AN ABSTRACT OF THE THESIS OF

Eva M. Schemmel for the degree of Master of Science in Fisheries Science presented on March 30, 2009.

Title: Managing Adult Hatchery Summer Steelhead for a Recreational Fishery with Reduced Hatchery and Wild Interactions.

Abstract approved:

David Noakes

Hatcheries whose purpose is to provide for a recreational fishery must minimize impacts on wild fishes. Management to reduce hatchery and wild interactions is especially important on river systems that contain Endangered Species Act (ESA) listed species. I examined adult hatchery summer steelhead, *Oncorhynchus mykiss,* behavior, current management and a potential future management practice in a river with both introduced and ESA listed steelhead. I used radio telemetry to determine hatchery summer steelhead activity, behavior, and examine management tactics in the Clackamas River, Oregon. I evaluated the movement and distribution of radio-tagged fish between July 2007 through January 2008 using a combination of fixed and mobile radio-tracking. In addition, I used electromyogram (EMG) transmitters to record activity and behavior while the fish were holding in their natal river. An EMG-tagged fish was caught on hook and line during tracking and is the first known instance of estimated activity levels during capture.

I evaluated the fish recycling program on the Clackamas River. Recycling involves the transport and release of adult steelhead back downstream following their collection at the hatchery to increase angler success. I estimated that up to 41% of recycled fish were caught in the recreational fishery. However, the majority of fish (44 - 67) were unaccounted for after release and may negatively affect wild populations. The Oregon Department of Fish and Wildlife is investigating the feasibility of sterilizing returning adult hatchery steelhead to reduce hatchery and wild interactions and increase recreational fishing opportunity. To evaluate the effect of sterilization on adult fish behavior, I gonadectomized and radio-tagged 40 hatchery summer steelhead and monitored their behavior and contribution to the fishery compared to sham-operated fish. Gonadectomized fish remained in the river, were distributed downstream of control fish, and were caught in the recreational fishery. Based on my results, I conclude that sterilization may be a useful technique to improve angler opportunity while minimizing the impact to wild fish. Behavior and activity of hatchery fish and their responses to management procedures should be closely monitored to better manage hatchery fisheries.

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Managing Adult Hatchery Summer Steelhead for a Recreational Fishery with Reduced Hatchery and Wild Interactions.

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Eva M. Schemmel

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

Eva M. Schemmel, Author

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CONTRIBUTION OF AUTHORS

David Noakes, Carl Schreck, and Shaun Clements contributed in development of the experimental design, data analysis, and editing of all chapters. Christian Torgersen contributed to data and spatial analysis and editing of all chapters.

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CHAPTER 1: INTRODUCTION

Many North American native salmonid populations are in decline due to habitat degradation, harvest, hatcheries, and hydropower impacts (Nehlsen et al. 1991; Young 1999). As a result, many salmon and trout stocks within the Pacific Northwest are listed under the Endangered Species Act of 1973. As of 2007, 314 native stocks of Pacific salmon, steelhead, and cutthroat (*Oncorhynchus sp.*) are at risk of extinction (Helfman 2007).

Hatcheries were established to mitigate for the decline in salmon and trout populations (Hilborn 1992). Hatchery fish provide for commercial, recreational, and tribal fisheries, as well as conservation, restoration and remediation (Flagg et al. 2000). In most instances, hatcheries have resulted in increased returns of adult fish relative to wild production alone, and currently contribute as much as 70-80% of coastal fisheries (Flagg et al. 2000). Traditionally, the majority of hatcheries focused on increasing harvest opportunities, rather than the impact of hatchery fish on their wild counterparts. Today, it is recognized that hatchery salmonids can have impacts on the fitness and behavior of wild fish (Young 1999; Levin and Williams 2002). The effects of hatchery fish on wild populations can be divided into three broad categories: changes in fishing pressure, ecological interactions, and biodiversity and genetics.

First, over-harvest of wild stocks in mixed stock fisheries leads to reduced survival of wild stocks (Flagg et al. 2000). Fishing pressure on abundant hatchery fish causes unsustainable mortality of less abundant wild fish (Nelson et al. 2005a). Furthermore, in a catch and release fishery, post-release mortality or sublethal effects on growth and fitness can occur (Cooke and Cowx 2004).

A number of studies have documented negative effects of hatchery production on wild populations through ecological impacts (Fleming and Petersson 2001; Kostow et al. 2003; McLean et al. 2005; Kostow and Zhou 2006). These include increased competition for food and territory, predation by larger hatchery fish on smaller wild cohorts, and negative social interactions when large numbers of hatchery fish are released into a population of small numbers of wild fish (Flagg et al. 2000). Kostow et al. (2003) reported a decline in native populations of winter steelhead, *Oncorhynchus mykiss,* due to competition for habitat and spawning sites with hatchery fish. Hatchery production may also regularly exceed the carrying capacity of a river, leading to density dependent factors that negatively influence the wild populations (Kostow and Zhou 2006).

Thirdly, there are a number of genetic risks associated with hatchery and wild interactions (Fleming and Petersson 2001). Genetic variability is often indirectly reduced in hatchery fish due to the absence of natural selection in the hatchery environment and, directly via artificial selection (Fleming and Petersson 2001). This loss in genetic variability can reduce fitness, alter the ability of a population to adapt to changing environments, and reduce the population's long-term viability (Fleming and Petersson 2001). For example, a recent study showed that traditional hatchery steelhead may have up to 45% lower fitness than wild steelhead (Araki et al. 2007). This reduced genetic variability can influence wild populations through interbreeding. This gene flow from hatchery fish to wild populations can lead to a reduction in fitness known as out-breeding depression (Fleming and Petersson 2001).

Today fishery managers recognize the influence of hatchery fish on the environment and place a great deal of emphasis on minimizing the interactions between hatchery fish and wild salmon and trout. To reduce the negative impacts of hatchery salmonids, hatchery managers are implementing new management tactics. However, the first step to managing hatchery salmonids is to know how they behave in the river. For example, hatchery steelhead behavior and activity levels are not well known during their long freshwater residency before spawning. Summer steelhead may spend over 6 months in their natal rivers before spawning (Robards and Quinn 2002). It is thought that steelhead hold in low velocity, cool water pools (Matthews et al. 1994; Nakamoto 1994; Nelson et al. 2005b) and exhibit activity patterns that allow for conservation of precious energy reserves (Rand and Hinch 1998). Knowing the habitats that steelhead utilize and their activity patterns in freshwater will provide valuable insights for recreational fisheries managers for not only reducing hatchery and wild interactions, but also for increasing angler opportunity.

A second step towards improving hatchery fishery management is to use the information about fish behavior and apply it to management. A common strategy for minimizing hatchery and wild interactions in the Pacific Northwest is to spatially separate hatchery fish from wild fish (Evenson and Cramer 1984; Lindsay et al. 2001; Dyson and Apperson 2005). Hatchery recycling programs have been established on many rivers to increase angling opportunities. Recycling involves the collection of adult hatchery fish at ladders and traps and then transporting them back downstream (Evenson and Cramer 1984; Lindsay et al. 2001). Typically, at the same time in such recycling programs, adult wild fish in the same river are allowed over upstream barriers and hatchery fish are not. This protects the spawning grounds of wild fish upstream of the barriers while increasing angling opportunities on hatchery adults downstream from those barriers (Evenson and Cramer 1984; Lindsay et al. 2001).

An additional approach to minimize hatchery impacts and expand recreational fisheries is to inhibit the reproduction of adult hatchery fish (Johnston et al. 1993; Dillon et al. 2000; Lindsay et al. 2000). The idea behind this strategy is to end interbreeding of hatchery and wild fish and reduce competitive interactions between them (Johnston et al. 1993; Dillon et al. 2000; Lindsay et al. 2000). Sterilization programs have been successful in closed environments such as lakes, and with non-anadromous salmonids (Johnston et al. 1993; Dillon et al. 2000; Kozfkay et al. 2006). Several techniques are available for sterilizing salmonids (Donaldson 1986; Feist et al. 1996). These typically include procedures such as production of triploids early in the life of the fish (Donaldson 1986; Feist et al. 1996). Triploids can be produced by subjecting recently fertilized eggs to high pressure or high temperature (Donaldson 1986; Feist et al. 1996). Individuals can also be exposed to steroid hormones as juveniles, to produce all-female or all-male cohorts (Donaldson 1986; Feist et al. 1996). The sex-reversed individuals can then be used in selective mating schemes to produce sterile offspring (Donaldson 1986; Feist et al. 1996).

However, sterilization treatments administered to anadromous salmonids early in their life history have not been successful for management purposes. Anadromous salmonids sterilized as juveniles have significantly reduced returns as adults to freshwater, and the majority of fish that have returned have secondary sexual characteristics and well developed gonads (Lindsay et al. 2000; Wilkins et al. 2001).

Now, sterilization of returning adults is being considered to expand the distribution of fish available for recreational fisheries.

My study is designed to address questions pertinent to recreational fishery management with the goal of reducing hatchery and wild interactions while providing increased angling opportunities. This study addresses the questions of steelhead behavior and activity in natal rivers, the success of the hatchery fish recycling program, and the use of sterile salmonids in freshwater fisheries. Answers to these questions will provide valuable information for hatchery fishery management and native fish conservation. This thesis is presented in the form of manuscript chapters. Chapter 2 deals with the relative activity levels and habitat use of adult hatchery summer steelhead. Chapter 3 evaluates the success of the hatchery recycling program. Chapter 4 considers the potential of sterilizing adult salmonids to provide for recreational fisheries with reduced hatchery and wild interactions. Chapter 5 provides a general discussion and conclusion.

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CHAPTER 2: USING EMG TELEMETRY TO ASSESS RELATIVE ACTIVITY AND HABITAT USE OF OVER-SUMMERING STEELHEAD, ONCORHYNCHUS MYKISS

Eva Schemmel, David Noakes, Carl Schreck, Christian Torgersen, and Shaun Clements

Abstract

Anadromous adult summer steelhead, *Oncorhynchus mykiss*, undertake an extensive, and energetically costly, migration from ocean feeding grounds to their natal rivers. Individuals may then spend up to nine months in freshwater before spawning in the late autumn or winter. The reproductive fitness of an individual will be related to the allocation of its energy resources. The behavior of these fish while in freshwater is likely to have a large effect on their energy requirements. We used electromyogram (EMG) radio telemetry to evaluate their habitat use and activity levels. The fish tended to reside in pools and had relatively low activity levels during the summer and autumn. We conclude that this behavior and pattern of habitat use enables the fish to conserve energy prior to spawning. During the study, we also documented the first known capture of an EMG-tagged steelhead by an angler. Activity levels were extremely high during capture but returned to baseline within minutes.

Introduction

Steelhead are iteroparous and capable of repeated spawning seasons. In the Pacific Northwest, steelhead populations are classified by their timing of river entry, with two main run types, winter and summer. Summer steelhead enter the river during the summer and remain in freshwater until spawning occurs in winter. Winter steelhead adults enter rivers during late autumn or winter and spawn soon afterwards. Summer steelhead may spend over nine months in freshwater and it is believed that they do not feed during this period (Robards and Quinn 2002; Salinger and Anderson 2006). Thus, energy conservation is of primary importance during this time. Reproductive success is influenced by behavior, including migratory behavior (Hinch and Rand, 1998).

Salmonid freshwater migrations are energetically costly (Brett 1983; Hinch et al. 1996; Hinch and Rand 1998; Rand and Hinch 1998; Geist et al. 2000; Hinch and Rand 2000; Standen et al. 2002; Cooke et al. 2006;). It is estimated that approximately 80% of stored energy is used in the spawning migration, leaving only a small fraction of the energy budget for reproduction and metabolism once they reach their spawning grounds (Brett 1983; Rand and Hinch 1998). Thus, the energy available for gonad development and reproduction is a function of the amount of stored energy and the energy costs of the spawning migration (Rand and Hinch 1998).

Swimming behavior is a major component of energy use during upriver migration in salmonids (Brett 1983; Rand and Hinch 1998; Standen et al. 2002 Geist et al. 2003). Salmon and trout have a large capacity for sustained swimming and they can alter their swimming speed to conserve energy (Brett 1983). Rand and Hinch (1998) suggested that upriver migrating salmonids have repeated temporal swimming patterns alternating between bursting and resting activity. Steelhead can choose one of two swimming patterns in constricted, high velocity areas: one is to move quickly though the area to reduce the amount of time of high energy expenditure, and the other is to utilize lower velocity sections within the constricted area to move upstream (Hinch and Rand 1998).

Steelhead may also conserve energy by holding in cool water pools once they have reached their natal rivers. It is typically thought that summer steelhead seek cool tributaries or deep pools as a thermal refuge (Nakamoto 1994; Nielsen and Lisle 1994; High et al. 2006), and also to conserve energy in low water velocity areas. High water temperatures increase metabolic costs and reduce the energy available for growth and reproduction (Fry 1947; Nielsen and Lisle 1994). Adult summer steelhead are known to use cool, thermally stratified pools during periods of high temperature (26 - 29°C) (Nielsen and Lisle 1994). Robards and Quinn (2002) also suggested that the cold freshwater habitats used by overwintering steelhead aid in energy conservation by allowing the fish to enter a relatively dormant state. It is believed that steelhead alter their behavior during periods of warmer water temperatures to reduce metabolic costs caused by those increased temperatures (Nielsen and Lisle 1994; Robards and Quinn 2002).

The Oregon Department of Fish and Wildlife simultaneously manages the recreational harvest of hatchery summer steelhead and the conservation of native winter steelhead in several major watersheds (ODFW 2007). The summer steelhead adults are available for recreational angling in rivers for several months prior to the spawning season. For management, it is critical to know how these adults behave during that time, and the details of their habitat distribution. We estimated the relative activity levels and habitat use of adult hatchery summer steelhead in the Clackamas River, Oregon. We monitored the behavior of steelhead implanted with electromyogram (EMG) transmitter tags over a series of 24 h tracking periods throughout the pre-spawning period to provide information on the location and swimming activity of individual fish.

We used EMG transmitters to determine the activity patterns of summer steelhead once they had returned to their natal river. Our objectives were to determine if diel activity was present and to determine if activity levels differed between habitat types. EMG transmitters are one of the most useful techniques for remotely monitoring fish activity by measuring relative muscle contraction activity (Okland et al. 1997; Geist and Brown 2002; Cooke et al. 2004b). EMG transmitters provide high spatial and temporal location resolution to give insight into the physiology and behavior of fish (Cooke et al.

2004b). EMG values can be used as quantitative estimates of overall fish activity (Cooke et al. 2004b; Cooke et al. 2008). When calibrated, EMG transmitters also allow for measurement of swimming speed and energy use (Cooke et al. 2004b; Brown et al. 2007; Cooke et al. 2008).

Materials and Methods

River System

The Clackamas River is a gravel-bed river that originates from the Cascades near Ollalie Lake and runs 215 km to its confluence with the lower Willamette River near Portland, Oregon, USA (Burkholder et al. 2008). The river drains an area of 2,430 km^2 and has a median annual flow is 75.7 m^3/s (Burkholder et al. 2008). The river discharge is regulated by four dams that have been built on the main stem of the river: River Mill Dam (river kilometer (rkm) 37), Faraday Dam (rkm 42), Diversion Dam (rkm 45), and North Fork Dam (rkm 47). North Fork Dam acts as a complete barrier to upstream fish passage. Our study area encompassed the stretch of river from North Fork Dam downstream to the confluence of the Clackamas and Willamette Rivers.

Telemetry Equipment

We used coded EMG transmitters (Lotek CEMG2-R16-25, dimensions: 16 x 45 mm, 11.9 g in air). Coded EMG transmitters measure the electrical potential between two electrodes placed in the red muscle of the fish (described further in Cooke et al 2004). The voltage corresponding to the duration and intensity of muscle contraction is rectified and summed over a 3 s time period. The average value, ranging from 0 to 50, is calculated and transmitted to the receiver. Low values represent lower muscle activity levels. All EMG transmitters transmitted on a 151.500 MHz frequency with a burst rate of 3 s. We used two receivers (SRX 600 and SRX 400, Lotek, Newmarket, Ontario, Canada) and four element yagi antennae (150 Mhz, Cushcraft, Manchester, New Hampshire, USA) to track the EMG-tagged steelhead. The receivers recorded the signal strength, time, tag code, latitude and longitude (SRX 600 only), and EMG output (from 0 to 50).

Tagging Procedure

We obtained 19 summer steelhead adults (mean mass ± SD = 3.2 ± 0.7 kg; mean fork length ± SD = 648 ± 32 mm) from the Oregon Department of Fish and Wildlife Clackamas Hatchery, 35 km upstream of the mouth of the Clackamas River. The fish were collected as they entered the fish trap at the hatchery and transferred to a holding raceway (16 - 19 °C) for tagging and surgery. The steelhead were tagged and released in July. We monitored their post release behavior between August and October 2007.

All fish were internally tagged with the EMG radio-transmitters. We anesthetized each fish individually for 8 min in a darkened container containing a buffered solution of 0.05% tricaine methanesulfonate (MS 222, Argent Chemical Laboratories, Redmond, WA). When the fish reached stage 3 anesthesia (Murray 2002) it was placed ventral side up on a surgical table. The gills were continuously perfused with a diluted solution (0.025%) of MS 222 though a perforated tube placed in the buccal cavity. A 6 - 8 cm ventral incision was made between the pectoral and pelvic fins (Okland et al. 1997). A radio transmitter was inserted into the body cavity through this incision. The antenna was positioned using a 15 gauge needle inserted through the initial incision and pushed though the body wall posterior to the pelvic fins. The EMG electrodes were inserted parallel to each other, approximately 10 mm apart into the red muscle of the fish using a stainless steel plunger. The electrodes were placed behind the lateral line approximately halfway along the fish's body. The transmitter was then pushed gently into the body cavity and the incision was closed using absorbable monofilament in a simple interrupted suture pattern. Surgical glue was applied around the antenna exit site to minimize tissue damage. Fish were tagged externally with individually numbered Floy tags to mark the fish for recognition by anglers. All instruments were rinsed in hydrogen peroxide and flushed with distilled water before each surgery. Each fish was also given an intramuscular injection of florphenicol (Nuflor, Germany; 10 mg/kg) and oxytetracycline (Aspen Veterinary Resources, Kansas City, MO; 11 mg/kg), immediately following surgery to minimize infections.

Following surgery, the fish were held in a flow-through raceway at the hatchery for 24 h to monitor condition before release. All fish survived and were swimming normally before release. The fish were then transported in aerated river water to the Barton Recreational Park, 21.5 rkm upstream from the confluence with the Willamette River, and released. The releases took place during the morning on four occasions between 23 July 2007 and 2 August 2007.

EMG Calibration

We calibrated two EMG transmitters to swimming speed using a Blazka respirometer (Booth et al. 1997). The transmitters were assigned randomly to one of seven winter hatchery steelhead (Table 1), obtained from the Alsea River, Oregon (mean body length ± SD: 627 ± 149 mm). The calibrations were done in April 2008 and thus the winter steelhead were reproductively mature. The transmitter was implanted following the methods outlined above. We tagged two fish per day. Following tagging, the fish were held in large, circular fiberglass tanks, with flow-through river water for at least 48 h before the calibration trial was performed (recovery time suggested by Brown et al. 2007). The tagged fish were subsequently placed in the swim tube and allowed to acclimate for 30 min at a velocity of 6 cm/sec. We found that a 30 min acclimation period was sufficient for EMG values to stabilize and for the fish to orient to the water flow. Following the acclimation period, water velocity was increased stepwise by 15 cm/sand held at the new level until 30 EMG records were recorded when the fish was swimming in the middle of the tunnel. The fish were forced to swim at increasing velocities until they reached exhaustion and could no longer swim. We considered this velocity to be the maximum swimming speed of the fish (U_{crit}). The EMG signal was recorded using a Lotek SRX 600 receiver. After the trials, the fish were euthanized and electrode placement was determined. We used the average EMG output at each velocity for each individual fish to calibrate transmitter output to swimming speed. We evaluated the relationship between mean EMG output and water velocity using a linear regression analysis. To standardize between fish, we calculated an activity index by dividing the mean EMG value at each velocity by the resting EMG value, recorded when the fish was anesthetized. A value of 1 represents resting activity. When calculated from the linear relationship of swimming speed and activity index, the maximum tag output of 50 equates to an activity index of 8.4.

Tracking and Analysis

The position of each individual was determined every 2-3 d, as part of a larger study. To monitor the behavior and habitat use of the EMG-tagged fish we randomly selected four fish and followed them over a 24 h period on at least two separate occasions per fish. Of the remaining 15 EMG-tagged fish, one was never detected after release and one was removed from analysis because the sex was unknown. EMG recordings were collected for the remaining 13 fish when they were in the vicinity of the fish randomly selected for 24 h tracking and during additional daily tracking efforts. For this study, we focused our efforts on tracking the four selected fish to obtain detailed habitat and movement records for individual fish over 24 h periods. The location and EMG data was downloaded to a laptop and imported into a database (MS Access). We sorted the data based on fish ID to obtain records of signal strength, date, time, GPS location, habitat, and EMG output. EMG output was subsequently correlated to activity levels using the calibrations described above. Habitat observations were classified as pool, riffle, or glide (Hawkins et al. 1993). The percent of time that the fish occupied the habitat was estimated from observations collected during each 24 h period. The location of each fish was plotted in ArcGIS (ESRI, 2007) using geo-referenced aerial photographs of the Clackamas River taken in August 2006. We calculated the movement of each fish, termed travel distance, based on the difference in river kilometers between the upstream and downstream position. Travel distances were measured in ArcGIS.

We used Analysis of Variance (ANOVA) to determine if activity levels differed between individual fish and between days tracked. We also used ANOVA to compare steelhead activity indexes in different habitats (pool, riffle, glide, or rapid) and during movement between habitats. All statistical analyses were performed in SPSS 15.0. Values are reported as means ± standard deviation.

Results

EMG Calibrations

We used an activity index to express changes in activity above resting levels in individual fish.

Resting EMG levels were similar for all fish (6.0 ± 1.0). The critical swimming speed (U_{crit}) was significantly different between individuals (mean: 174 ± 15cm/s; t-test: d. f. = 6, t = 25.918, $P < 0.01$; Table 1). Fish 2 was not run in the swim trial to its maximum swimming speed; hence no U_{crit} value was recorded for this fish. We observed considerable variation in the mean EMG output at a given velocity among the seven winter steelhead. The mean EMG values at each velocity were used to calculate the activity index. The mean activity index at U_{crit} was approximately 3.5 times the calculated resting activity index. The mean activity index was strongly correlated with swimming speed ($r^2 = 0.88$) and is described by the polynomial relationship $y = 0.0001x^2 + 0.002x + 1.4952$ (Figure 2).

Movement and Habitat Selection

Four EMG-tagged steelhead were randomly selected for 24 h tracking periods (Table 2). In some instances we were able to collect data on multiple fish during a single 24 h period because they were found in the same location. Fish A, B, and D were found primarily between rkm 34.8 and 35.3, in a deep pool just outside the hatchery creek entrance. In contrast, Fish C, held in an off-channel, sandy substrate pool and adjacent riffle just above the release site until December 12, 2007 when it was caught by an angler.

Fish movement was minimal during each 24 h period (mean: 145 ± 104 m; Table 3) and occurred in both the upstream and downstream direction. Fish D had the highest mean travel distance (mean: 237 ± 110 m). The steelhead tended to hold in pools the majority (73%) of the time, spending the remaining time in riffles.

Activity Levels

We observed relatively low activity levels in hatchery steelhead over-summering in their natal river (Figure 3). There was a considerable amount of variability between mean activity levels of individual fish (Table 2). The mean activity index for the 13 EMG-tagged fish not selected for 24 h tracking periods was 2.20 ± 1.23 times the resting activity index calculated from EMG tag calibrations using winter steelhead (Table 2). The mean activity index of the four 24 h tracked summer steelhead was 1.47 ± 0.36 times the resting activity. The mean activity index differed significantly among the four individuals (range: 0.71-1.95, ANOVA: d.f.=3, F-Value=96268.54, $P<0.01$). Fish A had a significantly lower mean activity index (0.71) compared to the three other fish that (range 1.47 to 1.95). Furthermore, the level was lower than the resting activity index value calculated during the laboratory swim trials.

The index of daily activity differed significantly between days for all individual fish (Table 4), although the observed differences were low (Table 3). It is unclear whether daily differences in activity levels for each steelhead tracked were due to seasonality, variation in behavior, or the location along the river that the fish occupied. We found that steelhead activity levels fluctuated over the 24 h tracking period with no clear pattern (Figure 4). We did not observe peaks in activity to correspond to light cycles and activity index values were similar for both day and night (Figure 5).

We found that activity levels depended on the type of habitat that the fish occupied. We found the lowest relative activity levels for steelhead holding in pools

(Table 5). The activity indexes increased by ~ 0.22 ± 0.15 when fish resided in riffles and were even higher (0.38 ± 0.47) during periods of movement (Table 5). There was more variability in the activity index when fish moved between habitats compared to when they held in pools or riffles (Table 5). The variability in the EMG output during periods of movement can likely be explained by changes in swimming velocity. For example, EMG values dropped to zero when the fish drifted downstream and were elevated EMG values when the fish traveled upstream.

Effect of Capture on Activity Levels

We recorded the capture of a fish by an angler (Figure 6). Fish D was caught at 08:20:31 on 3 September 2007. When the steelhead was hooked, the activity level immediately spiked and reached the maximum tag reading corresponding to an activity index of 8.4. The activity levels declined as the fish was brought onto the bank at 08:24:26. The fish was released at 08:24:52 and activity levels rapidly returned to resting levels. The fish was caught in a riffle just upstream of the hatchery creek entrance. After release, the fish moved downstream approximately 190 m and remained in a low velocity pool for several hours before returning to its original location.

Discussion

Activity Levels and Habitat Use

The majority of studies on adult steelhead during their freshwater phase have focused on understanding spawning migrations. We focused on the movements and activity levels of steelhead once they have reached their natal river. Our study suggests that summer steelhead have relatively low activity levels in their natal rivers and select habitats that allow for reduced energy costs. We were able to quantify activity levels and evaluate movements of summer steelhead.

The mean activity index of summer steelhead in the river was 1.4 times greater than the resting levels measured in winter steelhead. A previous study using EMG transmitters found that the transport costs to migration were minimal when sockeye salmon had a swimming speed of 105 cm/s(Hinch and Rand 2000). However, the upriver migration speed of sockeye salmon was in the range of 125 - 175 cm/s (Hinch and Rand 1998). The mean activity index of 1.4 for 24 h tracked steelhead and 2.2 for the remaining EMG tracked steelhead correlates to a mean swimming speed of 30 - 75 cm/s, significantly lower than previous studies. It is important to note that we averaged activity levels over time scales that may not reflect burst activity, which may result in an underestimate of activity levels of summer steelhead holding in their natal river. It has been suggested that short duration burst activity may represent a large portion of fish energetics (Cooke et al. 2004b). Averaging EMG output at scales even as small as 1 min may significantly underestimate activity (Cooke et al. 2004b). Reach characteristics and habitat type may also play a large role in steelhead activity levels (Standen et al. 2002; Cooke et al. 2004b).

The low activity levels that we observed may have been simply due to the fact that the fish had reached their final destination. The steelhead that we observed had already traveled a minimum of 160 km up the Columbia and Willamette Rivers to reach their natal river. Migration seems to have slowed or ceased at this point. The fish that we studied were near the upper limit of their migration route, with a complete barrier to migration just 12 rkm from the hatchery pool, where the majority of the tracked steelhead were located.

We primarily observed holding behaviors for summer steelhead. However, we did record EMG signals during periods of movement and found increased activity indexes and variability in the activity. Fish in riffles and during periods of movement had the highest calculated activity indexes. We observed that fish spent the majority of the time in pools where they had lower relative activity levels.

We did not observe any correlation between activity and the diel cycle. However, this does not mean that steelhead do not respond to photoperiod. Fish tended to reside in deep pools, whereas they may have been more responsive to diel cycles in other habitats. Brown, (1999) found no evidence for diel changes in activity in brown trout (*Salmo trutta*), white sucker (*Catostomus commersoni*), and common carp (*Cyprinus carpio*). However, it is generally accepted that fish movement is correlated to photoperiod (Bourke et al. 1996; Demers et al. 1996; Briggs and Post 1997; Cooke et al. 2004b). For adult salmonids, activity is thought to be highest during daylight hours (Banks 1969; Gowans et al. 1999; Venman and Dedual 2005). It has also been suggested that salmonid activity and migration rates increase during dawn and dusk (Banks 1969; Venman and Dedual 2005).

EMG Telemetry and Calibrations

Variation in the output from EMG transmitters implanted into different fish may be due to tag placement, fish sex, and fish size (Hinch et al. 1996; Booth et al. 1997; Thorstad et al. 2000; Geist and Brown 2002; Brown et al. 2007). It has also been suggested that variation in EMG output can be caused by changes in electrode placement (Brown et al. 2007). Brown et al. (2007) demonstrated variation in EMG output between individual fish and between EMG transmitters and suggested that EMG tags should be calibrated to individual fish before release in the field to get accurate measurements of activity. However, in most cases this is not a viable option. We used winter steelhead to calibrate the EMG transmitters used in summer steelhead. However, because we were interested in the relative, not absolute, activity levels of summer steelhead, we believe that the calibrations were adequate.

