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INTRODUCTION

Coastal cutthroat trout (*Oncorhynchus clarki clarki*) exhibit multiple life history types characterized by diverse migratory strategies, including anadromous, potomodromous, and freshwater resident forms. The factors contributing to life history variation within populations are not well understood, but probably are not strictly genetic (e.g. Johnson et al, in review). Variation in migration tendency within cutthroat populations may result from phenotype plasticity, influenced by density, frequency, or condition dependent processes (Hendry et al. 2004). For example, an individual cutthroat's choice to migrate at a given time or age may be a response to environmental conditions mediated by a genetically determined reaction norm (Hutchings 2004). This report summarizes a study undertaken to describe the expression of migratory behavior within coastal cutthroat trout populations, the relationship among migratory and non-migratory individuals, and the implications of life history diversity for management of cutthroat trout in tributaries of the lower Columbia River.

The relationship between resident and migratory populations (or resident and migratory individuals within populations) is of central importance for management of coastal cutthroat trout. In the lower Columbia River and southwest Washington State a proposed rule to list anadromous cutthroat as threatened under the federal Endangered Species Act (ESA) was withdrawn after the US Fish and Wildlife Service (USFWS) decided during its review process to include resident and anadromous forms in the same Distinct Population Segment (DPS). Debate over proposed ESA listing highlighted a general lack of knowledge about coastal cutthroat trout life history, relationships between resident and migratory forms, and estuarine habitat use in the lower Columbia River. In 2009, the decision not to list the DPS as threatened was remanded to the USFWS on the grounds that the Service had not adequately considered whether marine and estuarine habitats formed a significant portion of the range of the DPS (USFWS 2009).

We evaluated the distribution and abundance of coastal cutthroat trout in Big Creek and Bear Creek, two tributaries that join the Columbia River estuary from the south (Oregon) side roughly 30 kilometers from the ocean, and monitored the migratory behavior of cutthroat that emigrated from these streams and entered the Columbia River estuary. Big Creek is an interesting system because a fish weir and diversion dam at an ODFW hatchery, established in 1941 and refurbished in 1957, prevent cutthroat trout from passing upstream, isolating the cutthroat spawning population above the hatchery. Despite this barrier to upstream migration, offspring of resident cutthroat in the upper watershed continue to "smolt" and migrate downstream past the barrier. We were interested in the fate of these fish and their contribution to the adult population. Bear Creek, on the other hand, has always had full access for anadromous cutthroat through much of its drainage. These two systems permit a comparison of life history characteristics, migration, and survival of coastal cutthroat rearing in streams above and below migration barriers, and provide study sites in Oregon to compliment research by USFWS of coastal cutthroat migration behavior in tributaries entering the estuary from the north side of the Columbia River (USFWS 2008; and see Hudson et al. 2008; Johnson 2008; Zydlewski et al. 2008).

A major objective of our work in Big Creek and Bear Creek was to increase understanding of coastal cutthroat trout biology and the relationship between resident and migratory cutthroat in lower Columbia tributaries. Additionally, we sought to document habitat use in the Columbia River estuary by migrant cutthroat. Our specific objectives were to:

- Estimate abundance of coastal cutthroat trout in Big Creek (above hatchery barrier) and Bear Creek (above and below a large dam)
- Quantify the proportions of the cutthroat populations that are migratory, identify which individuals migrate and describe the timing of migration
- Describe habitats used by anadromous migrants and characterize migration behavior within the Columbia River estuary
- Measure estuarine/marine survival of anadromous individuals and document return to natal streams

METHODS

Study Sites

Big Creek and Bear Creek are stream networks in adjacent watersheds of the northern Oregon coast range that join the Columbia River at approximate river kilometers 34 and 30, respectively (Figure 1).

Big Creek drains a basin of 95 km². The basin is almost entirely privately owned and managed for commercial timber production. An Oregon Department of Fish and Wildlife hatchery is located at stream kilometer 4.3. Two stream-width weirs at the hatchery, constructed in 1941 and refurbished in 1957, largely prevent upstream passage of migratory fish (Figure 2). The weirs have jumps heights of up to 2.0 meters and likely function as complete barriers to upstream migration of cutthroat trout. The Big Creek hatchery began selectively passing upstream of the hatchery barriers naturally spawned (i.e. not fin-clipped) steelhead trout in 1996 and coho salmon in 2002 by trapping and hauling these fish to release points several kilometers upstream of the hatchery. Hatchery personnel occasionally passed cutthroat trout upstream as well, when cutthroat were captured in the upstream migrant trap at the hatchery. Numbers of cutthroat moved upstream annually since 2002 are listed in Table 1.

Bear Creek drains a 32 km² catchment immediately west of the Big Creek watershed and joins the Columbia approximately four kilometers downstream of the Big Creek confluence, near the western end of Svenson Island (Figure 1). The upper Bear Creek watershed forms the municipal water source for the City of Astoria, and the city maintains a large dam at stream kilometer 7.7 (Figure 2). This dam has blocked all passage of migratory fish since its construction approximately 90 years ago. An additional, smaller dam blocks upstream fish passage on Waterworks Creek (a.k.a. Cedar Creek) a tributary of Bear Creek at 1.3 km from the confluence with Bear Creek. The lower reaches of the Bear Creek basin are dominated by rural residential and commercial timber land use.

Study Approach

We estimated the population size of cutthroat within the watersheds and monitored the movements of individuals that emigrated from Big and Bear creeks using acoustic and PIT tag technology. We estimated the abundance and distribution of the cutthroat population in Big Creek watershed (2006 and 2007) and in Bear Creek watershed (2007) by estimating density of fish at random, spatially-balanced sites within the distribution of cutthroat (Figure 2). Downstream migrant cutthroat were enumerated at screw traps located low in the watersheds. All cutthroat had PIT tags implanted and selected fish were implanted with an acoustic tag. PIT antenna arrays were placed above tidewater in Big and Bear creeks to estimate the number and time of passage of the PIT tagged cutthroat. In addition, PIT tags were detected on bird colonies at East Sand Island. The movement of acoustic-tagged cutthroat was detected as they migrated to the ocean with a series of acoustic receivers placed through the Columbia River estuary (Figure 3).

Distribution and Abundance

We estimated cutthroat trout abundance upstream of the Big Creek hatchery weirs (2006 and 2007) and in the entire Bear Creek watershed (2007). Sampling was conducted during September 2006 and early October 2007 at random, spatially-balanced sites drawn from a sampling frame that included all tributaries with basin area ≥ 60 hectares (GRTS design; Stevens and Olson 2004)(Figure 2). This sample frame was presumed to encompass the entire distribution of cutthroat trout in each watershed (Aquatic Inventories Project, ODFW, unpublished data). We chose not to sample below the hatchery weirs in Big Creek to avoid encountering large numbers of adult salmon returning to Big Creek Hatchery. The estimates in Bear Creek were calculated separately for stream segments above (assumed resident population) and below (assumed anadromous) the barrier structures. Big Creek has 80.5 km of stream habitat above the barriers and Bear Creek has 16.8 above and 21 km below the dams. Sample reaches 40 to 150m long were temporarily closed with blocknets and abundance of cutthroat ≥ 90 millimeters fork length (approximately representing age 1+ trout) was estimated by multiple-pass removal electrofishing. Removal data were analyzed and abundance estimated for each site using program CAPTURE (White et al. 1982; 1999). Population estimates were then extrapolated to the full sample frame from linear trout density estimates at individual sites. A local neighborhood (NBH) estimator (Stevens and Olsen 2003) provided unbiased estimates of variance for the GRTS survey design.

Downstream Migrant Trapping

Abundance, timing, and size distribution of downstream migrant cutthroat trout were monitored with rotary screw traps in Big Creek (2006-2007) and Bear Cr (2007). Traps were operated from early March to late June or early July each year. The Big Creek trap was located immediately upstream of the upper hatchery barrier (stream kilometer 5.0) and the Bear Creek trap was at stream kilometer 2, immediately downstream of the confluence with Little Bear Creek (Figure 3). We also briefly operated a smolt trap in lower Big Creek at the head of tide in spring 2006. Because the hatchery Chinook and coho were considered ESU listed fish, we had to discontinue trapping at the lower Big Creek site once fish were released from Big Creek

Hatchery. Fish counts from the lower Big Creek trap are not reported here, but we did tag one cutthroat with an acoustic tag at the site. All cutthroat captured in the screw traps were enumerated, measured (FL), and weighed. A subsample of captured fish were marked with a caudal fin clip and released upstream of the traps to estimate trapping efficiency. Total abundance of downstream migrants was estimated as the number captured in the trap, adjusted by recapture efficiency.

PIT Telemetry

Age-1+ coastal cutthroat trout that were captured at migrant traps or by electrofishing were marked with internally implanted 23.75mm x 3.9 mm full duplex Passive Integrated Transponders (PIT-tags) (Destron-Fearing model TX1415BE, 0.57g dry weight). A total of 1572 cutthroat were tagged during all sampling efforts (Table 2). Minimum size tagged was 90mm in 2006 and 97mm in 2007.

A stream-width PIT-tag antenna array was operated near the head of tide in each stream to detect PIT-tagged fish leaving or entering each system (Figure 2). The Big Creek array consisted of five rectangular inductor coil antennas (each approximately 3.0 m x 1.2 m) arranged in a line stretching across the Big Creek channel. Antennas were powered by a multiplexing transceiver (Destron Fearing, Inc. model FS1001M). The system was powered by four 12V deep cycle batteries that were exchanged and recharged weekly. The Big Creek array was installed in August 2006 and operated as continuously as possible until mid-December 2008. Initially the antennas were anchored in a “pass-through,” vertical orientation, but after the antenna array was washed downstream by flood flows on November 5, 2006 the antennas were replaced in a “hybrid” or “pass-by” orientation (Connolly et al. 2008). Substantial lapses in operation were caused by flood damage during November 2006, December 2007, and late November 2008. Additional shorter lapses were caused by occasional equipment failure. Operation history of PIT-tag antennas is summarized in Figure 4. Adult fish also were scanned manually at Big Creek Hatchery where personnel may have observed PIT-tagged cutthroat that moved upstream in Big Creek while the antenna was not operating in November or December.

