North American Journal of Fisheries Management 29:1728–1742, 2009
American Fisheries Society 2009
DOI: 10.1577/M09-022.1

[Article]

Seasonal Movement of Dolly Varden and Cutthroat Trout with Respect to Stream Discharge in a Second-Order Stream in Southeast Alaska

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Abstract.—The relationship between the movement of small (<150-mm) Dolly Varden *Salvelinus malma* and cutthroat trout *Oncorhynchus clarkii* and stream discharge is not well known in streams of southeast Alaska. We measured movement in a small headwater stream using passive integrated transponder (PIT) tags and stationary antennas to record time and date of movement. Fish with PIT tags were detected by transceivers and stationary antennas in the stream. The date and time of detection at an antenna were matched with stream discharge (m^3/s) at the same date and time. Most Dolly Varden moved upstream during late summer and early fall. Most cutthroat trout movement was in May, and movement declined through the summer. Few fish moved during the winter. Most fish moved within a narrow discharge range, with a few moving at higher discharges. More than 97% of fish from both species were detected as moving upstream at discharges below the 5% exceedance level during the 4-year period of discharge measurements. Dolly Varden and cutthroat trout moved throughout the entire length of usable habitat in the stream. Connectivity throughout watersheds even within headwater streams is important and can be maintained for these species by use of road crossings that ensure passage over a range of flow conditions such as those described here.

Recent studies in southeast Alaska have demonstrated that both resident and anadromous salmonids are present in streams with gradients greater than 5% (Bramblett et al. 2002; Bryant et al. 2004). Bryant et al. (2004) reported small (<150-mm) Dolly Varden *Salvelinus malma* and coastal cutthroat trout *Oncorhynchus clarkii clarkii* in reaches with gradients of 15% or higher. Sea-run Dolly Varden were observed during the fall in pools situated in reaches with average gradients over 15%. Dolly Varden and cutthroat trout were the primary species using tributary reaches with gradients greater than about 6% (Bryant et al. 2004). Coho salmon *O. kisutch* fry also were found at gradients greater than 10% in the upper reaches of tributaries; however, they were most abundant at gradients less than 5%.

Movement of salmonids throughout watersheds is a generally accepted paradigm, and connectivity within small, high-gradient (>5%) streams and to downstream reaches is an important concern for management of these species (Gowan et al. 1994; Gowan and Fausch 1996). Seasonal movement is common among salmonids throughout their range (Peterson 1982; Swales et al. 1987; Bramblett et al. 2002; Bryant et al. 2004). Several studies have established that Dolly Varden and cutthroat trout move both within and among streams (Armstrong 1974; Swanberg 1997; Bonneau and Scarnecchia 1998; Adams et al. 2000). However, their movement patterns with respect to stream discharge in high-gradient streams are not well known, particularly for streams in southeast Alaska. Many high-gradient streams throughout southeast Alaska have road crossings that either do not allow fish passage or are barriers to movement at most discharge levels (U.S. Department of Agriculture 2005).

Two important questions are "What is the relationship between fish movement upstream and discharge?" and "Do fish move during periods of peak discharge?" The goal of this study was to examine movement of Dolly Varden and cutthroat trout in relation to stream discharge within a small, second-order, high-gradient

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Received February 17, 2009; accepted August 18, 2009
Published online November 5, 2009

(>5%) stream. Specific objectives were to (1) determine the range of discharges in which Dolly Varden and cutthroat trout move upstream; (2) document the seasonal movement of these fish; (3) determine the distance moved by the fish; and (4) describe the relationship between upstream movement and discharge based on the percentage of time discharge is exceeded.

Methods

Study site.—We intensively sampled a single stream, Hobo Creek, Alaska, located on a road system with access throughout the year. The study was designed as a case study to determine the movement of Dolly Varden and cutthroat trout in small, high-gradient streams under naturally occurring discharges. Dolly Varden and cutthroat trout are the primary species in these headwater streams. Coho salmon are present in Hobo Creek, and pink salmon *O. gorbuscha* spawn in the lower reaches. A few larger (>250 mm) anadromous Dolly Varden and cutthroat trout may have entered the stream, but we did not sampled them. The study required development of a methodology for measuring real-time fish movement without altering natural streamflow. Logistical and equipment constraints were an important consideration in the selection of the study site, and the initial phase of the study required considerable testing, development, and modification of instrumentation in the stream.

Hobo Creek is located on the Petersburg road system approximately 10 km from Petersburg, southeast Alaska (Figure 1). Hobo Creek is a second-order stream with gradients ranging from 2% in the lower reaches to about 15% in the higher reaches of the study section. The average width is about 1.5 m. The channel morphology in Hobo Creek is mainly controlled by bedrock. Channel form varies from reach to reach, with step pools in the higher-gradient reaches and plane bed and pool riffle morphology in the lower-gradient reaches. Hobo Creek is crossed by a bottomless, multiplate arch culvert located about 300 m from the stream's mouth; the streambed is encompassed within the culvert structure. Conditions in the culvert match stream conditions near the culvert, and fish of all sizes can move through the culvert unimpeded.