Our data likely reflect conservative estimates of activity. The summer steelhead in all probability had a higher maximum U_{crit} compared to the winter steelhead that were used to calibrate the transmitters. The calibrations were performed late in the season, when the fish were reproductively mature and ready for spawning. At this time, we would expect energy reserves to be low. We frequently recorded EMG values above the maximum values recorded in winter steelhead. We are confident that the data presented reflect the actual relative activity for summer steelhead. However, it is important to note that our conclusions were drawn from a small group of fish and may not pertain to fish outside this group. Conclusions were also drawn from a small number of 24 h tracking periods and may not apply to days that fish were not tracked.

The relationship between EMG output and swimming speed is likely to be a function of the difference in contraction energy between red and white muscle. Fish use red muscle for aerobic cruse swimming and white muscle is used for anaerobic burst swimming (Cooke et al. 2004a). The different muscle fibers in fish may produce different regression relationships between EMG output and swimming speed. A linear relationship between EMG output and swimming speed has been reported in the majority (82%) of studies prior to 2004 (Cooke et al. 2004b). The remaining18% described the relationship as polynomial (Cooke et al. 2004b). A polynomial relationship between EMG output and swimming speed may be the result of the combined relationship of EMG output from both red and white muscle fibers. One study found separate relationships between EMG output and swimming speeds for red and white muscle activity in the same fish (Geist et al. 2003). EMG swim trials for Chinook salmon suggest that a transition from predominantly red muscle to white muscle use occurs at a swimming speed of 135 cm/s (Geist et al. 2003). Therefore, the relationship between EMG transmitter output is likely influenced by red and white muscle.

Implications for the Fishery Management

Our study provides insight into the behavior of summer steelhead after they have returned to their natal rivers. The fish we used were of hatchery origin and were stocked in the river to provide for a recreational fishery. These fish tended to hold in pools near the release site and the hatchery. Movement was minimal and activity levels were low. Our results suggest that individual summer steelhead hold in the Clackamas River for long periods, and are available to anglers. At least two of the four fish followed in this study were caught by anglers during the study period. Fish C was caught by an angler in December and reported to the Oregon Department of Fisheries and Wildlife, and Fish D was caught by an angler while we were actively tracking. This is the first known instance of an EMG-tagged salmonid being recorded while being caught. Previous EMG studies have recorded EMG output during angling for smallmouth bass (Cooke et al. 2004b). The activity index of the fish caught was over 8.4 times its resting activity level. An activity index of 8.4 would correlate to a swimming speed of approximately 250 cm/s if we used the polynomial relationship ($y = 0.0001x^2 + 0.002x + 1.4952$; $R^2 = 0.88$) to relate EMG output to swimming speed. However, the activity exerted by the fish could be even higher because the fish reached the EMG transmitter's maximum output reading.

This study provides valuable insight into the activity levels and behavior of fish caught in a catch and release fishery. In summary, our results suggest that summer steelhead conserve energy resources primarily by holding in pools for several months before spawning. We suggest that pool habitats should be protected in natal rivers and that recreational anglers may increase their catch by targeting locations that have cool-water pools nearby.

Acknowledgements

This study was conducted with the approval of the IACUC of Oregon State University (AUP # 3587). We thank Matt Mesa and U.S. Fish and Wildlife Service Cook, WA office for loaning us the swim tunnel. We thank a number of ODFW personnel, including persons from the Fish Division, Clackamas and Alsea Hatchery and Oregon Hatchery Research Center. We thank Summer Peterman for her assistance in the field. The Oregon Department of Fish and Wildlife and Oregon State University provided financial support for this study. We thank Mike Vandentillaart from Lotek for technical advice and assistance. We also would like to thank anglers for their participation and reporting of tagged steelhead.

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Figures

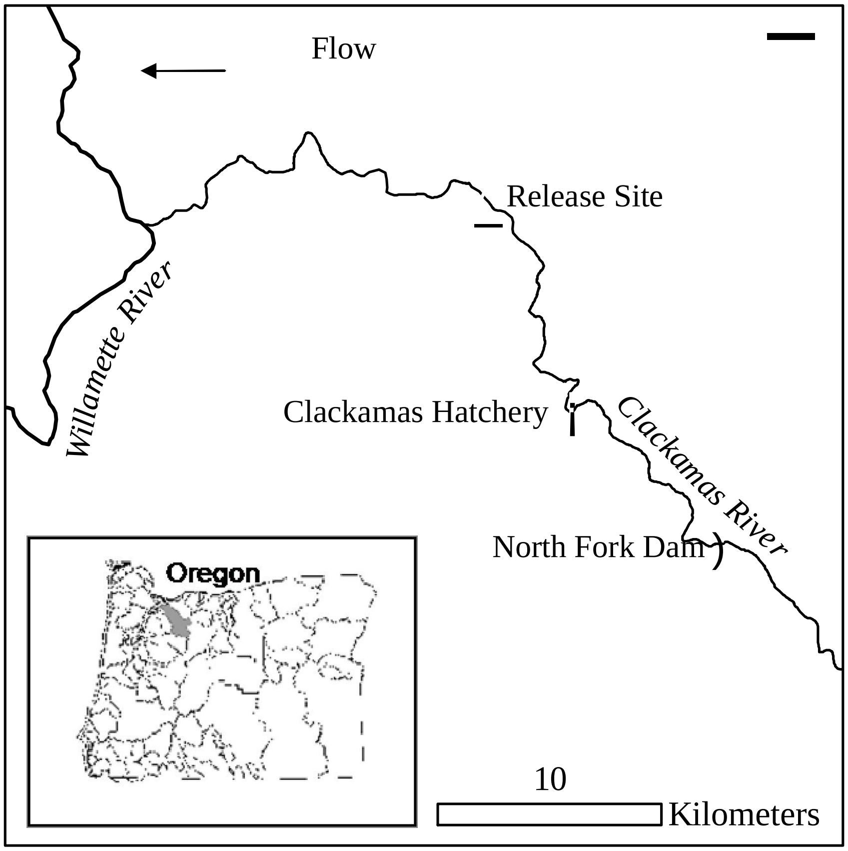

Figure 1. Study location, the Clackamas River, a tributary of the Willamette River in Oregon. The Clackamas River Basin is highlighted in gray in the state map. Fish were tagged at the Clackamas Hatchery and released downstream. Summer steelhead are not permitted to move above North Fork Dam.

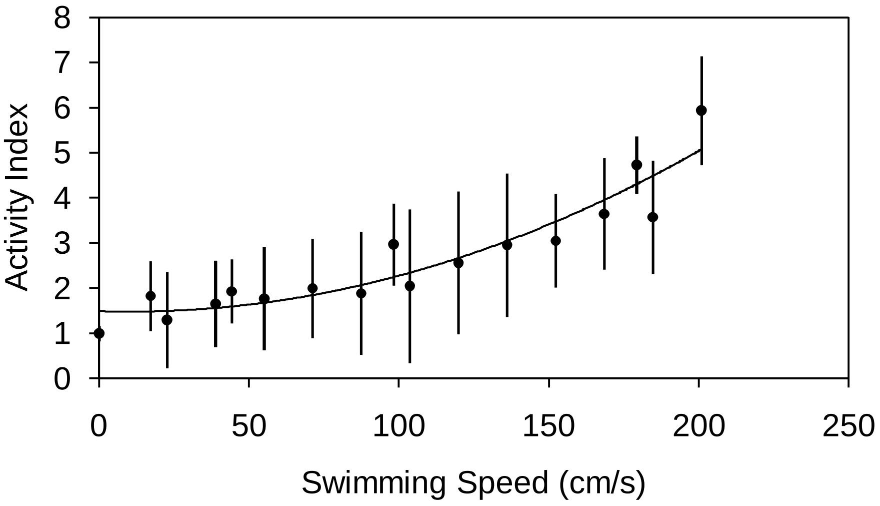

Figure 2. Calibration of swimming speed to activity index for winter steelhead run at increasing water velocities in a Blazka swim tunnel. Activity index was determined from EMG tag output divided by mean resting EMG values (5.95 ± 1.00). A value of 1 represents mean resting activity. Data are given as mean (± 1 S.D.) values from seven individual steelhead obtained at each swimming speed. The polynomial relationship is described by $y = 0.0001x^2 + 0.002x + 1.4952$; $R^2 = 0.88$.

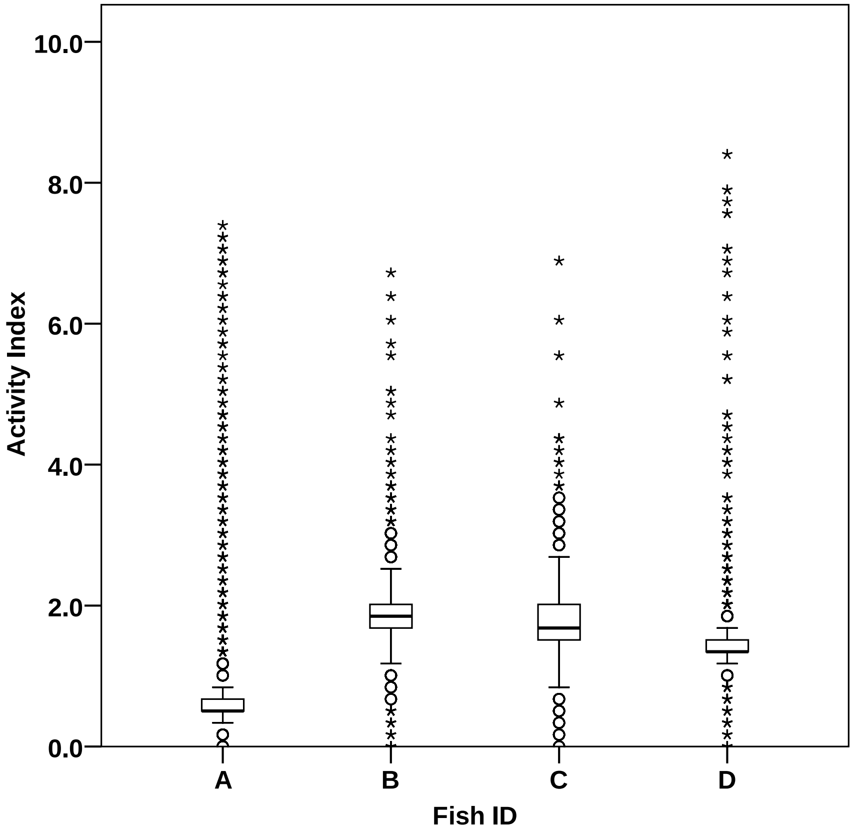

Figure 3. Activity levels for four summer steelhead in the Clackamas River. Activity levels at or below 1 represent resting activity levels. EMG values collected in the field were calibrated to activity levels using EMG swim tunnel calibrations from winter steelhead. Circles represent outliners and stars represent extreme outliners.

– Legend Page –

Figure 4. Mean hourly activity levels during 24 h tracking periods on various dates for four fish labeled A, B, C, and D. Hourly activity indexes were calculated when over 30 EMG detections were recorded per hour. Fish D was caught by an angler during the 2 September 2007 to 3 September 2007 tracking period.

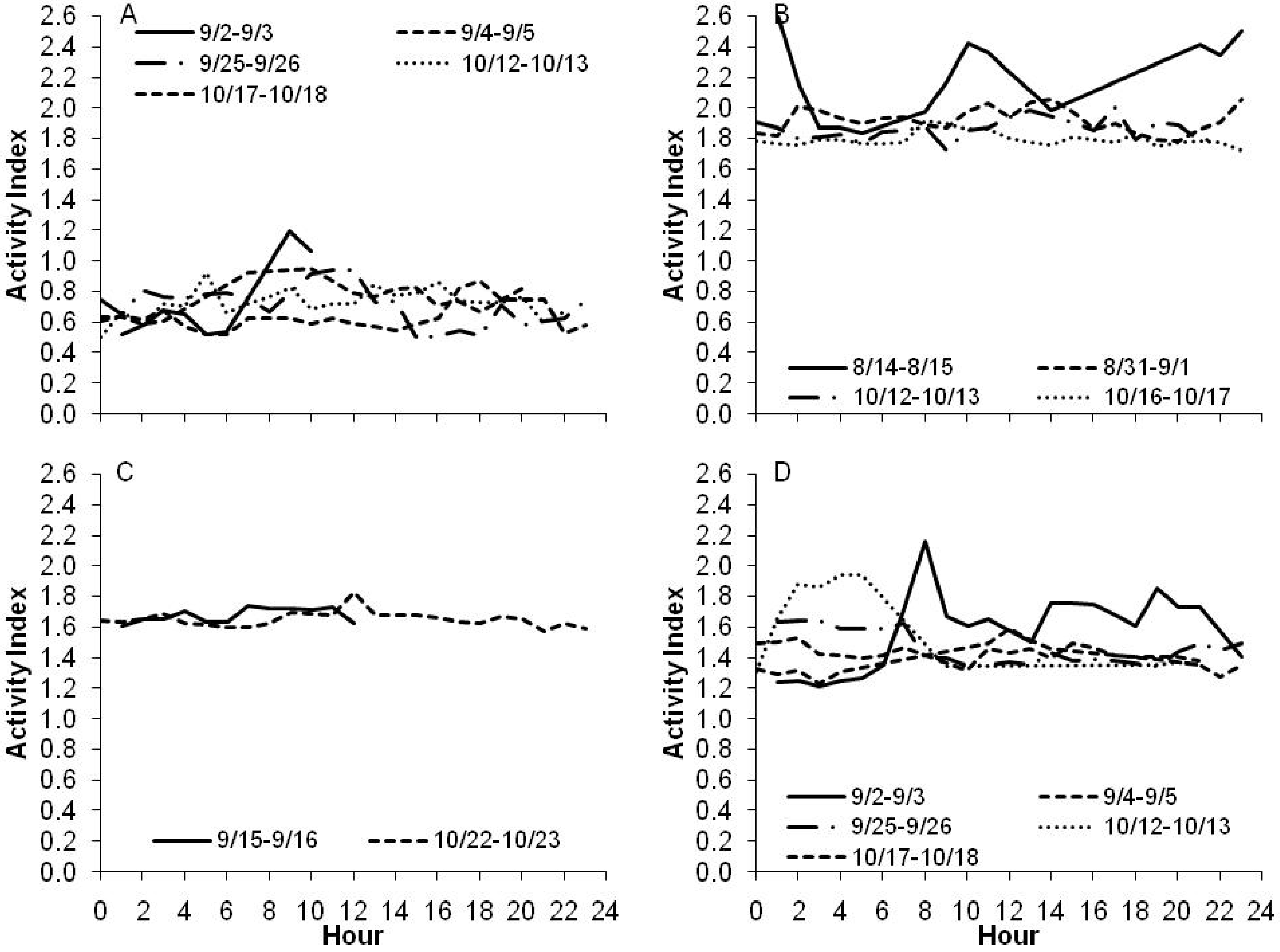

Figure 4. Mean hourly activity levels during 24 h tracking periods on various dates for four fish labeled A, B, C, and D.

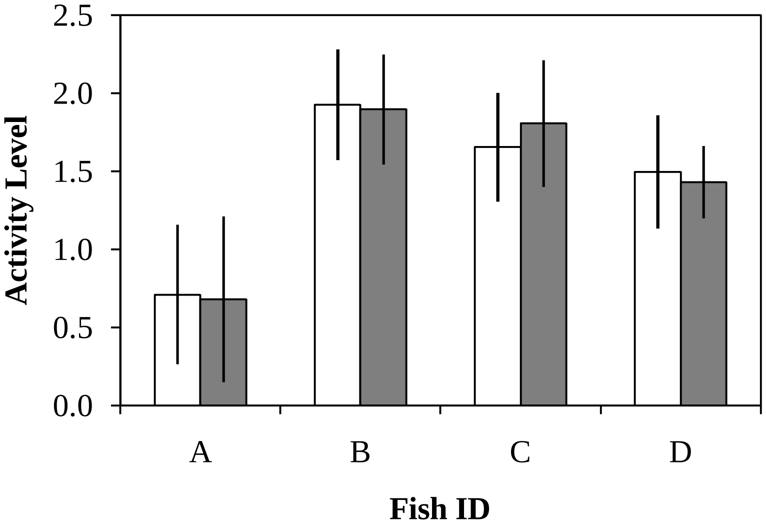

Figure 5. Mean day (clear bar) and night (grey bar) activity index for four EMG-tagged summer steelhead over multiple 24 hour tracking cycles. The duration of the day and night period was based on the time of sunrise and sunset on the day tracked. Error bars represent one standard deviation.

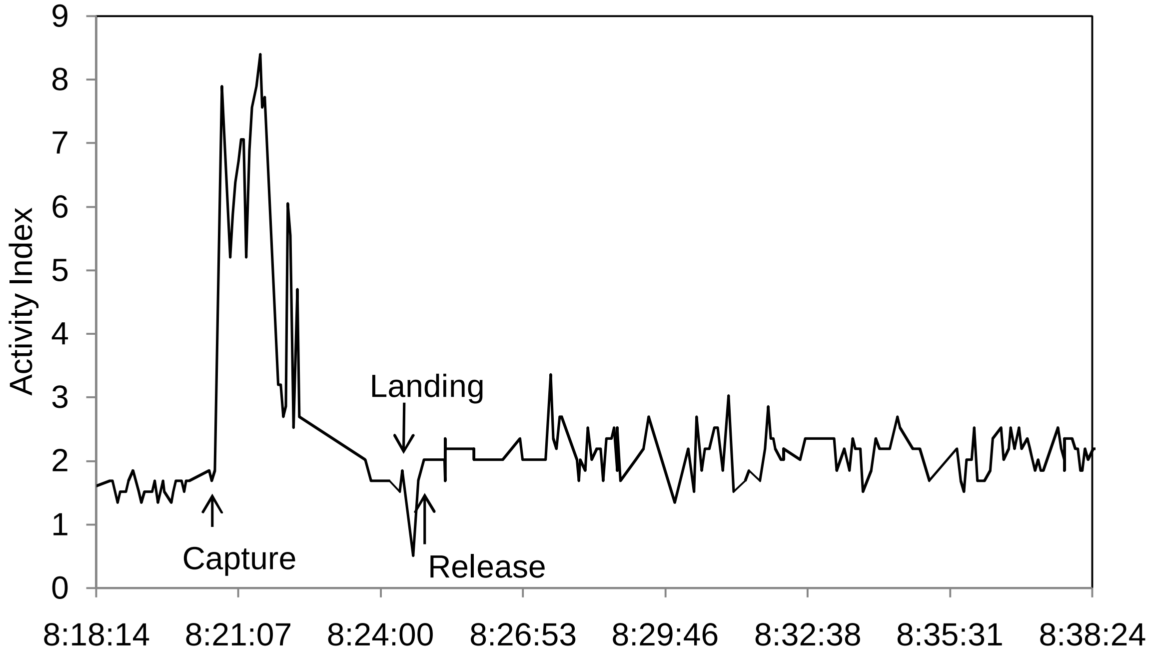

Figure 6. Activity levels for Fish D during the 9/2/07-9/3/07 tracking cycle. Fish D was caught by an angler at approximately 08:20 at the hatchery creek entrance. An activity level of 1 corresponds to resting activity levels.

Tables

Table 1. EMG-tagged winter steelhead used to calibrate EMG tags to swimming speed. Fish were allowed to recover a minimum of 48 h before trials. EMG calibrations were performed on winter steelhead in April 2008 using two separate EMG tags.

Fish No.	Tag ID	Sex	Fork Length (mm)	Tag Date	Trial Date	U-Crit (cm/sec)
1	A	F	650	April 2	April 5	180
2	B	F	660	April 2	April 7	
3	A	M	655	April 9	April 11	200
4	A	M	760	April 16	April 18	185
5	A	M	300	April 18	April 26	152
6	B	F	685	April 26	April 30	168
7	A	M	680	April 26	April 30	168

Table 2. Mean activity index levels for EMG-tagged steelhead that were not selected for 24 h tracking periods. Activity indexes were obtained from drift boat tracking, from

tracking periods less than 24 h, and during 24 h tracking of Fish A, B, C, or D (not shown). Activity Index was calculated from EMG values from the field calibrated from swim trials using winter steelhead. The activity index is calculated as the mean EMG value at velocity divided by the mean resting EMG value. An activity index of 1 represents resting activity for laboratory calibrated steelhead. Fish ID references fish distribution graphs in appendix.

Fish Number	Fish ID (Appendix)	Sex	Fork Length	# of Detections	Activity Index (mean ± std)
1	1	F	685	2212	3.78 ± 2.25
2	2	F	670	2454	4.35 ± 2.20
3	3	F	710	195	2.65 ± 1.78
4	5	F	665	1843	1.00 ± 0.31
5	7	F	690	297	2.21 ± 1.73
6	10	F	589	337	1.90 ± 0.97
7	11	F	605	10737	1.10 ± 0.25
8	12	M	710	197	4.57 ± 2.76
9	14	M	783	199	2.38 ± 1.73
10	15	M	792	18	2.42 ± 1.83
11	16	M	685	368	2.41 ± 1.91
12	17	M	688	205	0.78 ± 0.92
13	18	M	638	682	2.07 ± 1.65

Table 3. Data for four EMG-tagged fish tracked over 24 hour cycles from August through October 2007. Activity Index was calculated from EMG values from the field calibrated from swim trials using winter steelhead. Steelhead were only detected in pools and riffles during 24 h tracking. Fish ID references fish distribution graphs in appendix.

Fish ID	Fish ID (Appendix)	Sex	Fork Length (mm)	24 h Tracking Start Date	Number of EMG Detections	Activity Index (mean ± stdev)	Distance Traveled (m)	Habitat (% of observations)	
								Pool	Riffle
A	4	F	660	September 2	622	0.82 ± 0.49	0	100	
				September 4	5777	0.69 ± 0.25	245	100	
				September 25	13744	0.71 ± 0.35	0		100
				October 12	5744	0.74 ± 0.53	103	25	75
				October 17	7329	0.61 ± 0.50	160	100	
B	6	F	620	August 14	3670	2.20 ± 0.68	165	92	8
				August 31	29506	1.93 ± 0.33	85	42	58
				October 12	2872	1.86 ± 0.26	98	21	79
				October 17	3936	1.80 ± 0.23	230	100	
C	13	M	625	September 15	9435	1.67 ± 0.23	105	20	80
				October 22	9053	1.85 ± 0.41	0		
D	8	F	687	September 2	5402	1.67 ± 0.46	348	70	30
				September 4	7334	1.43 ± 0.20	154	100	
				September 25	11026	1.41 ± 0.23	34	100	
				October 12	764	1.45 ± 0.40	315	90	10
				October 17	1694	1.37 ± 0.23	131	100	

Table 4. ANOVA comparing daily activity indexes between 24 h tracking periods calculated from EMG telemetry for four individual fish.

Fish ID	d.f.	MS	F-Value	P-Value
A	4	18.70	104.28	0.01
B	3	130.02	1104.76	0.01
C	1	162.82	971.80	0.01
D	4	72.37	854.26	0.01

Table 5. ANOVA and steelhead activity levels in pools, riffles, and during periods of movement. Fish C was not included in analysis due to a lack of tracking periods and habitat observations taken during 24 h tracking. The EMG records were obtained from daily tacking periods, as well as 24 h tracking periods.

	Activity Index (mean ± stdev)							
Fish ID	Pool	Riffle	Movement	N	d.f.	MS	F-Value	P-Value
A	0.66 ± 0.45	0.71 ± 0.41		36205	1	23.85	126.45	0.01
B	1.88 ± 0.56	2.22 ± 1.17	1.92 ± 0.32	47017	2	466.44	883.95	0.01
D	1.45 ± 0.25	1.73 ± 0.23	2.16 ± 1.30	26092	2	135.41	1531.02	0.01

CHAPTER 3: USING RADIO TELEMETRY TO MONITOR A RECYCLING PROGRAM FOR STEELHEAD *ONCORHYNCHUS MYKISS*.

Eva Schemmel, Shaun Clements, David Noakes, and Carl Schreck

Abstract

Many salmonid hatcheries in the Pacific Northwest recycle adult fish. This involves the transport and release of adult salmon or steelhead (*Oncorhynchus* spp.) back downstream following their collection at the hatchery. The goal is to increase angler opportunity by providing additional opportunities for harvest. However, the effects of such programs have seldom been evaluated. We implanted radio-tags in adult hatchery origin steelhead captured at a hatchery and released downstream to estimate the number of recycled radio-tagged steelhead that were caught in the recreational fishery and their return to the hatchery. Behavior and location of the tagged fish over a period of 5 months after release were also monitored. The majority of the fish remained in the river near the release site or immediately downriver of the hatchery. Only 10% of the recycled fish were caught again in the trap at the hatchery. We estimated that angler harvest accounted 13 - 41% of the radio-tagged fish.

Introduction

Hatcheries were established in the Pacific Northwest to mitigate for the decline of salmon and steelhead trout (*Oncorhynchus* spp.) populations (Hilborn 1992). Traditionally, the majority of hatcheries focused on increasing harvest opportunities and supplementing wild populations. To increase harvest opportunities, many hatcheries “recycle” adult salmonids. Recycled fish are sometimes termed “re-runs”. Recycling involves the downstream transport and release of adult hatchery fish that have returned to a hatchery or sorting facility. The goal of a recycling program is to provide anglers with additional opportunities to catch returning salmonids that were not captured during their original migration back to the hatchery (Lindsay et al. 2001). The success of such programs is often measured in terms of increased angler harvest. However, other factors, such as the incidence of straying, are becoming increasingly important. Despite this, there have been few efforts to evaluate the success of most recycling programs on the behavior of adult salmonids.

Evenson and Cramer (1984) reported that only 9.5% of recycled Chinook, *O. tshawytscha*, were caught by anglers. During the 3 yr study, the return rate of recycled fish to the hatchery was 27 - 62% (Evenson and Cramer 1984). The study also estimated that 4% of the recycled fish strayed into other rivers (Evenson and Cramer 1984). Conversely, Dyson and Apperson (2005) found higher catch rates (35%) of recycled summer Chinook in a recreational fishery and only 1% returned to the hatchery. We used radio-telemetry to evaluate the behavior and angling-related mortality of adult steelhead that were part of a hatchery recycling program.

Methods

Study Site

We conducted the study on the Clackamas River, a tributary of the lower Willamette River, Oregon, USA (Figure 7). The Clackamas River hatchery recycling program began in 1998 when hatchery summer steelhead were no longer passed above a barrier dam, North Fork Dam, to protect native winter steelhead spawning grounds. We monitored the behavior of radio-tagged adult steelhead in a 45 river kilometer (rkm) reach of the Clackamas River downstream of North Fork Dam.

Fish Collection

We obtained 39 summer steelhead adults (2.9 ± 0.1 kg) from the Oregon Department of Fish and Wildlife (ODFW) Clackamas Hatchery 36 rkm upstream of the mouth of the Clackamas River (Figure 1). The fish were collected between 22 July 2007 and 1 August 2007 and held in a raceway for tagging with a temperature range of 16 - 19°C.

All fish were internally tagged with one of two coded radio-transmitters (Lotek NTC-6-2: dimensions 9.1 x 30.1 mm, 4.5 g in air or Lotek CEMG2-R16-25: dimensions 16 x 45 mm, 11.9 g in air). We anesthetized each fish individually for 8 min in a darkened container containing a buffered solution of 0.05% tricaine methanesulfonate (MS 222, Argent Chemical Laboratories, Redmond, WA). Each fish was also given an intramuscular injection of florphenicol (10 mg/kg) and oxytetracycline (11 mg/kg) following surgery, to minimize the possibility of infection.

Following surgery we held the fish in a flow-through raceway at the hatchery for 24 h to monitor their condition before release. The fish were then transported in aerated river water to the Barton Recreational Park, 21 river kilometers (rkm) upstream from the confluence with the Willamette River (Figure 7), and released into the Clackamas River following ODFW protocols for recycling. Tagged steelhead were released during the morning, with four releases occurring between July 23, 2007 and August 2, 2007.

Tracking and Analysis

We used a combination of fixed monitoring stations and mobile tracking to record the location of radio-tagged, recycled steelhead. The fixed monitoring stations were located at seven sites throughout the study reach (Figure 7). Mobile tracking included river rafting and foot surveys. In general, we surveyed the entire study reach every 3 d during the summer (August) and fall (November). The location of each radio-tagged steelhead was recorded using GPS and imported into ArcGIS (ESRI, 2007) for analysis.