The Bear Creek array was constructed in October 2007 and was designed similarly to that in Big Creek. The array was made up of three antennas, each approximately 2.4 m x 1.2 m, anchored in a “pass-by” orientation spanning the Bear Creek channel. The Bear Creek transceiver (FS1001M) was powered by 12V batteries that were continually recharged with AC power from a nearby residence. Bear Creek PIT-tag interrogation and transceiver diagnostic data were downloaded directly from the transceiver memory via a wireless modem.

Interrogation efficiency for each PIT-tag antenna array was calculated using PIT-tag recovery data from piscivorous bird colonies in the lower Columbia River estuary. The Pacific States Marine Fisheries Commission (PSMFC) recovers PIT tags from breeding colonies of Caspian Terns and Double-Crested Cormorants at East Sand Island and Miller Sands in the lower Columbia River estuary. Because neither bird species forages within Big Creek or Bear Creek, PIT tags that were implanted in fish within the two watersheds and later recovered on bird colonies must have passed the stationary PIT-tag antennas before the tagged fish were exposed to avian predation. Accordingly, detection efficiency of each antenna array was calculated as the

proportion of tags released in the upper watershed and subsequently recovered on bird colonies that also were detected on the antenna array.

Acoustic Telemetry

To evaluate estuarine habitat use, migration behavior, and survival of migrant coastal cutthroat trout, we tagged a sample of cutthroat captured at the migrant traps during 2006 and 2007 with individually coded hydroacoustic transmitters (Vemco, Ltd. transmitters, models V9 and V7; tag dimensions: V9 = 29mm long x 9mm diameter, 4.7g (in air); V7 = 20mm x 7mm, 1.6g; battery life range: 132-374 days). Prior to tagging, cutthroat were anesthetized (MS-222, $\leq 50 \text{ mg}\cdot\text{L}^{-1}$), measured, and weighed. Tags were implanted in the peritoneum through a ventral incision using techniques similar to Zydlewski et al. 2008. Incisions were closed with two to four non-absorbable nylon monofilament sutures. Tagged cutthroat were allowed to recover for at least four hours in an aerated 75L cooler or a perforated 190L barrel anchored in stream and were released several hundred meters downstream of the trap site of capture. Fish tagged in Big Creek were released downstream of the lower hatchery barrier to prevent tagged fish from re-entering the migrant trap. A total of 105 cutthroat were tagged during two years using both model V9 and model V7 transmitters. The smallest cutthroat tagged with V9 and V7 transmitters weighed 42g and 30g, respectively (Table 3).

Acoustically-tagged fish were detected with a network of stationary receivers (hydrophones) anchored in the Columbia River estuary and the lower reaches of Big and Bear Creeks (Figure 1). Receivers recorded the unique identification code of detected transmitters and the date and time of detections. Open water receivers were moored as described in Clements et al. (2005), and additional receivers were attached to pilings on the channel margins. Receivers were downloaded approximately bi-weekly. We deployed 22 receivers at strategic locations in island and slough habitat between Tongue Pt and Blind Slough (Figure 3). In addition, the Columbia River Inter-Tribal Fisheries Commission (CRITFC) maintained receivers at the mouth of the Columbia River (Figure 3) and the Pacific Ocean Shelf Tracking (POST) Project maintained a receiver array that spanned the estuary at the Astoria-Megler Bridge.

Avian Predation

Juvenile salmonids migrating through the Columbia River estuary are commonly consumed by Caspian terns and double-crested cormorants (Collis 2001). The birds nest in the lower Columbia River on East Sand Island, but feed throughout the estuary and nearshore ocean. PSMFC personnel scan the bird colonies for PIT tags, and although tag detection is not 100% efficient, tag recoveries indicate a minimum known rate of predation of tagged fish. Using tag recoveries from the bird colonies, we determined the minimum number of coastal cutthroat trout tagged in Big Creek and Bear Creek that succumbed to avian predation. We also evaluated the body size and migration timing of cutthroat known eaten by birds.

RESULTS

Distribution and Abundance of Coastal Cutthroat Trout within the Big Creek and Bear Creek Watersheds

The GRTS survey design (Figure 2) and NBH estimator provided a spatially balanced survey design and estimate of the distribution and abundance of cutthroat trout rearing in the Big and Bear Creek watersheds (Table 4) within 30% confidence limits. Thirty-four sites were sampled in Big Creek in 2006 and twenty-six sites in 2007. The population of age-1 cutthroat in Big Creek above the hatchery was 17,258 (95% confidence interval $\pm 28\%$) and 16,267 (95% confidence interval $\pm 30\%$) in 2006 and 2007 respectively.

Separate abundance estimates were made for cutthroat populations above and below migration barriers in Bear Creek. Thirty-five sites were visited in Bear Creek, 21 sites below and 14 sites above the barriers. The population of age-1+ cutthroat in 2007 above and below the barriers to migration were 3,886 (95% confidence interval $\pm 30\%$) and 1057 (95% confidence interval $\pm 19\%$) respectively. We do not believe that the populations above and below the Bear Creek dam have more than a rare opportunity to interchange.

In Big Creek, coastal cutthroat trout were observed at 28 of 34 sites sampled in 2006 and 24 out of 27 sites sampled in 2007. Median density of age-1+ cutthroat was 0.133 fish \cdot m or 0.044 fish \cdot m⁻² wetted channel area in 2006 (range 0 to 0.69 fish \cdot m⁻¹ and 0 to 0.293 fish \cdot m⁻²) and 0.176 fish \cdot m or 0.039 fish \cdot m⁻² in 2007 (range 0 to 0.69 fish \cdot m⁻¹ and 0 to 0.23 fish \cdot m⁻²; Table 4). The spatial distribution of cutthroat density, including sites where cutthroat were not observed, is depicted in Figure 5. The distribution and densities were very similar in Big Creek between years. Sites where cutthroat were absent generally were dry or had very little water at the time of the survey. The approximate drainage area of sites with no cutthroat ranged up to 120 hectares.

In Bear Creek, the median density of age-1+ cutthroat above the dam and diversion structures was 0.278 fish \cdot m⁻¹ (range 0 to 0.52) and 0.113 fish \cdot m⁻² (range 0 to 0.198). Two of the 14 sites above the barriers were dry and not included in the estimate, considered non-target. In 18 sites below the barriers, age 1+ cutthroat median densities were 0.038 fish \cdot m⁻¹ (range 0 to 0.159) and 0.0167 fish \cdot m⁻² (range 0 to 0.055).

Median lengths of cutthroat varied significantly between years in Big Creek and above and below the barriers in Bear Creek (Wilcoxon Rank Sum Test, $p=0$) (Table 5). Cutthroat were larger in Big Creek in 2006 than in 2007. More larger fish were present in 2006 (Figure 6). In Bear Creek, fish were significantly larger below the barriers. The median fork length below the barriers was 126 mm, with a range of 90 mm to 194 mm. The median above the barrier was 112 mm, with a range of 90 mm to 218 mm. More small age-1 cutthroat were sampled above the barriers, although the size range was similar (Figure 7).

Size and timing of downstream migration to Columbia River

Coastal cutthroat trout were captured in the Big Creek smolt trap from March until the traps were removed in late June or July, but peak downstream migration occurred in late May and early June (Figure 8). We estimated that 474 cutthroat (95% confidence interval = 171 to 777) emigrated from the watershed above the hatchery intake structure in Big Creek during spring 2006. Migrants ranged in size from 128 mm to 244 mm fork length, median of 175 mm. In 2007, approximately 603 cutthroat (95% confidence interval = 159 to 1,047) left the upper Big Creek watershed at 126 mm to 218 mm fork length, median of 166 mm (Figure 9). Based on smolt trap estimates, migrant cutthroat were approximately 3.6 % of the total population of comparable size cutthroat in the Big Creek watershed. Trap efficiency averaged 22% and 18% in 2006 and 2007 respectively. Three cutthroat recaptured at the screw trap in 2007 grew 36-56 mm after they were tagged during the electrofishing survey the previous September.

Timing of downstream migration in Bear Creek was similar to Big Creek (Figure 8). We estimated that 475 cutthroat (95% confidence interval = 55 to 1,097) left the watershed in spring 2007. Trap efficiency averaged 15%. The migrants ranged in size from 137 mm to 254mm fork length, with a median of 187 mm.

Downstream migration of coastal cutthroat trout was also observed by PIT telemetry, as cutthroat tagged during electrofishing efforts in the upper watersheds were detected at Big Creek and Bear Creek PIT antennas. Peak detection of downstream migrant cutthroat at the Big and Bear Cr PIT antennas occurred in May and June, coincident with the timing of peak cutthroat catch at the smolt traps (Figure 8). Detection of migrants occurred most often at night (Figure 10), and cutthroat in Big Creek were detected most often near the center of the stream channel (Figure 11).

