be characteristic of cutthroat trout (Giger 1972b; Loch and Miller 1988; Pauley et al. 1989). On this occasion, the water salinity at the upper site was 37‰ due to a strong tide and the temperature was 11ºC, conditions which mimic that of the offshore ocean. Although marine species are common at the upper site during late summer, the presence of northern anchovy was not observed in such abundance in previous years (T. Cornwell, Oregon Department of Fish and Wildlife, personal communication).

Giger (1972b) noted that the diet of cutthroat trout shifted from one dominated by insects to one dominated by sand shrimp and fish as the cutthroat moved downstream through the estuary. This change was attributed to differences in prey availability in different estuary regions (see also Trotter 1997). The present study indicated that prey species consumed varied significantly among sites. However, fish, invertebrates, and terrestrial invertebrates were consumed at all locations (Figures 2 and 4).

Site-specific feeding behavior by cutthroat trout in relation to habitat conditions was evident. Pelagic fish were the main fish prey at sites 1 and 3, while benthic fish were the primary fish prey at site 2. All aquatic invertebrates found in stomach samples in this study were benthic infauna, except mysids, which are considered epibenthic. The predominance of benthic invertebrates and fish prey in the diet of cutthroat trout at site 2, as well as a higher frequency of rocks within stomachs, suggests that these cutthroat trout were feeding primarily on the bottom unlike cutthroat trout at the other two sites. The large marsh channel system which enters at site 2 is known to support a higher average density of benthic macroinvertebrates than other marsh areas in the estuary (Gray et al. 2002). No variation in the consumption of terrestrial prey was observed in relation to cutthroat body size or sample site. However, 20% of cutthroat had been feeding on terrestrial invertebrates, which are an energy rich and readily available food source, particularly at site 3 (Gray et al. 2002).

Ivlev's electivity index (Straus 1979) and log of the odds ratio (Gabriel 1978) were used to assess if cutthroat trout were selecting for certain fish prey at each site. It is important to recognize that our sample sizes are small, and also that sampling bias may exist because prey availability was determined by seine netting. Capture efficiency with a 0.6 cm mesh beach seine is lower for benthic than for pelagic species, although fish as small as 35 mm are effectively sampled at this mesh size (Lyons 1986). We were not able to measure invertebrate availability at each site, which is unfortunate because in many cases invertebrate prey dominated stomach contents. Despite this, we feel that these electivity data provide insight regarding fish prey selectivity, and match what we expected based on observations from the field. By our electivity results (Table 3), cutthroat trout selected different prey fish in different locations in the estuary even though availability was similar. Ivlev's electivity index and the log of the odds ratio showed that juvenile shiner perch, northern anchovy, Pacific herring, and surf smelt were selected for at sites 1 and 3, and that staghorn sculpin and surf smelt were selected for at site 2. Cutthroat trout did not feed on the available Chinook salmon fry or shiner perch at site 2. Cutthroat trout at site 2 were oriented toward benthic food sources, but at sites 1 and 3 pelagic fish were preferred. Chinook fry, juvenile flatfish, saddleback gunnel, and sand lance were not selected for. Thus, while cutthroat may appear opportunistic in their feeding behavior at times (e.g., foraging on a pulse of available northern anchovies), habitat can influence their prey selectivity.

Four cutthroat trout had been feeding on Chinook salmon fry. Of these four, the smallest cutthroat trout was 268 mm, and the other three were 338, 351, and 374 mm. One additional occurrence was noted the following year when a cutthroat trout was collected containing a PIT tag that had been placed in a Chinook fry (D. Hering, Oregon State University, personal communication). It is debatable how important juvenile salmonids are to cutthroat trout diet. Trotter (1997) concluded that predation on salmonids by cutthroat trout "seems to be situational." He cites four articles where little or no predation on salmonids was recorded, but two others that list young salmonids as a principal food source. Our electivity results showed that although occasional predation on salmonids was occurring, they are not a preferred food source for cutthroat trout despite the abundance of Chinook fry in the estuary (frequently the most common fish species caught in our nets). Only large cutthroat trout were observed to have fed on Chinook fry, even though cutthroat of all sizes were capable of consuming fish larger than the fry.

The Salmon River estuary provides high quality habitat during an important phase in the life cycle of anadromous cutthroat trout. The estuary supports invertebrate, terrestrial, and fish prey that are important components of cutthroat diet. It may also provide relief from many ocean predators, such as Pacific hake, spiny dogfish, sub-adult salmon, and seals (Giger 1972b). Given the ample prey resources and potentially reduced risk of predation in the estuarine environment, a life history that utilizes these habitats may be quite advantageous for coastal cutthroat trout. Johnston (1982) hypothesized that certain populations of coastal cutthroat trout may reside in streams longer due to the availability of eggs from spawning salmon. In this way, the cutthroat are able to take advantage of a plentiful food source while also avoiding exposure to marine predators. We hypothesize that similar pressures may encourage longer estuarine residences for the Salmon River cutthroat trout.