We used the radio-telemetry data to determine when fish had returned to the hatchery, the incidence of straying, and estimate the unreported catch rate. The time of return to the hatchery was based on the first detection at the confluence of the Clackamas River and Dog Creek (a tributary connecting the hatchery to the Clackamas River), hereafter termed the “hatchery entrance”. Thus, it does not represent recapture in the hatchery trap. Fish that were re-caught in the Clackamas Hatchery trap were recorded and subsequently recycled back downstream by ODFW personnel to the original release location. The Clackamas Hatchery trap was closed between 29 September 2007 and 01 March 2008. The number of fish that re-entered the trap is therefore based on the current operating procedure and may have been higher had the trap been open continuously. The incidence of straying was estimated as the percent of the radio-tagged steelhead that did not return to the hatchery trap and were not caught in the recreational fishery.

To estimate angler catch we used a combination of voluntary reporting and inference based on the loss of signals from radio-tagged fish. We used a variety of methods to encourage voluntary angler reporting. Each fish was externally tagged with an individually numbered tag that provided contact details to report the catch. The study was also widely publicized among local angling groups and was featured on television, in press releases, and on the ODFW website. We also posted information on the study at major fishing areas along the lower river. Catch reports were collected at the ODFW Clackamas office and at the ODFW Clackamas Hatchery. The catch reports included information on catch location, time, gear used, and fish condition.

Despite our efforts, the volunteer reporting rate was probably low, although we have no way to estimate the true rate. During the study, we received several anecdotal reports from anglers who witnessed other anglers catching and keeping radio-tagged fish. Oregon State law prohibits the retention of a radio-tagged fish so it is possible that some anglers chose not to report their catch. We estimated the number of recycled steelhead that were caught but not reported based on the disappearance of radio-tagged fish. Disappearances were estimated by the non-detection of fish that had previously been recorded several times within the study reach, and had neither migrated outside the study reach nor been recovered. The time of disappearance was based on the last known record from the fixed monitoring stations or the manual surveys. The known and estimated catch values are reported separately by month. The estimated catch represents the maximum catch of recycled radio-tagged steelhead.

Results

Behavior

Only four (2 males, 2 females) of the radio-tagged steelhead (10.2%) not caught by anglers were recaptured in the trap at the hatchery. These fish were caught in September 2007 and March 2008. The first fish re-entered the trap on 9 September, 36 d after release. Three of the four fish were recycled for a second time; however, the last returning steelhead re-entered the trap in March and so it was not recycled. All three of the fish that were recycled for a second time returned to the hatchery trap for a third time.

The majority of fish moved upriver following release but tended to reside in the river at the hatchery entrance. In total, from July to March, we estimated that 85.7% (n = 18) of females and 69.2% (n = 9) of males not reported as caught in the recreational fishery returned to the hatchery entrance after being recycled downstream. These estimates include the fish that returned to the hatchery trap. A large percentage of the recycled steelhead moved upriver to the hatchery entrance during August, one month after release (females: 66.7%, n = 14; males: 23.1%, n = 3) (Figure 8). However, most of the fish took between 2-4 months to cover the 15 rkm between the release site and the hatchery entrance (Figure 8).

We did not observe any of the radio-tagged fish entering into the tributaries of the Clackamas River during the period in which we were actively tracking the fish (July-Dec). However, in December, a tagged steelhead female was caught by an angler in one of the major tributaries to the Clackamas River, Eagle Creek. None of the radio-tagged fish passed the lower-most receiver placed at the confluence of the Willamette and Clackamas River.

Angler success

Anglers reported catching 12.8% (n = 5) of the radio-tagged steelhead. Radio-tagged fish were caught throughout the study period, but harvest peaked in September and December. Most of the reported landings occurred at the release location and the entrance to the Clackamas Hatchery. This matches the general distribution of fish that we observed during the radio-tracking.

The estimated catch of recycled steelhead was higher than the reported catch. We estimated that 41% of radio-tagged recycled steelhead were caught in the fishery prior to the end of the active tracking period (December) (Figure 9). In addition, two (5%) of the radio-tagged fish were recovered dead from the river during the study period, although they did not appear to have died from hooking or tagging related injuries. In another instance, we recovered a radio-tag in shallow water at a popular fishing location near the hatchery creek entrance, possibly discarded by an angler after capture of the fish.

The incidence of fish straying may increase after recycling fish downstream. The incidence of straying is 44 - 67% after accounting for non-angler fish mortality, angler catch, and return to the hatchery trap. The conservative estimate of 67% only accounts for fish that were reported caught by anglers. The incidence of straying of 44% is the estimate if angler catch is as high as 41%.

Discussion

Our results show that recycled hatchery fish are caught in a recreational fishery. A minimum of 12.8% of recycled steelhead were caught during the study, based on our surveys of recreational anglers. However, a significant number (28%) of radio-tagged fish could not be accounted for at some time during the study period. Given that detection efficiency at the lower most fixed monitoring station was close to 100%, the disappearance of tagged fish must be explained by tag failure, natural predation, or fishing mortality. There are relatively few natural predators within the study area, and the range of the radio transmitter would have allowed for detection of fish within 100 m of the river. Because of the intensive fishing effort on the river over a period of several months and the high number of radio-tagged fish that could not be accounted for, we speculate that many of these non-detections are the result of unreported angler harvest of radio-tagged steelhead. Under this assumption, our estimate of harvest is considerably higher (~41%). However, estimates of fishing related mortality based on the non-detection of fish carry some uncertainty and represent the maximum level of harvest.

While recycling programs increase the number of fish available to anglers, they may also increase the incidence of straying. Our results suggest that most fish tended to move towards the hatchery after being recycled. However, very few fish (~10%) were actually recaptured in the hatchery trap. The majority tended to reside near the entrance to the hatchery, and may thus be considered “strays”. The return rates of recycled fish to the hatchery entrance were above 69% and were higher for females than for males. We had one incidence of a recycled steelhead straying into a tributary closer to the time of spawning (captured in December). However, none of our radio-tagged fish passed the receiver at the mouth of the Clackamas River. We were not able to evaluate whether the other fish that were not recaptured in the hatchery trap also strayed into spawning areas because the transmitters were not functional during the spawning period (Feb-Mar). Recycled fish that do not re-enter the hatchery trap may pose a conservation threat to wild fish.

In general, it appears that the majority of the recycled fish are unaccounted for after downstream release (Lindsay et al. 2001). In addition, there are concerns regarding increased straying of hatchery fish after they have been transported downstream. There is evidence that homing fidelity is decreased in fish that are recycled several times (Lindsay et al. 2001). Such a decrease may lead to an increase in competition, interbreeding, and density dependent interactions with wild salmonids (Kostow et al. 2003; Hayes et al. 2004; Kostow and Zhou 2006; Araki et al. 2007).

The benefit of recycling programs will likely depend upon the river system, fish stock, and program management. Our results suggest that the recycling program for adult summer steelhead on the Clackamas River does result in an increased number of fish available for the recreational fishery. However, the large number of recycled fish that were not caught by anglers and did not re-enter the hatchery might raise concerns for the impact on wild stocks within the Clackamas and nearby river basins. We speculate that it may be possible to reduce the incidence of straying in this program by managing the operation of the hatchery trap to ensure that a greater proportion of fish are caught. In general, recycling programs that operate in areas where wild stocks are threatened should be closely monitored for straying. If managed properly, it appears that recycling programs can increase angler success.

Acknowledgements

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Figures

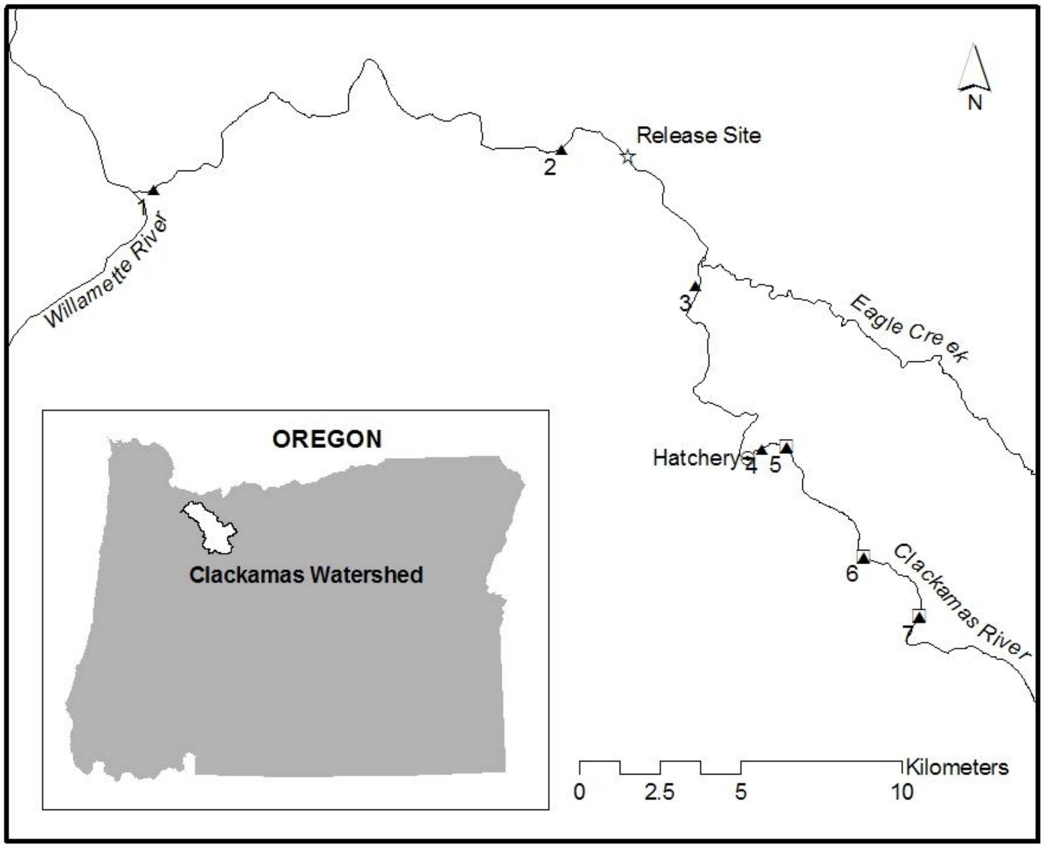

Figure 7. Locations of the fixed monitoring stations (1-7). Station 1 is at the confluence of the Clackamas and Willamette Rivers. Stations 5-7 were located on dams; River Mill Dam, Diversion Dam, and Faraday Dam, respectively. Tagged steelhead were released at Barton Park (Release Site).

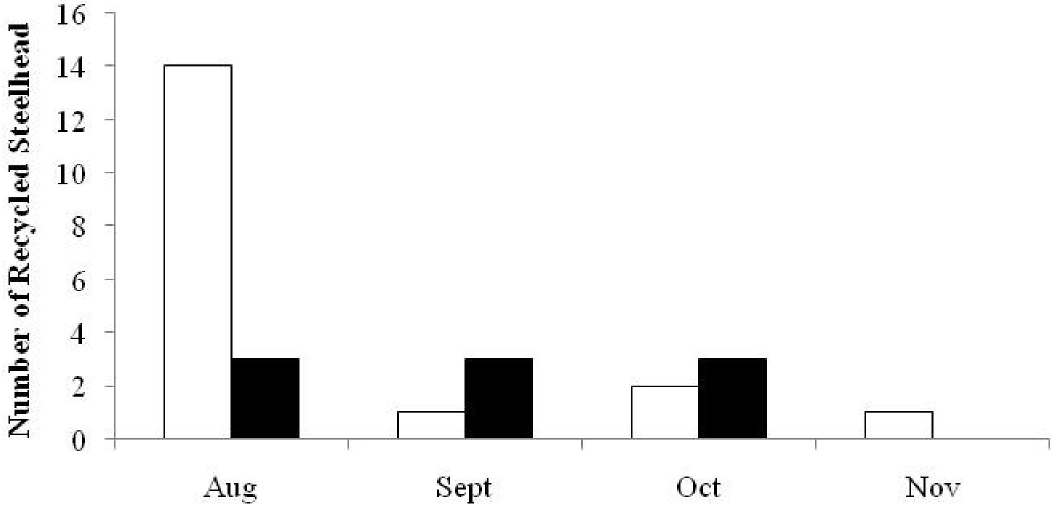

Figure 8. Monthly return of female and male radio-tagged adult summer steelhead to the entrance of the Clackamas Fish Hatchery. Returns were based on the first date of detection at the mouth of Dog Creek (the tributary that connects Clackamas hatchery to the Clackamas River). We released 15 males (black bars) and 24 females (white bars). Steelhead caught in the fishery were removed from the analysis.

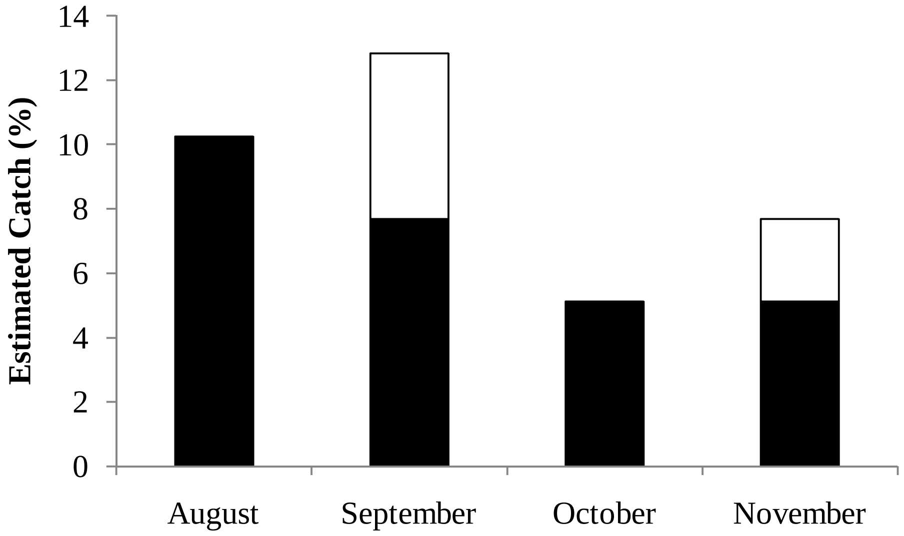

Figure 9. Estimated angler catch of radio-tagged recycled summer steelhead between August and November 2007 in a recreational fishery in the Clackamas River. The height of the bar represents our estimate of angler catch based on reports from anglers (clear portion) and those fish that could not be accounted for during surveys of radio-tagged fish in the study area (black portion). An additional 5.7% (n = 2) of recycled steelhead were reported caught by anglers in December (data not shown).

CHAPTER 4: EFFECT OF GONADECTOMY ON THE BEHAVIOR OF HATCHERY SUMMER STEELHEAD (*ONCORHYNCHUS MYKISS*): IMPLICATIONS FOR HATCHERY AND WILD INTERACTIONS.

Eva Schemmel, David Noakes, Carl Schreck, Christian Torgersen, and Shaun Clements

Abstract

The Oregon Department of Fisheries and Wildlife has considered inhibiting reproduction of hatchery salmonids as a management strategy for reducing hatchery and wild salmonid interactions while expanding recreational fishing opportunities. This study assessed the behavior of reproductively inhibited fish. We studied the behavior of gonadectomized (castrated) hatchery summer steelhead in the Clackamas River. Our hypothesis was that steelhead that have undergone gonadectomy would have altered residence times and migration patterns in the river compared to sham-operated fish. We described the behavior of sterilized adult hatchery steelhead, measured their residence times in the river, and determined if sterilized steelhead would be available to anglers. We tagged and released 40 sterilized fish and 39 sham-operated fish and followed them by radio-tracking from July through December. Most fish movements were in the upstream direction for both sterilized and sham-operated steelhead. None of the tagged steelhead left the Clackamas River System during the study period. Gonadectomized steelhead river positions were downstream of sham-operated steelhead and gonadectomized fish had lower hatchery return rates. Castrated fish remained in the river, mostly downstream of the hatchery and were caught by anglers at about the same rate as sham-operated fish. We conclude that inhibiting reproduction may be a useful method for managing freshwater hatchery fisheries in the presence of wild native fishes.

Introduction

Hatchery reared salmonids are widely stocked throughout the world to supplement wild populations and provide for harvest opportunities (Hilborn 1992; Kozfkay et al. 2006). Given the declines in wild populations and the increasing awareness about the effects of genetic mixing (Flagg et al. 2000; Chilcote 2003), many programs now use sterile hatchery fish to minimize the risks associated with hatchery programs (Iwamoto and Sower 1983; Donaldson 1986; Dillon et al. 2000; Lindsay et al. 2000; Kozfkay et al. 2006).

The stocking of sterile salmonids has proved to be a successful management tool for supporting recreational fishing in lakes and in systems with resident fish species, such as trout, in rivers and streams (Johnston et al. 1993; Dillon et al. 2000). Introducing sterilized salmonids can be beneficial for recreational fisheries by increasing the number, size, residence time, and flesh quality of the fish. Sterilizing salmonids can block reproductive migrations and related mortality, thus increasing the number of fish in older age classes, and consequently led to a population composed of larger fish (Johnston et al. 1993; Kozfkay et al. 2006). Residence time is also increased because sterilized fish have reduced mortality and emigration rates because they do not spawn (Kozfkay et al. 2006). Sterilization is also known to increased the quality and size of the fish (Dillon et al. 2000; Kozfkay et al. 2006). However, stocking sterilized fish in lakes does not always prove to be a successful management procedure. For example, sterilized trout have poor survival when stocked into high elevation lakes due to strong competition with native stocks (Kozfkay et al. 2006).

Attempts to stock sterile anadromous salmonids have been relatively unsuccessful (Lindsay et al. 2000). In most instances, the sterilization of anadromous species during the juvenile stages results in low and inconsistent returns to freshwater (Lindsay et al. 2000; Wilkins et al. 2001). For example, sterilization during the juvenile stage lowered the adult returns of steelhead trout, *Oncorhynchus mykiss*, by 70-80% (Lindsay et al.

2000; Lindsay et al. 2001). In addition, the majority of returning fish were male, displayed secondary sexual characteristics, and viable sperm (Lindsay et al. 2001). Similarly, Wilkins et al. (2001) reported a 75% reduction in the harvest of triploid Atlantic salmon, *Salmo salar*, relative to controls. Given the low returns of salmonids sterilized as juveniles, the sterilization of anadromous adult salmonids following their return from the ocean may be the only viable option for stocking sterile fish in river systems. To evaluate the potential of this technique, it is important to understand the effects of sterilization on fish physiology and behavior.

Currently, salmonids are sterilized by a variety of treatments that are administered during the embryo or juvenile stage. These include sex steroid hormone (androgen) treatments, chromosome manipulations, and hybridization (inter-species breeding) (Feist et al. 1996). Currently the only established method for sterilizing adult salmonids is surgical gonadectomy to remove the reproductive tissues (Utter et al. 1983). Sterilization causes changes in physiology and behavior of fishes. The physiological consequences in sterilization include increased growth (Utter et al. 1983; Basant et al. 2005), delayed maturation (Benfey and Arnold 1984), extended survival (Utter et al. 1983; Basant et al. 2005), and altered sex hormone levels (Schreck et al. 1972; Borg 1998; Delvin and Nagahama 2002). Increased somatic growth is likely caused by the diversion of energy from gamete production to somatic tissues (Utter et al. 1983). Sterilization prevents or delays maturation and thus reduces the mortality associated with reproduction (Benfey and Arnold 1984).

Sterilization also has a number of effects on the behavior of fish. For example, Basant et al. 2005 reported that sterile fish were less responsive to environmental stimuli and were less aggressive. Similarly, triploid females do not exhibit courtship behavior or spawning activity, whereas triploid males may develop secondary characteristics and exhibit spawning behaviors (Kozfkay et al. 2006). The concern regarding stocking sterile salmonids is that sterilized fish will have different migratory behaviors and may still retain spawning behaviors resulting in infertile mating with native fish and increase competition at spawning grounds (Johnson et al. 1986).

Given the low returns of salmonids that are sterilized during the juvenile stage, fisheries managers have recently questioned the feasibility of inhibiting the reproduction of returning adult salmonids. The reasoning for targeting adult salmonids is to increase returns to freshwater rivers and streams to provide for a recreational fishery. However, little is known about the behavior of salmonids that are sterilized during the adult life history phase. Salmonid migrations are at least partially regulated by sex hormones (Estay et al. 1998; Munakata et al. 2001; Leonard et al. 2002). Migration from ocean feeding grounds to freshwater spawning grounds correlates with increases in sex hormone levels (Maule et al. 1996; Leonard et al. 2002; Cooke et al. 2006). Testosterone, estradiol, and 11-ketotestosterone appear to be the main sex hormones regulating both upstream and downstream salmon migrations (Estay et al. 1998; Munakata et al. 2001). Returning salmon have elevated levels of testosterone, estradiol-17β, 11-ketotestosterone, 17α-hydroxyprogesterone, and 17α, 20β-dihdroxy-4-pregnen-3-one (DHP) (Estay et al. 1998; Munakata et al. 2001). Sex hormones and steroids in anadromous salmonids generally peak during the pre-spawning months close to the time of spawning and then decrease at spawning (Frantzen et al. 1997; Leonard et al. 2002; Cooke et al. 2006).

Given the influence of sex hormones on migration, a change in sex hormones induced by sterilization treatments may cause changes in salmonid migratory behavior. If behavior is modified, recreational fisheries may decline and native salmonids may be negatively affected. However, if successful, producing sterile adult fish could greatly benefit recreational fisheries and minimize genetic mixing of hatchery and wild stocks. For sterilization of returning salmonids to be useful in hatchery fishery management, fish must have little or no negative impact on wild populations. The fish must also have an extended residence time in the river, and be available to anglers.

Our objective was to evaluate the effect of gonadectomy on migratory behavior of hatchery adult steelhead. Specifically, we measured the effect of gonadectomy on freshwater residence time, migratory behavior, reproductive physiology, and contribution to the fishery. We used radio-telemetry to monitor the behavior of gonadectomized steelhead in a recreational fishery.

Materials and Methods

River System

The Clackamas River is a tributary of the lower Willamette River, Oregon. The Clackamas River Basin contains both hatchery and wild populations of salmon and trout and is a popular fishing destination. The Clackamas River contains a wild population of winter steelhead listed as threatened under the Endangered Species Act (1998). Oregon Department of Fish and Wildlife (ODFW) introduced Skamania stock hatchery summer steelhead into the Clackamas River in the 1970s (Kostow et al 2003). Today, the ODFW Clackamas Hatchery acclimates 175,000 summer steelhead smolts for release into the Clackamas River in April (ODFW, 2007).

There are four dams on the main stem of the river: River Mill Dam (river kilometer (rkm) 37), Faraday Dam (rkm 42), Diversion Dam (rkm 45), and North Fork Dam (rkm 47). North Fork Dam is a barrier to fish passage. The practice of passing hatchery summer steelhead above the North Fork Dam began in 1975 to provide for a recreational fishery in the upper river (Kostow et al 2003). ODFW began adipose fin-clipping hatchery summer steelhead at the Clackamas Hatchery beginning with the 1997 brood year. In the early 2000s, hatchery summer steelhead were no longer passed above the North Fork Dam due to concerns regarding the native winter steelhead population. To mitigate for the loss of this fishery, the returning summer hatchery stock adults were instead recycled downstream to provide additional fishing opportunities. We chose this system because it is a popular fishing area which would benefit from the reintroduction of hatchery fish into the upper river.

Experimental Treatments

We obtained 79 summer steelhead adults (mean mass ± SE = 2.9 kg ± 0.1 kg) from the Oregon Department of Fish and Wildlife (ODFW) Clackamas Hatchery, 35 km upstream of the mouth of the Clackamas River. The fish were collected as they entered the fish trap, and transferred to a holding raceway (16 - 19°C) for tagging and surgery. The study was conducted between July 2007 and March 2008. The steelhead were tagged and released in July, and actively tracked until January 2008.

The fish were randomly divided into two treatments; gonadectomized (gonad removal, n = 40) and sham-operated (gonad intact, n = 39). To evaluate the behavior of fish following release all fish were implanted with a radio transmitter. We used two types of radio transmitters; Lotek NTC-6 coded nano tags (4.5 g in air) and electromyogram

(EMG) tags (11.9 g in air). All gonadectomized fish (40) and 20 sham-operated fish were implanted with NTC-6 nano tags. The EMG transmitters were implanted into 19 of the sham-operated fish to provide additional information on activity levels. The EMG transmitters measure the voltage potential of the muscle, which then can be calibrated to swimming speed (see Chapter 2). Transmitter battery life for both tags was estimated to be six months.

Surgical Procedure

We anesthetized each fish individually for 8 min in a darkened container containing a buffered solution of 0.05% tricaine methanesulfonate (MS 222, Argent Chemical Laboratories, Redmond, WA). The fish was placed ventral side up on a surgical table. The gills were continuously perfused with a diluted solution (50%) of MS 222 through a perforated tube placed in the buccal cavity (see Okland et al. 1997 for tagging protocol; details of tagging procedure are also outlined in Chapter 2). A 6 - 8 cm ventral incision was made between the pectoral and pelvic fins. Sex was determined from visual observation of the gonads when they were excised. A radio transmitter was then inserted into the body cavity and the incision was closed using absorbable monofilament in a simple interrupted suture pattern. Each fish was given an intramuscular injection of florphenicol (Nuflor, Germany; 10 mg/kg) and oxytetracycline (Aspen Veterinary Resources, Kansas City, MO; 11 mg/kg), to minimize the disease risk. We also marked the fish externally with individually numbered Floy tags to identify them for recognition by anglers.

Following surgery the fish were held in the raceway for 24 h to monitor condition before release. All fish survived and appeared to be swimming normally before release.

The fish were then transported in aerated river water to the Barton Recreational Park, 21 rkm upstream from the confluence with the Willamette River, where they were released. The releases took place during the morning on five occasions between 23 July 2007 and 3 August 2007.

Telemetry Equipment

We monitored the post-release behavior of the tagged fish using a combination of fixed and mobile tracking. We used seven fixed monitoring stations to monitor movement throughout the study area. Each station consisted of a Lotek SRX receiver and two yagi antennas (4 element). One antenna monitored the area upstream of the site and the other monitored the area downstream. The receivers recorded the signal strength, time, tag code, and the antenna number for each detection when fish were in range of the antennas. During analysis it was possible to determine the direction of movement by analyzing the signal strength and time of detection on the up- and downstream antennas. A fixed monitoring station was placed at the Clackamas River mouth to record the passage of fish leaving the system (rkm 0.5). Three of the seven fixed stations (5, 6, and 7) were located on dams. The fixed stations were operational from August 2007 to January 2008.

We used two receivers (Lotek SRX 600 and Lotek SRX 400, Lotek, Newmarket, Ontario, Canada) and two four-element yagi antenna (150 Mhz, Cushcraft, Manchester, New Hampshire, USA) to actively track EMG-tagged steelhead. Active tracking included drift boat tracking, tracking on foot, and tracking individual fish for 24 h periods. Fish were randomly selected for 24 h tracking. We used mobile tracking by rafting the lower Clackamas River at regular intervals, approximately every 3 days in summer (August and September) and fall (November). The receivers recorded the signal strength, time, tag code, GPS location, and EMG code values (0 - 50). GPS positions were recorded using an integrated GPS antenna with the receiver. The receiver recorded GPS positions when there were at least four satellites in range.

Data Analysis

We used ArcGIS (ESRI, 2007) software for our analyses of fish movement and distribution. The Clackamas River Route was generated by modifying the Clackamas River Layer obtained from the Oregon Geospatial Enterprise Office (Source: EPA, Scale: 1:250,000) to match Clackamas River 2006 aerial photographs taken in August 2006 (pixel resolution: 1.0 m). GPS fish locations were plotted in ArcGIS along the Clackamas River route to obtain fish positions in river kilometer units. Linear referencing was used to locate the GPS fish positions along the Clackamas River route with a search radius of 200 m from the GPS points to the route. Most of the steelhead GPS positions were located along the route, with 99% of all detections within less than 100 m of the route.

Steelhead movement and habitats occupied during 24 h tracking periods were determined from careful observations and GPS positions. Steelhead positions were mapped in ArcGIS on the geo-referenced aerial photographs of the Clackamas River. Steelhead movement was calculated as the difference between upstream and downstream positions, termed travel distance. Travel distances were measured in ArcGIS. Habitat observations taken during 24 h tracking periods were classified as pool, riffle, or run (Hawkins et al. 1993). The percent of time that the fish occupied a particular habitat was estimated from observations collected during 24 h tracking periods.

Movement rates were estimated from the difference in fish positions in river kilometers divided by the time between detections. Mobile tracking detections were used to estimate movement rates. Median movement rates were calculated for each treatment from movement rates over the entire study period (August 2007 to January 2008). Mann-Whitney non-parametric tests were used to compare movement rates between gonadectomized and sham-operated females and gonadectomized and sham-operated males. Results were considered significant at $P < 0.05$.