Most tagged cutthroat detected at the PIT antennas emigrated during the spring following tagging. Three cutthroat tagged in Big Creek during summer 2006 remained in the stream for another summer, however, and moved downstream in May and June 2008. Such individuals made up 12% of the total migrant cutthroat observed from the 2006 tagging group in Big Creek. (Outmigrant monitoring of the 2007 tag group from Bear Creek is still ongoing.) Additional cutthroat appeared to migrate downstream in the autumn and were detected at the antenna for the first time in November or December. This apparent autumn migration corresponded with the time of year when PIT antennas were most likely to malfunction so interpreting autumn movements is difficult. Individuals that moved downstream in autumn or remained in the stream an extra year before migrating in the spring did not appear to differ in size or condition when tagged from those that migrated during the first spring following tagging.

Few of the fish tagged in Big Creek watershed in 2006 and 2007 were detected at the PIT antenna (Table 6). Only 3.8-4.8% were detected, which corresponds well with the number of cutthroat estimated to pass through the screw trap in 2007 (603 fish) compared with the previous summer's population estimate in the watershed in 2006 (17,003), or about 3.5%. In contrast, approximately 28% of the cutthroat tagged in Bear Creek in 2007 migrated pass the PIT antenna in 2008 (Table 6). One tag code detected at the antenna was recorded to have been deployed upstream of the Bear Creek dam, but we suspect that this was a data entry error, and in fact no

fish migrated downstream over the dam. Similarly no cutthroat tagged upstream of the Cedar Cr dam were detected at the antenna.

Migrants from Big Creek watershed were tagged primarily in Big, Coon and Elk Creeks (Figure 9). The migrants in Bear Creek were tagged in Bear, John Day, and Little Bear creeks. Small streams and streams above the barriers in Bear Creek were not a source of migrants to the estuary.

Detection Efficiency of PIT Antenna Arrays

The Big Creek PIT antenna array was generally efficient at detecting tagged fish migrating downstream in the spring (Table 7). Seventeen 23mm PIT tags deployed in Big Creek were detected subsequently on East Sand Island (including tags from both cutthroat and steelhead), and of these 88% were first detected at the Big Creek antenna array. Moreover, the antenna detected 302 out of 354 (85%) 12mm PIT tags implanted in hatchery Chinook salmon released from Big Creek Hatchery and subsequently detected at the bird colony. The antenna array appeared even more efficient at detecting adult fish returning to Big Creek in autumn, when stream flows were typically lower. Five PIT-tagged coho salmon returned to the Big Creek Hatchery during October and November 2007, and all of them (100%) were first detected at the Big Creek antenna array in September or October.

Estuarine Migration and Survival

We implanted acoustic transmitters in 44 coastal cutthroat trout in Big Creek during 2006 (Table 3). One of these was captured and tagged at the lower Big Creek smolt trap, and the remainder were captured and tagged at the upper Big Creek smolt trap. Tagged fish ranged from 151 mm to 364 mm fork length (median = 183 mm). During 2007, 36 cutthroat were tagged at the upper Big Creek smolt trap and 29 were tagged at the Bear Creek smolt trap (Table 7) (the lower Big Creek trap was not operated during 2007). Cutthroat tagged during 2007 ranged from 152 mm to 215 mm fork length (median 175 mm) in Big Creek and 153 mm to 216 mm (median 186 mm) in Bear Cr (Table 3).

Results of acoustic telemetry are summarized in Table 8. Between 30% and 58% of acoustically tagged cutthroat were not detected entering the estuary at the mouth of Big Creek or Bear Creek, presumably because these fish shed their tags, died, or did not continue downstream after tagging. Of those fish that did enter the estuary, 60% from Big Creek in 2006, 33% from Big Creek in 2007, and 20% from Bear Creek in 2007 were detected entering the ocean. Upon entering the Columbia estuary, almost all tagged individuals appeared to make rapid, directed movements toward the ocean (Table 9). Among those fish detected at the mouth of the Columbia, migration time from tributary mouths to ocean entry ranged from 15 hours to 6.5 days. Median travel time from Big and Bear creeks to the mouth of the Columbia was approximately 29 to 90 hours, corresponding to a migration rate of 0.47 to 1.2 km/hour.

Only one individual cutthroat trout was observed to remain in estuary over summer. A 203 mm, 79.6 g cutthroat tagged April 23, 2007 in Bear Creek appeared to reside all summer in the estuary, moving at least as far downstream as Tongue Pt and as far upstream as Russian

Island. The fish returned to tidal slough habitat near the mouth of Bear Creek in September, 2007, and then moved into Bear Creek and upstream through the Bear Creek PIT antenna in December, presumably on a spawning migration.

Marine/estuarine survival

The rate of return to Big Creek and Bear Creek of both acoustic tagged and PIT tagged cutthroat trout detected emigrating from the tributaries into the Columbia estuary was low (Table 10). In Big Creek, none of 30 acoustically tagged fish that emigrated in spring 2006 returned to the stream, and 1 out of 53 PIT and/or acoustic tagged migrants (2%) returned to the stream after emigrating in spring 2007.

In Bear Creek, 1 out of 20 fish (5%) returned to the stream from the 2007 acoustic tagged group, and 2 out of 25 PIT tagged fish that were detected emigrating in spring 2008 returned in autumn 2008. One of the two returning fish from Bear Creek returned to Big Creek, however, indicating some straying among tributaries occurs. Accordingly, it is possible that some tagged fish may have returned to other, un-monitored streams.

Avian predation

One confirmed source of marine/estuarine mortality was predation by birds nesting on East Sand Island. PIT tags from Big Creek and Bear Creek coastal cutthroat trout were detected on both Caspian tern and Double-crested cormorant colonies during both years of the study. Tag detection is not 100% efficient so these estimates are conservative.

Confirmed mortalities from avian predation made up 5.3 % of the total outmigrant cutthroat from Big Creek in 2006, 15.4% of the Big Creek migrants in 2007, and 14.8% of Bear Creek migrants in 2007 (Table 11). One individual was tracked to the ocean entrance before being consumed, and another may have been eaten as far upstream as Russian Island.

DISCUSSION

The two drainages paired in this study are not identical, but do provide an opportunity to compare the population characteristics and migratory behavior of cutthroat trout. The watersheds are adjacent, have similar geology and vegetation, but Bear Creek is slightly smaller with only 38 km of stream compared to 79 km in Big Creek. Big Creek has had an artificial migration barrier low in the drainage for 68 years, and only recently permitted the passage of coho, steelhead, and a few cutthroat. Bear Creek was dammed in the upper drainage for municipal water supply, but the lower 21 km has always had full access to the estuary.

Upstream of the migration barriers, Big and Bear creeks supported similar densities of cutthroat trout. The density of cutthroat below the barrier in Bear Creek was 25% of that above the barriers and in Big Creek above the hatchery weir. Competition with steelhead and coho

may have resulted in lower densities of cutthroat in lower Bear Creek. A higher proportion of migrants from Bear Creek may also account for some of the difference.

Length frequency distributions were different above and below the barriers in Bear Creek, but also between years in Big Creek. The differences may be confounded by the definition of age-1+ at 90mm, but it is difficult to distinguish between juvenile steelhead and juvenile cutthroat below that size. Growth may have been faster in 2006, but older 200-250mm cutthroat were also observed more often in Big Creek in 2006 than 2007. In 2007, cutthroat were larger in the Bear Creek streams that were open to anadromy than they were in the resident section or in Big Creek. The larger average size may not be due to differential migration because the migrants detected at the PIT antenna the following spring were representative of the summer population, assuming a growth of 36-56mm over the winter as observed in Big Creek.

The proportion of the population that migrates to the estuary is much higher (almost an order of magnitude) in Bear Creek, assuming overwinter survival in Big and Bear Creeks were similar. Cutthroat migrating out of Bear Creek were also larger on average than in Big Creek. Cutthroat tagged at smolt traps were assumed to be migratory, but not all were detected at the head of tide. Following release, cutthroat tagged at the screw trap in Big Creek had to migrate past the two hatchery weirs and travel 4.3 km to the head of tide.

A large proportion of acoustically tagged cutthroat were not detected leaving their natal tributaries after between captured and tagged at downstream migrant traps. Undoubtedly this was due in part to tag loss and post tagging mortality. It is also possible, however that some of these fish were resident or potamodromous individuals that simply remained in the stream following release. Our smolt trap capture of PIT tagged cutthroat indicated that some fish remained in the stream following initial capture in migrant traps and were captured again several weeks or even a year later with no indication (i.e. from PIT tag detection) that they had migrated to the Columbia estuary.

Of the cutthroat tagged at the screw traps, 40-70% left Big and Bear creeks and were detected at the confluence with the Columbia River in Cathlamet Bay. Twenty to 40% of these fish were detected at Tongue Point in the central estuary. The cutthroat moved quickly through the estuary, spending at most 5 days before being detected at ocean entrance, with one exception. One cutthroat (203 mm) left Bear Creek in the spring and moved around the estuary between Tongue Point and Russian Island, returning to mouth Bear Creek in September, where it remained until December before moving upstream. However, only 14-41% of the emigrants made a successful journey, the others disappearing or being eaten by birds. Avian predation accounted for at least 5-30% of the cutthroat; this estimate is a conservative because recovery of tags on East Sand Island is not 100% efficient. Birds may be a significant source of mortality but only accounted for a portion of the mortality. The balance between delayed mortality caused by handling/tagging, straying, bird predation, and fish predation is difficult to partition.

The estuary environment does not appear to play a significant role as a rearing environment based on the number of acoustic tagged fish detected at head of tide but not at ocean. We might have expected the complex channel network and productive sand flats and wetlands to have provided good rearing habitat, but fish generally passed the array of acoustic

receivers in Cathlamet Bay quickly (with one notable exception). Extensive surveys conducted in the Columbia River estuary in 1980-81 reported only 60 cutthroat caught in all estuary zones during April through December (Bottom and Jones 1990) over a two year period.