Our findings differ from previous studies that have concluded that the estuary has little influence in cutthroat trout subsistence. Giger (1972b) "discarded" an estuarine diet study of cutthroat trout in the Nestucca, Alsea, and Siuslaw estuaries because it appeared that little or no feeding took place in the summer and fall. However, the Salmon River estuary may be unique among contemporary Pacific Northwest estuaries because of its abundant marsh habitat (Figure 1), much of which has been restored in the past 30 years. These marshes provide productive habitat for many of the prey species upon which coastal cutthroat trout feed (Gray et al. 2002; Bottom et al. 2005). Most Pacific Northwest estuaries have experienced habitat loss due to human activities such as development and channel dredging. Perhaps it is the complex and productive habitat of the Salmon River estuary that encourages and sustains an estuarine life strategy for coastal cutthroat trout.

Conclusions

Cutthroat trout in the Salmon River estuary feed actively during the summer months. The estuary supports a variety of prey species, both invertebrate and fish, which are consumed by cutthroat trout of all sizes. Invertebrates constituted a larger portion of the diet of small cutthroat trout while the larger trout were more pisciverous. As most previous studies have suggested, cutthroat trout feed on most types of available fish and invertebrates; however, our study found that they do show preference towards certain species at each site. No significant differences were noted in the amount of fish, invertebrate, and terrestrial invertebrate prey consumed by site, although variation in prey species consumed was noted and is attributed to differences site-specific habitat.

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Diet of Coastal Cutthroat Trout in South Puget Sound

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Extended Abstract.—The diet of coastal cutthroat trout *Oncorhynchus clarkii clarkii* has previously been documented in some portions of the historical range (Armstrong 1971; Giger 1972; Loch and Miller 1988), but in many areas there is little information about the diet of this cutthroat trout subspecies. In this study, cutthroat trout consumption of salmon eggs and fry, interactions with other fish species, and the management implications of this behavior were investigated in South Puget Sound. It was hypothesized that coastal cutthroat in salt water feed heavily on chum salmon *O. keta* eggs and fry when available. Specific objectives were to: 1) measure occurrence of prey in the diet of coastal cutthroat in estuaries, 2) document coastal cutthroat predation or scavenging of salmon, and 3) clarify coastal cutthroat interspecific interactions in estuaries.

A sample of 115 coastal cutthroat trout was captured with artificial flies in four South Puget Sound tributary inlets from 24 July 1999 to 8 April 2002. Following anesthesia, coastal cutthroat trout were measured (fork length), and a scale sample was collected. Gut contents were collected by gastric lavage and, following revival, each fish was released on site. Stomach samples were identified, measured, weighed to the nearest 0.001 g. Each taxon was summarized by percent frequency of occurrence, numerical composition, and contribution to the total weight of prey (Bowen 1996).

Salmon eggs and chum fry made up a large part of the diet during the period when chum salmon were present in the area (October-to-January, March, and April), and these eggs and fry were more often found in stomachs of larger cutthroat trout (Figure 1). The non-salmon fish diet consisted of shiner perch *Cymatogaster aggregata*, Pacific herring *Clupea pallasii*, Pacific sand lance *Ammodytes hexapterus*, and arrow goby *Clevelandia ios*. Invertebrates were mainly gammarid amphipods Crangonyctidae, shrimp *Pandalus* spp., isopods Isopoda, and clam Myoida necks.

Larger cutthroat trout apparently consumed salmon eggs and chum fry when they were available in estuaries and shifted to alternative food items when they were absent. Increased coastal cutthroat trout fecundity and fitness may be associated with the movements of salmon, particularly in South Puget Sound where concentrations of chum salmon adults or fry are present before and after coastal cutthroat trout spawn (Northcote 1997). Polychaetes, non-salmon fish, and invertebrates more frequently occurred in all cutthroat trout diets when salmon eggs and fry were not present, but sample size limited statistical power to evaluate relationships among prey size, cutthroat trout length, and seasonal diet shifts. The relative weights of diet items imply relationships among food value, selection preferences, and temporary abundance of the prey items, in spite of low selection frequency, as in the case of salmon eggs.

A number of questions about the dynamics of food habits and availability remain unanswered. For example, do estuary-dwelling coastal cutthroat trout have better survival rates than those that reside elsewhere? What is the role of coastal cutthroat trout in estuary food webs? Some important information could be gained by comparison of seasonal distribution and growth patterns of coastal cutthroat trout in estuaries and by understanding interspecies interactions in the terrestrial-marine ecotone.