Steelhead distributions were calculated using fixed receivers and mobile tracking. River positions were averaged for each individual over the study period. Sexes were analyzed separately using median non-parametric tests to determine if river positions of gonadectomized fish differed from sham-operated fish. Differences in river positions of gonadectomized and sham-operated radio-tagged steelhead were also analyzed by comparing the daily mean treatment river positions from drift boat tracking. Only drift boat tracking positions were used to reduce bias in fish positions due to the fact that not all of the radio-tagged fish are in range of fixed stations. Mean treatment positions were only on days where a minimum of half of the fish in each treatment were located. Linear regression was performed to determine if there was a relationship between mean river positions and time for each treatment (sham-operated females, gonadectomized females, sham-operated males, and gonadectomized males). Distributions were also compared by determining the range of each treatment. This was accomplished by dividing the Clackamas River into four reaches designated by fixed stations ((1) Downstream of Release, (2) Release, (3) Hatchery, and (4) Upstream of Hatchery). The percent of each treatment that was detected in each reach was calculated to determine if differences in distribution existed between gonadectomized and sham-operated steelhead. Results were considered significant at $P < 0.05$.

The returns of tagged fish in different treatment groups, and different sexes, to the Clackamas Hatchery were compared to determine if gonadectomy affects hatchery returns. Return to the hatchery was measured by two criteria: (1) return to the hatchery trap and (2) return to the hatchery entrance. The time of return to the hatchery was based on the first detection at the confluence of the Clackamas River and Dog Creek (the tributary connecting the hatchery to the Clackamas R.), hereafter termed the “hatchery entrance”. Thus, it does not represent the time at which fish were actually recaptured in the hatchery trap. Fish that were re-caught in the Clackamas Hatchery trap were recorded and subsequently recycled back downstream for release again at the original release location. The Clackamas Hatchery trap was not operational for the full study period, and was closed from 29 September 2007 to 01 March 2008. The number of fish that re-entered the trap is a therefore based on the current operating procedure and may have been higher had the trap been open continuously.

Voluntary reporting was used to measure angler catch. We used a variety of methods to encourage voluntary angler reporting. Each fish was externally tagged with an individually numbered external (Floy) tag that provided contact details to report the catch. The study was also widely publicized among local angling groups and was featured on television, in press releases, and on the ODFW website. We also posted information on the study at major fishing areas along the lower river. Catch reports were collected at the ODFW Clackamas office and at the Clackamas Hatchery. The catch reports included information on catch location, time, gear used, and fish condition. The fish that were caught by anglers during our active tracking period (before 25 November 2007) were removed from our analysis (n = 7). Also, two radio-tagged steelhead (1 sham-operated female and 1 gonadectomized male) were never detected post release so they are not represented in our analysis. A sham-operated female was removed from analysis because of suspected tag failure. SPSS 5.0 was used for statistical analyses. Values are reported as means ± standard error.

Effect of Gonadectomy on Physiology

We held a group of 40 hatchery summer steelhead at an experimental laboratory to determine the effect of gonadectomy on sexual maturation and sex hormone levels. We collected hatchery summer steelhead from the ODFW Santiam and Clackamas Fish Hatcheries and transported them to the Fish Performance and Genetics Laboratory at Oregon State University. The fish were randomly divided into two treatment groups: gonadectomized and sham-operated. The gonadectomy surgical procedure was performed as described above. Sham-operated fish were given the same surgical procedure with the reproductive tissue left intact. Following surgery, the fish were held in a 3 m diameter circular tank. The fish were treated regularly with hydrogen peroxide to prevent bacterial and fungal infections. Individuals were handled to test for reproductive maturity throughout December and January. Fish were terminated when the sham-operated individuals reached reproductive maturity, to determine the level of gonad regeneration in gonadectomized fish.

Results

Residence Time and Fish Disappearance

No tagged steelhead left the system past the fixed receiver located at the confluence of the Clackamas River and Willamette River (Station 1). We estimated that 20 out of 79 radio-tagged steelhead (11 sham-operated and 10 gonadectomized) were unaccounted for after four months. The reported fish disappearance includes the two fish that were never detected post release and the fish that disappeared before the end of the active tracking period in December. Fish disappearance occurred during all months of active tracking. The mean rate of disappearance was ~ 6 - 7% per month for both sham-operated and gonadectomized steelhead.

Movement and Distribution

Median movement rates for all treatments were below 0.2 rkm per day (Figure 11). Movement rates were different between gonadectomized and sham-operated females (non-parametric median test; n = 494, d. f. = 1, median = 0.02, Chi-Square = 36.07, P <0.01) but not between gonadectomized and sham-operated males (non-parametric median test; n = 351, d. f. = 1, median = 0.02, Chi-Square = 0.03, P > 0.87).

Four sham-operated steelhead and three gonadectomized steelhead were randomly selected for 24 h tracking. Fork lengths were similar for the seven steelhead tracked with a range of 620 – 687 mm (Table 6). Mean distance traveled during 24 h tracking periods was 134 ± 25 m for sham-operated and 98 ± 58 m for gonadectomized. Most steelhead were found in the same location for repeated 24 h tracking periods (Table 6). We found that during our 24 h tracking periods, steelhead held in pools, glides, and riffles, but not in rapids (Table 6). Sham-operated steelhead were found in pools 75% of the time, whereas gonadectomized steelhead were found to hold in pools only 32% of the time. We observed that when steelhead held in riffles and glides they were usually near obstructions such as large boulders or large woody debris.

Gonadectomized steelhead were found downstream of sham-operated (Table 7). Mean gonadectomized female river positions were downstream of mean sham-operated female river positions (see Table 7; Mann-Whitney, $P = 0.02$). Gonadectomized females had a median distance from release of 1.7 rkm compared to the 10.0 rkm distance from release for sham-operated steelhead females. Mean gonadectomized males river positions were downstream of sham-operated males' river positions, but the difference was not found to be significant (see Table 7; Mann-Whitney, $P = 0.19$). The gonadectomized males had a median distance from release of 1.8 rkm and the median distance from release for sham-operated males was 8.8 rkm. There was a positive relationship between sham-operated steelhead river positions over time (Figure 12; sham-operated females: $R^2 = 0.72$, $P < 0.01$; sham-operated males $R^2 = 0.89$, $P < 0.01$). No relationship was found between gonadectomized steelhead river positions and time (Figure 12; gonadectomized females: $R^2 = 0.02$, $P < 0.70$; gonadectomized males $R^2 = 0.10$, $P < 0.21$).

The ranges of sham-operated and gonadectomized steelhead were similar (Figure 12). However, gonadectomized steelhead utilized areas downstream of sham-operated steelhead (Figure 13). Approximately one third of both female and male gonadectomized steelhead were detected in reaches above the hatchery, whereas approximately two thirds of sham-operated steelhead were detected in reaches above the hatchery (Figure 13).

Hatchery Returns

Similar return rates were observed for gonadectomized and sham-operated fish to the hatchery trap. The hatchery trap was only in operation from July through September 2007 until it reopened in March 2008. During this time, two gonadectomized and two sham-operated females, and one gonadectomized and two sham-operated males entered the hatchery trap. Three of these returns to the hatchery trap were in March when the trap reopened. In March, one sham-operated female, one gonadectomized female, and one gonadectomized male were found in the trap. Returns to the trap were similar for gonadectomized and sham-operated fish. However, there were reduced returns of gonadectomized steelhead to the Hatchery creek entrance. Returns to the hatchery entrance were reduced for both gonadectomized females and males (Figure 14). Return rate of gonadectomized females to the Hatchery entrance was reduced by 41%, and return rates for gonadectomized males were reduced by 12%, compared to sham-operated fish. Timing of returns was similar for both gonadectomized and sham-operated steelhead but timing of return differed between sexes. The majority of the females that returned were detected at the hatchery within one month post release; whereas the males returned to the hatchery from August to November (one to four months post release).

Fishery

A substantial number of radio-tagged steelhead were reported caught by anglers (n = 13 reported, n = 11 reported with tag ID). Approximately 10% of sham-operated and 18% of gonadectomized steelhead were reported as caught in the fishery. Two sham-operated females and 2 gonadectomized females were reported to ODFW from August through December. An additional gonadectomized female is suspected of being caught, but was not reported. Five gonadectomized and 2 sham-operated males were reported. An additional gonadectomized male is suspected of being caught. The suspected catches are inferred from recoveries of radio tags in parking lots or on banks of popular fishing areas.

Effect of Gonadectomy on Physiology

The effect of gonadectomy was examined for 5 male and 10 female hatchery summer steelhead. We observed gonad regeneration in four out of the five remaining gonadectomized males. Gonad regeneration occurred from both the anterior and posterior end of the testis (Figure 15). All 10 of the gonadectomized females were completely sterilized and there was no sign of gonad regeneration (Figure 15).

Discussion

Effect of Gonadectomy on Behavior

We used gonadectomy procedures in combination with radio tracking to determine how sterilized fish will behave in a recreational fishery. The goals of stocking sterile adult salmonids into river systems are to both reduce hatchery and wild interactions and to increase fishing opportunities. The goals of this study were not only to test these assumptions, but also to determine if sterilized fish will remain in the river.

Our results suggest that sterilization of adults may reduce interactions with wild fish. We found that interactions may be minimized because the majority of sterilized fish may hold downstream of wild fish and their natural spawning areas. However, it is important to note that we tracked these fish prior to spawning and further research is needed to determine sterilized fish behavior during their typical time of spawning. We did find that sterilized females held in the river longer without returning to the hatchery and maintained positions in the river downstream of sham-operated females. We found a similar pattern for males, but it was not statistically significant.

Our results suggest that sterilization of adult steelhead does not reduce angler catch rates, and may even increase catch rates. Based on angler surveys, sterilized steelhead are readily caught in the recreational fishery. However, because of the low reporting rate we were not able to quantify the catch rate. We speculate that gonadectomized fish may be harvested at a higher rate because we found that they are less likely to migrate back to the hatchery. Previous studies concur with our finding that sterilized fish are readily caught in recreational fisheries (Dillon et al. 2000; Kozfkay et al. 2006).

We found that none of the tagged steelhead passed the mouth of the Clackamas River. During the six-month study period (August through January) we would have been able to detect out-migrating fish from detection from our array of fixed stations. Unfortunately, due to the limited battery life of the radio tags (6 months) we were not able to determine if or when the gonadectomized steelhead emigrated out of the Clackamas River. The observed late returns of both sham-operated and gonadectomized steelhead to the hatchery trap in March suggest that at least a few fish may have remained in the river system for longer than seven months.

Twenty seven percent of the radio-tagged steelhead (11 sham-operated and 10 gonadectomized) were unaccounted for after four months. We made multiple excursions along the entire length of the lower Clackamas River. We feel that we would have detected the fish if they were within the area. If fish left the system, they would have been detected by fixed receivers. While tag failure or terrestrial predation may have occurred, we feel that fishing mortality is the most likely cause of the majority of fish disappearances.

We observed very low movement rates for both sham-operated and gonadectomized steelhead. The low movement rates observed likely reflects the holding behavior of summer steelhead during the months before spawning. This holding behavior has been observed in previous studies. Both steelhead and Atlantic salmon have been suggested to have three freshwater phases: a migratory phase, a winter holding phase, and a spawning phase (Hockersmith et al. 1995). In particular for our study, Kostow (2003) also mentioned a long holding period for summer steelhead on the Clackamas River. Steelhead holding patterns are mainly observed in deep, low velocity water (Hockersmith et al. 1995). Our study found that adult summer steelhead hold in pools, but also in glides and riffles. We suggest that the habitat occupied may be in part due to proximity to the hatchery as well as environmental factors such as temperature, cover, and groundwater hydrology. While we did find a difference in habitats occupied by gonadectomized and sham-operated fish, we did not track enough gonadectomized steelhead for multiple 24 h tracking periods to determine if they have significantly altered habitat preferences.

Effect of Gonadectomy on Physiology

Sterilization treatments may the affect the behavior and physiology of females to a greater degree than males. We have found that sterilization treatments on steelhead produced “essentially” sterile females, but may not have effectively sterilized males (Johnstone 1985). Similarly, Benfey et al. 1989 found that triploid rainbow trout females do not undergo physiological maturation, whereas males do. Also, in sterilized rainbow trout, female hormone levels remain basal, while males have elevated sex steroid levels and develop secondary sexual characteristics associated with spawning (Benfey et al. 1989). The different physiological response to sterilization can also be seen by comparing gonad to body ratios with the Gonadal Somatic Index (GSI). Triploid females have a reduced GSI and poorly developed ovaries compared with female diploids, whereas triploid males have reduced GSI but well developed testes (Benfey and Sutterlin 1984; Johnson et al. 1986).

Our study found that gonad regeneration occurred in the majority of the castrated males, but not in any of the gonadectomized females. Unilateral gonadectomy in male rainbow trout results in an increase in the size of the remaining gonad (Robertson 1958).

Gonad regeneration has also been reported for both female and male castrated grass carp, *Ctenopharyngodon idella* (Underwood et al. 1986). The majority of the castrated males had regenerated testis with seminal fluid (Underwood et al. 1986). Only a small percentage of the females were found with ripe eggs that may have been viable (Underwood et al. 1986). In males, remnant gonad tissue is necessary for gonad regeneration (Robertson 1958; Underwood et al. 1986). We believe that the surgical gonadectomy procedure was effective for females. However, surgical gonadectomy of males was often not complete, which in all likelihood resulted in gonad regeneration.

Can Sterilization be Used in Fishery Management?

Previous studies on the effect of sterilization on migration behaviors have focused on returns of juvenile treated salmonids. They have found that when salmonids are sterilized as juveniles it results in reduced returns to natal rivers and fisheries (Lindsay et al. 2000; Wilkins et al. 2001). The reduced returns in previous studies may have been caused by reduced response to environmental stimuli as a result of triploidy (Basant et al. 2005). What is not known is whether the reduced response is caused by a treatment effect on the central nervous system or a change in sex hormone levels (Basant et al. 2005). However, we found that when steelhead were sterilized as adults after they have entered the river, they stayed in the river and were available for recreational fisheries.

Our study illustrates the influence of sterilization via gonadectomy on salmonid behavior. However, sterilizing adult salmonids has obvious limitations. For one, our study observed gonadectomized steelhead behavior before spawning. We do not know how sterilized salmonids will behave during the spawning period. Another limitation is the development of an economical and efficient sterilization method for adult salmonids.

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Figures

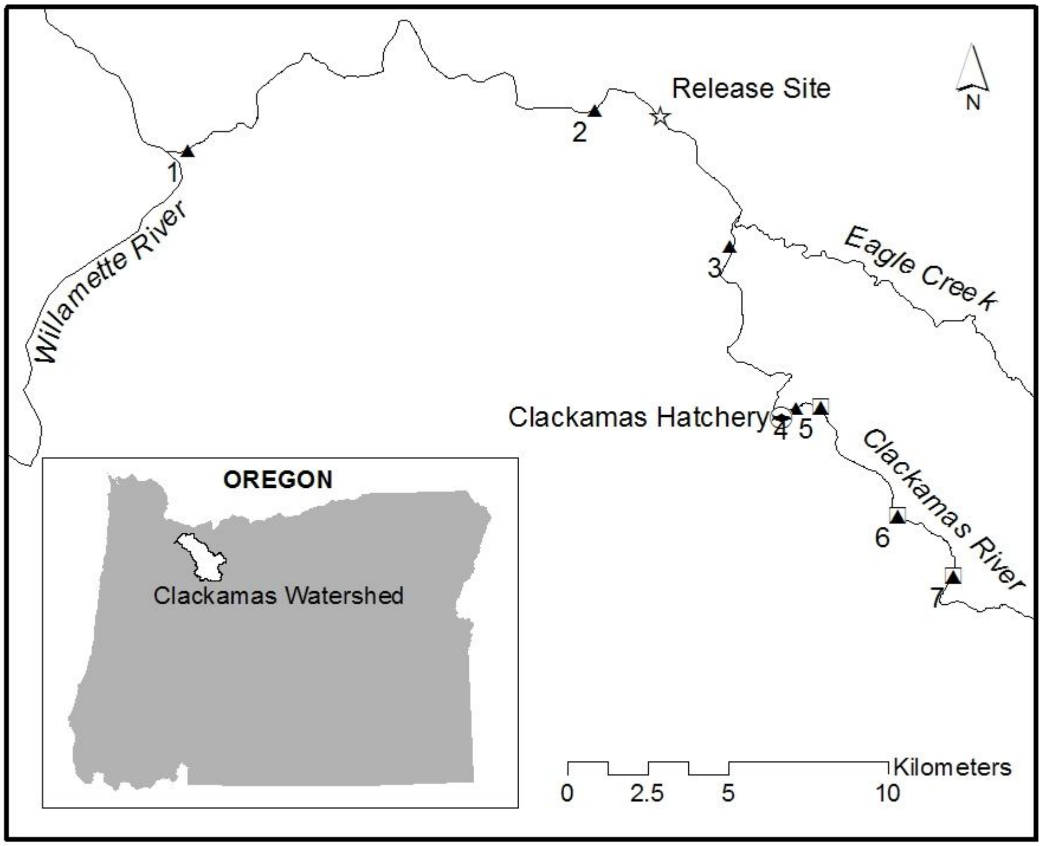

Figure 10. Study location, the Clackamas River, a tributary of the Willamette River in Oregon. The Clackamas Watershed is highlighted in white in the state map (inset). We tagged fish at the Clackamas Hatchery (marked by the fish symbol) and released them downstream (star symbol on main map). The seven fixed receiver locations are represented by triangles and are numbered from the furthest downstream receiver. Diversion Dam (Station 7) and North Fork Dam mark the upper limit for summer steelhead. Wild winter steelhead are passed above North Fork Dam.

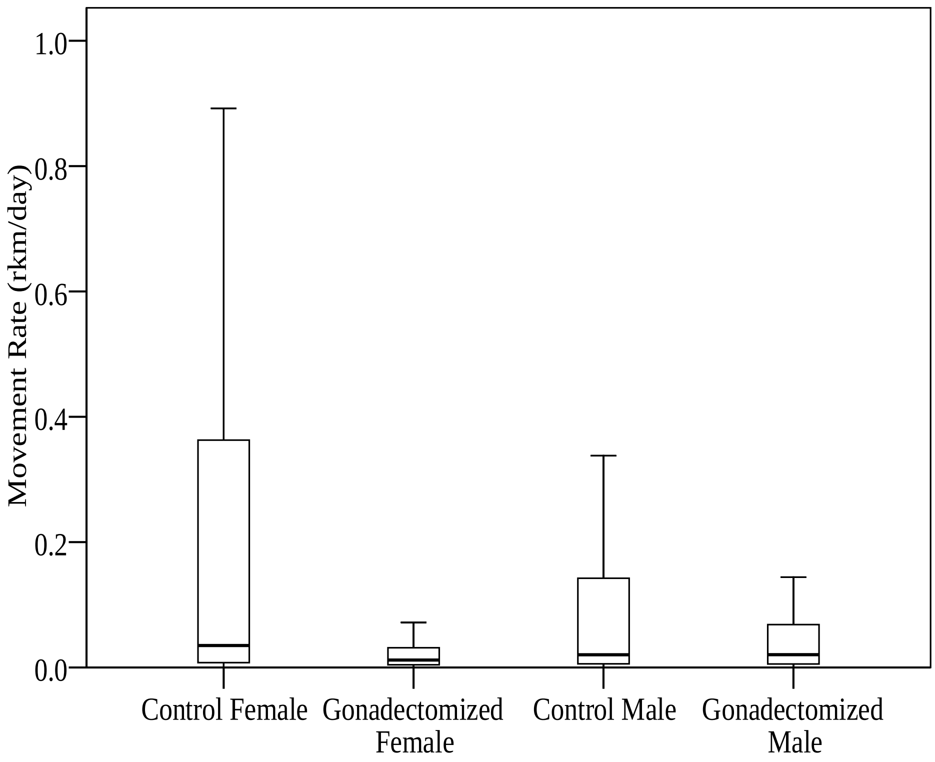

Figure 11. Movement rates for radio-tagged steelhead from August - December. Non-parametric tests show that control females had a higher median movement rate compared to gonadectomized females (Mann-Whitney; P = 0.01). Fish positions were collected from drift boat tracking. Outliers are not shown

– Legend Page –

Figure 12. Distribution of radio-tagged steelhead from release. Fish positions were collected from drift boat tracking from rkm 36.5 to rkm 21.0 (release location), with occasional drift tracking below the release location. Results are displayed as mean positions per drift tracking day where at least 50% of the treatment was detected (control females n = 21, gonadectomized females n = 23, control males n = 13, gonadectomized males n = 12). Females are represented with gray symbols on the left and males with white symbols on the right. Gonadectomized steelhead are represented by squares. Error bars represent one standard error.

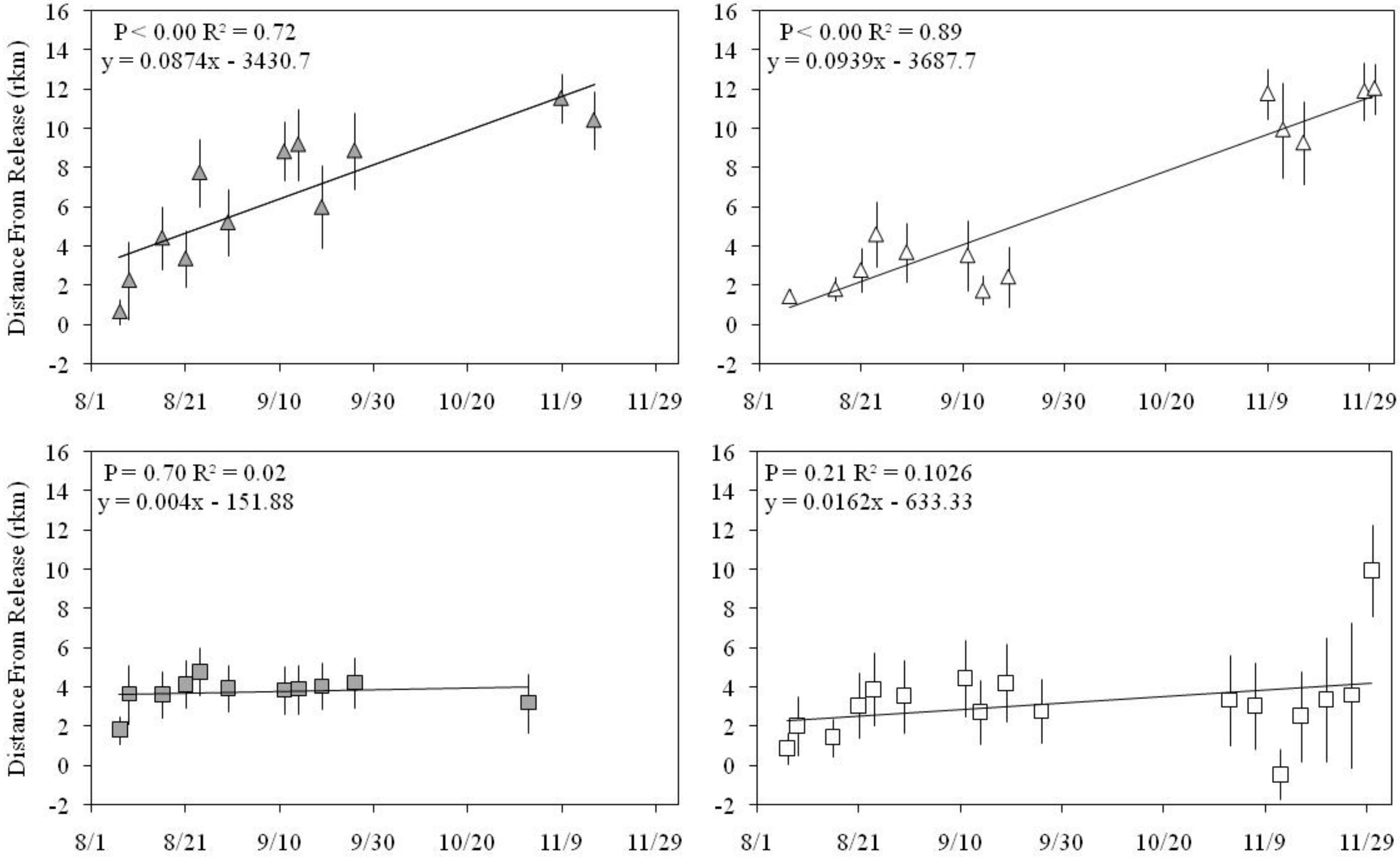

Figure 12. Distribution of radio-tagged steelhead from release.

– Legend Page –

Figure 13. Range of radio-tagged summer steelhead on the Clackamas River determined from fixed stations and mobile tracking. Figure 'A' represents females and figure 'B' represents Males. Gray bars represent gonadectomized treatments. Range is measured as percent of individuals in each treatment that were detected in predetermined reaches (control females n = 21, gonadectomized females n = 23, control males n = 13, gonadectomized males n = 12). The Clackamas River was divided into four reaches (Downstream of Release, Release, Hatchery, and Upstream of Release) based on locations of fixed receivers. The diagram of the reaches is on the right for reference. The star on the diagram marks the release location and the fish marks the Clackamas Hatchery.

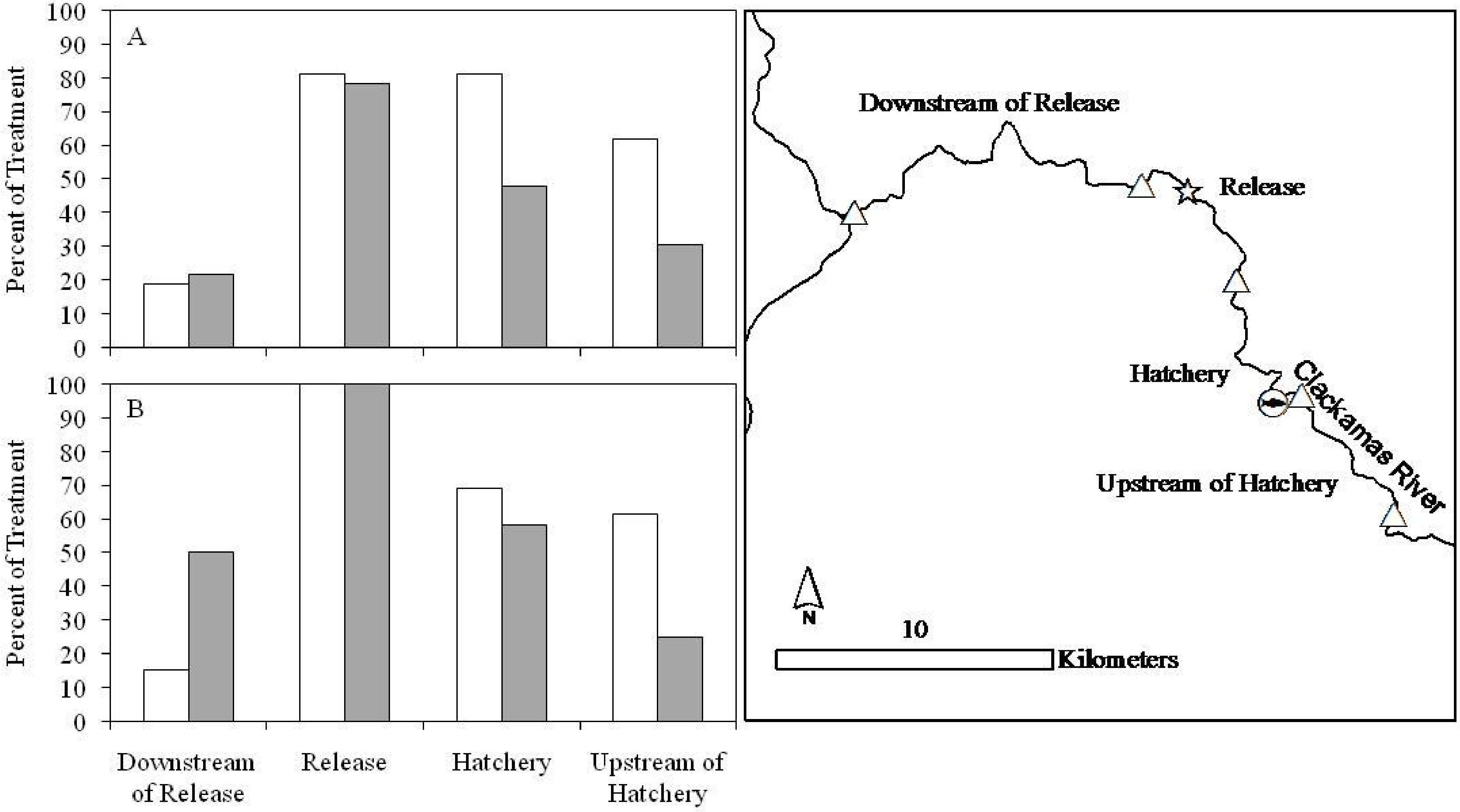

Figure 13. Range of radio-tagged summer steelhead on the Clackamas River determined from fixed stations and mobile tracking.