Hobo Creek extends 2.5 km from origin to mouth. The length of our study section was 1,150 m, and this section began 188 m upstream of saltwater influence. The upstream boundary of the study section was close to the upper extent of fish habitat and included most of the available fish habitat in the stream. The study reach was divided into 10-m increments and marked with white, 18-mm-diameter polyvinyl chloride (PVC) pipe to identify stream sections where fish were captured.

Fish sampling.—The goal of sampling for Dolly Varden and cutthroat trout was to capture and tag as many fish as possible during each sample period. The entire study reach (1,150 m) was sampled at least three times during the spring, summer, and fall of 2001–2006. Spring samples occurred in April and May, early summer samples were taken in June and July, and late-summer samples were taken in August and September. Fall samples were completed in October and November. Fish were captured and tagged throughout the entire length of the study reach.

Fish were captured using minnow traps baited with salmon eggs that were placed in perforated Whirl-pak bags (Nasco). Forty traps were spaced at about 2-m intervals beginning downstream. After at least 1 h, fish were removed from the traps and the traps were reset upstream. The entire length was usually completely sampled in 3 or 4 d. The location (midpoint of the 10-m section) was recorded for each fish (≥60 mm) that was captured or recaptured. All fish were identified and measured (fork length, mm) and were scanned for passive integrated transponder (PIT) tags. Only 60-mm and larger Dolly Varden and cutthroat trout were tagged. Location of capture, fish length, and PIT tag number were recorded. The adipose fin of all tagged fish was removed to monitor potential tag loss. Recaptured fish were identified by tag number and were re-measured. A small number of juvenile coho salmon also reside in the stream but were not tagged. Most juvenile coho salmon were smaller than 65 mm, and these fish do not remain in the stream for more than two summers.

Antenna configuration.—We used two types of stationary antennas to detect PIT tags in cutthroat trout and Dolly Varden (Jenkins and Smith 1990; Zydlewski et al. 2001). The antenna arrays at Hobo Creek consisted of three half-duplex (HD) arrays (with four antennas each) and two full-duplex (FD) antenna arrays (with two antennas each; Figure 2). The antenna array for the FD system consisted of paired antennas about 2 m apart, each with its own transceiver. The upper and lower antennas of the first FD (FD1) array were installed in 2003 at 371 and 369 m above the culvert. The upper and lower antennas of the FD2 array were installed in May 2005 at 461 and 459 m above the culvert. Recording times were synchronized and checked at least weekly. The HD arrays consisted of four antennas that were multiplexed into a single transceiver so that fish were recorded sequentially as they passed through each antenna. The antennas in the first HD (HD1) array were installed in August 2004 at 77, 79, 107, and 109 m above the culvert. In 2005, two additional HD arrays were installed; the HD2 antennas were installed at 558, 563, 584, and 588 m above the