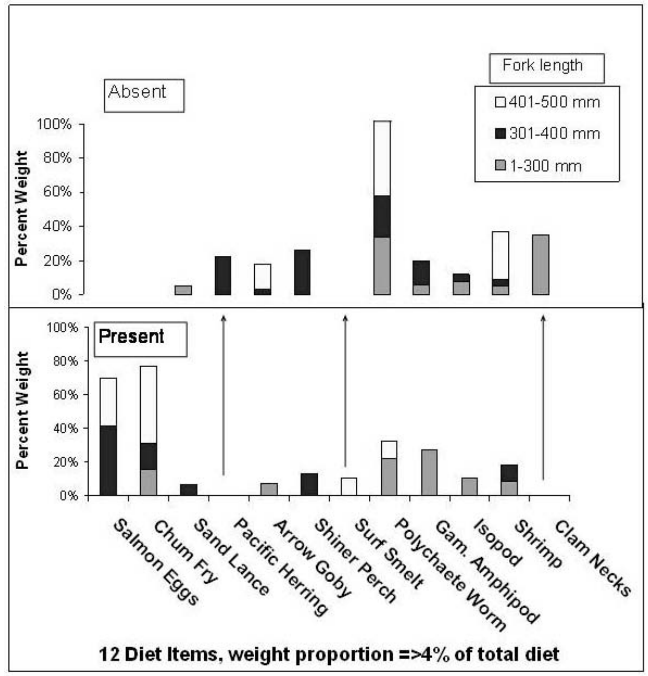

FIGURE 1—Diet items by coastal cutthroat trout length in the absence and presence of chum salmon.

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PART FIVE

ABSTRACTS OF OTHER CONTRIBUTED PAPERS

Editors' note.—Dr. Robert Behnke was invited by the 2005 symposium organizers to speak at the evening banquet. Dr. Behnke played an integral role at the 1995 symposium with his opening presentation on the evolution, systematics, and structure of coastal cutthroat trout. Dr. Behnke is recognized as a world authority on the classification of salmonid fishes and has been a champion of western trout conservation. The abstract below was submitted to the organizers prior to the symposium.

Some Food for Thought Concerning Coastal Cutthroat Trout

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Abstract.—Several interesting questions remain open for further research on the evolutionary history of *Oncorhynchus clarkii clarkii*. The subspecies has been isolated from all other subspecies for a million years or more, yet no ancient (preglacial) relict populations such as in Kamchatka are known. Why has there been no contact between the subspecies *clarkii* and *lewisi* in the Columbia River basin? Coastal cutthroat trout are known to be highly predacious, especially in lakes where they coevolved with resident coastal rainbow trout. Why then, are there no 9 kg (20 lb) coastal cutthroat trout, comparable to other subspecies of *O. clarkii?* What is programmed into their life history that constrains large maximum size? The largest documented weight for coastal cutthroat trout is 5.4 kg (12 lb) from Crescent Lake, an ultra oligotrophic water on the Olympic Peninsula. The cutthroat trout native to Lake Washington, on the other hand, has essentially year-round conditions for growth and abundant forage, but they only attain about half the maximum size of the Crescent Lake cutthroat trout. Lake Washington exemplifies the unpredictable nature of environmental changes that affect coastal cutthroat trout. After the Cedar River was diverted to Lake Washington and a direct outlet to Puget Sound was created, nonnative sockeye salmon and longfin smelt became abundant. After many years of intensive research on Lake Washington by the University of Washington, a 1978 report on trophic connections and fish production found rainbow trout and cutthroat trout to be so rare that they played no role in ecosystem functioning. Since then, the native cutthroat trout responded to the abundant forage of juvenile sockeye salmon and longfin smelt to greatly increase their abundance, based entirely on natural reproduction. For a coastal cutthroat trout population, the Lake Washington cutthroat trout do exhibit impressive age-growth statistics, but far from producing a world record. Is there some sort of built-in "growth governor" in *O. c. clarkii*?

Current Status of Coastal Cutthroat Trout in California

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Abstract.—Coastal cutthroat trout in California are found from the Eel River estuary north to the Oregon border. Information on status and occurrence of coastal cutthroat trout is presented. Coastal cutthroat trout information has been gathered from various agencies, tribes, and private interests. Cutthroat data are usually acquired incidental to survey and monitoring efforts for other anadromous salmonids with few studies actually targeted on coastal cutthroat. Notable, however, are survey records going back to the 1980s for several streams such as South and Middle Forks of the Smith River and Redwood Creek. The California Department of Fish and Game manages coastal cutthroat trout under the "species of special concern" designation, focusing on habitat protection. In recent years, special angling regulations (reduced bag limits and gear restrictions) have been implemented. A new program featuring angling opportunities for California's native trout, the Heritage Trout Program, will hopefully increase public appreciation for coastal cutthroat trout and for their conservation.