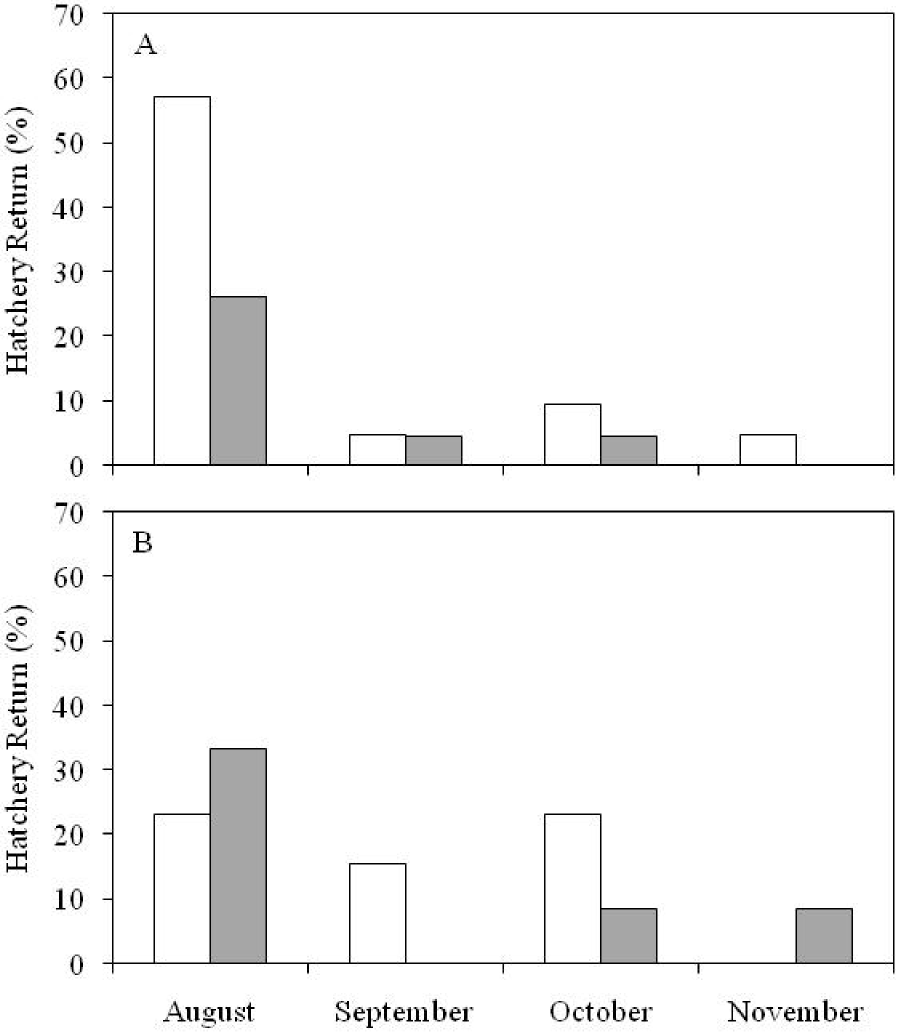

Figure 14. Return of females (A) and males (B) to the Clackamas Hatchery Entrance. The gray bars represent gonadectomized treatments. Results are given as percent of treatment (control female n = 21, gonadectomized females n = 23, control males n = 13, gonadectomized males n = 12).

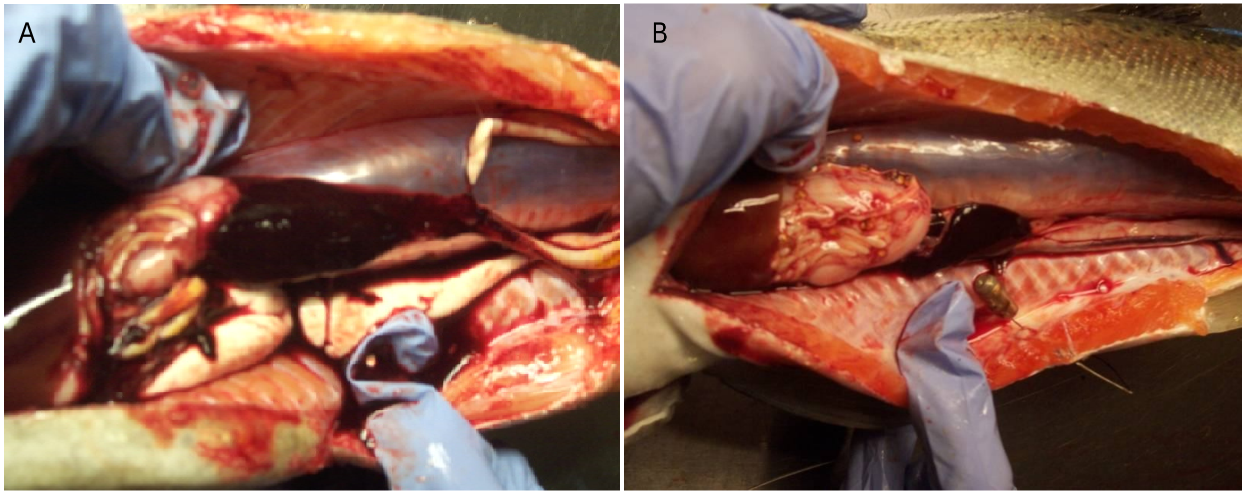

Figure 15. Gonad condition in males (A) and females (B) approximately 6 months post surgical gonadectomy. Gonad regeneration is visible in males but not females.

Tables

Table 6. Habitat type and movement of four control and three gonadectomized steelhead determined from 24 h tracking from August 2007 through October 2007.

Fish ID	Fish ID (Appendix)	Sex	Treatment	Fork Length (mm)	24h Tracking Start Date	Mean Position (rkm)	Distance Traveled (m)	Habitat (% of time)		
								Pool	Riffle	Glide
6	4	F	C	660	2-Sep	34.8	0	100		
					4-Sep	35	245	100		
					25-Sep	34.7	0		100	
					12-Oct	34.1	103	75	25	
					17-Oct	35	160	100		
8	6	F	C	620	14-Aug	21.7	165	92	8	
					31-Aug	31.9	85	42	58	
					5-Sep	35.1	140	92	8	
					12-Oct	35.1	98	21	79	
					17-Oct	35	230	100		
9	13	M	C	625	3-Aug	23.2	105	20	80	
					15-Sep	23.2	56	81	19	
12	8	F	C	687	2-Sep	35	348	70	30	
					4-Sep	35	154	100		
					25-Sep	34.8	20	100		
					12-Oct	35	315	90	10	
					17-Oct	35.1	131	100		

Continued

Table 6. (Continued) Habitat type and movement of four control and three gonadectomized steelhead determined from 24 h tracking from August 2007 through October 2007.

								Habitat (% of time)		
Fish ID	Fish ID (Appendix)	Sex	Treatment	Fork Length (mm)	24h Tracking Start Date	Mean Position (rkm)	Distance Traveled (m)	Pool	Riffle	Glide
44	47	F	G	640	13-Sep	23.6	116		100	
					4-Oct	23.6	84		100	
					13-Oct	23.6	0		100	
					22-Oct	24.2	0	100	0	
55	53	F	G	680	18-Sep	32.3	25		100	
					27-Sep	35.2	490	100*		
71	60	F	G	650	20-Sep	24.9	40	70		30
					9-Oct	24.8	31	6		94
					22-Oct	24	0	100		

*Fish found in a pool in Dog Creek, the tributary that leads to the hatchery, for 30% of the time and a different pool in the Clackamas River for 70% of the time.

Table 7. Steelhead positions in river kilometers from release site. The release site is located at river kilometer 21. Mean river positions were calculated for each radio-tagged steelhead from detections from fixed receivers and mobile tracking. Fish that were caught in the fishery were removed from analysis.

Sex	Treatment	N	Median Distance from Release	Mean Distance from Release (± std error)	Mean Rank	Sum of Ranks	P-Value
Females	Control	20	10.0	9.6±1.2	26.75	535	0.02
	Gonadectomized	23	1.7	4.6±1.5	17.87	411	
Males	Control	13	8.8	7.8±1.7	14.85	193	0.19
	Gonadectomized	12	1.8	4.1±2.0	11.00	132	

CHAPTER 5: CONCLUSIONS

Hatchery fish may have indirect (Flagg et al.2000; Cooke and Cowx 2004; Nelson et al. 2005), ecological (McMichael et al. 1999; Flagg et al.2000; Levin and Williams 2002; Weber and Fausch 2003; Hayes et al. 2004), and genetic (Fleming and Petersson 2001; Kostow 2004; Araki et al. 2007) impacts on wild populations and it is important that managers reduce those impacts to sustain wild populations into the future. Hatchery salmonids may also have broad positive impacts by providing a valuable food source, creating jobs, and supporting both coastal and freshwater tribal, commercial, and recreational fisheries (Nehlsen et al. 1991). When we focus on local Oregon rivers, there are management strategies available for hatchery fisheries managers to increase recreational angling opportunities while reducing hatchery and wild fish interactions. An understanding of hatchery salmonid in river behavior is needed. In addition, management measures that can be taken are the spatial separation of hatchery and wild populations through recycling programs, and inhibiting the reproduction of returning adult hatchery salmonids.

Activity and Behavior

Understanding the activity and behavior of summer steelhead in natal rivers will allow for the development of better management practices and help target habitats that may be critical for salmonid survival and reproduction. Knowledge of hatchery fish behavior will also increase angler opportunities by helping anglers target steelhead locations. We have found that the majority of hatchery summer steelhead utilize all habitats except riffles and hold in one general location for weeks to months. In addition, we found that hatchery summer steelhead have very low activity levels in their natal rivers. Their activity indexes, as measured by EMG tags, were on average only 1.4 times their resting activity.

We also found that hatchery steelhead were most numerous at the hatchery and release locations after they were transported downstream. Management methods to expand their spatial distribution beyond these locations would benefit the recreational fishery. One possible management approach might be to use multiple release locations of hatchery fish (smolts) along the river through acclimation ponds which would increase the number of returning adult steelhead to these areas. In addition, transporting returning hatchery adults downstream to multiple release locations through recycling programs may also expand steelhead distribution.

Recycling Programs

Oregon rivers that have, or historically had, recycling hatchery programs include the South Santiam (ODFW 2008), the upper Rogue (Evenson and Cramer 1984), and the Clackamas (ODFW 2007). Recycling programs increase fishing opportunities and can reduce hatchery and wild interactions on spawning grounds. Recycling programs spatially separate hatchery and wild salmonids and give anglers a second chance to catch the fish. We found this to be the case for the Clackamas River, with up to 41% of the recycled radio-tagged steelhead caught by anglers. However, recycling programs may also reduce hatchery returns and increase straying (Lindsay et al. 2001). We found that while this management tactic protects wild salmonids on their spawning grounds, it may increase interactions between hatchery and wild fish downstream. The literature on recycling programs is limited, with few published studies. Our research concurs with these studies. While recycling fish may increase angler catch, the majority of the fish do not return to the hatchery. Further evaluation of this management strategy should be done, especially in rivers with endangered wild populations.

Inhibiting Reproduction

Inhibiting the reproduction of hatchery fish in areas containing native stocks may be an effective fisheries management strategy. We already know a great deal about the methods used to sterilize juvenile salmonids (Donaldson 1986; Feist et al. 1996), the behavior of those sterilized fish (Dillon et al. 2000; Lindsay et al. 2000; Kozfkay et al. 2006), and their physiology (Fagerlund et al. 1979; Benfey and Sutterlin 1984; Johnstone 1985; Johnson et al. 1986; Benfey et al. 1989; Johnston et al. 1993). The obvious, and critical, limitation of juvenile salmonid sterilization programs is the very low return rate of those fish as adults to the natal rivers. Lindsay et al. (2000) found that return rates were typically lower than 25% of the number of returning controls, and the majority of the returning fish had well developed gonads and exhibited secondary sexual characteristics. This study is one of the first to evaluate the potential benefits of sterilizing returning adult salmonids after they enter rivers. The major question of interest was if sterilized adults have altered behavior and movement, and if they are available to freshwater fisheries.

Even with the large body of knowledge on the subject, salmonid migratory behavior and activities are not completely understood. While physiology plays a role (Cooke et al. 2008), salmonid migrations are believed to be largely under genetic control (Quinn 2005). It is also known that photoperiod, temperature, and flow influence salmonid migrations (Quinn et al. 1997; Robards and Quinn 2002; High et al. 2006; Cooke et al. 2008). Most likely, it is a combination of environmental, physiological, and genetic factors that influence migration (Quinn 2005).

Adult female salmonids appear to be the better candidate for sterilization treatments. They are effectively sterilized from triploid treatments, hormone treatments, and gonadectomy procedures; whereas treated males often develop secondary sexual characteristics and occasionally reach maturity (Johnstone 1985; Lindsay et al. 2000). The difference in treatment success between the sexes may be that gonad maturation in males may be a quicker process that requires less energy (Beamish 1979). In any event, we found that sterilized females seemed to behave as if they were reproductively sterile and may not reach spawning grounds. This may reduce interactions where hatchery and wild fish distributions overlap. In addition, we found that gonadectomized females remained in the river, were caught in the recreational fishery, and were distributed downstream from control fish. These behavior patterns indicate that sterilization of returning adult females may be a viable management tactic to reduce wild interactions while providing for a recreational fishery.

This study demonstrates the potential of inhibiting reproduction of returning adult salmonids in a recreational fishery. The next step is to establish an adult treatment method for hatchery salmonids as they return to freshwater. However, a thorough evaluation of the interactions of reproductively inhibited fish and wild fish should be done before this management tactic is considered.

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APPENDICES

Appendix I. Spatial analysis of radio-tracked summer steelhead in the Clackamas River, Oregon

Oregon State UNIVERSITY OSU

Background

Fish telemetry data can be difficult to analyze and visually represent. Spatial analysis in ArcGIS (ESRI, 2007) was used to determine positions of radio-tracked adult summer steelhead along the Clackamas River, Oregon. The following analysis was used to estimate river kilometer fish positions for all radio-tracked fish and travel distances of fish tracked over 24 h periods. These analyses were used in a larger study to determine hatchery summer steelhead movement and distribution in the Clackamas River in from July 2007 to January 2008.

Methods

Study Area

The Clackamas River is a tributary of the lower Willamette River, Oregon, USA (Figure 1). The Clackamas River is a 6th order, gravel-bed river that originates from the Cascades near Ollalie Lake and runs 215 km to its confluence with the Willamette River (Burkholder 2007). Its drainage area is 2,430 km^2 and its median annual flow is 75.7 m^3/s (Burkholder 2007). The river discharge is regulated by four dams located throughout the main stem of the river: River Mill Dam (river kilometer (rkm) 37), Faraday Dam (rkm 42), Diversion Dam (rkm 45), and North Fork Dam (rkm 47). North Fork Dam acts as a barrier to fish passage. The study area encompassed the stretch of river from North Fork Dam to the confluence of the Clackamas and Willamette Rivers.

Tracking Protocol and Telemetry Equipment

Two types of radio transmitters were used (Lotek NTC-6 coded nano tags (4.5 g in air) and electromyogram (EMG) tags (11.9 g in air)). A total of 79 adult hatchery steelhead were tagged at the hatchery and released downstream at Barton Park. Seven receivers were set up as fixed monitoring stations, which recorded tagged steelhead movements in the Clackamas River in order to determine residence times. Each station consisted of a Lotek SRX receiver and two yagi antennas (4 element). One antenna monitored tagged steelhead upstream of the receiver station and the other monitored tagged steelhead downstream of the station. When a fish swam in range of the antenna, a signal was sent to the receiver which recorded the signal strength, time, tag code, and the antenna number. Direction of fish movement was determined by comparing the signal strength and time of detection on the up and downstream antenna. A fixed monitoring station was placed at the Clackamas River mouth to record the passage of fish leaving the system (rkm 0.5). Three of the seven fixed stations were located on dams: stations 5, 6, and 7. Fixed stations were operated from August 2007 to January 2008.

Two receivers (Lotek SRX 600 and Lotek SRX 400, Lotek, Newmarket, Ontario, Canada) and two four element yagi antenna (150 Mhz, Cushcraft, Manchester, New Hampshire, USA) were used to actively track tagged fish. Manual radio tracking included drift boat tracking, foot tracking, and tracking individual fish for 24 h periods. The receivers recorded the signal strength, time, date, tag code, GPS location (UTM coordinates), and EMG code values (from 0 to 50). GPS positions coordinates were recorded using an integrated GPS antenna with the LOTEK SRX 600 receiver when at least four satellites were in range.

Data Analysis

We used ArcGIS (ESRI, 2007) for our analysis of fish movement and distribution. All of the layers were projected geographically in North American Datum 1983 (NAD

83) and projected in UTM zone 10. Units are in meters. GPS fish positions were plotted in ArcGIS along the Clackamas River Route to obtain fish positions in river kilometer units. The Clackamas River Route was generated by modifying the Clackamas River Layer obtained from the Oregon Geospatial Enterprise Office (Source: EPA, Scale: 1:250,000) to match Clackamas River 2006 aerial photographs taken in August 2006 (Watershed Sciences, pixel resolution: 0.9 m). The linear referencing extension was used to locate the GPS fish positions along the Clackamas River Route with a search radius of 200 m from the GPS point to the route. Most of the steelhead GPS positions were located along the route, with 99% of all detections within 100 m of the route.

Steelhead movements and habitats occupied during the 24 h tracking surveys were determined from manual observations and GPS positions. Steelhead positions were mapped in ArcGIS on geo-referenced aerial photographs of the Clackamas River (Figure 2). Steelhead movement was calculated as the straight-line difference between the furthest upstream and downstream position, termed travel distance. This is considered a minimum travel distance since fish usually do not travel in straight lines. Travel distances were measured in ArcGIS. Habitat observations were classified as pool, riffle, or run. The percent of time that a fish occupied a particular habitat type was estimated from observations collected during 24 h tracking periods.

References

ESRI (Environmental Systems Research Institute). 2007. ArcGIS 9.2. Environmental Systems Research Institute, Redlands, California "(software)".

Figures

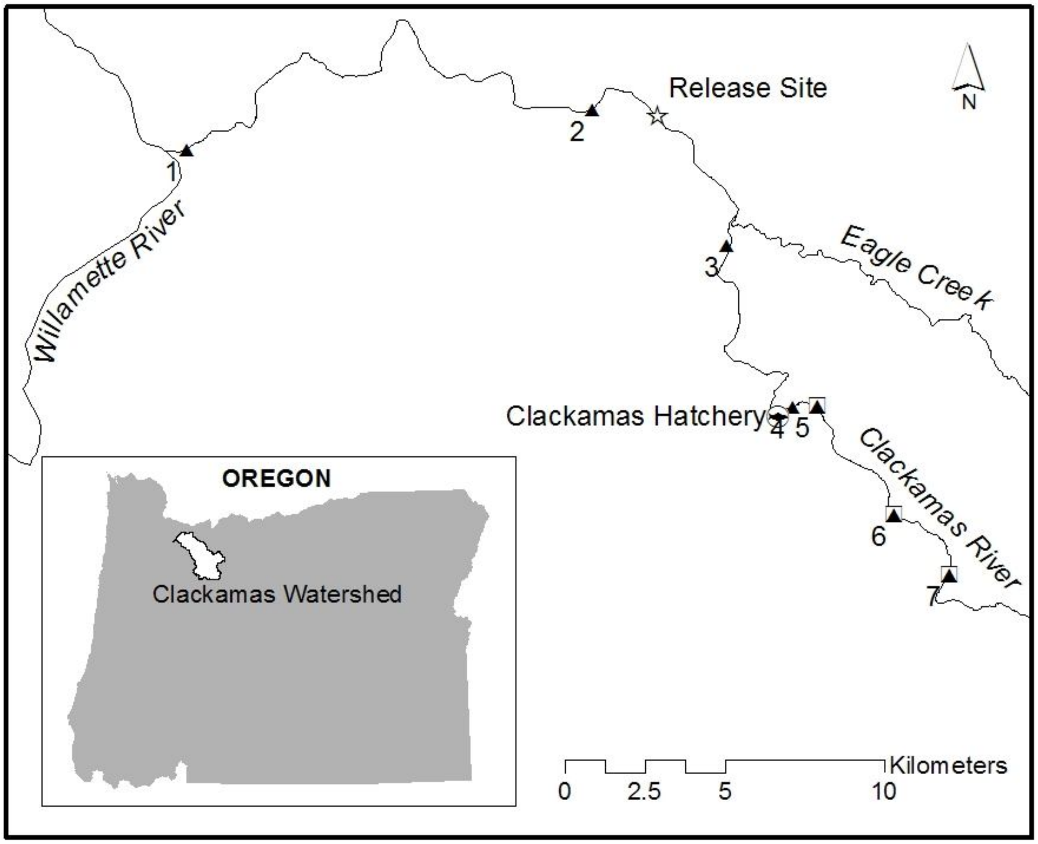


Figure 16. The study area along the Clackamas River, Oregon. Receivers are represented by triangles and dams are represented by squares. The release location of radio-tagged steelhead is represented by the star. Steelhead were tagged at the Clackamas Hatchery. Eagle Creek is the main tributary of the lower Clackamas River.

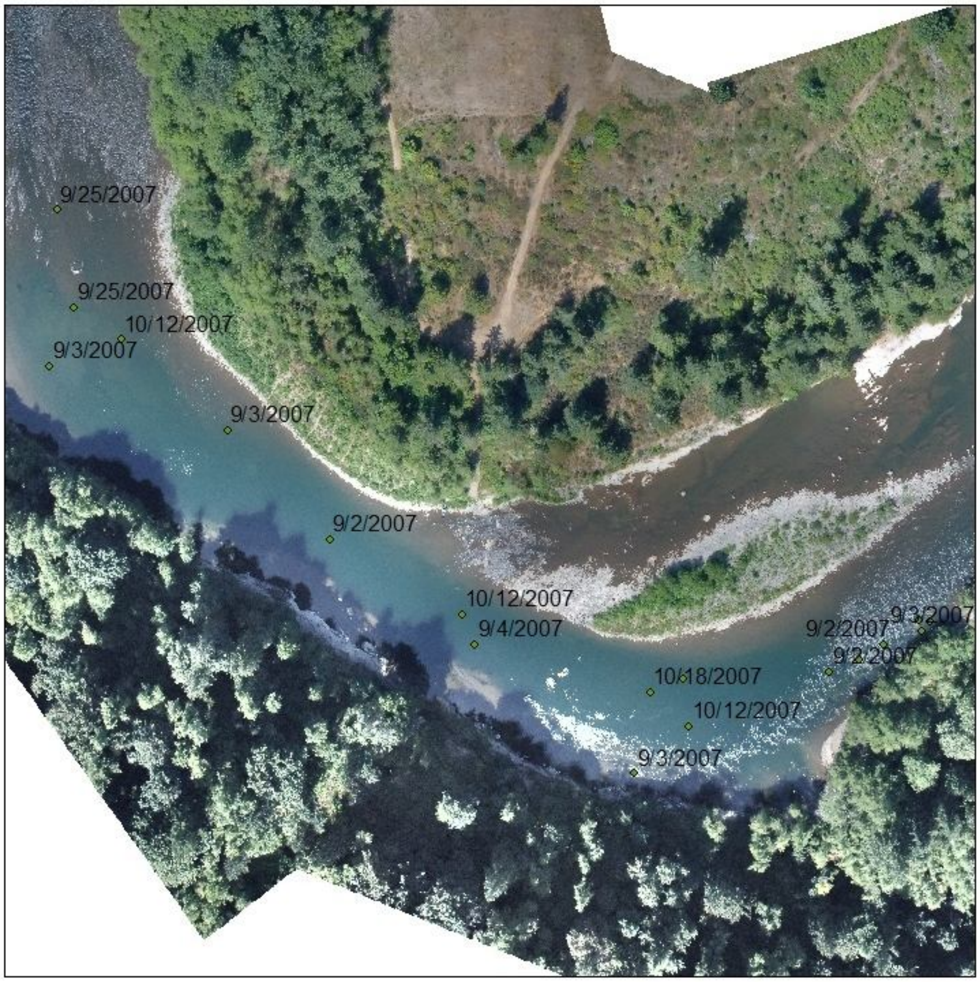


Figure 17. Positions of Fish ID 12 during a 24 h tracking periods labeled by date. Fish positions were determined from observations of fish location and plotted on aerial photographs of the Clackamas River, taken August 12th, 2006 with a pixel resolution of 0.9 m (Watershed Sciences, Corvallis, OR).

Appendix II. Tables and figures for individual radio-tagged steelhead

Table 8. Radio-tagged summer steelhead. “C” represents control treatments and “G” represents gonadectomized treatments. “F” represents female and “M” represents male.

Tag ID	Fish ID	Tag Type	Treatment	Sex	Weight (kg)	Tag Date	Release Date
500.10	1	EMG	C	F	3.4	23-Jul-07	25-Jul-07
500.20	2	EMG	C	F	2.5	23-Jul-07	25-Jul-07
500.30	3	EMG	C	F	3.4	23-Jul-07	25-Jul-07
500.60	4	EMG	C	F	2.5	24-Jul-07	25-Jul-07
500.70	5	EMG	C	F	3.1	24-Jul-07	25-Jul-07
500.80	6	EMG	C	F	2.0	24-Jul-07	25-Jul-07
500.11	7	EMG	C	F	3.1	1-Aug-07	2-Aug-07
500.12	8	EMG	C	F	3.0	25-Jul-07	26-Jul-07
500.14	9	EMG	C	F	3.3	26-Jul-07	27-Jul-07
500.16	10	EMG	C	F	2.9	25-Jul-07	26-Jul-07
500.20	11	EMG	C	F	3.8	1-Aug-07	2-Aug-07
500.50	12	EMG	C	M	3.5	23-Jul-07	25-Jul-07
500.90	13	EMG	C	M	2.7	24-Jul-07	25-Jul-07
500.10	14	EMG	C	M	3.8	24-Jul-07	25-Jul-07
500.13	15	EMG	C	M	5.3	25-Jul-07	26-Jul-07
500.15	16	EMG	C	M	2.7	26-Jul-07	27-Jul-07
500.17	17	EMG	C	M	2.9	1-Aug-07	2-Aug-07
500.18	18	EMG	C	M	2.5	2-Aug-07	3-Aug-07
380.22	19	Nano	C	F	2.9	23-Jul-07	25-Jul-07
380.24	20	Nano	C	F	2.3	23-Jul-07	25-Jul-07
380.26	21	Nano	C	F	2.6	23-Jul-07	25-Jul-07
380.29	22	Nano	C	F	2.5	2-Aug-07	3-Aug-07
380.30	23	Nano	C	F	2.9	23-Jul-07	25-Jul-07
380.32	24	Nano	C	F	2.6	23-Jul-07	25-Jul-07
380.37	25	Nano	C	F	2.7	24-Jul-07	25-Jul-07
380.39	26	Nano	C	F	2.9	24-Jul-07	25-Jul-07
380.43	27	Nano	C	F	2.4	24-Jul-07	25-Jul-07
320.53	28	Nano	C	F	2.6	25-Jul-07	26-Jul-07
320.56	29	Nano	C	F	3.1	25-Jul-07	26-Jul-07
320.72	30	Nano	C	F	2.6	1-Aug-07	2-Aug-07
320.77	31	Nano	C	F	2.2	2-Aug-07	3-Aug-07

Continued

Table 8. (Continued) Radio-tagged summer steelhead. “C” represents control treatments and “G” represents gonadectomized treatments. “F” represents female and “M” represents male.