Returns to Big and Bear Creeks were very low, less than 10%. The ocean and Columbia River plume environments are not any more hospitable than the estuary. The fish emigrating from Bear Creek did not fare much better than those from Big Creek. We might have expected better returns from a population that has anadromous access. The emigration rate was substantially higher (eight times higher) but the return rate was only two to four times higher. A larger sample size of fish, or a longer study may improve the comparison.

The resident population in Big Creek did not provide a large number of migrant cutthroat (<5% of the population) and only 1 of approximately 150 fish that entered the Columbia River returned after migrating to the estuary. Some straying between systems was observed. One cutthroat tagged and detected leaving in Bear Creek returned to Big Creek the following fall. Though limited, the anadromous population in Bear Creek used a estuary and ocean to some extent.

CONCLUSIONS

- A measurable fraction of coastal cutthroat trout from Lower Columbia River tributaries enters the estuary, even in Big Creek where upstream migration has been blocked for generations.
- In stream without a migration barrier, the proportion of cutthroat trout using estuary is much higher, nearly 30% of tagged fish in lower Bear Creek.
- Most of those fish that enter the estuary appear to migrate rapidly toward the ocean. While doing so, migrants occupy habitats throughout the ~30+ km distance between natal tributaries and the ocean. At present these habitats do not appear to provide rearing opportunity as much as a migratory corridor.
- One notable exception: at least one fish from Bear Cr, appeared to spend all summer in the estuary, moving at least between Tongue Pt and Russian Island, before returning to Bear Creek the following December. It resided in estuarine slough habitat outside Bear Creek mouth between September and December.
- While in the estuary avian predation can be substantial, up to 15%.
- Estuarine/marine survival appears to be low based on tag returns. Some migrants did return, however, including fish that strayed between streams.
- We have limited evidence of straying between basins. Thus, estuarine habitat provides a corridor for genetic exchange among local populations.

Our evidence supports the ideas that (a) cutthroat are adapted to use the estuary, (b) they do use it, and (c) by supporting life history diversity within populations, estuarine habitat is significant to the resilience of the Distinct Population Segment.

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Washington.

Table 1. Number of cutthroat trout passed upstream of Big Creek Hatchery by trap and haul, annually 2002-2008.

	2002	2003	2004	2005	2006	2007	2008
Cutthroat trout passed upstream of Big Creek Hatchery	0	0	6	9	14	6	14

Table 2. Location, method of capture, and number of cutthroat PIT-tagged in Big and Bear creeks.

Stream	Capture methods	
	Smolt trap	Electrofishing
Big Creek		
2006	110	637
2007	94	421
Bear Creek		
2007	51	259

Table 3. Size, date, time, and location of cutthroat implanted with acoustic tags in 2006 and 2007.

Watershed	Year	Tag type	Sample size	Length (mm)	Dates
Big Creek	2006	V7-2L-R04K	14	151 – 206	5/30 – 6/15
	2006	V9-2L-R04K	30	169 – 364	5/1 – 5/24
	2007	V7-2L-R04K	12	152 – 173	5/7 – 6/12
	2007	V9-2L-R04K	24	171 – 215	4/30 – 6/17
Bear Creek	2007	V7-2L-R04K	7	153 – 186	4/23 – 5/30
	2007	V9-2L-R04K	22	170 – 216	4/23 – 5/30

Table 4. Population estimates and mean densities of cutthroat in Big Creek above the hatchery weirs and Bear Creek above and below the municipal dams.

2006 Big Creek estimate						
Statistic	Kilometers	NResp	Estimate	StdError	LCB95Pct	UCB95Pct
Total	80.47	34	17258	2448	12460	22057
Mean (m ⁻¹)		34	0.214	0.030	0.155	0.274
Mean (m ⁻²)		34	0.067	0.011	0.047	0.088
2007 Big Creek estimate						
Statistic	Kilometers	NResp	Estimate	StdError	LCB95Pct	UCB95Pct
Total	80.47	26	16267	2490	11387	21147
Mean (m ⁻¹)		26	0.202	0.031	0.142	0.263
Mean (m ⁻²)		26	0.059	0.011	0.037	0.081
2007 Bear Cr above barrier						
Statistic	Kilometers	NResp	Estimate	StdError	LCB95Pct	UCB95Pct
Total	16.77	12	3,841	610	2644	5038
Mean (m ⁻¹)		12	0.270	0.040	0.180	.350
Mean (m ⁻²)		12	0.100	0.020	0.070	0.140
2007 Bear Cr below barrier						
Statistic	Kilometers	NResp	Estimate	StdError	LCB95Pct	UCB95Pct
Total	21.025	18	1057	101	860	1255
Mean (m ⁻¹)		18	0.053	0.005	0.043	.063
Mean (m ⁻²)		18	0.021	0.002	0.016	0.025

Table 5. Fork length (mm) of cutthroat in Big Creek 2006 and 2007 and Bear Creek above and below the barrier in 2007.

Groups	Count	Mean	Std Error
Bear Creek below	100	128.8	2.2
Bear Creek above	256	116.5	1.4
Big Creek 2006	696	130.7	1.3
Big Creek 2007	704	115.9	1.5

Table 6. Number of fish detected at PIT antenna the spring following tagging (year + 1).

Stream	Year	Tagged electrofishing		Detected at PIT antenna		
		N	Fork Length	N	Fork Length	Proportion Migrant
Big Creek	2006	622	90 – 310mm	26	93 – 158 mm	0.048*
	2007	422	100 – 278 mm	14	115 – 181 mm	0.038*
Bear Creek	2007	89	100 – 218 mm	27	104 – 162 mm	0.30**

*adjusted for antenna efficiency

**below barrier sites only

Table 7. Efficiency of PIT detection estimated as a percent of the individuals collected on the bird colony at East Sand Island relative to the individuals also detected at the PIT antenna . Fish were PIT-tagged at Big Creek hatchery, Big and Bear creeks smolt traps, and electrofishing in Big and Bear creeks.

<u>Hatchery Chinook Released Spring 2007 (12mm tags)</u>	
Total recovered on bird colonies	354
Detected at antenna	302
Antenna efficiency	0.85
<u>Steelhead and Cutthroat (23mm tags)</u>	
Total recovered on bird colonies	17
Detected at antenna	15
Antenna efficiency	0.88
<u>Coho (12mm tags)</u>	
	<u>2007 smolt trap</u>
Total recovered on bird colonies	6
Detected at antenna	5
Antenna efficiency	0.83

Table 8. Detection of acoustic tagged fish in estuary and on the bird colony at East Sand Island. The number and percent of acoustically tagged cutthroat that were detected at several points during the downstream migration.

Stream	Year	N	Detected at:				
			Tributary mouth	Russian Island	Tongue Point	Ocean	Bird Colony
Big Creek	2006	44	30 (70%)	25 (57%)	22 (50%)	18 (41%)	2*
	2007	36	15 (42%)	8 (22%)	7 (19%)	5 (14%)	1*
Bear Creek	2007	29	20 (69%)	--	9 (31%)	4 (14%)	6

* one fish each year preyed upon after entering ocean

Table 9. Migration rates of acoustic tagged fish after tagging to ocean entrance.

Stream	Year	N	Elapsed time range (h)	Median elapsed time (h)	Median Speed (km/hr)
Big Cr	2006	18	14.8 – 154.0	28.7	1.20
	2007	5	31.1 – 69.2	43.0	0.80
Bear Cr	2007	4	36.3 – 138.5	89.7	0.47

Table 10. Survival of Cutthroat implanted with acoustic and PIT tags in the watershed and at the screw trap, and detected at the PIT antenna in 2007, or were acoustic tagged and detected at the mouth of Big or Bear creeks. All fish implanted with acoustic tags were also PIT tagged.

Stream	Tagging		Number Tagged	Migrants	
	Location	Year tagged		Detected	Returned
Big Creek	Screw trap	2006	44	30*	0
	Watershed	2006	40	30	1
	Watershed	2007	458	29	1
Bear Creek	Screw trap	2007	29	20*	1
	Watershed	2007	89	27	2

* The PIT antennas were not in place in Big Creek in spring 2006 or Bear Creek in spring 2007 to estimate outmigrants, numbers include acoustic tags only.

Table 11. Rates of bird predation calculated from recoveries on East Sand Island. Acoustic tag recoveries are in addition to the PIT tags.