Movements of Coastal Cutthroat Trout in Abernathy Creek and Chinook River, Two Tributaries of the Columbia River

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Abstract.—Coastal cutthroat trout movements were studied in Abernathy Creek and the Chinook River, tributaries of the Columbia River. The Chinook River (river kilometer 6) is a low gradient system that historically witnessed high tidal influences and today is subjected to more moderate tidal intrusions. Abernathy Creek (river kilometer 76) is a higher gradient system subjected to little tidal influence. In Abernathy Creek, cutthroat trout were PIT tagged in 2001, 2002, and 2003 (n = 462, 498, and 533, respectively) by electrofishing upstream of stationary arrays. Monitoring arrays were constructed at river kilometers 2.9 and 5.0, and allowed interrogating the entire flow volume (year-round at a 50 millisecond resolution) without obstructing the path of the fish. Similarly in the Chinook River, cutthroat trout were tagged in 2002 and 2003 (n = 470 and 310, respectively). Monitoring arrays were constructed at river kilometer 0.1 and 6.0. In both systems, electrofishing in the fall and backpack interrogation (Abernathy only) resulted in recaptures of non-migrant trout. Downstream movements in both systems were greatest in the spring and coincident with steelhead and coho salmon smolt migrations. This behavior in conjunction with increased gill Na+,K+-ATPase (versus non-migrants captured in the fall) indicated a smolting pattern similar to other salmonids.

Sea-Run Cutthroat Trout Life History: Should I Stay or Should I Go?

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Abstract.—Historically, little has been known about the migration patterns of anadromous coastal cutthroat trout in the estuary and ocean. We used both passive integrated transponder (PIT) tag and acoustic tracking techniques to monitor the movement of individuals through the estuary. Over the course of 18 months, approximately 750 fish were PIT tagged and 42 were tagged using acoustic transmitters. The combination of methods has allowed us to identify three life history types: 1) an ocean migrant form that migrates through the estuary and out to sea and, upon return, may spend a number of months in the estuary before migrating upstream; 2) a spring and summer estuarine resident form that does not migrate to the ocean but, rather, resides in the estuary for many months and exhibits strong site fidelity while doing so; and 3) a potential estuarine overwintering life history that remained in the estuary throughout the winter months. Life history types were not associated with size. Over half of the acoustically tagged fish exhibited the estuarine resident life history, suggesting this strategy is not rare. The large number of PIT tag recaptures has enabled us to infer growth rates of estuarine residents versus ocean migrants.

Coastal Cutthroat Trout Shoal Spawning in a High Montane Lake of the Cascade Range of Oregon

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Abstract.—We observed shoal spawning in an isolated population of coastal cutthroat trout in Bull Run Lake. Fish utilized shoal areas in the lake for spawning in addition to spawning in lake tributaries. Shoal spawning occurred over a period of one month from May-June, and peaked 2-3 weeks before tributary spawning. Redd construction was most often observed near adjacent boulders or large rocks, presumably for cover. Spawning depths ranged from 1 foot (0.3 m) to greater than 12 feet (3.7 m). Most shoal spawning occurred on an area of roadbed gravels placed for maintenance of water withdrawal facilities. Up to 50 fish at one time were counted in the main shoal area and some fish, identified by unique markings, were observed remaining in the area for several weeks. Shoal spawning on natural lake substrates was also observed but numbers of fish were few and the areas were found to be scarce, widely dispersed, and small in size. Success of shoal spawning on artificial substrates may be limited. A total of 191 fry were counted from 18 redds that had fry caps installed over them. We observed coastal cutthroat trout eating coastal cutthroat eggs; in some instances all the eggs were consumed before the female could bury them.