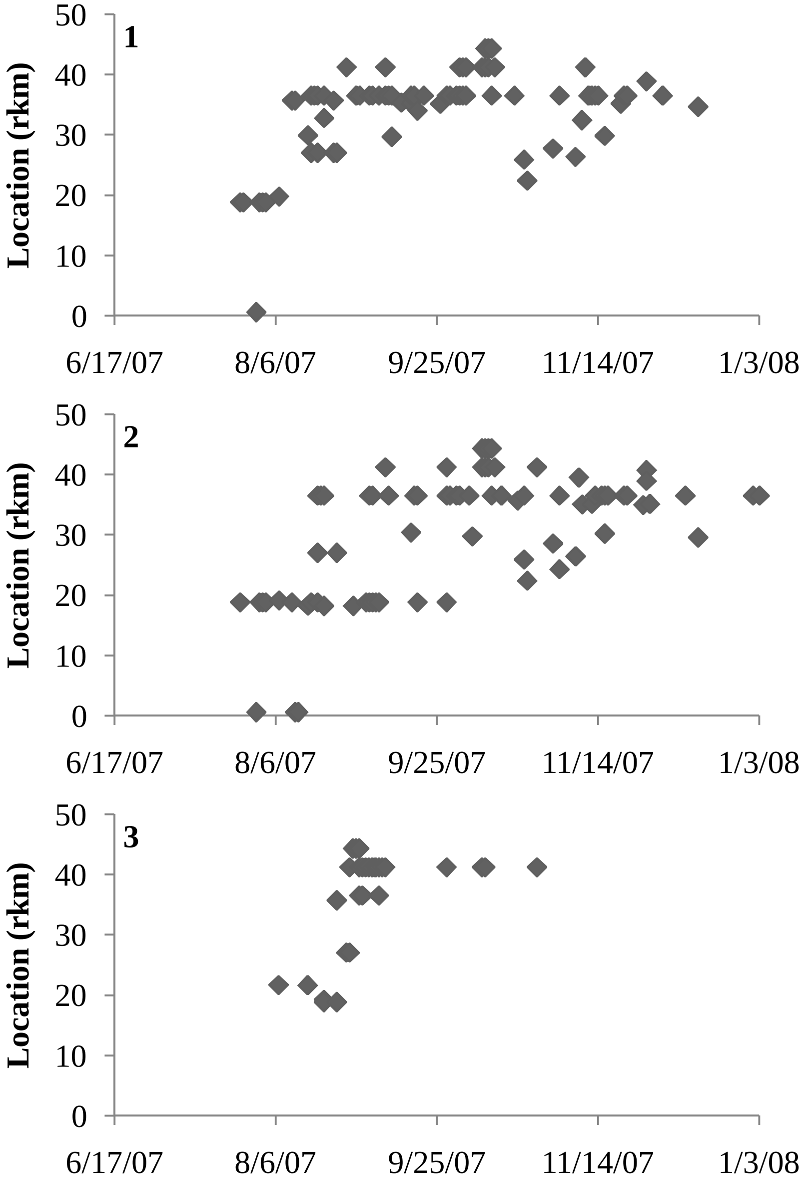
Tag ID	Fish ID	Tag Type	Treatment	Sex	Weight (kg)	Tag Date	Release Date
380.20	32	Nano	C	M	2.0	2-Aug-07	3-Aug-07
380.28	33	Nano	C	M	2.9	23-Jul-07	25-Jul-07
380.35	34	Nano	C	M	2.4	24-Jul-07	25-Jul-07
380.49	35	Nano	C	M	3.8	25-Jul-07	26-Jul-07
320.58	36	Nano	C	M	1.5	26-Jul-07	27-Jul-07
320.64	37	Nano	C	M	3.4	26-Jul-07	27-Jul-07
320.68	38	Nano	C	M	3.0	1-Aug-07	2-Aug-07
320.74	39	Nano	C	M	2.9	1-Aug-07	2-Aug-07
380.27	40	Nano	G	F	3.9	23-Jul-07	25-Jul-07
380.31	41	Nano	G	F	2.6	23-Jul-07	25-Jul-07
380.33	42	Nano	G	F	2.4	23-Jul-07	25-Jul-07
380.34	43	Nano	G	F	2.9	24-Jul-07	25-Jul-07
380.38	44	Nano	G	F	2.3	24-Jul-07	25-Jul-07
380.41	45	Nano	G	F	3.8	24-Jul-07	25-Jul-07
380.42	46	Nano	G	F	3.3	24-Jul-07	25-Jul-07
380.44	47	Nano	G	F	2.4	24-Jul-07	25-Jul-07
380.45	48	Nano	G	F	2.3	24-Jul-07	25-Jul-07
380.48	49	Nano	G	F	2.7	25-Jul-07	26-Jul-07
380.49	50	Nano	G	F	3.6	1-Aug-07	2-Aug-07
380.50	51	Nano	G	F	2.0	25-Jul-07	26-Jul-07
320.51	52	Nano	G	F	2.9	25-Jul-07	26-Jul-07
320.55	53	Nano	G	F	3.2	25-Jul-07	26-Jul-07
320.59	54	Nano	G	F	3.8	26-Jul-07	27-Jul-07
320.60	55	Nano	G	F	3.4	26-Jul-07	27-Jul-07
320.65	56	Nano	G	F	2.3	1-Aug-07	2-Aug-07
320.66	57	Nano	G	F	3.7	1-Aug-07	2-Aug-07
320.67	58	Nano	G	F	2.6	1-Aug-07	2-Aug-07
320.70	59	Nano	G	F	2.5	1-Aug-07	2-Aug-07
320.71	60	Nano	G	F	2.9	2-Aug-07	3-Aug-07
320.76	61	Nano	G	F	2.6	2-Aug-07	3-Aug-07
320.78	62	Nano	G	F	2.2	2-Aug-07	3-Aug-07
320.79	63	Nano	G	F	2.9	2-Aug-07	3-Aug-07
380.21	64	Nano	G	M	5.5	23-Jul-07	25-Jul-07

Continued

Table 8. (Continued) Radio-tagged summer steelhead. “C” represents control treatments and “G” represents gonadectomized treatments. “F” represents female and “M” represents male.

Tag ID	Fish ID	Tag Type	Treatment	Sex	Weight (kg)	Tag Date	Release Date
380.23	65	Nano	G	M	3.5	23-Jul-07	25-Jul-07
380.25	66	Nano	G	M	2.5	23-Jul-07	25-Jul-07
380.36	67	Nano	G	M	1.3	24-Jul-07	25-Jul-07
380.40	68	Nano	G	M	3.1	24-Jul-07	25-Jul-07
380.46	69	Nano	G	M	3.0	24-Jul-07	25-Jul-07
380.47	70	Nano	G	M	3.1	25-Jul-07	26-Jul-07
320.52	71	Nano	G	M	3.7	25-Jul-07	26-Jul-07
320.54	72	Nano	G	M	2.9	25-Jul-07	26-Jul-07
320.57	73	Nano	G	M	3.0	25-Jul-07	26-Jul-07
320.61	74	Nano	G	M	2.1	26-Jul-07	27-Jul-07
320.62	75	Nano	G	M	2.7	26-Jul-07	27-Jul-07
320.63	76	Nano	G	M	2.5	26-Jul-07	27-Jul-07
320.69	77	Nano	G	M	4.5	1-Aug-07	2-Aug-07
320.73	78	Nano	G	M	4.6	1-Aug-07	2-Aug-07
320.75	79	Nano	G	M	1.6	2-Aug-07	3-Aug-07

Figure 18. Fish positions along the Clackamas River from mobile and fixed receiver detections from July 2007 to January 2008. Fish that are not shown were never detected. Fish 23, 24 and 64 were never detected post release. Tag ID 380.49 from Fish ID 35 was recovered and reused in Fish ID 50.



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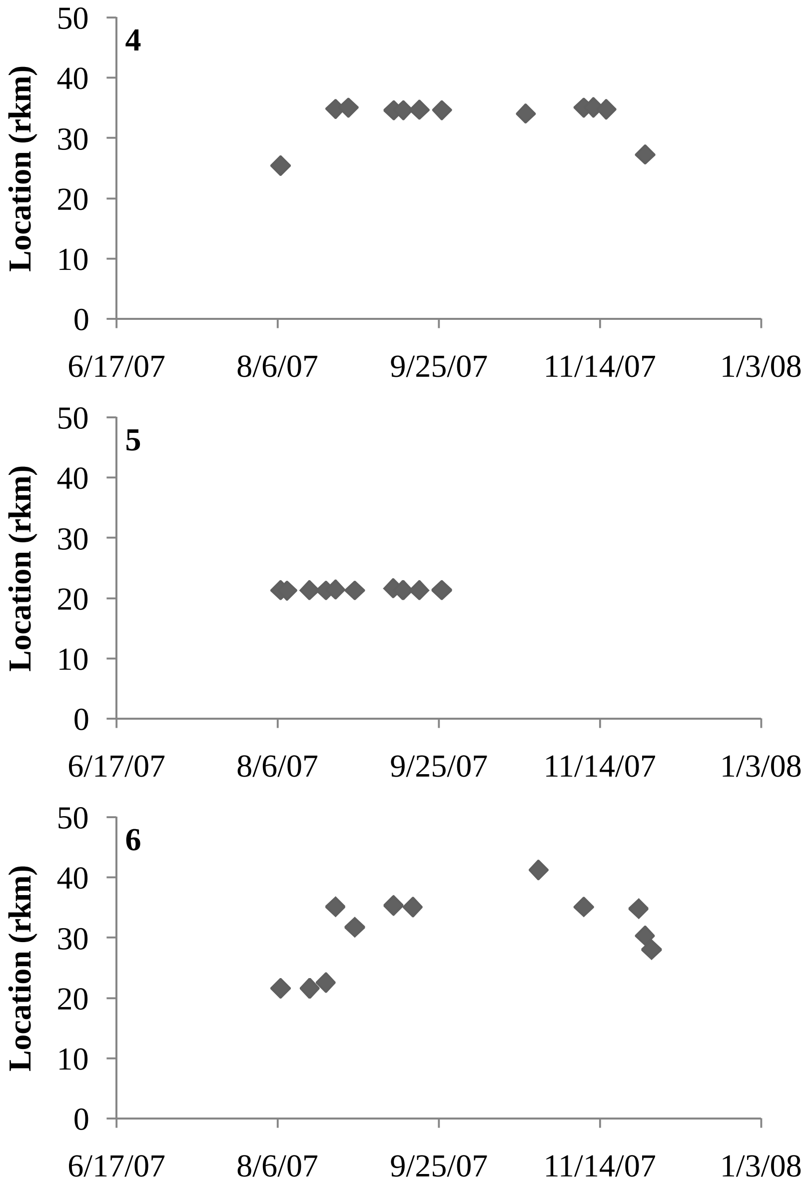

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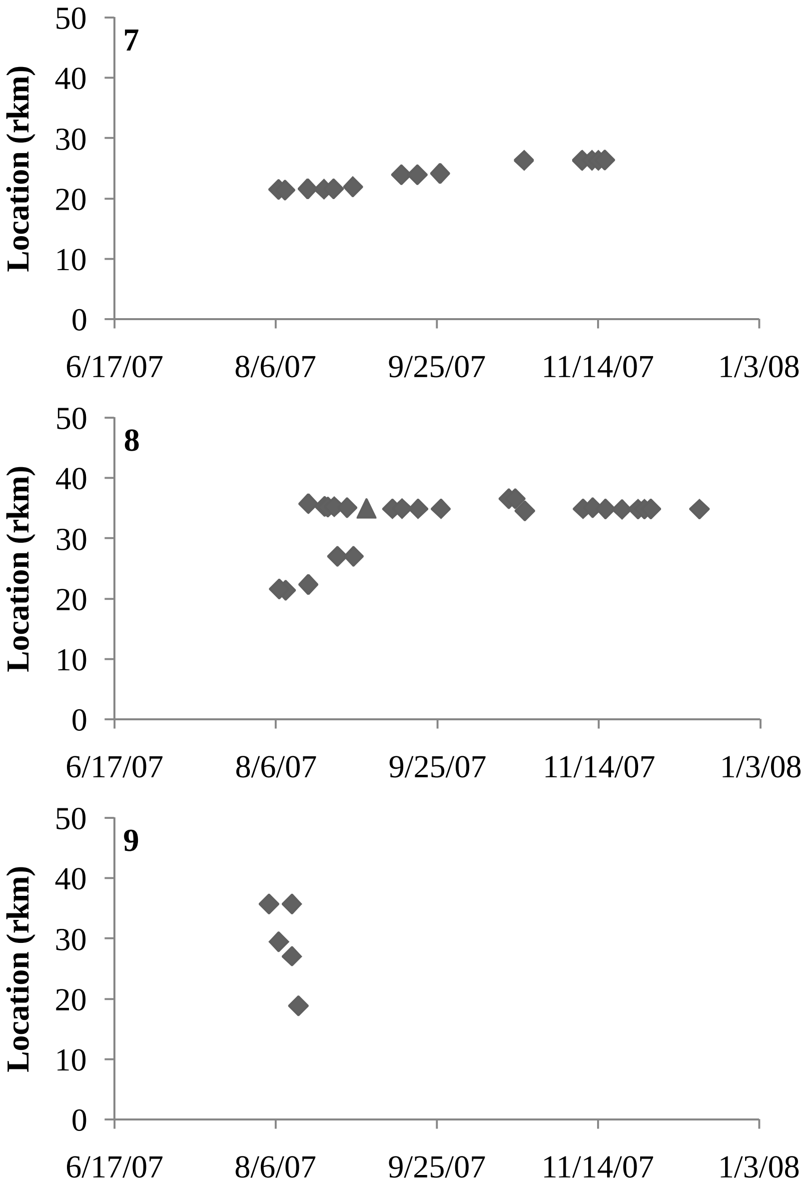

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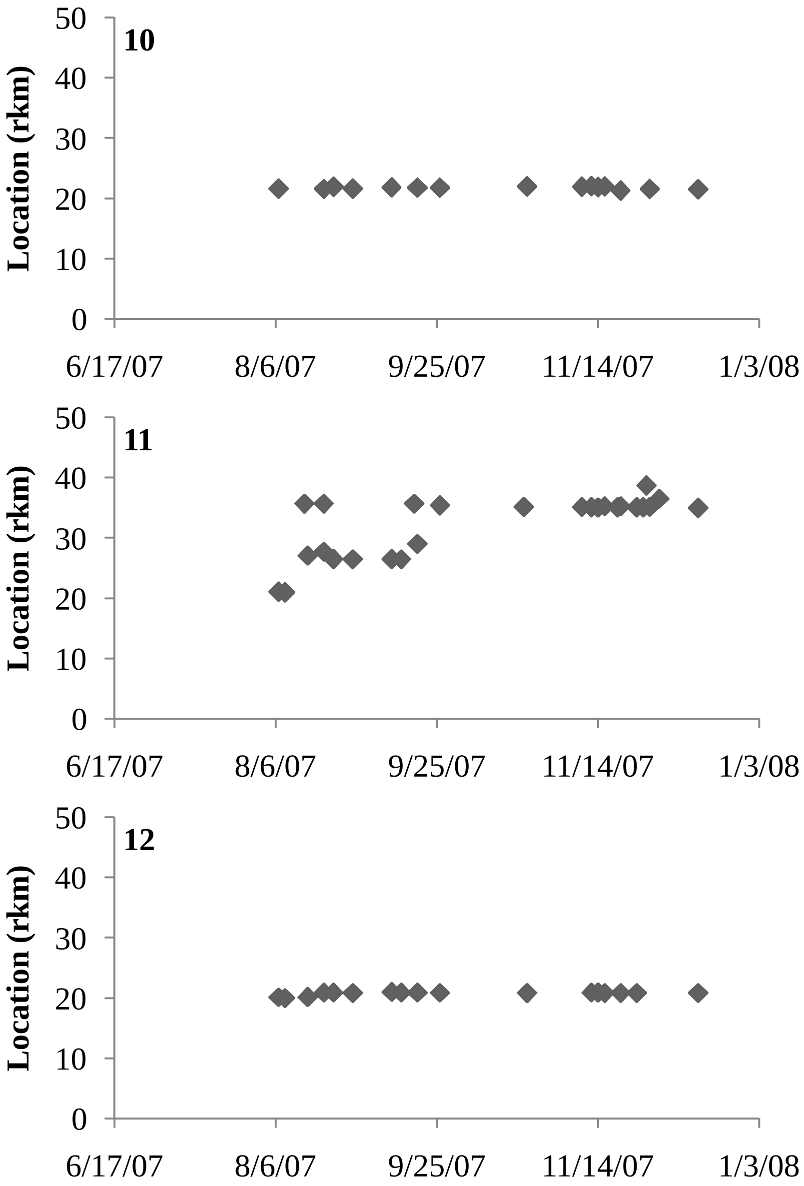

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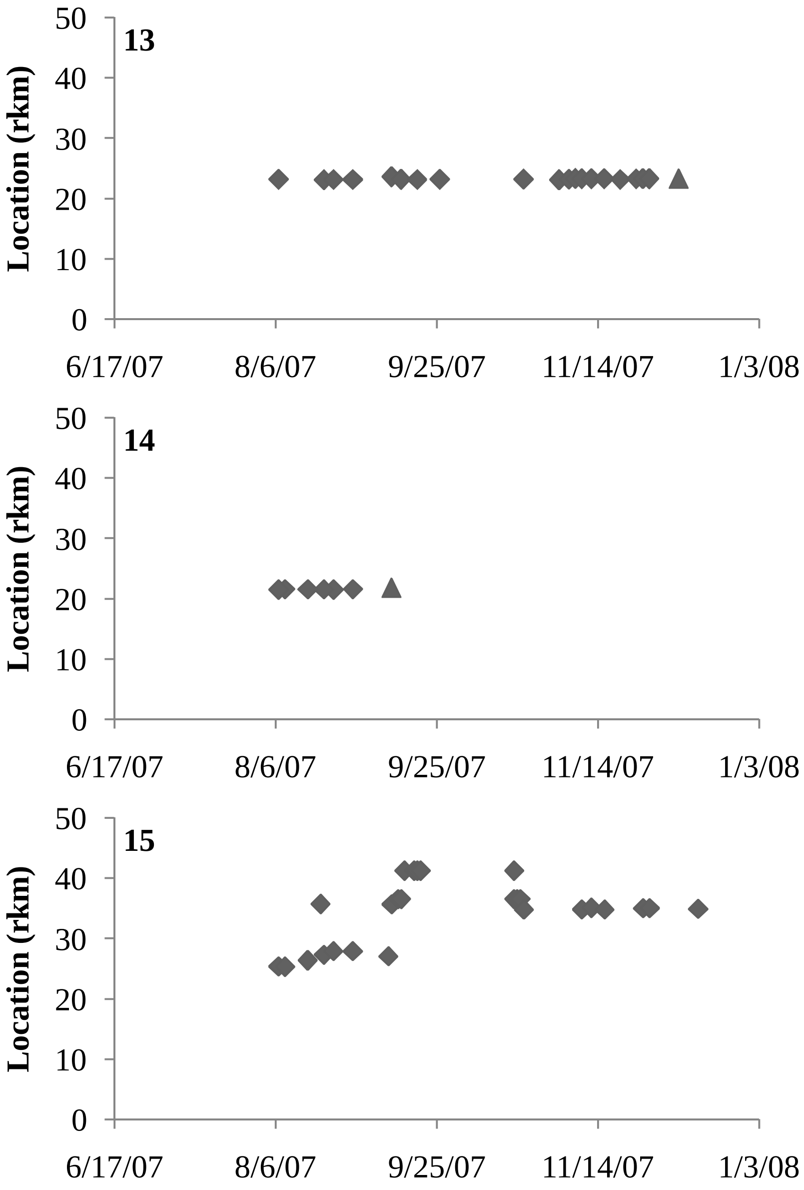

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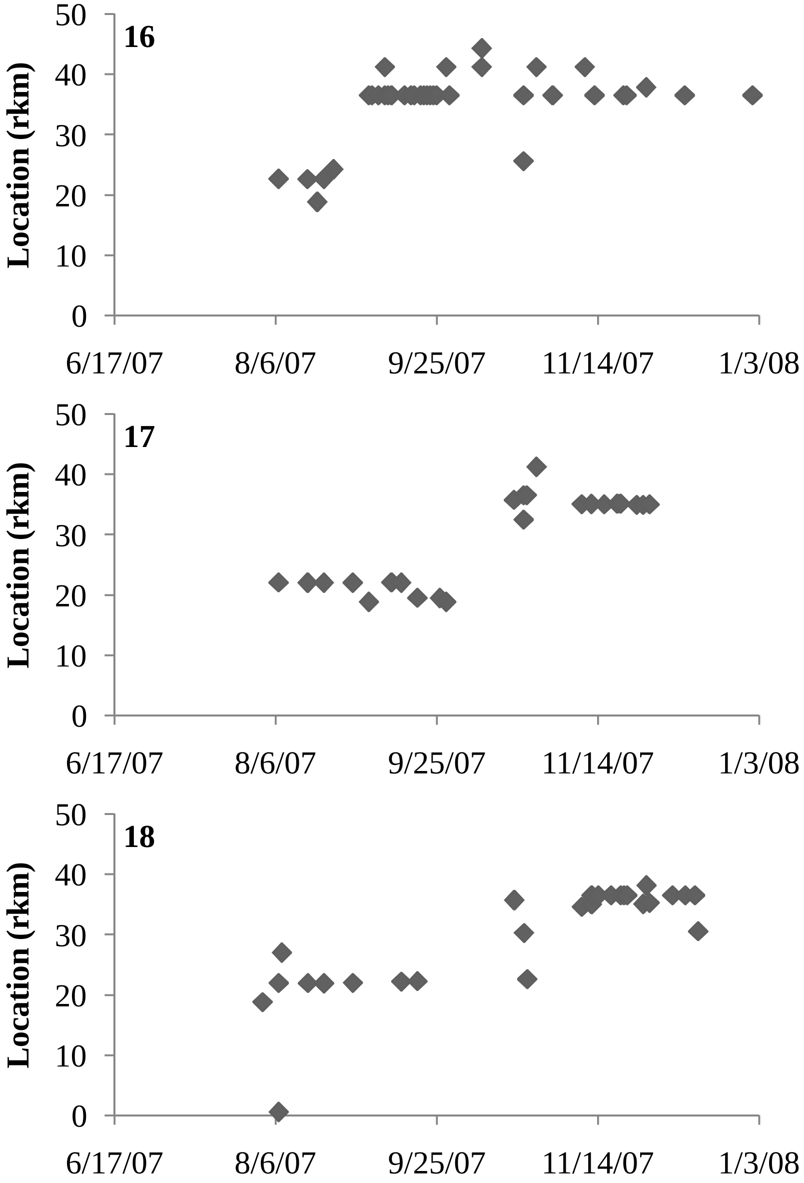

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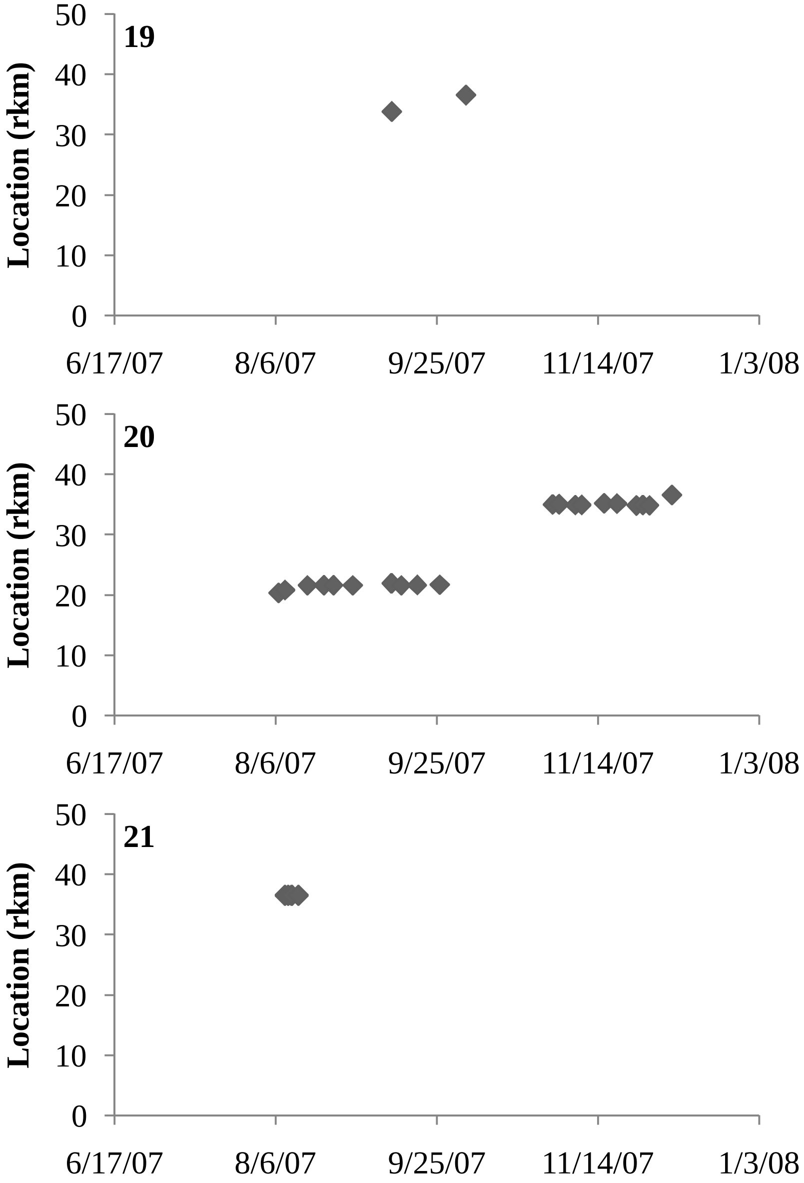

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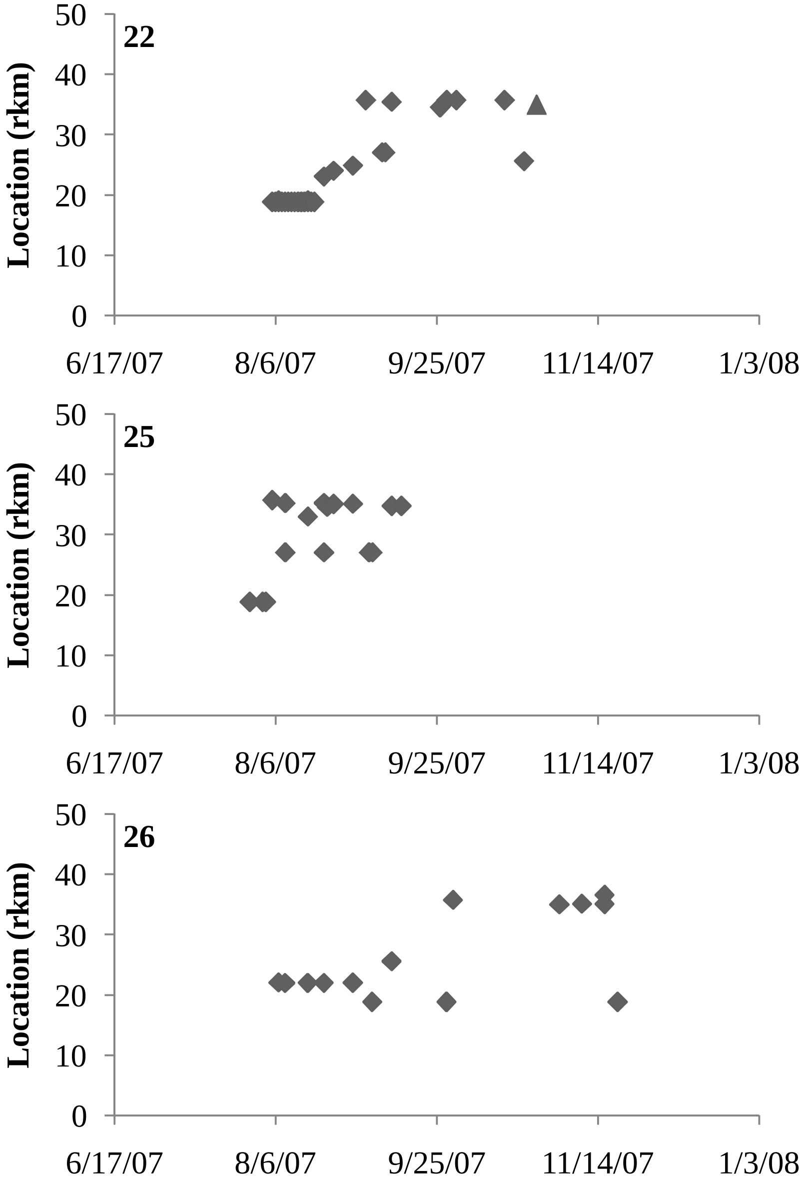

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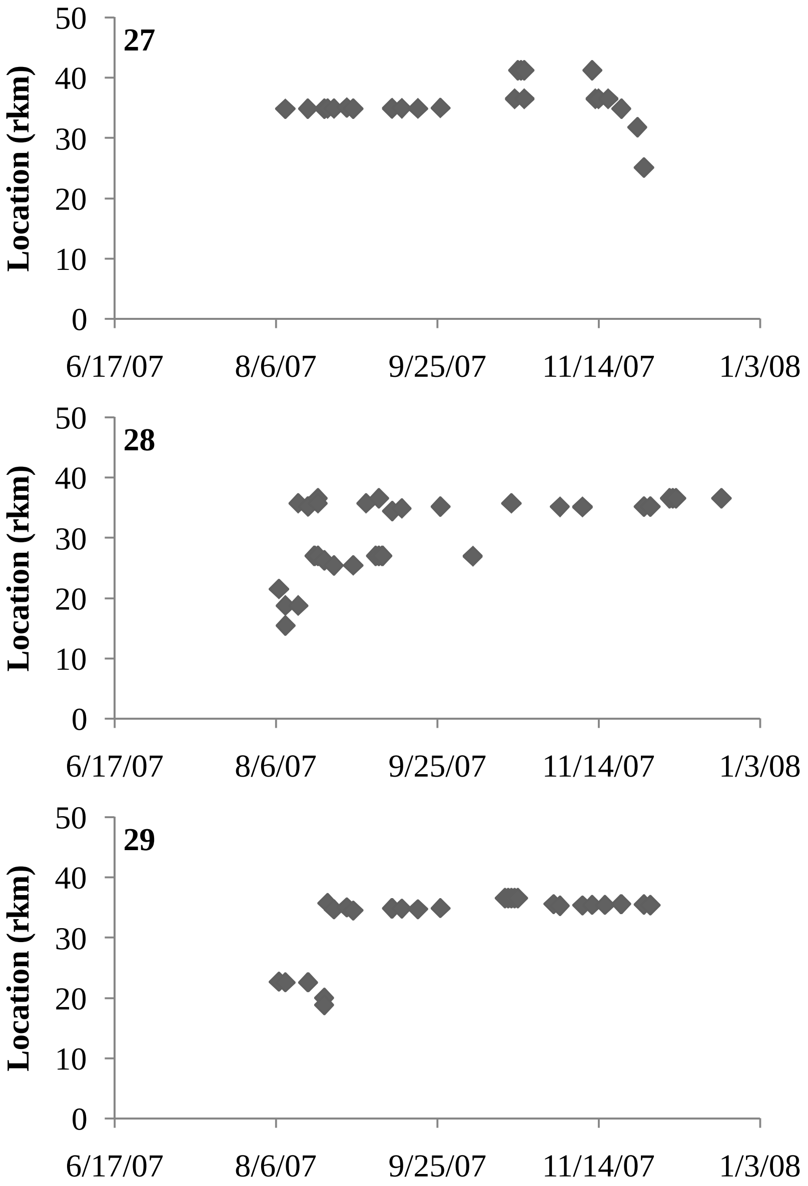