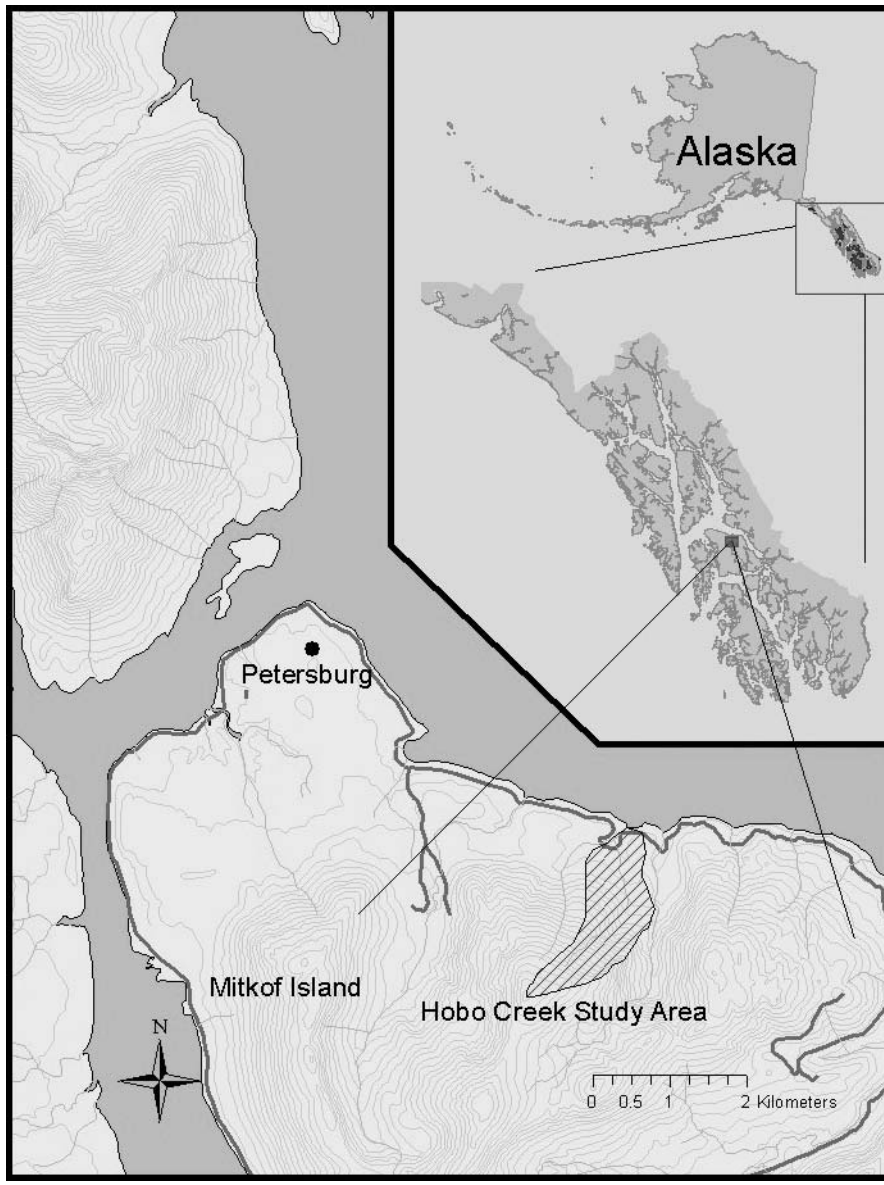

FIGURE 1.—Location of the Hobo Creek watershed (cross-hatched area) and study area near Petersburg, Alaska.

culvert, and the HD3 antennas were installed at 826, 829, 888, and 890 m above the culvert (Figure 2).

The FD antennas were enclosed in a watertight PVC casing and were 75 cm across and 30 cm high. The size of the antenna was limited by the type of transceiver (DC powered) and did not span the stream width. Rather than constrict flow, the paired rectangular antennas were each placed in a structure that contained the antenna (without altering the stream substrate) on one side and a high-gradient (>10%), smooth chute on the other side. The chute effectively blocked upstream movement of fish at all flows, thereby forcing fish moving upstream to pass through the two antennas. However, some fish moving downstream were able to pass down the chute and were not detected. Detection of fish moving upstream was our primary concern. The HD antennas were marine-grade, 12/2-AWG (American wire gauge) cable (10 × 4 mm) that formed a rectangular loop (approximately 1.5 × 2.0 m depending on the width of the stream) around the stream cross