Cutthroat Trout as Successful Urbanites

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Abstract.—Coastal cutthroat trout *Oncorhynchus clarkii clarkii* are ubiquitous inhabitants of stream systems throughout the Pacific Northwest. Their abundance is determined by many factors including habitat, water quality, food availability, species interactions, and fish harvest management. In anadromous reaches, juvenile cutthroat are usually sympatric with coho salmon *O. kisutch* and steelhead trout *O. mykiss*. Coho spawn in the fall, emerge from the gravel in early spring, and rear primarily in pools and slower reaches before emigrating the following spring as yearling smolts. Cutthroat abundance is generally determined by interactions with cohabitants, particularly coho. In productive lowland streams, at the smolt stage coho usually outnumber cutthroat by factors of at least 50:1 throughout western Washington. As watersheds become developed, expansion of impervious surfaces conveys runoff directly into stream channels altering natural flow patterns and water quality. In such watersheds, fall spawning salmonids are at a disadvantage. Even moderate rainstorms become redd scouring torrents given the magnified stream power. In addition, because winter precipitation is not stored in wetlands and as groundwater for flow maintenance, the resultant extreme low summer flows reduce carrying capacity for rearing juvenile salmonids. Because cutthroat spawn in the spring as flows are generally declining, their eggs survive at apparently much higher rates than those of coho. When cutthroat fry emerge in an urban stream there are few if any coho fry to compete with for food and space. In six small tributaries to Lake Washington sampled in July 2003, juvenile cutthroat fry densities averaged $0.67/m^2$ while coho averaged only $0.03/m^2$. These rates are significantly higher and lower than respective cutthroat and coho densities measured with the same methods in the same reaches one decade earlier. These findings are also supported by ongoing downstream migrant trapping that began in the 1970s.

Variation in Morphology Among Cutthroat Trout of Western North America

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Abstract.—The purpose of our study was to compare morphological variation in cutthroat trout species to determine whether ecologically based differences within a species are as great as between known species. In salmonid fishes, populations that occupy flowing water or stream habitats tend to follow distinct morphological patterns in comparison to those occupying standing water or lake habitats. We sampled native populations of cutthroat trout species, including Bonneville, coastal, Colorado River, westslope, and Yellowstone cutthroat to test this hypothesis. Ecotypic variation in morphology is often displayed in features associated with swimming and feeding ecology. Our research focuses on morphological diversity related to swimming features in cutthroat trout. In order to conserve biodiversity, biologists must accurately document appropriate levels of diversity between and within species. Intraspecific variation can be an important component of biodiversity, but it is often ignored by the "species" level approach to documenting biodiversity. Given that many cutthroat trout species are of conservation concern, our project provides a better understanding of intraspecific variation existing within these species.

The Puget Sound Acoustic Tracking Array: Is Big Brother Watching Coastal Cutthroat Trout?

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Abstract.—Acoustic tagging and tracking methods are increasingly being used in fisheries research to investigate movement behavior and species life history traits. Throughout the Puget Sound, Washington, researchers are using this technology to investigate multiple species including Chinook and coho salmon, bull trout, steelhead, sixgill shark, English sole, and lingcod. These efforts primarily rely on remote tracking methods where acoustic receivers are submerged and subsequently recovered for data acquisition. Collectively, there are over 100 acoustic receiver nodes being maintained throughout the region that feasibly allow for individual identification of thousands of tagged individuals. Researchers recognize this opportunity and are collaborating towards development of a large-scale acoustic detection array to track tagged individuals over several months and years. Within this "acoustic framework," there is research need and unprecedented opportunity to improve our understanding of coastal cutthroat trout.

Compared Population Response of Bella Coola/Atnarko River Steelhead and Cutthroat Trout to a Closure of a Long-term Steelhead Fishery

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Abstract.—The Bella Coola/Atnarko system on British Columbia's Central Coast has provided an exceptional opportunity to investigate and compare life history strategies of co-existing populations of steelhead *Oncorhynchus mykiss* and cutthroat trout *Oncorhynchus clarkii clarkii*. Habitat partitioning, based on stream size, has limited interspecies competition between rearing steelhead and cutthroat trout. Juvenile assessments have revealed that each species employs a different "strategy" to produce adequate number of parr to seed available habitat. Steelhead are more fecund and spawn in larger systems producing higher fry densities. Steelhead fry are more susceptible to density dependant mortality and natural extremes in flow and habitat alteration. Steelhead smolts demonstrate large-scale ocean migrations making them more susceptible to ocean survival conditions. Cutthroat spawn in smaller, more stable streams and appear to show lower fry production capabilities but higher fry-to-parr survival. Cutthroat parr and smolts undertake moderate anadromous migrations remaining close to estuaries. They also migrate back and forth into streams during their adult life cycle. In the early 1990s both steelhead and adult cutthroat population numbers on the Bella Coola were severely reduced, at or below conservation levels. A closure in the steelhead fishery has led to increases in both populations. However, eliminating the use of bait, higher fry-to-parr survivals, and limited ocean rearing requirements have led to a magnitude larger and more balanced recovery of Bella Coola/Atnarko cutthroat trout.