Group	PIT tags	Acoustic tags
Big Creek Spring 2006	5.3%	6.7%
Big Creek Spring 2007	15.4%	6.7%
Bear Creek Spring 2007	14.8%	30%

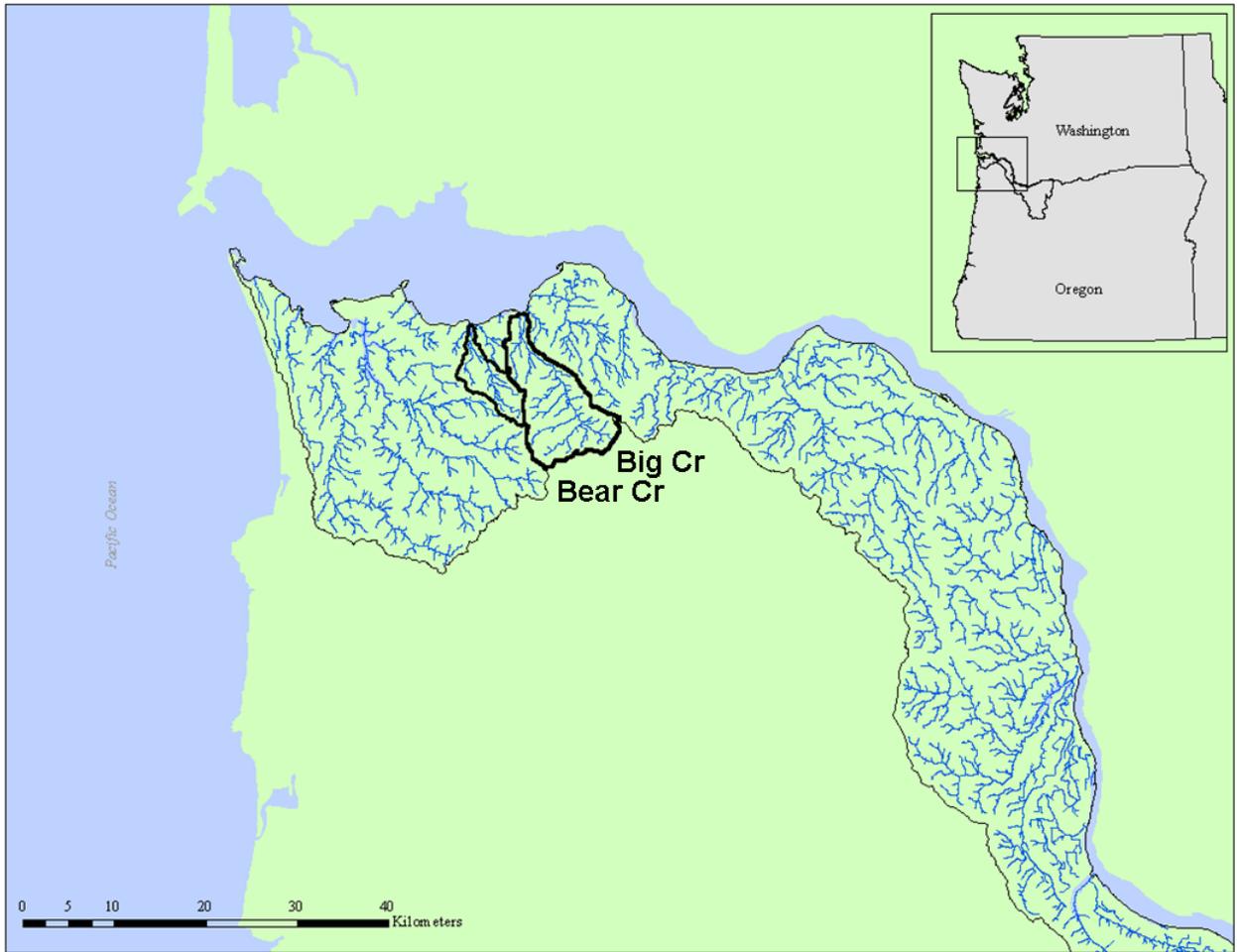


Figure 1. Location of Big Creek and Bear Creek watersheds on the lower Columbia River, Oregon.

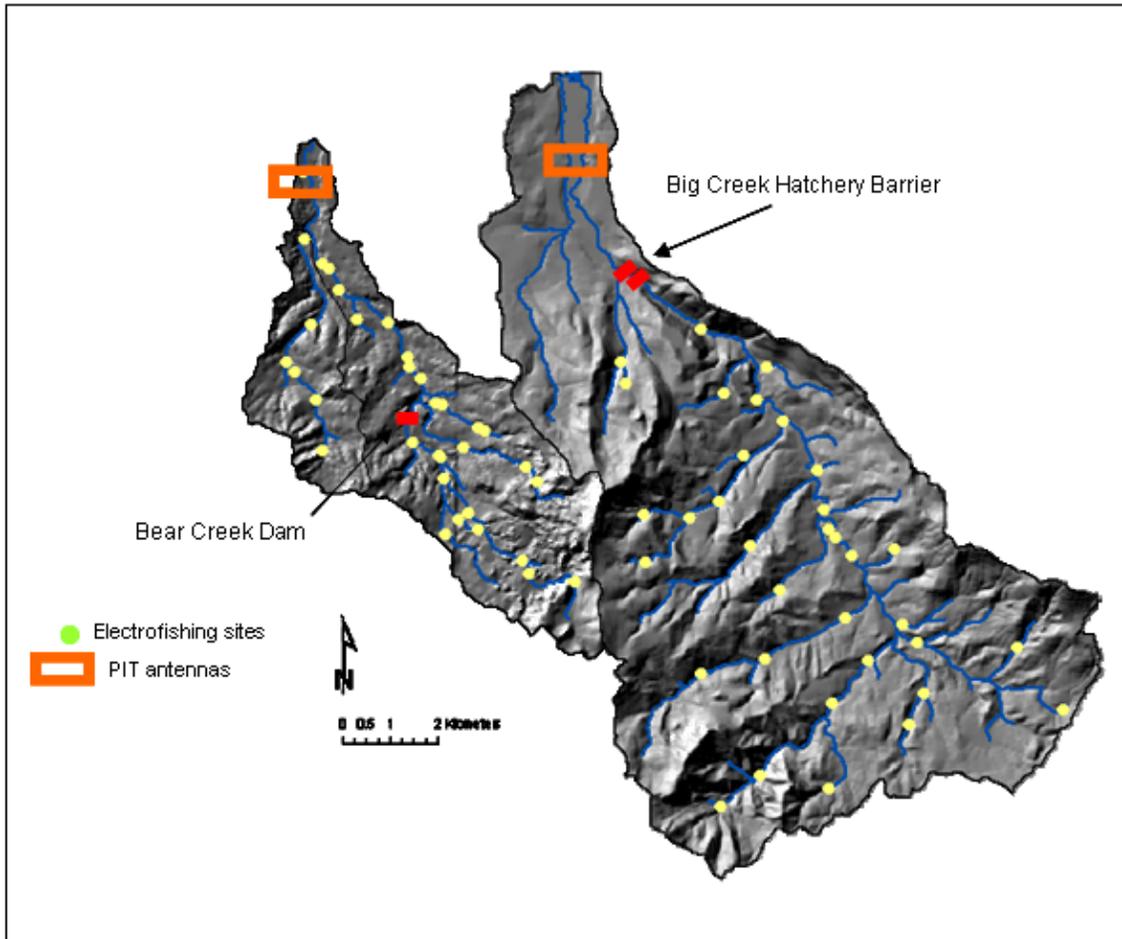


Figure 2. Location of electrofishing sites and PIT arrays in Big and Bear creeks.

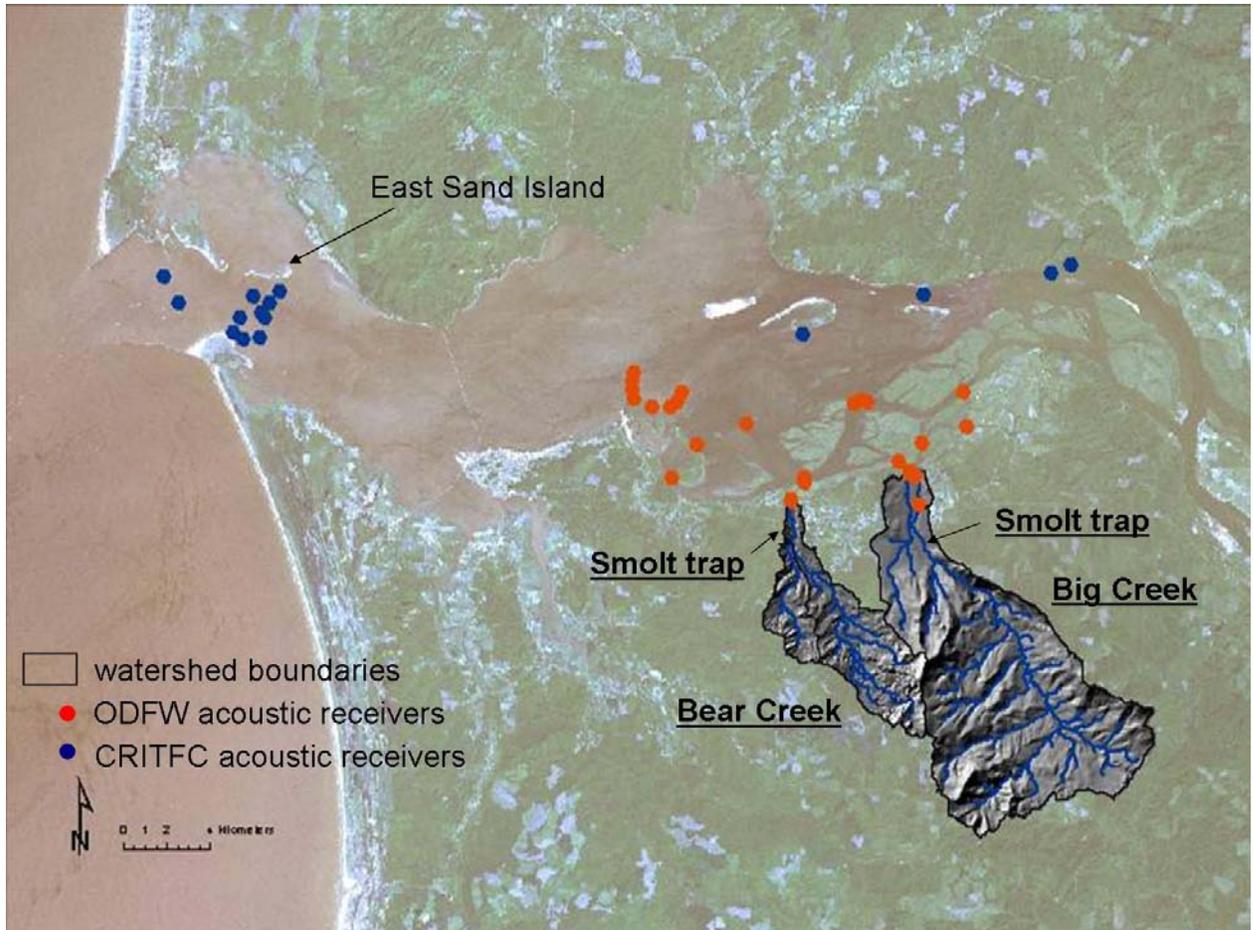


Figure 3. Location of smolt trap and acoustic receivers in the Columbia River estuary.