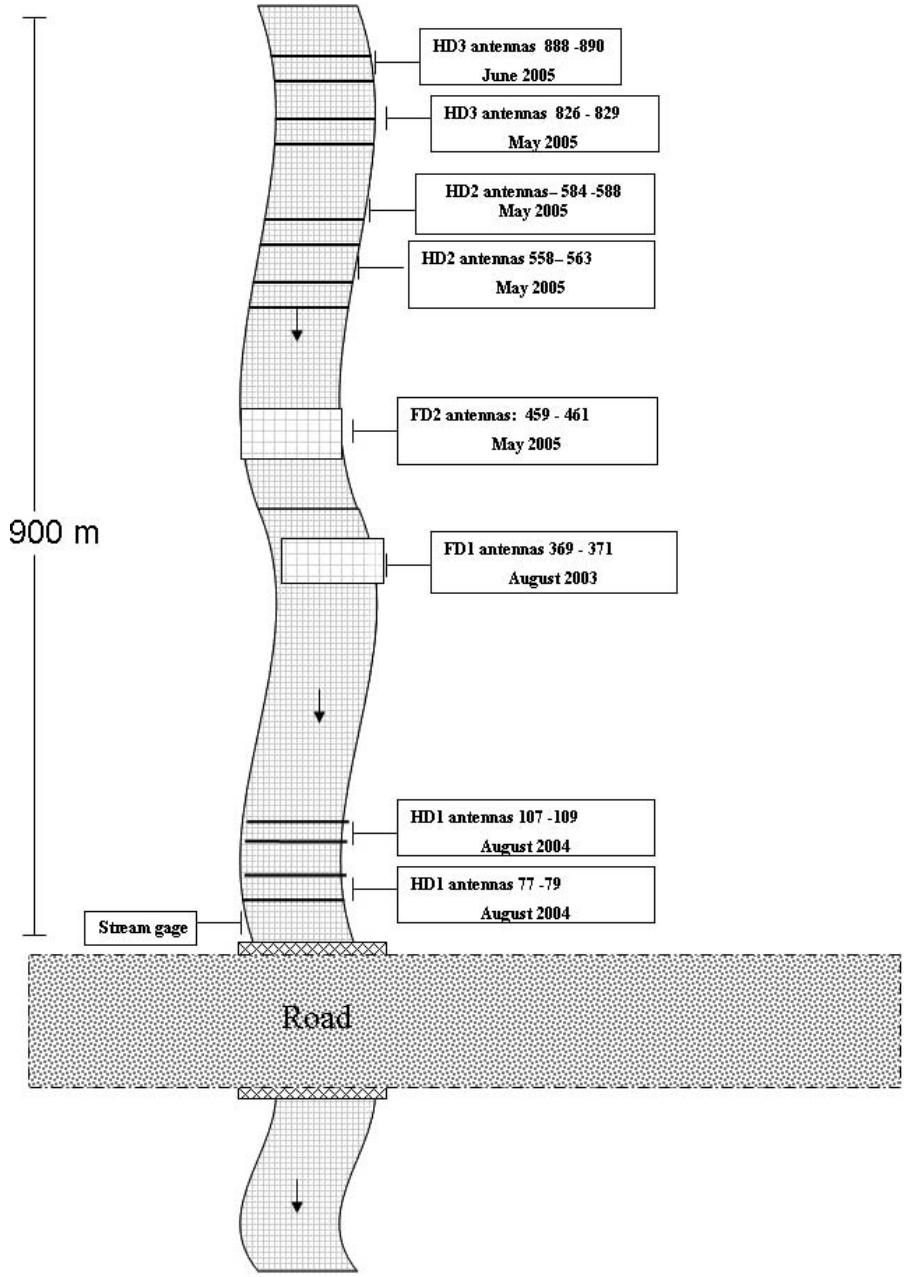

FIGURE 2.—Locations of the full-duplex (FD) and half-duplex (HD) antenna arrays, and antenna distances (m) from the road crossing, along the study reach in Hobo Creek, Alaska.

section. They were anchored on the stream bottom and secured with support cables. No structure in the stream was needed to hold the HD antennas.

The 11.5- × 2.1-mm FD tag was injected into cutthroat trout (≥60 mm) and Dolly Varden (≥60 mm) with a syringe-type injector (Jenkins and Smith 1990). From 2001 to April 2004, the FD tag was placed in all 60-mm and larger fish. After April 2004, the 23-mm HD tags were surgically placed into all 110-mm and larger fish and the FD tags were injected into smaller fish. Fish smaller than 110 mm were not tagged with the larger tags because of the potential for inducing

mortality or influencing fish movement behavior. Smaller HD tags were not available at the time of the study. Initially, all fish tagged with the larger HD tags and a subset of fish tagged with the FD tags were retained overnight to monitor tag retention and survival. No mortalities associated with tagging were observed.

As fish moved past the antenna, transceivers recorded the tag number and detection date and time for each fish. Detection of fish moving upstream was an important part of the study. For a fish to be identified as moving upstream, it had to be detected at a lower antenna at a time earlier than the detection at an upstream antenna. If fish were not detected sequentially at two or more antenna, direction could not be determined. Fish were not used in the analysis of movement versus discharge if the direction of movement could not be determined. Cutthroat trout and Dolly Varden were analyzed separately.

Passive integrated transponder tag systems using a pass-through antenna system where the fish swims through the antenna are reasonably efficient at a wide range of flow conditions (Connolly et al. 2008). Connolly et al. (2008) observed 100% detection at low discharges and 95% detection at the highest discharges in their pass-through system. The system installed in Hobo Creek also was a pass-through system. The antennas were periodically tested by passing a tag attached to a stick at various locations near and through each antenna. The test tag was detected consistently at discharges higher than 0.5 m^3/s. When the tag was not detected, discharge was less than 0.5 m^3/s, and usually the problem was associated with low battery power or antenna tuning issues, which were corrected. These occurrences were rare (<2% of the tests). The ability of the antenna to detect tags did not appear to be affected by water flow conditions during these checks. The water level at these discharge regimes did not create conditions conducive to fish movement around the antennas; that is, if fish were moving, they would have been detected at the antennas. More than 20,000 detections (all antennas combined) were recorded over the 2004–2006 sample period; many of these were multiple detections of the same fish, instances in which fish direction could not be determined, or both.