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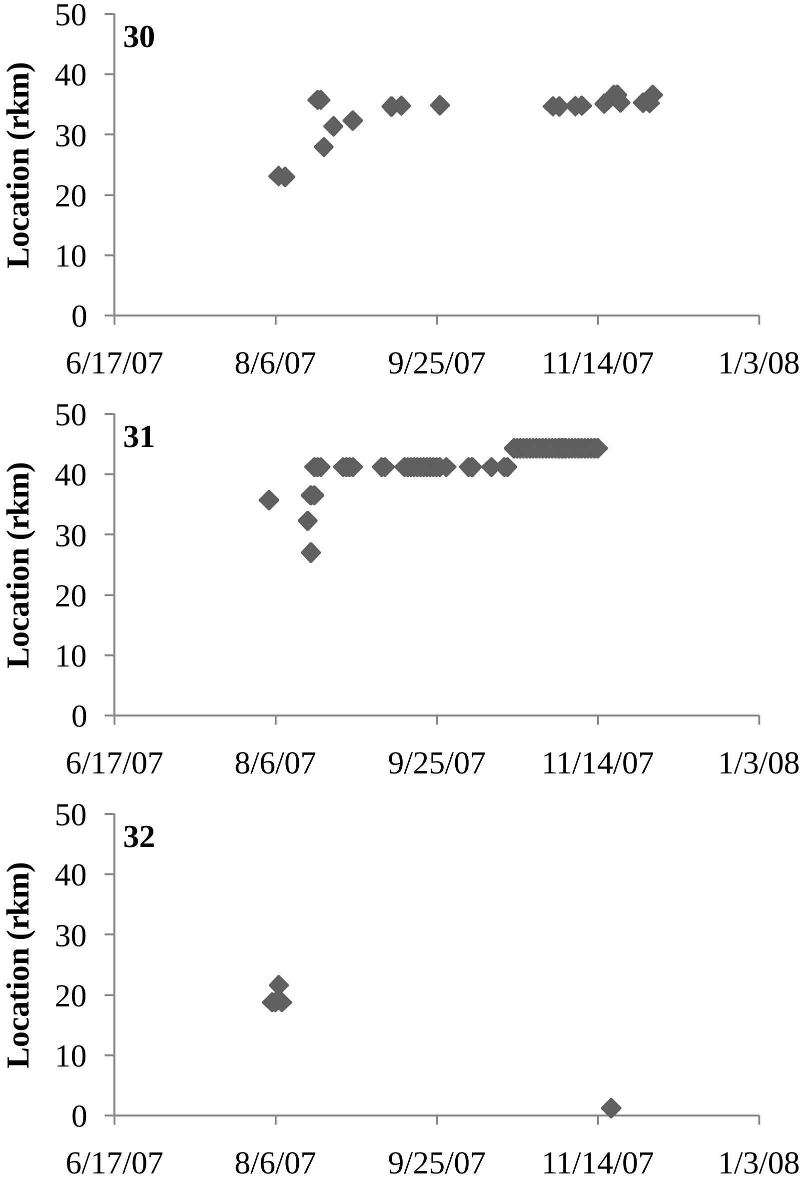

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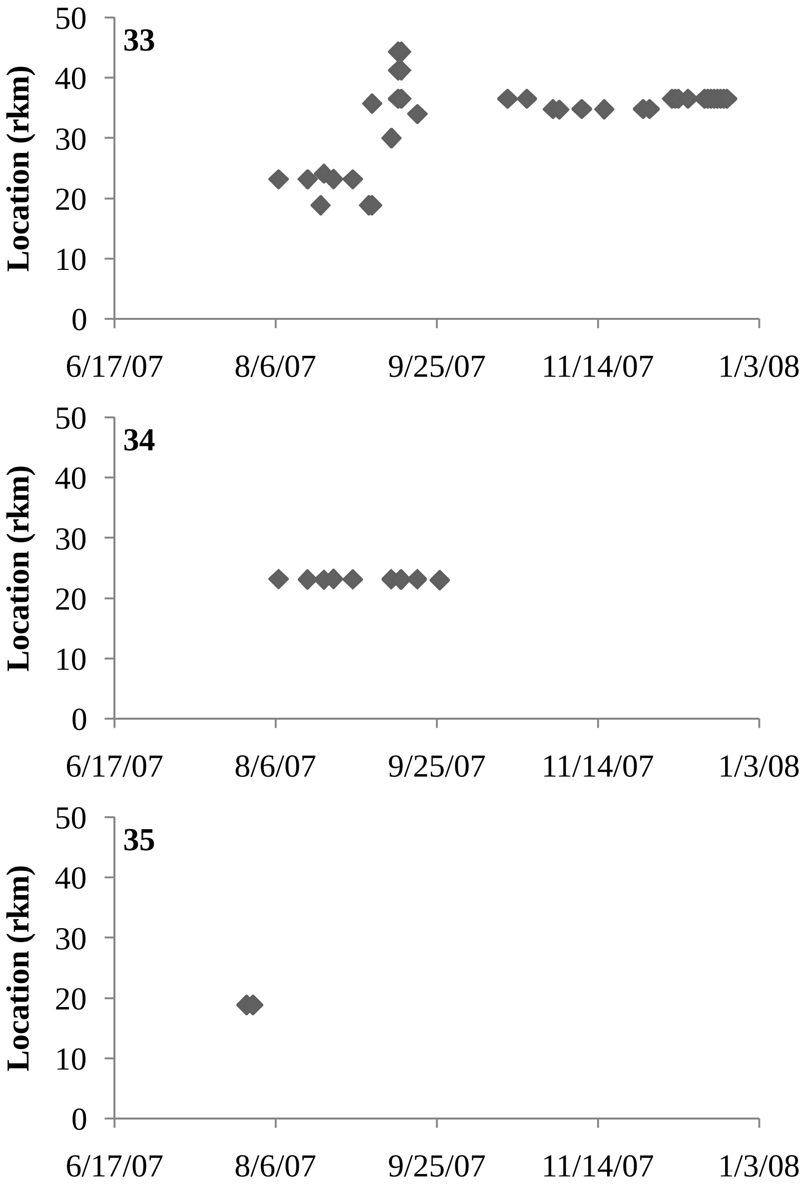

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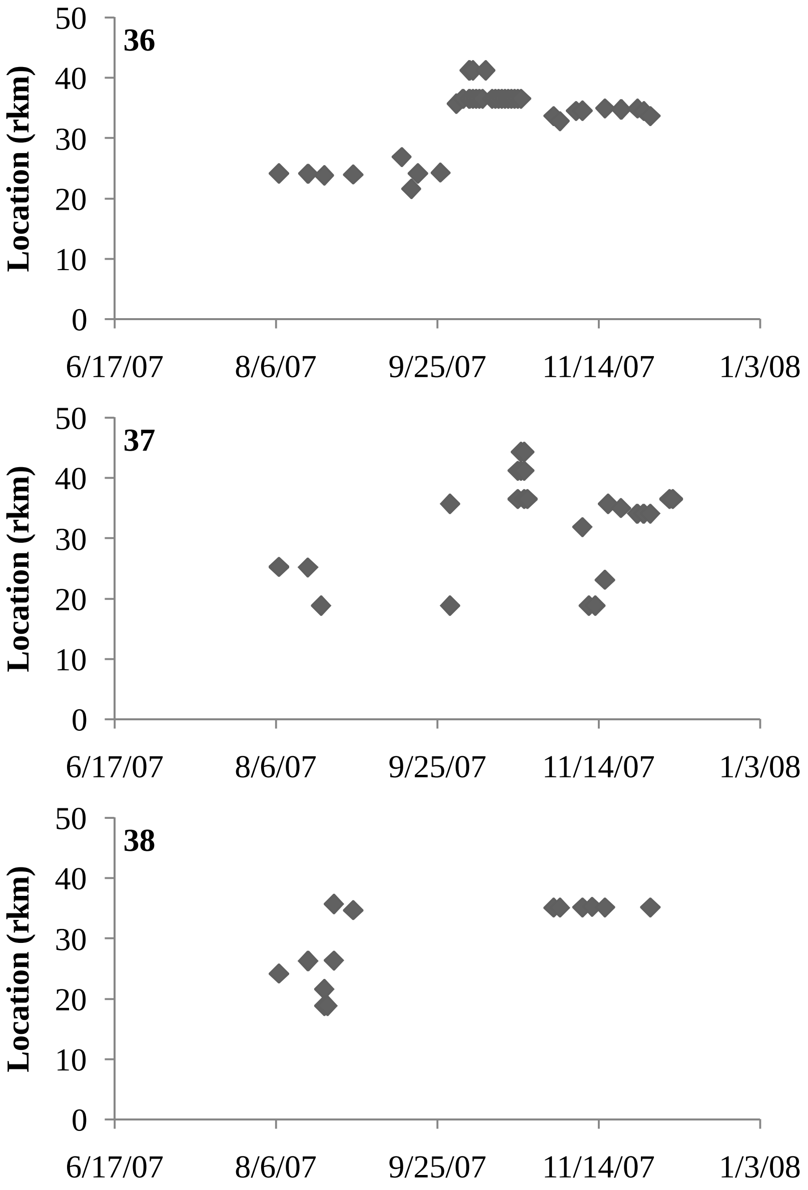

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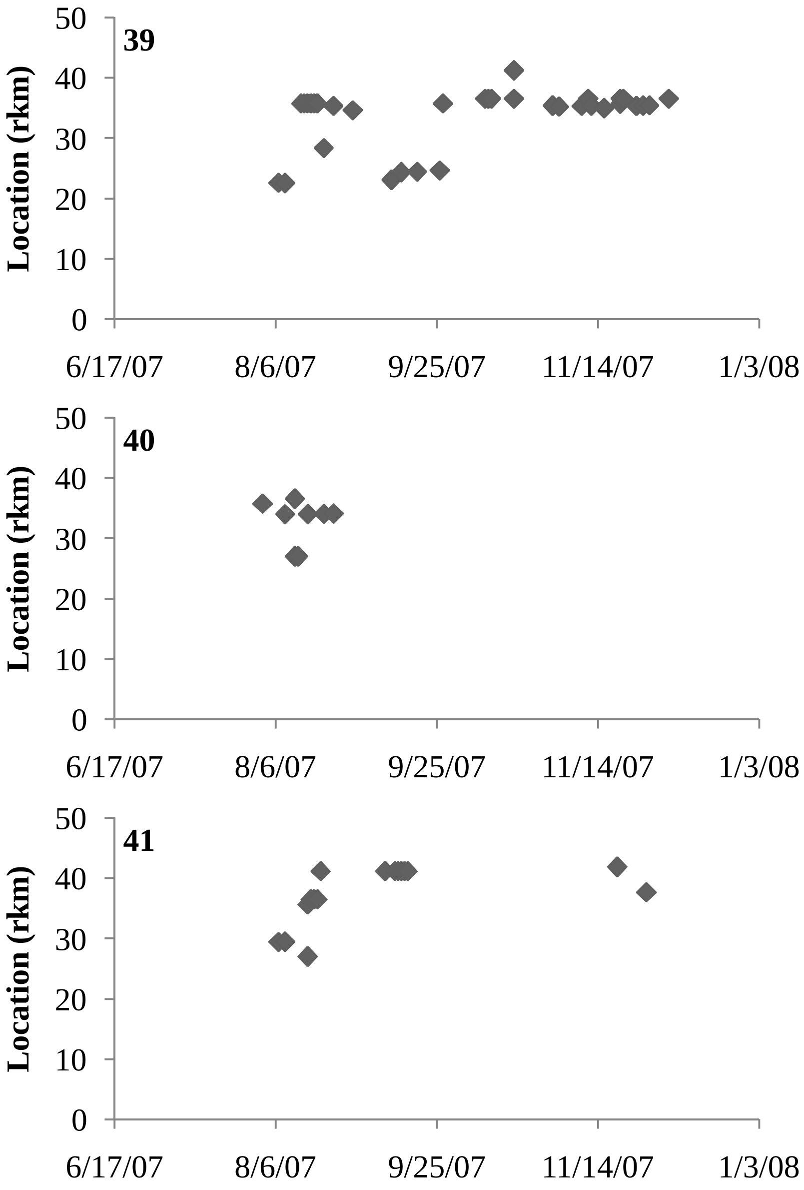

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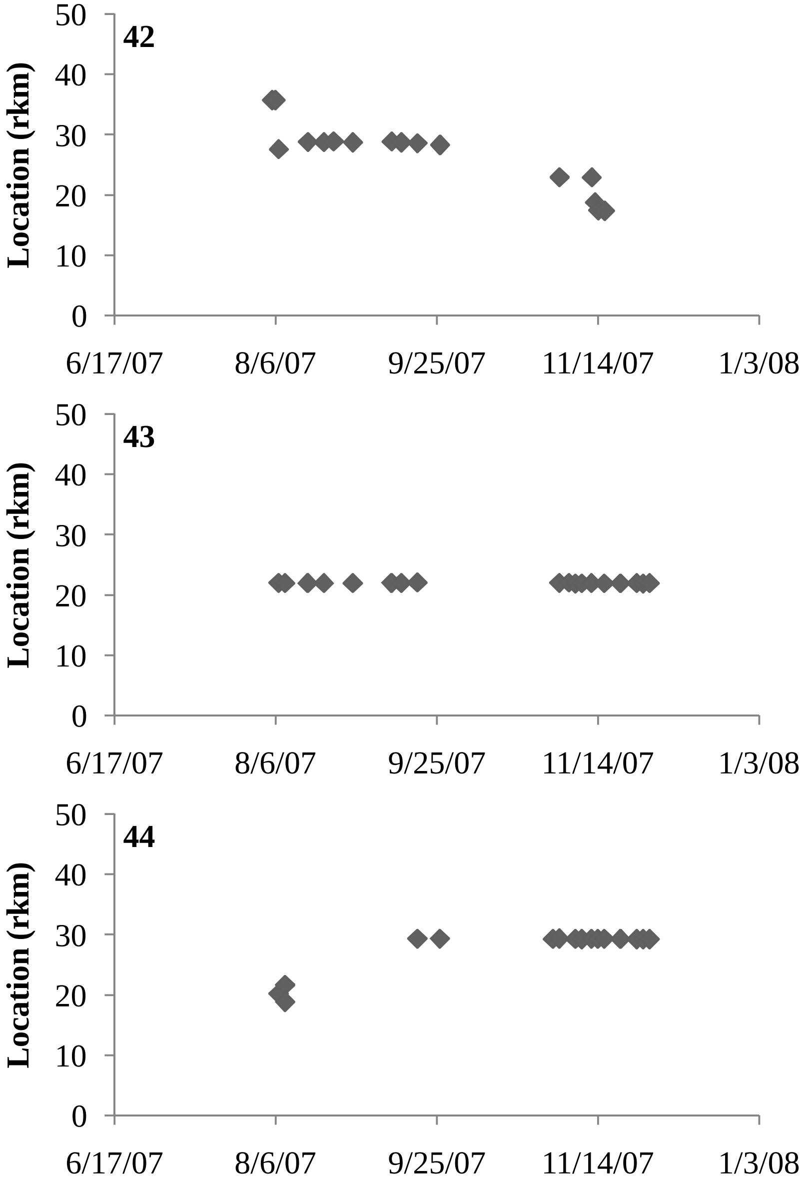

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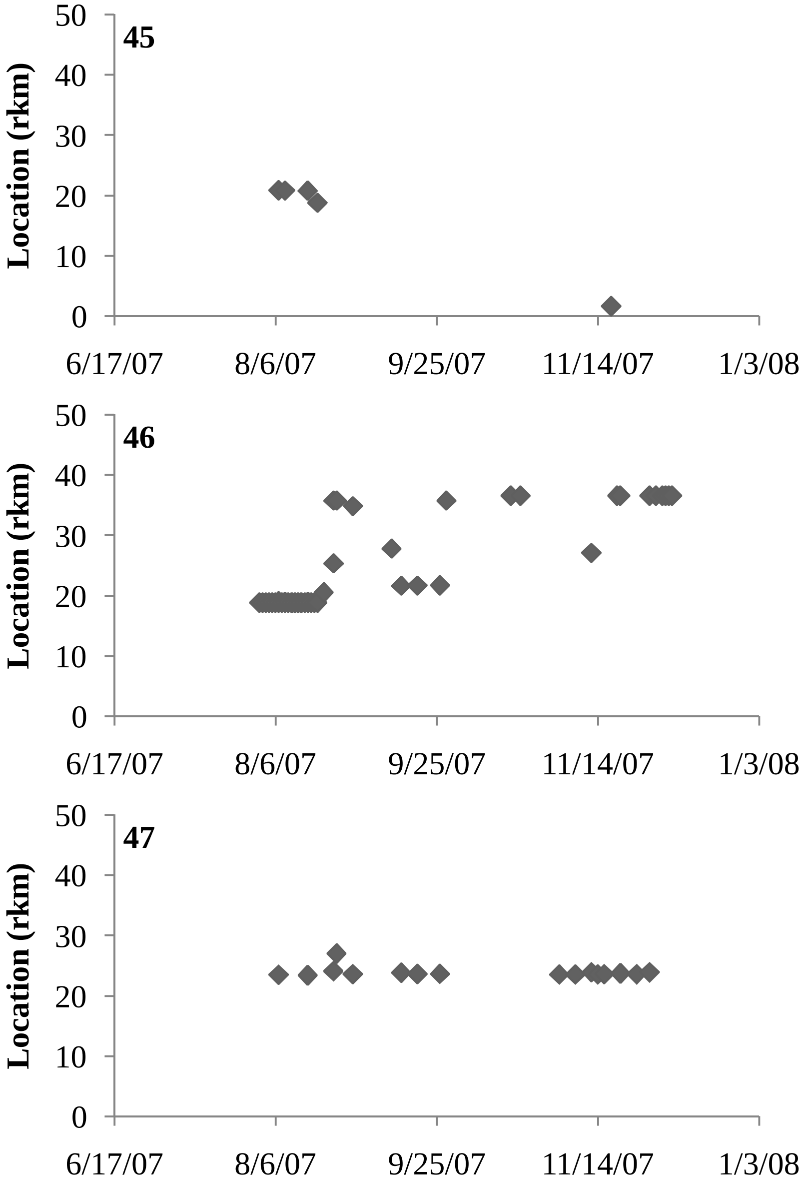

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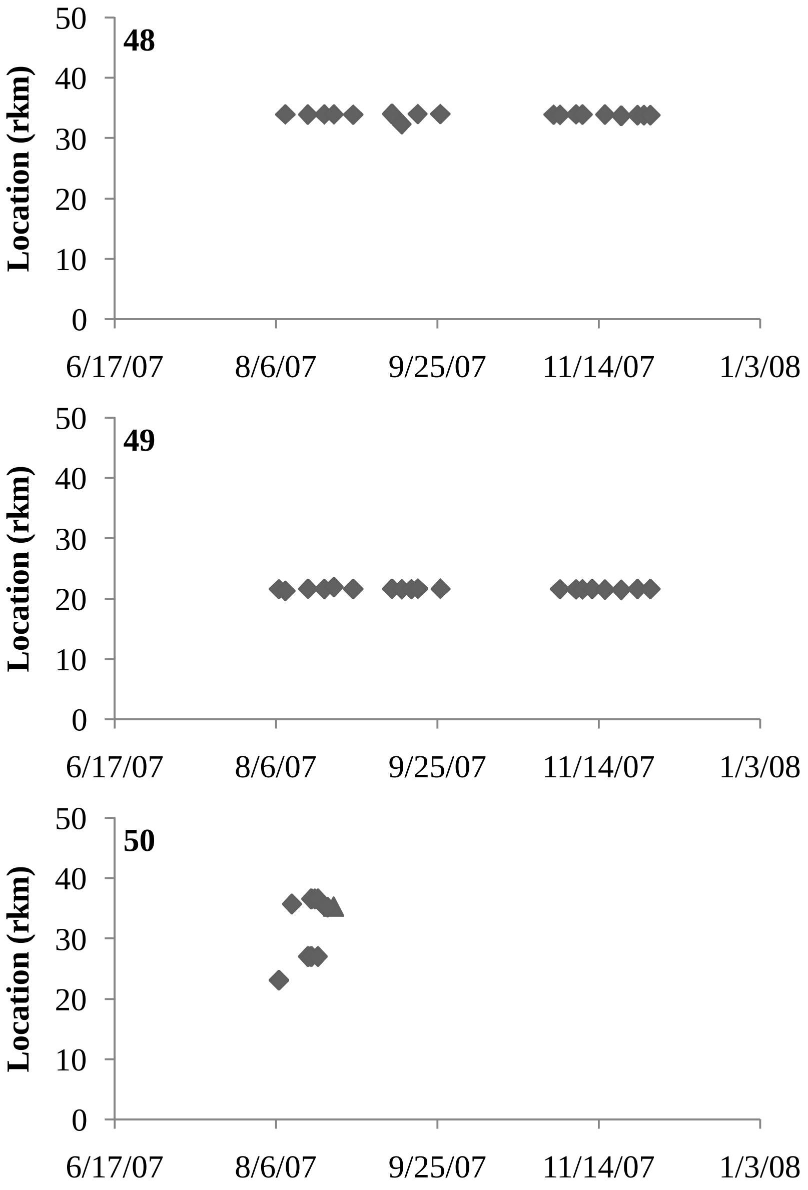

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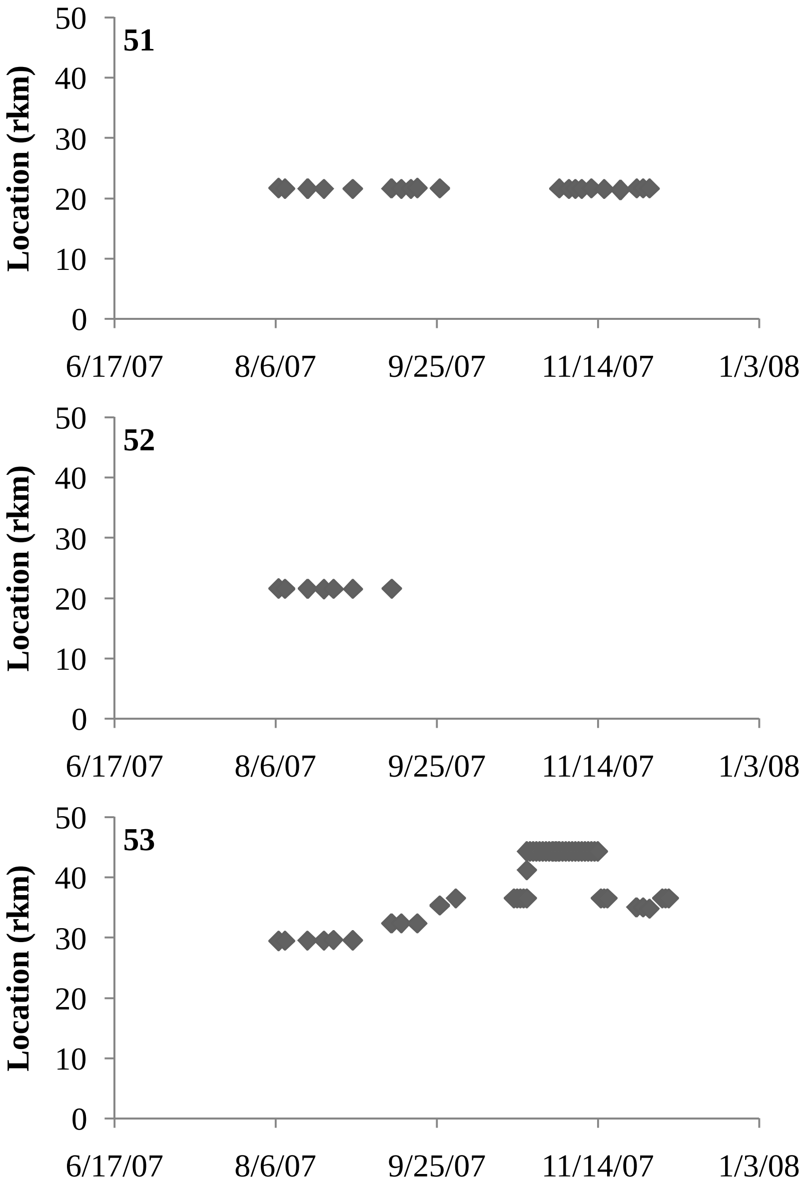

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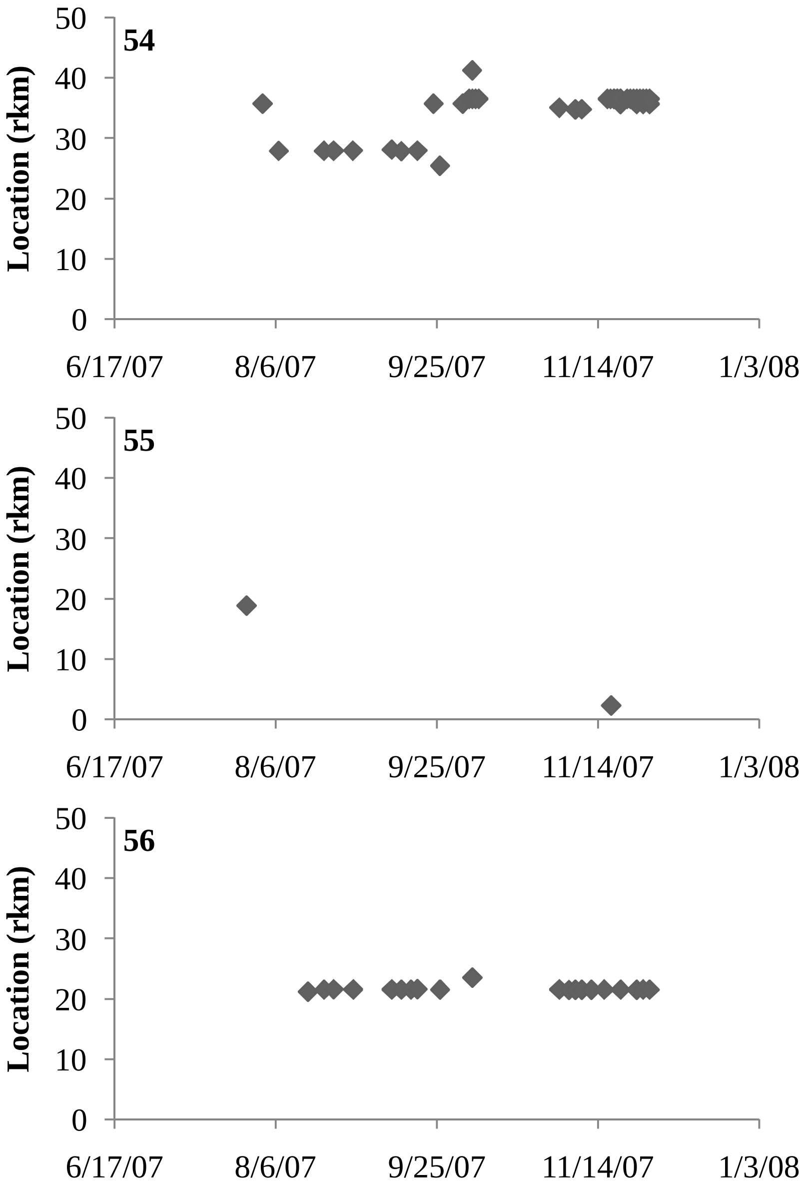