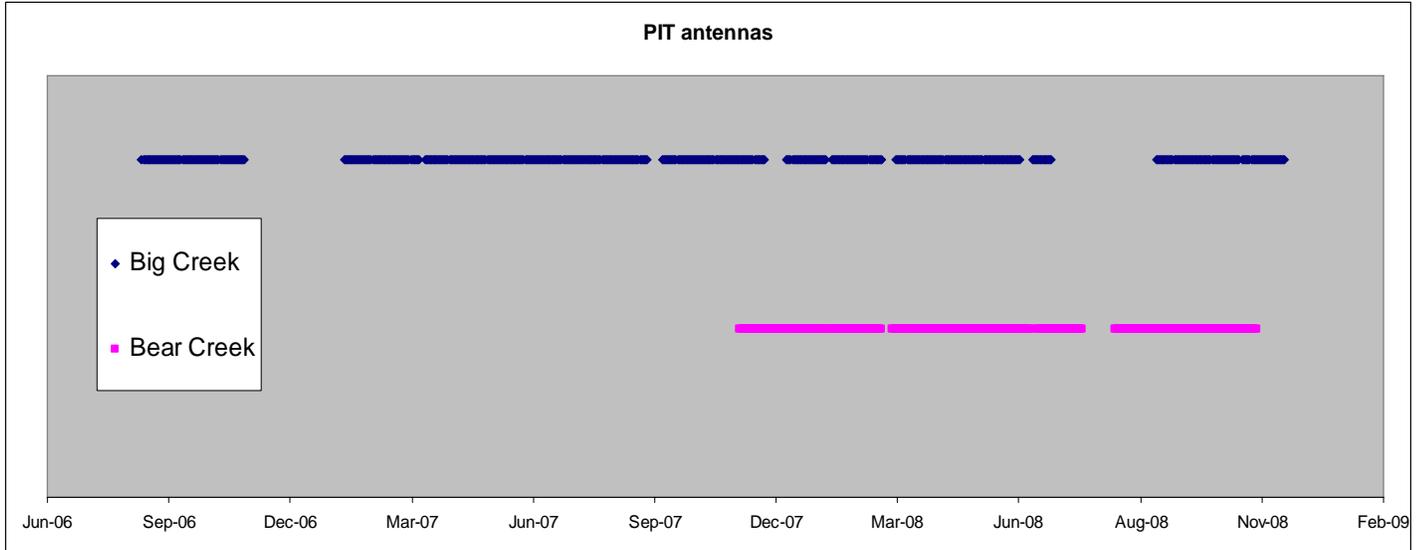


Figure 4. Timeline of operation of PIT antennas in lower Big Creek (upper line) and lower Bear Creek(lower line) from August 2006 through December 2009.

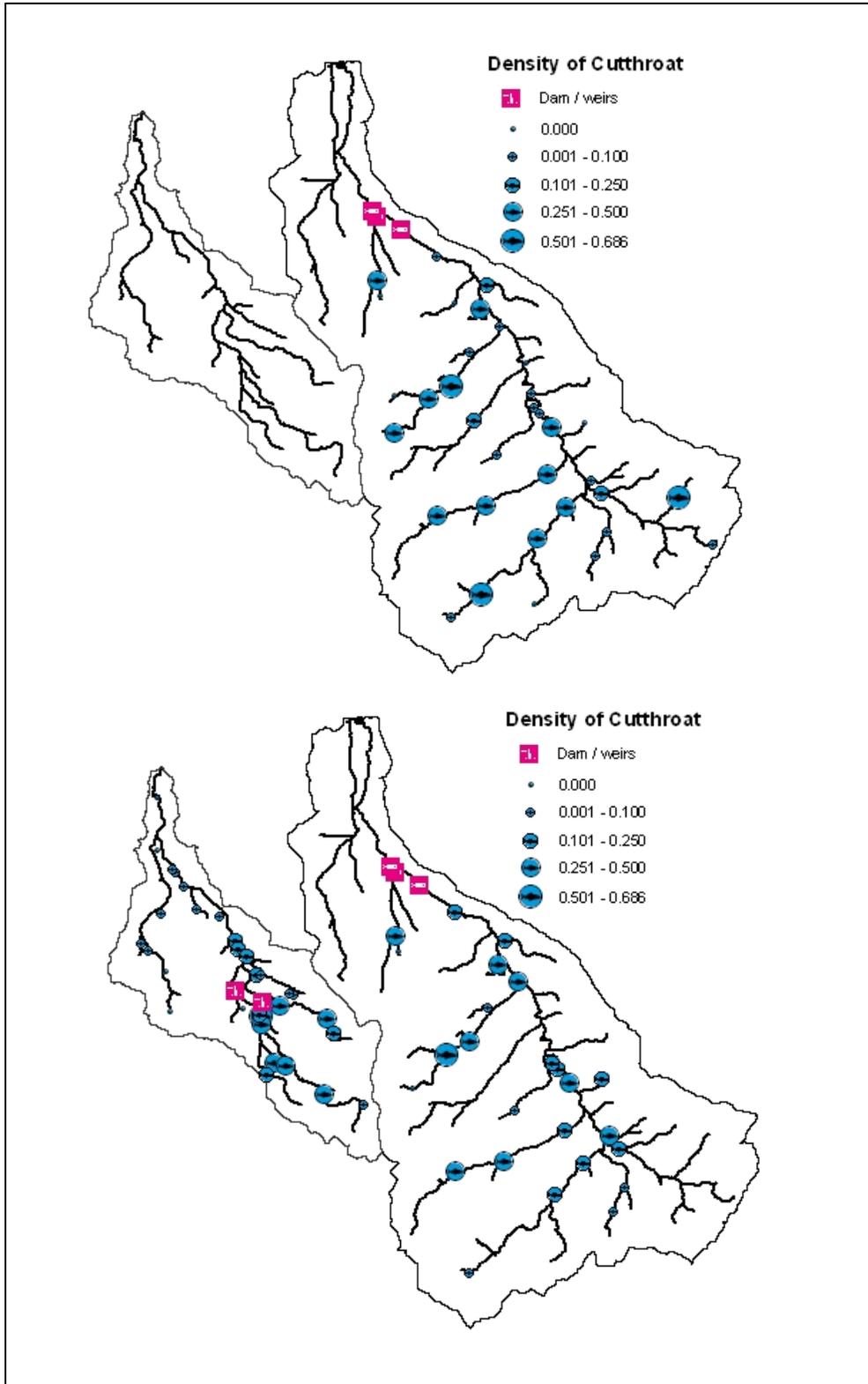


Figure 5. Density of cutthroat in Big and Bear creeks in 2006 (top) and 2007 (bottom).

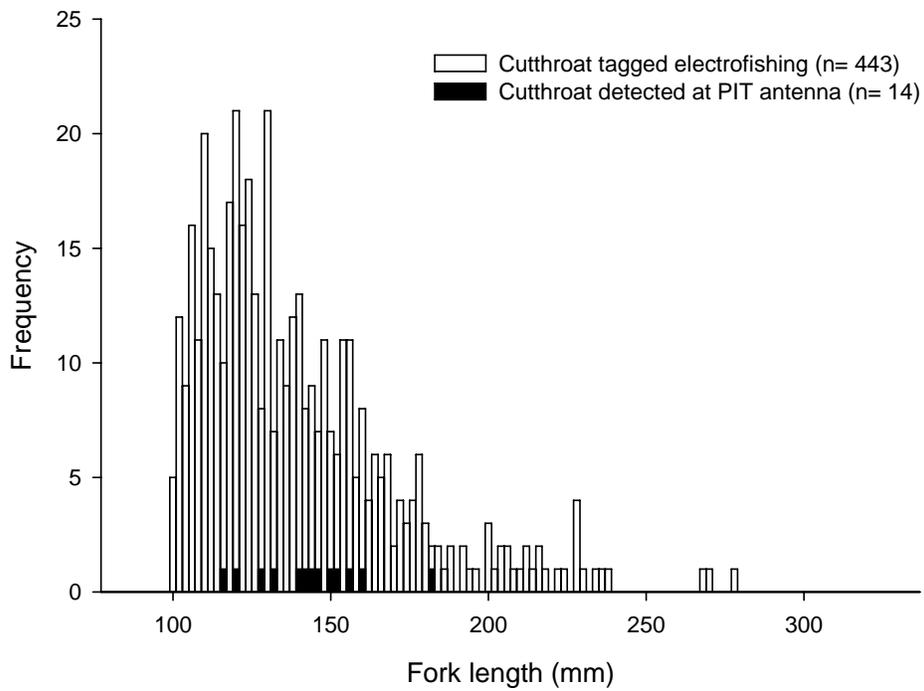
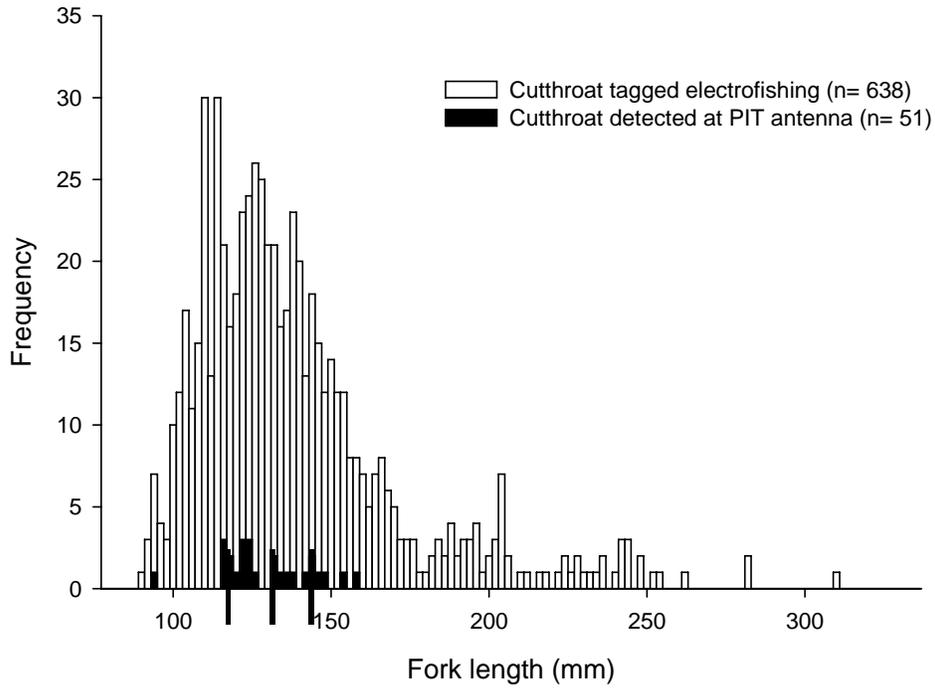