Stream discharge and stage.—A record of stream discharge was taken to establish flow duration for Hobo Creek. In October 2000, the Tongass National Forest (U.S. Department of Agriculture, Forest Service [USFS]) installed a gaging station with a pressure transducer approximately 30 m above the road crossing in a stable pool within a bedrock-controlled reach that was located upstream of any influences of the existing culvert (Figure 2). During gage operation, stage (with date and time) was recorded every 15 min. In October 2004, the U.S. Geological Survey (USGS) installed a real-time stage monitoring system in the same pool as the USFS transducer. Data from the USFS gage continued recording as a backup to the USGS gage and provided sufficient overlap between gages to correlate the stage readings between them. To allow use of the maximum period of record, the USFS and USGS gages were correlated to correct for differences between the base stages of the transducers.

Twenty-five discharge measurements were taken at differing stage heights throughout the period of record to assist in the development of a stage–discharge rating curve. The discharge measurements were determined in accordance with USGS procedures (Rantz 1982). Discharge measurements ranged from 0.028 to 2.025 m^3/s. Discharges correlated to stream stage were used to develop a River Analysis System (Brunner 2006) model of the channel section where the gage and stage measurements were taken. The model was calibrated with several representative, spaced discharge measurements representing the low to high range of the recorded discharge, and a rating curve was developed. Key rating curve descriptor points were taken and logarithmically expanded to develop an incremental stage–discharge relationship (Rantz 1992). The stage–discharge relationship was then correlated to all stage measurements. Questionable stage measurements due to ice conditions were removed from the data set.

A flow duration analysis of instantaneous flows for the period of record (2001–2006) was completed. The flow duration was used to estimate the exceedance discharge, defined as the discharge that is equaled or exceeded for a given percentage of time based on the period of record. For example, a 5% exceedance discharge is a discharge that is exceeded 5% of the time; conversely, flows are less than the 5% exceedance discharge 95% of the time. Table 1 lists the 1, 2, and 5% exceedance discharge values for Hobo Creek during the period of record. Exceedance discharge provides biologists, engineers, and regulatory agencies with a measure to understand the percentage of time and thresholds of streamflow when fish passage occurs. We used the entire period of record to determine exceedance discharges for fish movement data collected from 2004 to 2006.

The stream gage was located about 30 m downstream from the downstream-most antenna array and 700 m below the upstream-most antenna array; therefore, the discharge measurements derived from the stream gage are not precisely the same as those occurring at the antenna installations when each fish was detected. The distances between the gaging station

TABLE 1.—Hobo Creek, Alaska, annual exceedance discharge values (m^3/s) from each water year and average values over the period of record (2001–2006).

Exceedance percentage	Water year						Average (2001–2006)
	2001	2002	2003	2004	2005	2006	
1%	1.1241	1.2094	1.1380	1.5087	1.1380	1.2986	1.2363
2%	0.8583	0.9381	0.7272	0.9172	0.8019	0.8815	0.8540
5%	0.5069	0.5485	0.4228	0.5151	0.4751	0.4828	0.4918

and the antennas are relatively short, and the discharge measurements at the gage are a reasonable approximation of discharge conditions at the antennas throughout the stream.

Analysis.—Three interdependent sets of data were generated during the study: (1) fish that were captured and tagged, and tagged fish that were recaptured over the course of the study; (2) fish that were detected at the antennas; and (3) stream stage converted to discharge (m^3/s). Periodic instream fish sampling created a population of individually marked fish that were identified by species, size, and location of capture. A subset of these fish was recaptured, some multiple times, over the course of the study. This created a record of fish size and history of capture for individual fish. As each fish passed the antenna, the location of the antenna and tag number were recorded as well as the date and time of detection at the antenna. Stream stage was recorded at 15-min intervals along with the date and time. The three sets of data were merged to provide the species and size of fish that passed an antenna at a given date and time and discharge level.

Direction and distance moved were estimated from the capture and recapture samples. The direction of movement was determined by subtracting the previous capture location (m above the culvert) from most recent capture location. For example, a fish captured at 70 m in May and recaptured at 200 m in July moved 130 m upstream during the interval between the sample periods. This represents net movement and does not record all movement that may have occurred during the interval. We used all fish captured during 2002 through fall 2006 to determine the distance moved between sample periods, the number of fish that moved, the direction of movement, and the number that remained in the stream section between sample periods.

Fish detected at the antennas during 2004–2006 were used in the analysis of movement and discharge. The relationships between stream discharge and flows through the antennas were not reliable as the antennas were constructed before 2004. The dates and times of individual fish detections at the antennas were matched with the dates and times associated with stream discharge records. Direction of movement was determined based on the time sequence of fish detections at the paired antennas. Fish moving upstream were detected at the lower antenna first. The relationship between movement and discharge was derived from fish for which the direction of movement could be detected and for which the distance moved was 20 m or greater. Direction of movement could not be determined for a large number of detections; in most cases, such fish appeared to reside near the antenna and were detected on multiple occasions, often over 50 times. These fish were easily identified by the short distance moved (usually $\leq$2 m) accompanied by multiple detections within 1 d and were removed from the analysis.