Review of Life History of Sea-Run and Resident Cutthroat Trout in Southeast Alaska

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Abstract.—I reviewed literature including unpublished reports from state and federal agencies on the life history of cutthroat trout with an emphasis on studies conducted in southeast Alaska. The current distribution of cutthroat trout in southeast Alaska originated from the Columbia River drainage. Cutthroat trout may be anadromous or potamodromous (lake and stream), or reside entirely in headwater streams. Anadromous cutthroat in southeast Alaska return to natal spawning streams after only a few months at sea but may use more than one stream for spawning during their lifecycle. Migratory fish tend to grow to larger sizes than resident fish. In southeast Alaska, spawning typically occurs in spring for resident and potamodromous fish and late summer to early fall for anadromous cutthroat trout. Little information on the early life history, including incubation time, is available for cutthroat in Alaska; however fry have been observed in shallow lateral habitats in early summer. In southeast Alaska, cutthroat trout are sympatric with juvenile coho salmon, Dolly Varden, and rainbow trout. However, morphological characteristics may control habitat selection and interaction. Cutthroat are opportunistic feeders. Diet changes with body size, available prey, season, and time of day. Small cutthroat are typically planktivorous while larger cutthroat are piscivorous.

Hybridization Among Sympatric Anadromous Steelhead and Cutthroat Trout: The Potential Impacts of Captive Brood Smolt Releases at the Keogh River, British Columbia

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Abstract.—Anadromous steelhead *Oncorhynchus mykiss irideus* and anadromous cutthroat trout *Oncorhynchus clarkii clarkii* are examples of closely related sympatric species that remain distinct despite very similar life history profiles. However, intermediate hybrids are known from almost all sympatric coastal British Columbia populations where hybrids have been the study focus. A recent pilot study investigating the frequency of cutthroat/steelhead hybridization among seaward migrating smolts on the Keogh River has suggested reciprocal hybridization (F_1 and F_2 evidence of maternal lineage in both species) has occurred in the past, and the potential for increased hybridization exists since wild steelhead populations were augmented with a conservation based captive brood program. During 2002, a total of 67 steelhead and cutthroat seaward smolts were sampled with the aim of identifying the background steelhead/anadromous cutthroat hybridization rate in the watershed. The results indicated that 6% of identified steelhead smolts were hybrids and approximately 27% of fish identified as cutthroat had a hybrid lineage. The life history of these hybrid smolts is undocumented and poorly understood; however all hybrids were back crossed individuals, suggesting that some F_1 hybrids survive to successfully spawn at maturity. It is likely that most F_1 hybrid progeny are male cutthroat spawning with female steelhead, however there is mtDNA evidence suggesting F_2 backcrosses occur in several parentage directions and these results suggest reciprocal hybridization has historically occurred in the Keogh River.

Habitat Use and Movement of Sea-Run Cutthroat Trout in the Salmon River Estuary

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Abstract.—"It can be said that Oregon's estuaries act as a funnel through which all anadromous salmonids must pass through during the course of their lifetime" (R. Giger). While sea-run cutthroat trout often migrate extensively and are thought to be highly dependent on estuaries, their life history and habitat requirements are poorly understood. The goal of this research was to determine the role that the estuarine environment plays in the life history of sea-run cutthroat trout in Oregon's Salmon River. We used both passive integrated transponder (PIT) tag and acoustic tracking techniques to monitor the movement and growth of individuals in the estuary. Over the course of 18 months, approximately 750 fish were PIT tagged and 42 were tagged using acoustic transmitters. Through the duration of the project we identified an "estuarine resident" life history type that does not migrate to the ocean. Instead, they rear extensively in the estuary for many months and exhibit strong site fidelity while doing so. Coastal cutthroat trout were found in the estuary every month of the year, including the winter months. Habitat use was not closely associated with salinity, temperature, or tide. Main stem sites were consistently occupied, while marsh channel habitats were used only rarely. Estuarine growth was highly variable, but averaged 0.46 mm/day.

PART SIX

CLOSING MATERIALS

Coastal Cutthroat Trout: Past, Present, and Future

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Summarizing this symposium provides a great opportunity to reexamine some of the findings of the first coastal cutthroat trout symposium held in Reedsport, Oregon in 1995 and use this as a template to evaluate changes that have occurred over the 10-year period between meetings. Of course, the impetus for the initial meeting was the precipitous decline in the anadromous life history type of this native salmonid and the perception that the situation was not being addressed appropriately. Even the name of the symposium—Sea-Run Cutthroat Trout: Biology, Management, and Future Conservation—reflected this focused interest, but papers presented at the meeting and published in the proceedings reflected all of the diverse life histories expressed by the subspecies.

The historical range of coastal cutthroat trout extended from Humboldt Bay, California to Prince William Sound, Alaska. We learned during the 1995 symposium that although much of the historical range of the subspecies was still occupied in some states, habitat degradation was a major issue along the west coast of California, Oregon, Washington, and the southern portion of British Columbia. Anadromous populations were largely depressed in these areas, and many of the remaining populations exhibited the potamodromous life history in headwater portions of coastal watersheds. One of the key goals of the meeting was to "encourage the development of a coordinated management plan to restore sea-run cutthroat trout populations."