Figure 6. Length frequency of cutthroat PIT tagged (clear bars) and detected (black bars) in Big Creek watershed 2006 (top) and 2007 (bottom).

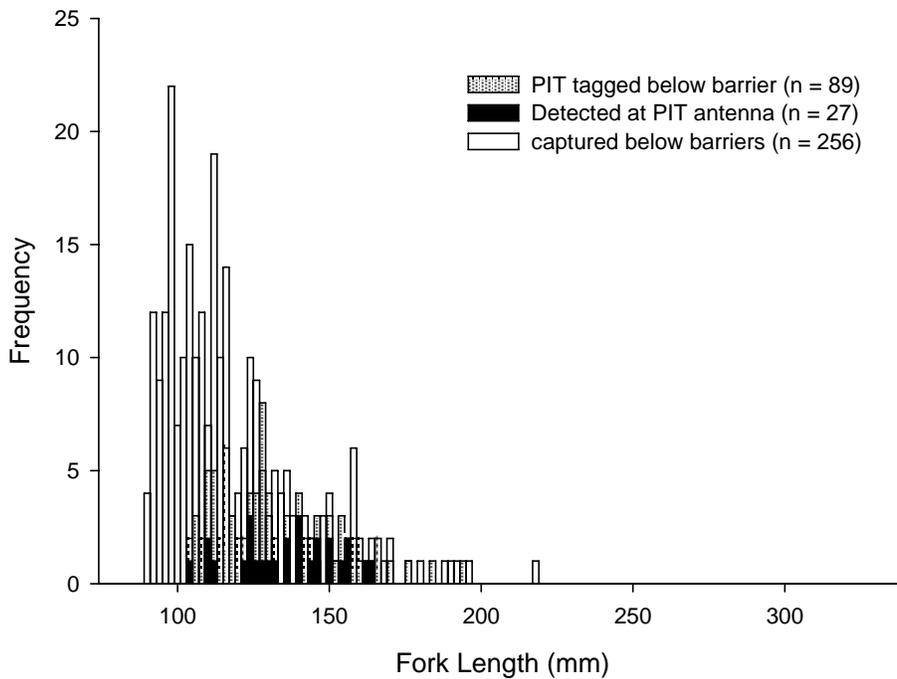
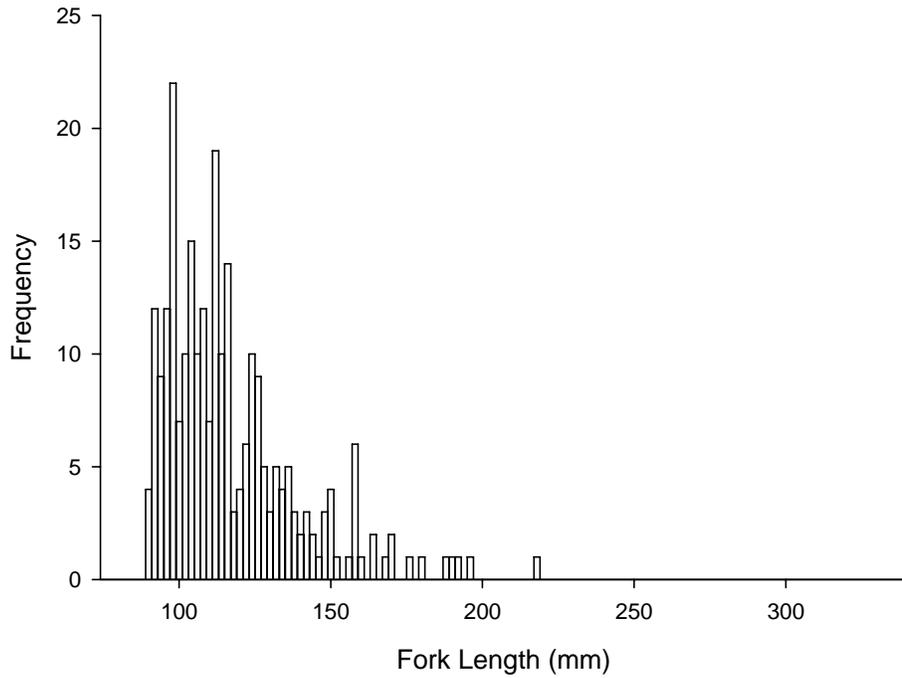


Figure 7. Length frequency distributions of cutthroat captured electrofishing above barriers (top) and below barriers (bottom) in Bear Creek, 2007. Black bars indicate fish detected at PIT antenna during spring 2008.

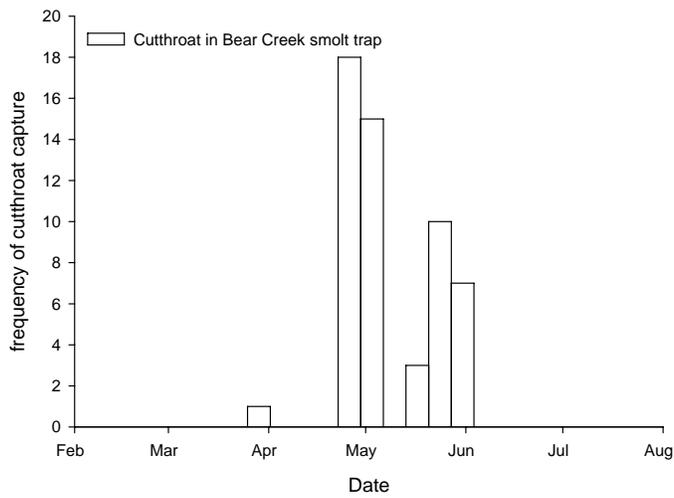
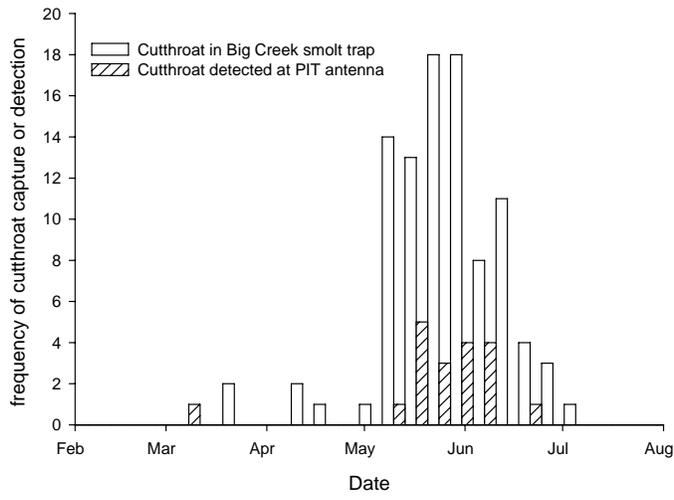
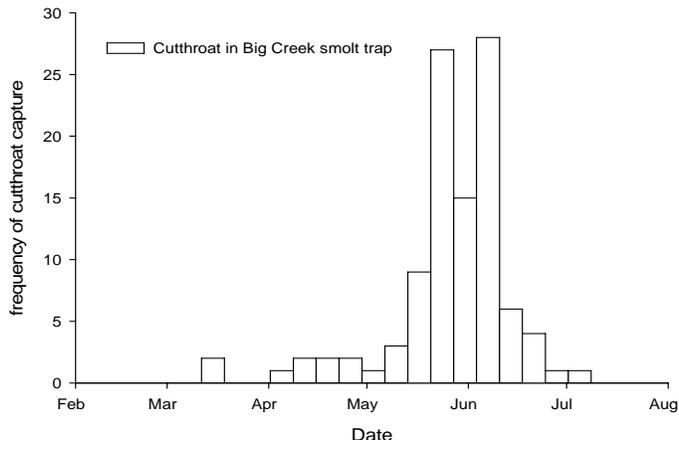


Figure 8. Downstream migration timing through Big Creek smolt trap in 2006 (top) and smolt trap and PIT antennae in 2007 (middle), and Bear Creek in 2007 (bottom).