Stream discharge was derived from stream stage recorded at 15-min intervals. The stream discharge nearest to the time of a fish's detection was used to determine the relationship between movement and discharge. The stream discharge data and number of fish detected during each discharge interval were merged into a single data set for analysis. The distribution of movement over the range of stream discharges was determined by the number of fish detected during each discharge interval. The relationship between numbers of fish detected and discharge was described by the cumulative percentage of fish detected as moving ($\geq$20 m) upstream (y) plotted against discharge (x; m^3/s) for all antennas.

Results

Over the course of the study, 695 cutthroat trout and 802 Dolly Varden were tagged. Of these, 221 cutthroat trout and 238 Dolly Varden were detected at one or more of the antennas. Many fish were detected multiple times. Some fish were recaptured but were not detected at the antennas; 275 cutthroat trout and 375 Dolly Varden were never recaptured or recorded at any antenna. These fish may have died or migrated out of the watershed. Tagged fish were more or less evenly distributed throughout the stream. Most fish of both species were 110 mm fork length or smaller, and the length distribution was skewed toward smaller fish

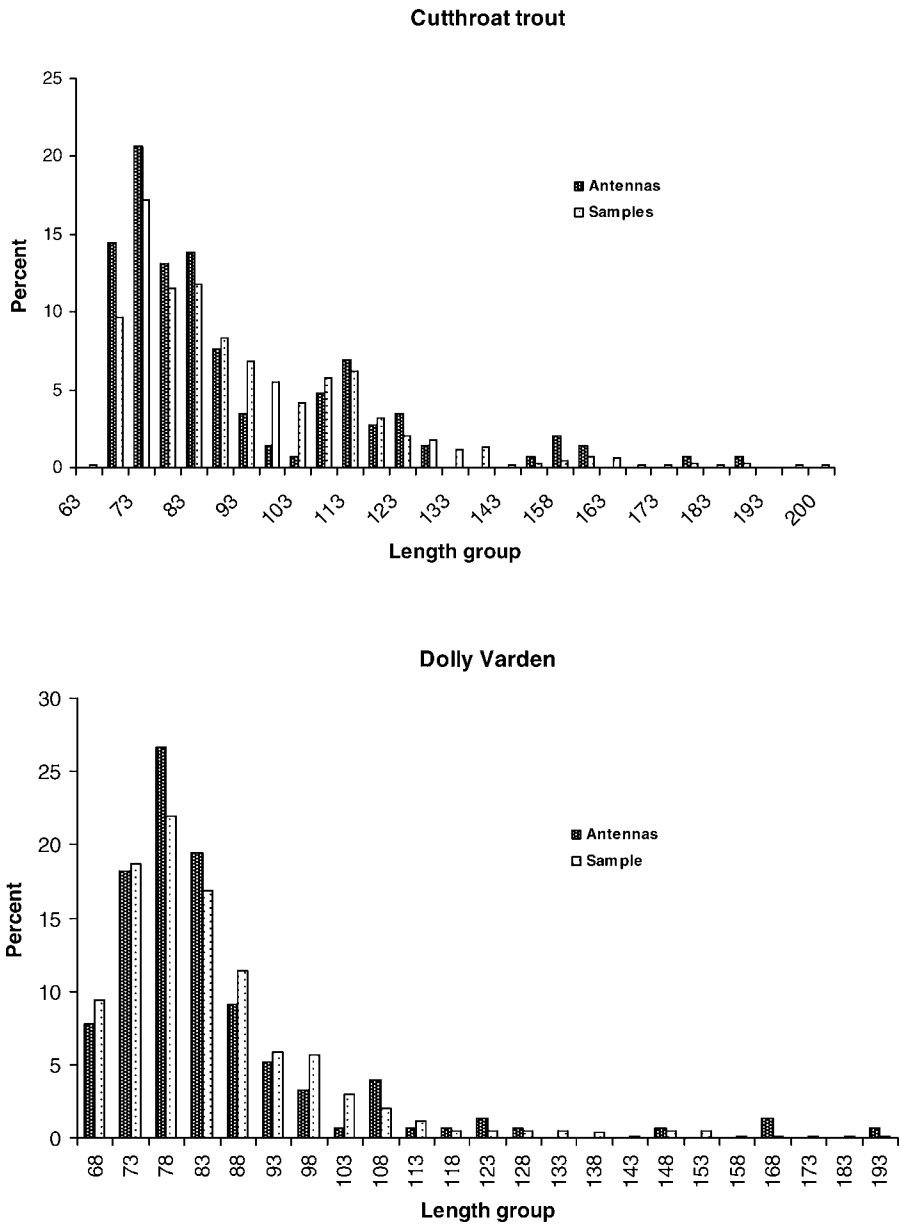

FIGURE 3.—Length frequencies (fork length, mm) of cutthroat trout (upper panel) and Dolly Varden (lower panel) captured and tagged (no recaptures) during sampling and the last known length of fish detected at the antennas (no repeat detections) in Hobo Creek, Alaska.