The coastal cutthroat trout in the Umpqua River watershed were listed as "endangered" under the Endangered Species Act (ESA) following the first symposium. In the decade between meetings, however, a coast-wide status review of coastal cutthroat trout failed to support that listing (see Johnson, this volume), but there was evidence to propose listing of the Southwest Washington/Columbia River Evolutionarily Significant Unit (ESU) as threatened. Moreover, in 1999 the U.S. Fish and Wildlife Service was given sole ESA jurisdiction of the subspecies.

Information presented at the current meeting underscores the broad interest that has been generated for the coastal cutthroat trout since the Sea-Run Cutthroat Trout Symposium. Efforts by state and provincial management agencies to assess current distribution and management status have increased; however, in many areas the information is not sufficient to make definitive statements about status. Consequently, an interagency group has been formed to share data and investigate potential areas for collaboration in research and management of the coastal cutthroat trout (see Griswold, this volume).

The variety of new information presented at this 2005 symposium concerning aspects of the biology and habitat requirements of the subspecies was truly impressive. New studies detailing genetic variation within the subspecies have been conducted at the rangewide-, ecoregion-, and watershed-scales. Research findings have yielded new insights into genome structure in major coastal river systems and isolated headwater populations in Alaska and Oregon. Phenotypic studies focused on differentiation of coastal cutthroat trout from closely related steelhead and the hybrids of the two fishes, and the intraspecific variation among stream dwelling individuals of cutthroat trout subspecies. A number of studies examined movement at a variety of spatial scales from stream segments in isolated headwater streams to anadromous and amphidromous migrations between saltwater and freshwater. Feeding and growth studies provided new insights among life history types and in a variety of habitats, including those recently affected by watershed-scale fire events. The intricacies of life history variation were explored in a number of talks, and we even learned of a population that exhibited shoal-spawning behavior in a lake located in the Oregon Cascade Range. The influence of habitat on these biological characteristics was explored in numerous presentations at the meeting.

After listening to these outstanding talks and reading the papers in detail, several overarching issues begin to emerge. Certainly, the need for interagency cooperation and coordination is at the forefront of these observations. Fortunately, there has been progress, and it is apparent that there is a willingness to continue to expand and develop initial efforts to insure the persistence of the coastal cutthroat trout. At the same time, it is apparent that one of the initial necessities is a range wide assessment of historical and current distribution and evaluation of factors influencing observed changes. Such an assessment will require the application of a rigorous statistical sampling framework to insure inferential power. Furthermore, new information on the effects of habitat on distribution, abundance, and persistence is needed throughout the range of the coastal cutthroat trout, and it will be important to recognize and delineate differences among the wide variety of life history types of this polytypic subspecies. A hierarchical approach to such research may provide a means to approach the complexities related to these issues.

Finally, it will be important to recognize that the factors influencing distribution and persistence of coastal cutthroat trout are dynamic. Fish-habitat relationships are continually modified by natural and anthropogenic disturbance. In addition to common environmental relationships that have been studied over the past century, we must now face the influence of climate change and the potential synergistic effects that it will have with those factors that have already been documented to negatively affect the subspecies.

There has been a substantial amount of effort and ink contributed to our understanding of anthropogenic activities that have reduced the historical distribution and abundance of native salmonids. In the Pacific Northwest, we often cite the "four H's": habitat, hatcheries, hydropower, and harvest. At this meeting, we learned even more about the importance of addressing these factors to insure coastal cutthroat trout persistence. It addition, it may be useful to recognize that there is a fifth "H", hypocrisy, which has historically, and often continues, to hinder our best efforts for resource conservation. The necessity to move beyond interagency jurisdictional conflicts and reach consensus on overarching goals and values is paramount if we are to succeed. There are complex relationships between persistence and the spatial distribution and biological organization of coastal cutthroat trout that are directly related to success of conservation, and these relationships seldom respond to arbitrary political boundaries. In the end, it may be important to "just do it."