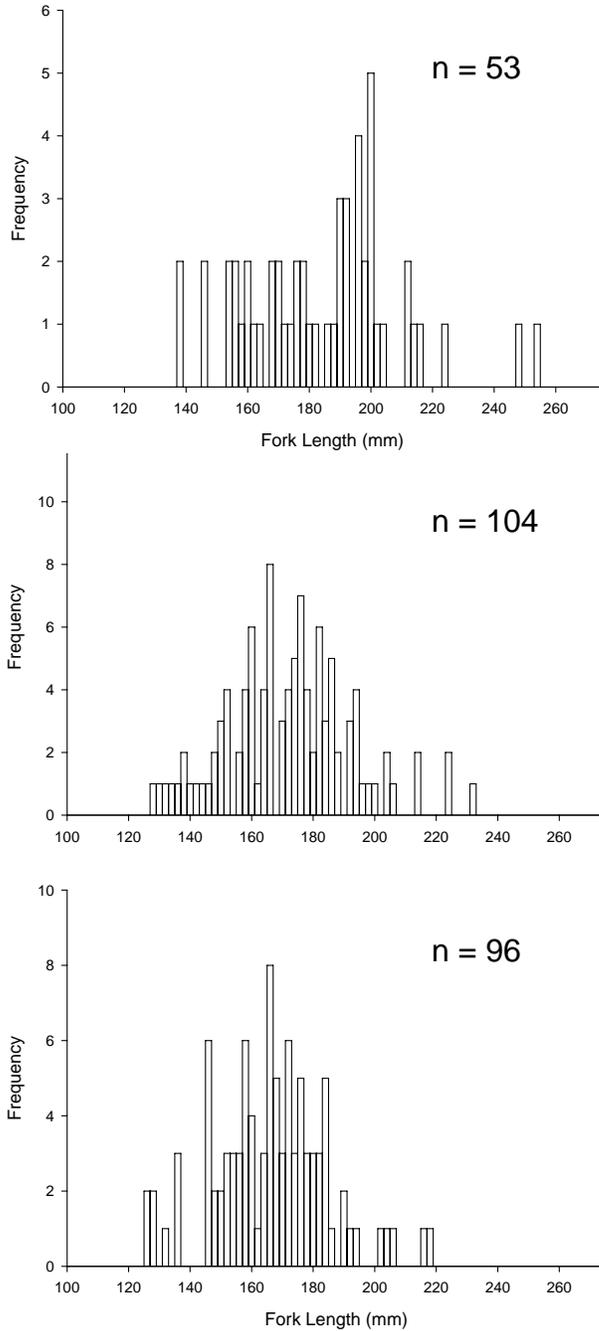


Figure 9. Fork lengths of downstream migrating cutthroat in Bear Creek 2007 (top), Big Creek 2006 (middle), and Big Creek 2007 (bottom).

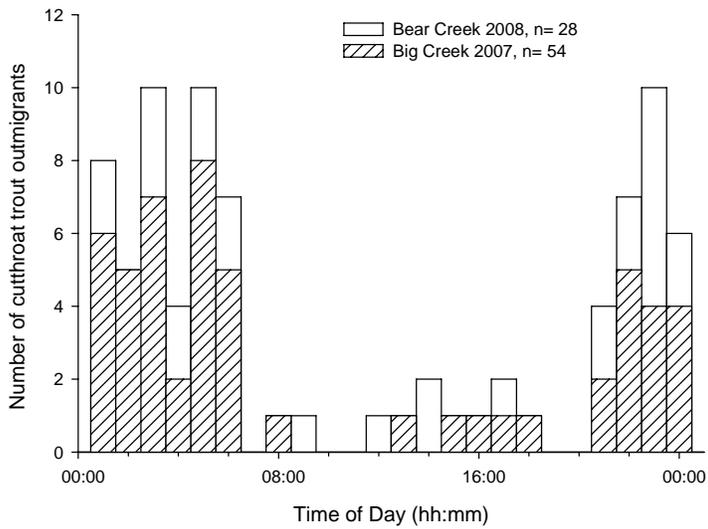


Figure 10. Diurnal timing of migration through the PIT antennae in Big Creek and Bear Creek.

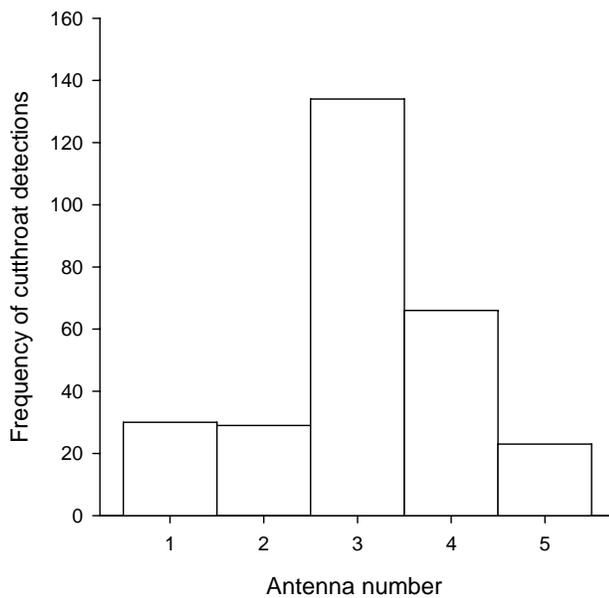


Figure 11. Horizontal migration of fish through PIT antennas in Big Creek. Antennae 1 abuts the left bank and antennae 5 abuts the right bank

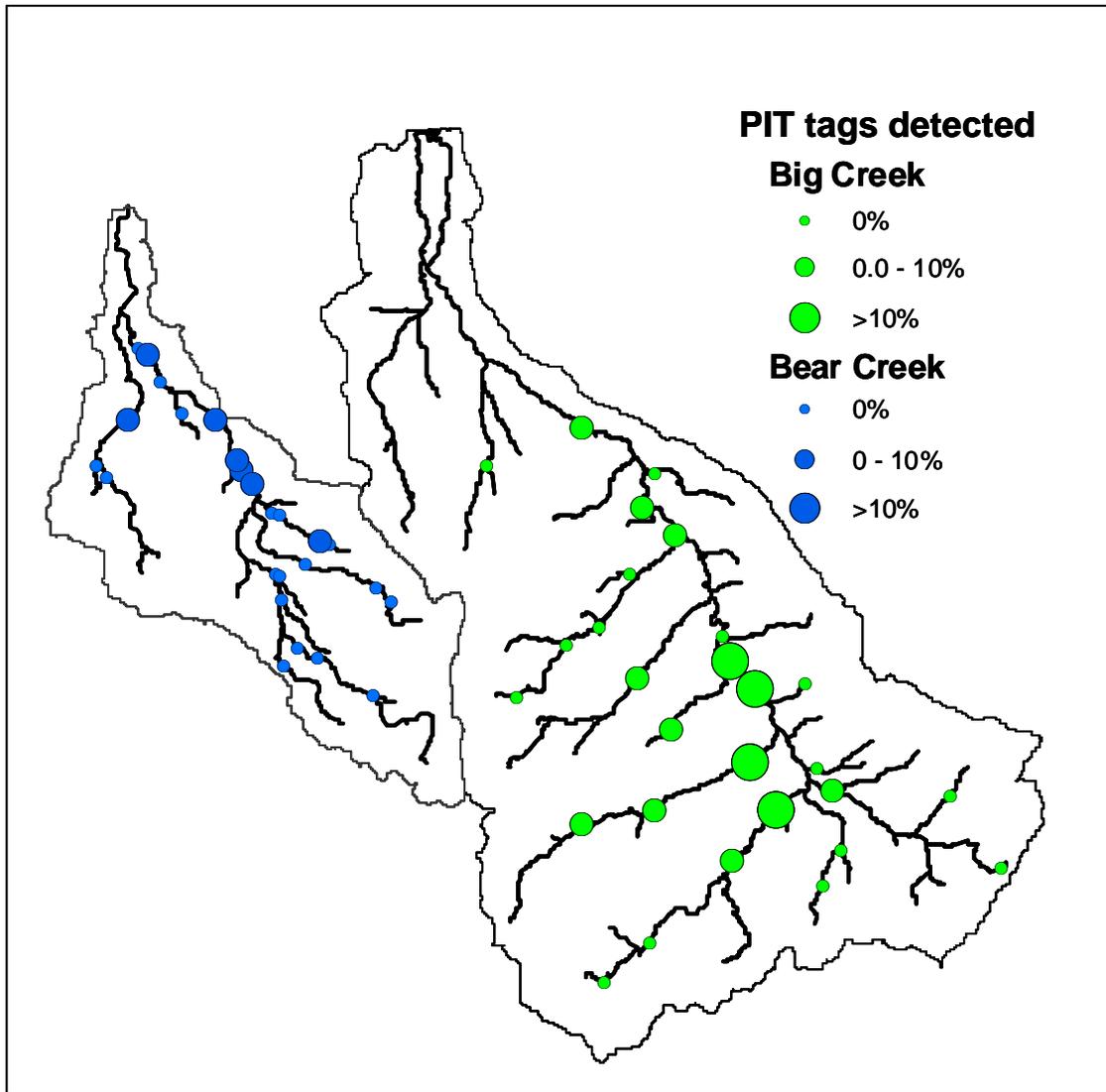


Figure 12. Tagging location of PIT tagged cutthroat detected at the mouth of Big and Bear creeks. The percent at each site represents the proportion of recaps of tagged fish in each watershed. The proportion in Big Creek combines 2006 and 2007 sampling years.