(Figure 3). The modal fork length was 75 mm for cutthroat trout and 78 mm for Dolly Varden.

Movement between Sample Periods

For all seasons, more than 60% of both Dolly Varden and cutthroat trout were recaptured in the same location (Table 2). For both species, the percentage of fish recaptured upstream was higher than the percentage recaptured downstream in the spring sample. However, more fish were recaptured in different locations both upstream and downstream in the late-summer sample than in other periods (Table 2). Most Dolly Varden and cutthroat trout that moved were recaptured 50 m or less from the point where they were

TABLE 2.—Percentage of cutthroat trout and Dolly Varden that moved upstream, moved downstream, or were recaptured in their previous location by season between capture–recapture sample periods in Hobo Creek, Alaska, 2002–2006 (χ^2 test: $P = 0.007$ for cutthroat trout; $P < 0.0001$ for Dolly Varden).

	Cutthroat trout percentage			Dolly Varden percentage		
Season	No movement	Down	Up	No movement	Down	Up
Spring						
By direction	60.9	14.7	24.4	75.0	4.7	20.3
By season	11.3	17.8	11.3	12.8	19.2	4.8
Early summer						
By direction	70.2	13.6	16.2	81.7	6.4	11.9
By season	28.9	26.3	23.1	36.6	29.7	17.6
Late summer						
By direction	64.2	20.3	15.5	68.5	18.4	13.1
By season	38.1	36.2	49.8	33.5	35.7	55.2
Fall						
By direction	71.2	12.5	16.3	72.7	15.5	11.8
By season	21.8	19.7	15.8	17.1	15.4	22.4

last captured; however, a few fish were recaptured more than 200 m upstream or downstream (Figure 4).

Stream Discharge

Hobo Creek is a flashy stream that responds rapidly to intense rainfall. The highest monthly mean discharges occur during September through January. Maximum discharge may exceed mean monthly discharge by an order of magnitude. Peak discharges are of short duration, usually less than 4 h. Based on a 5-year record of discharge measurements in Hobo Creek, a stream discharge of 1.24 m^3/s was exceeded 1% of the time (Table 1). Discharges of 0.85 and 0.50 m^3/s were exceeded 2% and 5% of the time, respectively. The highest discharge events occurred in September, and discharges greater than 2.88 m^3/s were observed during October through December (Figure 5). Bank-full conditions in Hobo Creek occur at a discharge of about 2.88 m^3/s and have a 50% chance of occurring in any given year.

Movement of Fish Detected at Antennas

The number of detections of fish moving a distance of 20 m or more was 363 for Dolly Varden and 444 for cutthroat trout. Dolly Varden were detected 1,448 times as moving upstream or downstream by a distance of 2 m or more; cutthroat trout were detected 3,122 times. The totals represent fish that may have been detected at several times and at several antennas. A large number of Dolly Varden were detected as moving downstream in April and May, and most upstream movement of this species was detected during August through October (Figure 6). Most upstream movements of cutthroat trout were detected in May and June, but upstream movements were also detected in September and October. No fish were observed moving upstream in January.

The length frequency distributions of the fish captured and tagged and of fish detected at the antennas followed similar patterns for both species (Figure 3). However, larger fish were detected at the antennas than were tagged for both species (Kolmogorov–Smirnov two-sample test: $P < 0.0001$). No relationship was observed between fork length and discharge for either species.

Most Dolly Varden and cutthroat trout were detected as moving upstream at discharge intervals between 0.01 and 0.10 m^3/s (Figure 7). Few fish of either species were detected at discharge intervals above 0.5 m^3/s. Four cutthroat trout and one Dolly Varden were detected as moving upstream at discharges greater than 0.85 m^3/s. The Dolly Varden (85 mm in November 2003) was detected as moving upstream at the FD2 antennas (Figure 2) on 2 December 2004 at a discharge of 2.7 m^3/s. A cutthroat trout (96 mm in June 2003) was detected as moving upstream at the FD1 antennas on 5 October 2004 (0825 hours) when discharges were 0.53 m^3/s (antenna at 369 m) and 0.55 m^3/s (antenna at 371 m). This individual was detected again on 5 October (1117 hours) at the FD2 antennas and was moving upstream at a discharge of 2.15 m^3/s for both antennas. This cutthroat trout was detected several other times by one of the FD2 antennas, but the direction could not be determined. It was detected as moving downstream through the FD1 antennas on 19 April 2005, when the discharge was 0.55 m^3/s. All fish had moved over 20 m from the point of last capture or detection when they were detected as moving past the antennas.