Postscript

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In his postscript for the 1997 Sea-Run Cutthroat Trout Proceedings, Dr. Jim Hall (Oregon State University, Emeritus Professor) commented on the pressing scientific issues facing researchers and managers who were concerned with coastal cutthroat trout at that time. As an attendee of the Coastal Cutthroat Trout 2005 Symposium in Port Townsend, Washington a decade later I noticed that the need for information on these topics was still great and that many of the themes Dr. Hall had identified featured prominently in the agenda. I also noticed that technical and analytical advances were allowing us to make progress in many of these areas. For example, in the area of coastal cutthroat trout natural hybridization and introgression with steelhead and rainbow trout Bayesian statistics appear to provide a means for estimating the abundance of steelhead when cutthroat trout and hybrids are present (Hankin et al., this volume). Another theme Dr. Hall identified was the complex ecological and genetic interactions between above and below barrier populations of trout. Multiple approaches often used in combination appear to be teasing out some patterns in these populations. These approaches rely on high tech tools such as microsatellite DNA, now a standard tool for understanding the population structure of any organism, but at the time of the first symposium researchers were just starting to apply to fish species. In addition, landscape scale statistical analysis has also undergone significant development. In combination these tools are helping us understand patterns that were previously undetectable (Guy et al., this volume). Finally, our lack of understanding of anadromous coastal cutthroat trout use of estuaries created a "black box" of information during a critical life history phase of the subspecies. In the present volume a paper is presented using acoustic tagging arrays allowing researchers to more thoroughly examine the role of estuaries for coastal cutthroat trout (Krentz et al., this volume).

Thus, the culmination of the 2005 Coastal Cutthroat Trout Symposium and the publication of its proceedings is a significant contribution to the science and management of the subspecies coastal cutthroat trout. But wait! While this is true and many thanks go out to the organizers and editors of the 2005 symposium, it is also true that in some areas we face similar challenges to those of a decade ago—if not decades ago—such as the difficulty of estimating abundance of coastal cutthroat trout. Few long-term data sets exist from which trends of coastal cutthroat trout populations can be extrapolated. Determining whether a coastal cutthroat trout population is healthy or not is still outside our reach, even with the technological and analytical advances we have made.

Thus, there is a still a need to identify the issues that are hindering collection of scientific information that will help assess the status of coastal cutthroat trout and continue to move our understanding of this complex subspecies forward. Currently, in some regions, biologists report population declines for some life history forms of the subspecies (Connolly et al. 2002, Slaney and Roberts 2005). In other regions biologists report that populations are stable (Goodson 2005) or increasing (Johnson et al. 2005). However, throughout the range of coastal cutthroat trout, representatives from state, federal, and provincial agencies agree that information regarding the biology and status of coastal cutthroat trout is too limited to make good decisions about how to prioritize conservation, management, and research. To address these complex problems, a collaborative effort among state and federal partners was initiated following the 2005 Coastal Cutthroat Trout Symposium held in Port Townsend, Washington. In the spring of 2006, this group identified a goal of "developing a consistent framework to help guide and prioritize conservation, management, research, and restoration of coastal cutthroat trout throughout their native range." To address this goal, the group proposed hosting a series of science and management cutthroat trout workshops that would identify the impediments to gathering and sharing data. This group was formally established (November 2006) and is referred to as the "Coastal Cutthroat Trout Executive Committee."

The Coastal Cutthroat Trout Executive Committee has hosted two workshops, a Science Workshop and Monitoring Workshop, held in 2006 and 2007, respectively. The Science Workshop covered a wide range of topics relevant to the biology and management of coastal cutthroat trout and included representatives from tribal, federal, and state agencies. There was clear consensus among the participants that two issues were of primary concern and were ultimately identified as the highest priority among all participants. First, the complexity of life history of coastal cutthroat trout creates challenges for understanding all other aspects of their biology. Second, there was strong consensus among participants that the lack of information regarding the status and trends of coastal cutthroat trout populations is a significant problem for agencies charged with their management.

To address the latter issue a workshop devoted to monitoring coastal cutthroat trout populations was organized and held in 2007. At that meeting the focus of discussion was largely on the challenges for monitoring distribution, abundance, and diversity of coastal cutthroat trout. Following the meeting the development of a range-wide framework (based on geographic information system

[GIS]) for documenting the known distribution of coastal cutthroat trout was proposed. This effort will be underway in the fall of 2007. For more information on the coastal cutthroat trout executive committee and the workshop outcomes go to (http://www.fws.gov/columbiariver/cctsym.html).

In addition to this effort the coastal cutthroat trout has been included in the Western Native Trout Initiative (WNTI), a collaborative effort that funds research and provides a framework for management and conservation of native species (http://westernnativetrout.org/). Efforts such as those by the Coastal Cutthroat Trout Executive Committee and WNTI seek to provide consistent progress and a collaborative spirit among agencies, researchers, and managers.

In the intervening years between the 1995 Sea-run Cutthroat Trout symposium and the present effort there have been significant scientific and technological advances that have furthered our understanding of this complex and beautiful subspecies of trout. However, science and technology alone are not going create the conditions for the long-term persistence of the range of diverse coastal cutthroat trout life history forms and populations. To do this it will take the continued collaboration, good will, and hard work of scientists and managers in cooperation with citizens who care about the future of coastal cutthroat trout.

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Appendix: List of Reviewers

The editors wish to acknowledge and thank the following people for contributing to these proceedings by providing critical reviews of extended abstracts and papers:

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