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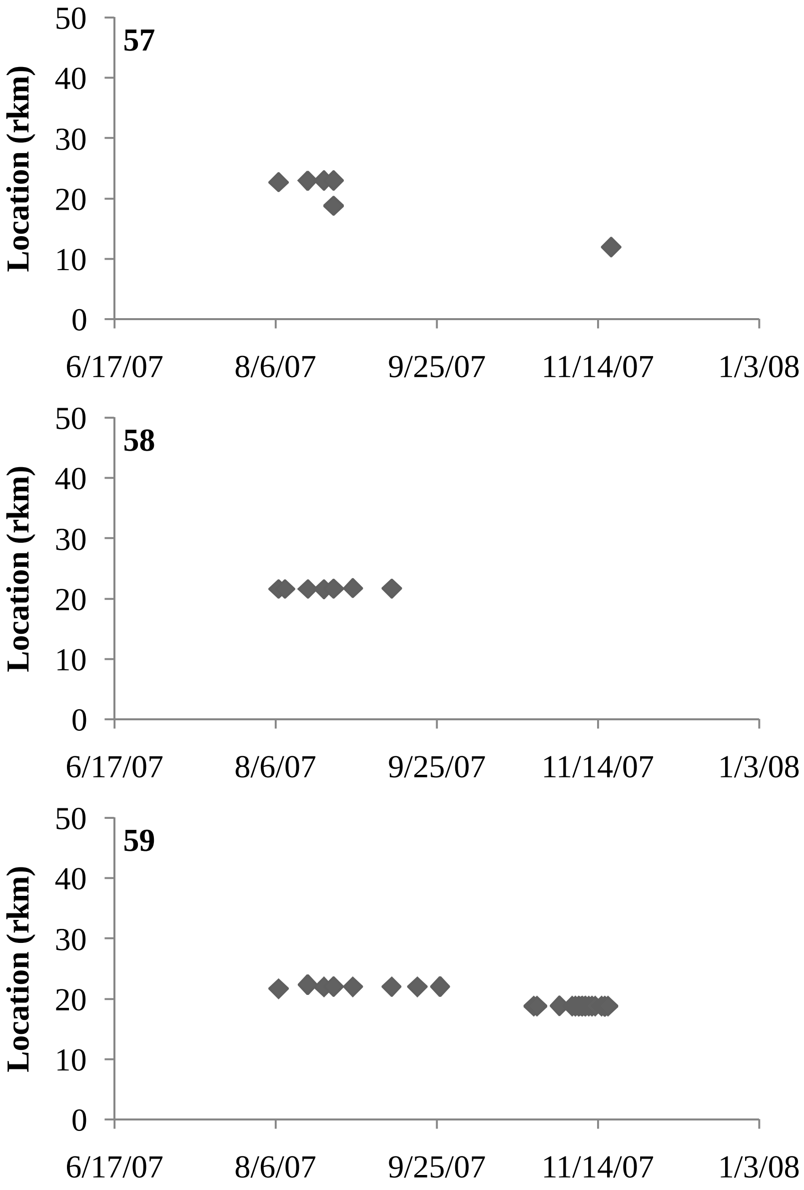

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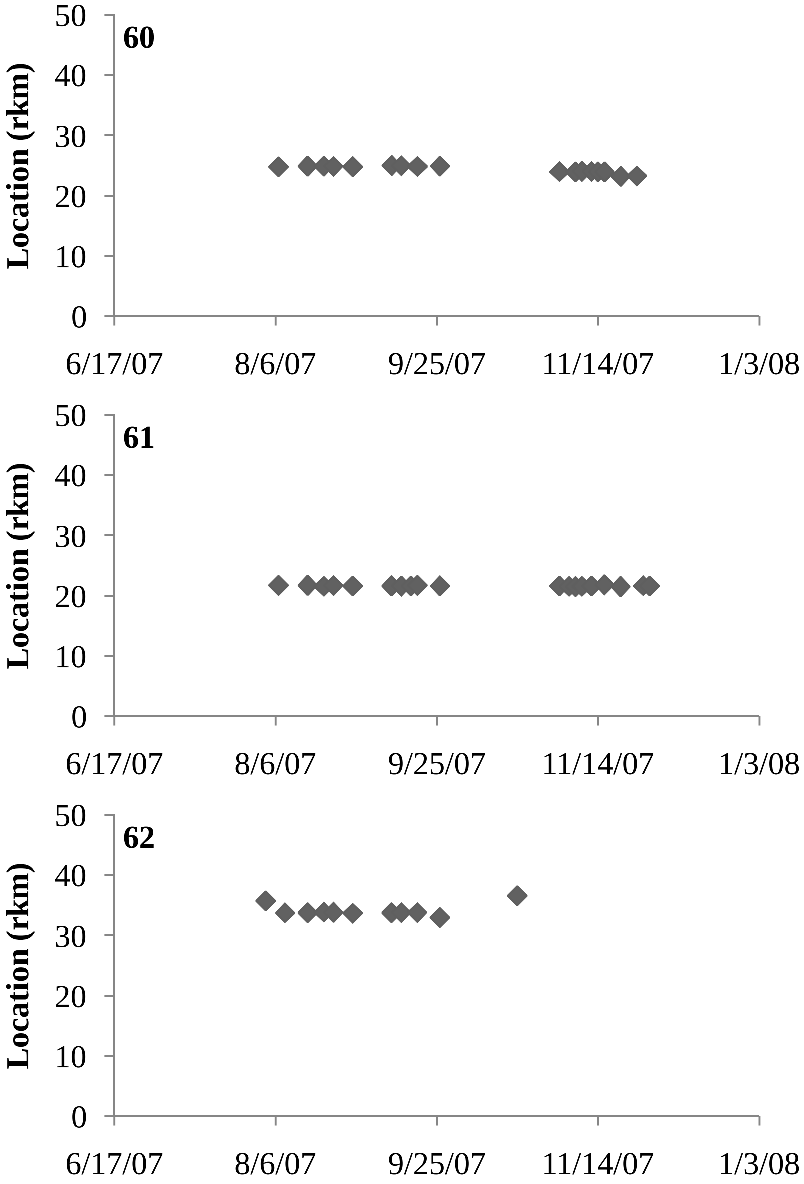
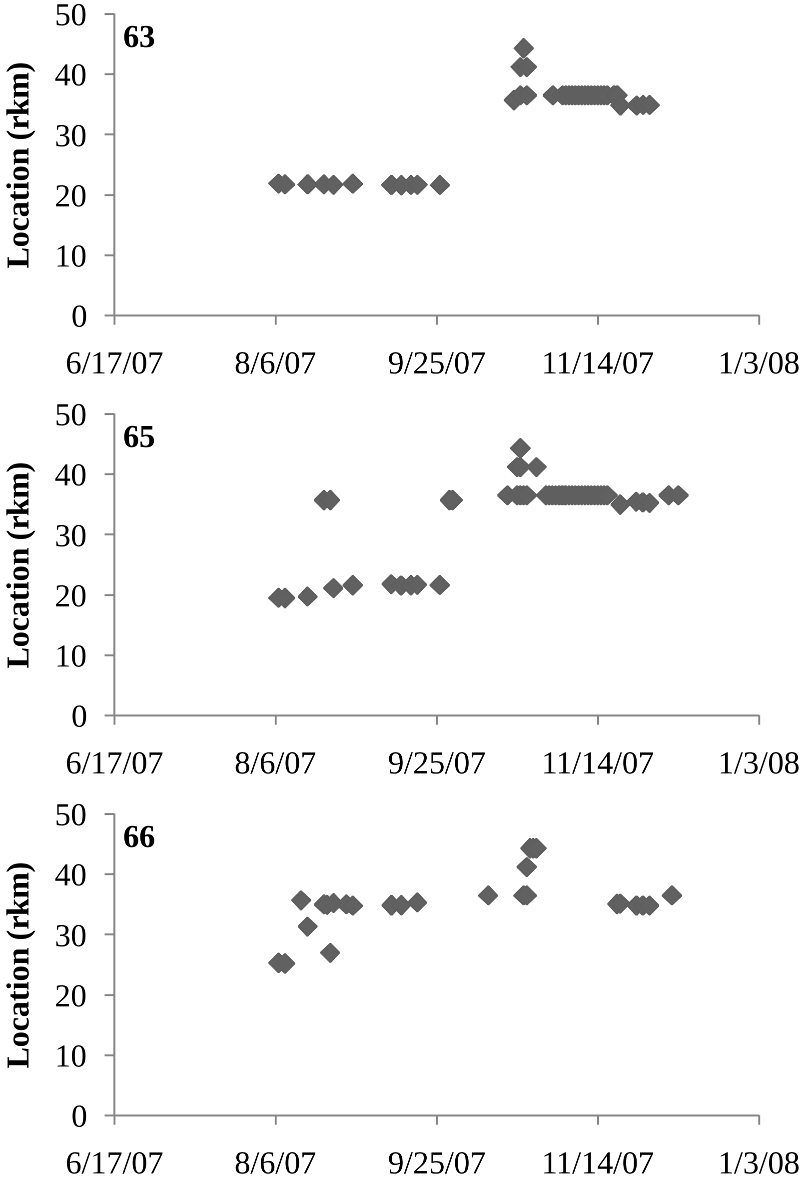


Figure 18. (Continued)



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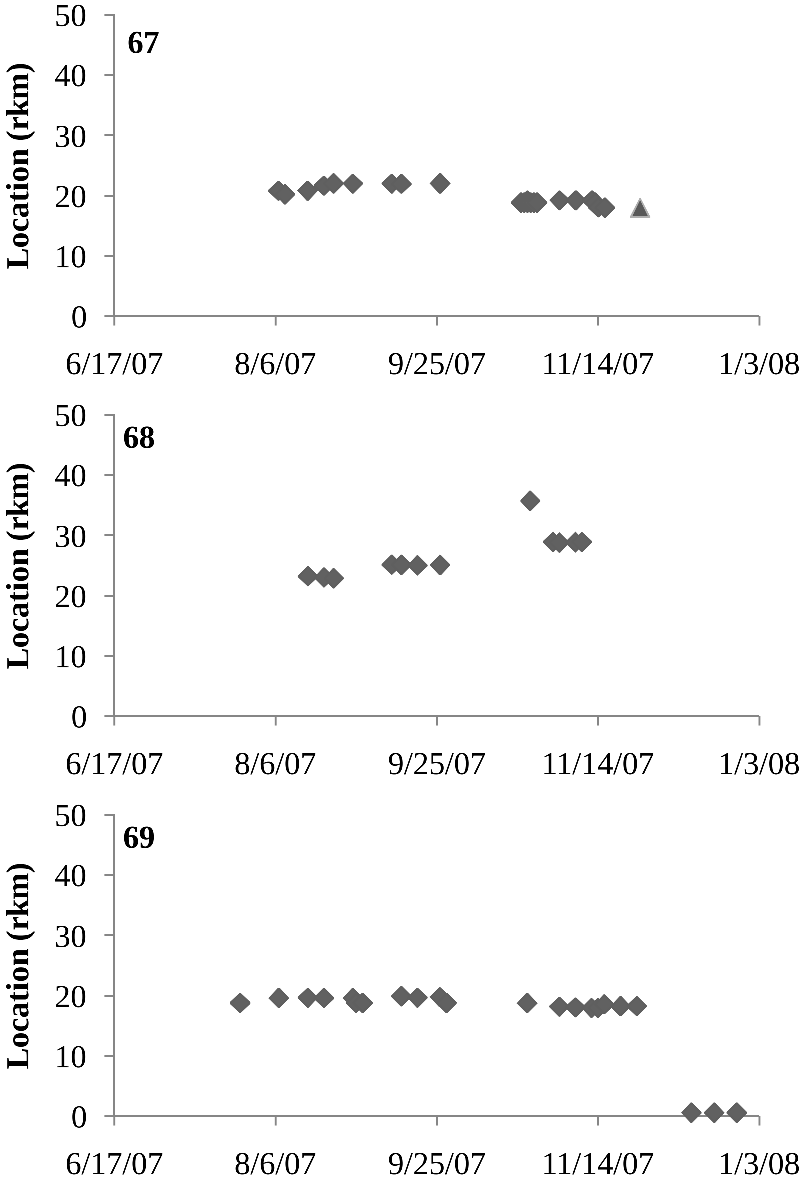

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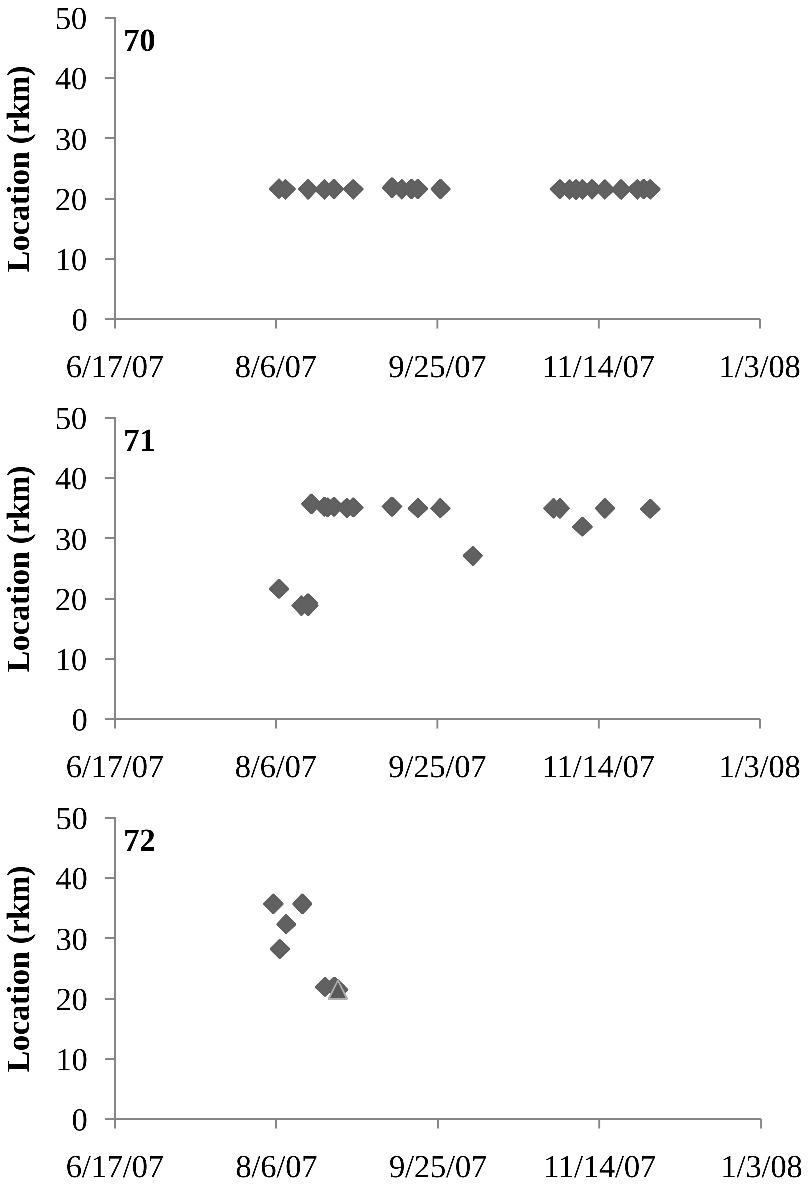

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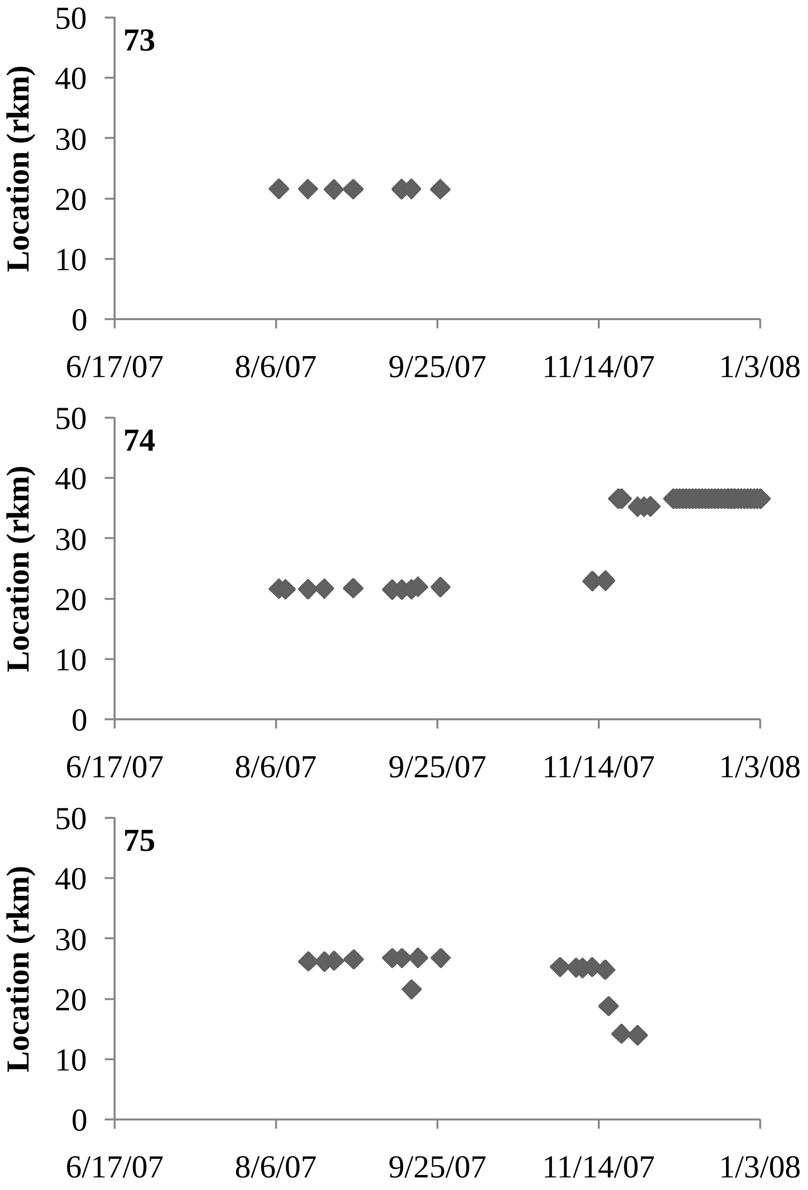

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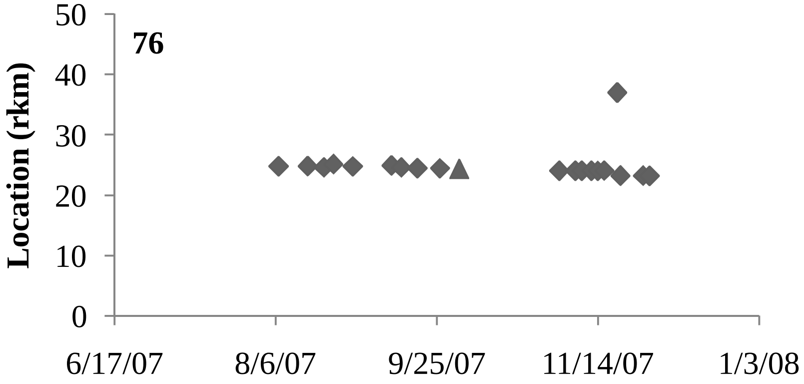

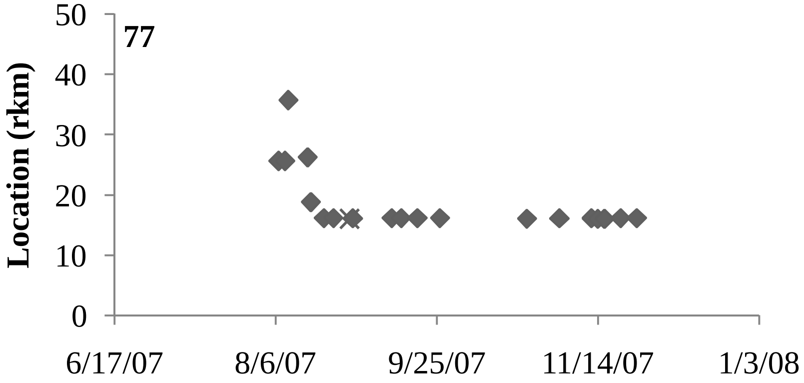

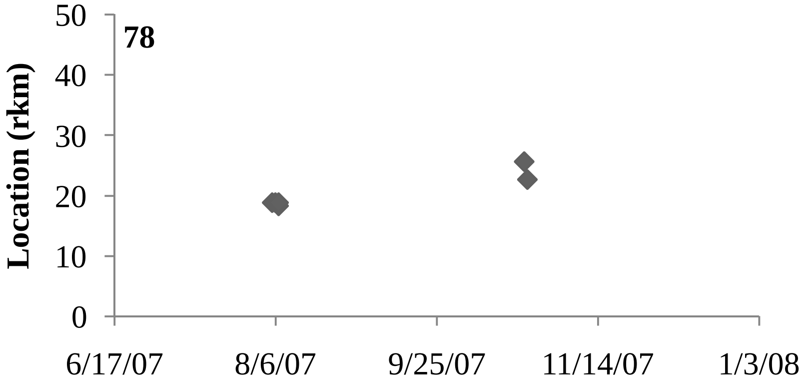

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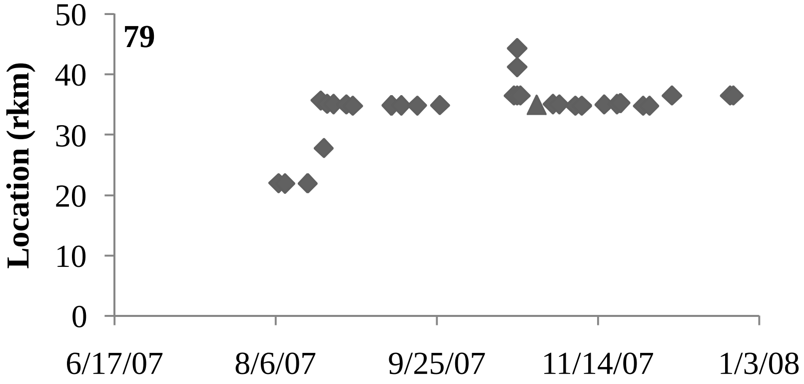

Appendix: III. Blazka Swim Tunnel Operation

Eva Schemmel and Pat Naas

Design

The Blazka swim tunnel is a tube within a tube design that can be used as a flow through or closed system (described in Booth et al. 1997 and Thillart et al. 2004). The swim chamber sits on a steel frame. A forklift is needed to transport the equipment due to its size and weight. The swim chamber can be raised with a hydraulic lever at the bottom, middle of the frame. The lever is used to tilt the chamber up at an angle to partially fill with water before fish is placed in chamber. The motor (Model: Lincoln Electric AF4P10T61) and turbine are connected at the rear of the swim tube. The lid is at the opposite end of the tube and is O-ring pressurized and bolted into place. The lid must be removed to insert a fish tail first into the inner swim chamber. A flow straightener is then placed inside the inner chamber and the lid resealed. Tighten the bolts on the lid to prevent leaking. A pump is needed to fill the swim chamber. For a flow through system, pump water in at motor end and out at lid end of swim. The swim chamber has four openings in the outer chamber for dissolved oxygen or temperature ports. If not using these ports, it is recommended that they be plugged to reduce oxygen bubbles in the swim chamber that disturb flow and reduce visibility.

Dimensions

Inner Tube Diameter: 46 cm

Outer Tube: 60 cm

Power

220 volt power is needed to operate the motor. AC drive (model:IDM Controls Inc. CIMR-P5U27P5) is used to power the system.

Flow Measurement

A flow meter is needed to measure water flow and calibrate water flow to amperage output.

Use and Setup

1. The swim tunnel should be located out of direct sunlight to avoid vision obstruction and reduce the stress on the fish.

2. Level the swim tunnel and its mount. The mount should be placed on a trailer or similar platform to ease this process.

Safety Note: Strap the mount's front end to the platform or tipping may occur.

Safety Note: Avoid placing any part of your body beneath the tube, especially when raising or lowering.

3. Raise the swim tunnel with the hydraulic lift until it sits at about a 45-degree angle.

4. Fill the swim tunnel from the rear, using the water valves located just in front of the motor. We used a hose from a water pump and duct taped the other end to the swim tunnel valve.

5. Before water begins spilling out the open front end of the unit, shut off the water.

Note: We anesthetized our fish for 8 minutes with 2.5 ppm MS-222 before placing them in the swim tunnel.

6. Insert the fish tail first into the tube.

7. Insert the straw array/flow straightener into the tube with the wide end up front and the tapered end facing the rear.

Note: Do not stress the bolts of the front cover by forcing the cover into place.

8. Attach the front cover. Set the bottom bolt first, then slide in the remaining bolts.

9. Attach black bolt fasteners

10. Ensure the front drain valves are closed.

Note: When tube fills completely, a small jet of water will erupt from the front.

11. Resume filling tube. When full, slowly open one front valve until only a small and steady trickle of water escapes from the front top relief port.

Note: If the relief port or probe ports on top of the tube allow air bubbles in, water visibility and velocity will be compromised. The relief port is easily managed by adjusting *either of the front water valves. In addition, the probe ports can be blocked up completely.*

12. We allowed the fish at least 30 min to acclimate to the swim tunnel at a velocity of 6 cm/sec.

13. In normal operation, water flows to the rear of the respirometer through the inner tube as the impeller pulls it. Once it hits the rear wall, it's forced through the outer tube back to the front.

14. Carefully monitor the fish for signs of fatigue and stress.

Note: If the fish rests on the back of the tube, it can be shocked with two electrical lines hooked up to a 9-volt battery. There are electrodes built into the metal bands at the rear of the tube. It's not necessary to leave the battery hooked up; touch the leads to the battery to apply the shock and immediately disconnect.

15. When run is complete, shut of power and pump.

16. Open front value and use hydraulic lever to tilt up so fish will be in water until removal from swim chamber.

Safety Note: Avoid placing any part of your body beneath the tube, especially when raising or lowering.

17. After water drains to half-way, open front cover by loosening bolts to allow excess water to spill out.

Note: Have a net ready to catch the fish.

18. Remove front cover completely and hold net under chamber to catch fish. Have second person lower the chamber via hydraulic lever. Allow fish to slide out into the net.

References

Booth, R. K., R. S. McKinley, et al., F. Okland, and M. M. Sisak (1997). In situ measurement of swimming performance of wild Atlantic salmon (*Salmo salar*) using radio transmitted electromyogram signals. Aquatic Living Resources 10: 213-219.

Van Den Thillart, G., V. Van Ginneken, F. Korner, R. Heijmans, R. van der Linden, and A. Gluvers (2004). Endurance swimming of European eel. Journal of Fish Biology 65:312-318.

Supplementary Pictures

1. Motor

2. Blazka Respirometer: During fish removal after trial was run.

3. Adjusting water flow to remove air bubbles. Picture on right is the correct adjustment. Slight overflow prevents air bubbles.

Appendix IV: Supply List

Table 9. Supplies for fish surgery, radio telemetry, and blood plasma analysis.

General Description	Company/Model
Surgical Supplies:	
Coded nano radio tag	Lotek, NTC-6-2 Dimensions:9.1X30.1mm, 4.5g
EMG tag	Lotek, CEMG2-R16-25 Dimensions:16mm
Radio Receiver, PPM	Lotek, SRX 600
Antenna Switch Box	Lotek, ASP-8
Floy/Spaghetti tag	Floy Tag & Mfg. Inc Contact: Betsy Conrad #1-800-843-1172 Model: 3"T-bar Anchor Tag FD-94, Color blue with black labels
Pistal grip Mark II W/	Floy Tag & Mfg. Inc
Long regular needles	Floy Tag & Mfg. Inc
Long needle sharpeners	Floy Tag & Mfg. Inc
Suture Tool	Needle holder VWR 21909-358
Anesthesia	Tricaine methanesulfonate (MS-222, Argent Chemical Laboratories, Redmond, WA)
Stress Coat	Aquatic Ecosystems
Operation Table	Aluminum 60" custom built at OHCR
Scalpel	Curved blades
Large fish nets	
Sterilizing Agent	Hydrogen peroxide
Suture	Maxon , ESutures.com 19mm needle, 3/8 circle reverse cutting
Latex Gloves	
Sharps Container	
Water-proof data sheets	
Receiver Supplies:	
Radio Receiver, PPM	Lotek, SRX 600
Antenna Switch Box	Lotek, ASP-8
Car Batteries	Minimum one per receiver
Battery trickle chargers	85-300A 12V 1.5 amp NAPA to continuously charge batteries hooked up to receivers
Solar panels	For receivers without power outlets
Attenuators	To increase and balance signal strength (
Antenna Tripod/Bases	To anchor and set up antennas

Table 9. (Continued)

Hormone Analysis:	
Clinical Centrifuge	VWR #82013-800, 120 volts
4ml Lithium Heparin Vacutainers	VWR # BD366667
6ml Lithium Heparin Vacutainers	VWR# BD367886
1 ml Tuberculin Syringe	VWR#BD309602
Needle 20G 1.5”	VWR #VT7215
Needle 18G 1.5”	VWR#BD-305196
Needle 21G 1.5”	VWR#BD-305165
Disposable Pipet 1.2ml	VWR#16001-170
Heparin Natelson Tubes	VWR#14705-018
Critoseal	VRW#18000-298
Micro-Hemtocrit Tube Reader	VWR#15176-816
Natelson Capillary Tube	VRW#14705-020
Sodium Heparin Vacutainers 2ml	VRW#BD367671
Microcentrifuge Tubes: 0.5ml	VWR#89000-010
Microcentrifuge Tubes: 1.5ml	VWR#89000-028