The cumulative percentage of fish detected as moving upstream rose asymptotically between dis-

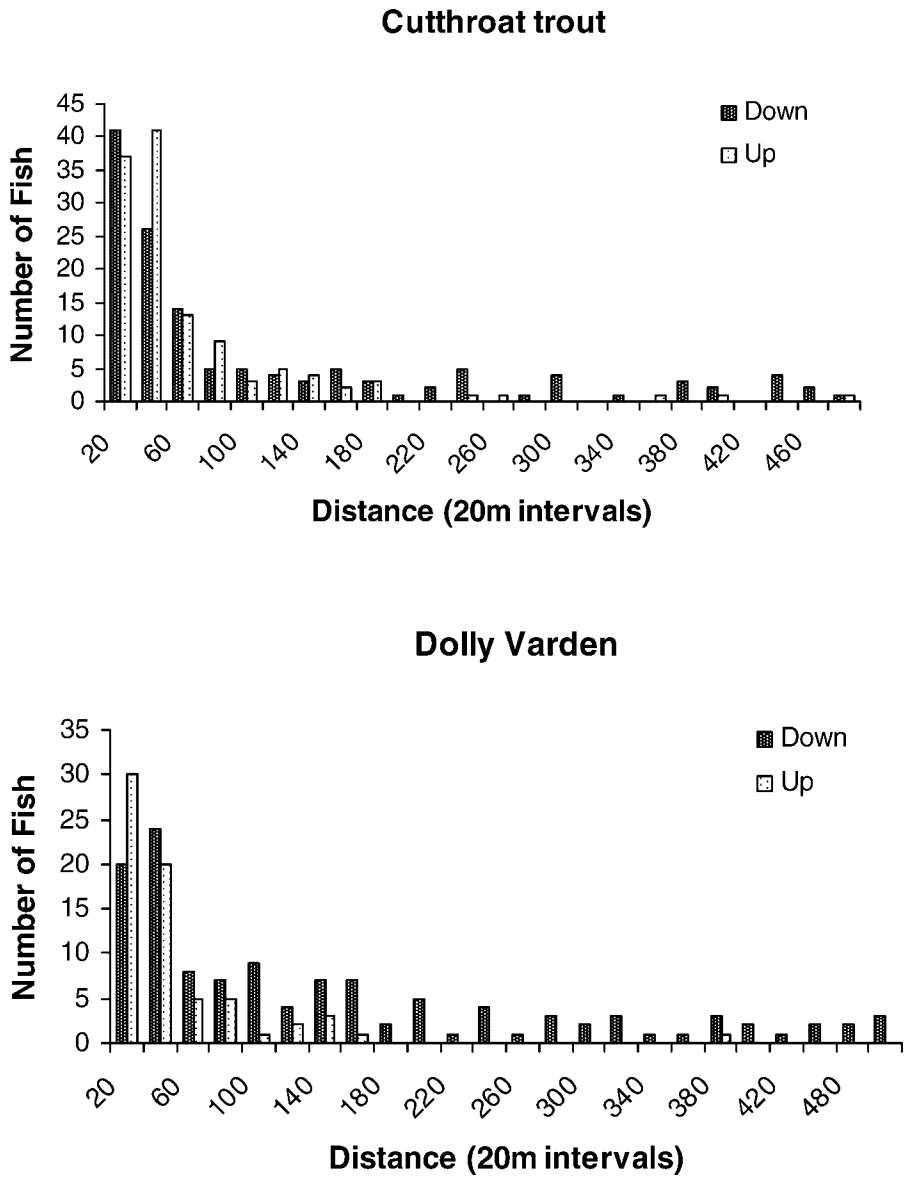

FIGURE 4.—Distance (20-m intervals) moved by cutthroat trout (upper panel) and Dolly Varden (lower panel) between sample periods during capture–recapture sampling in Hobo Creek, Alaska, 2002–2006 (down = number recaptured downstream from previous capture location; up = number recaptured upstream from previous capture location).

charges of 0.011 and 0.600 m^3/s (Figure 7). More than 97% of the fish moved upstream when stream discharge was less than 0.566 m^3/s; this discharge level was exceeded 5% or less of the time during 2002–2006 (Figure 7). Less than 1% of Dolly Varden and cutthroat trout were detected at 1% exceedance flows. For both species, all fish moved upstream at discharges that were below bank-full conditions (2.88 m^3/s) for Hobo Creek.

Discussion

Hobo Creek is similar to many headwater streams that are used by Dolly Varden, cutthroat trout, and coho salmon throughout southeast Alaska and the Pacific Northwest (Rosenfeld et al. 2002; Bryant et al. 2004, 2007). In Oregon and British Columbia, headwater streams were important spawning and rearing areas for resident cutthroat trout (Moore and

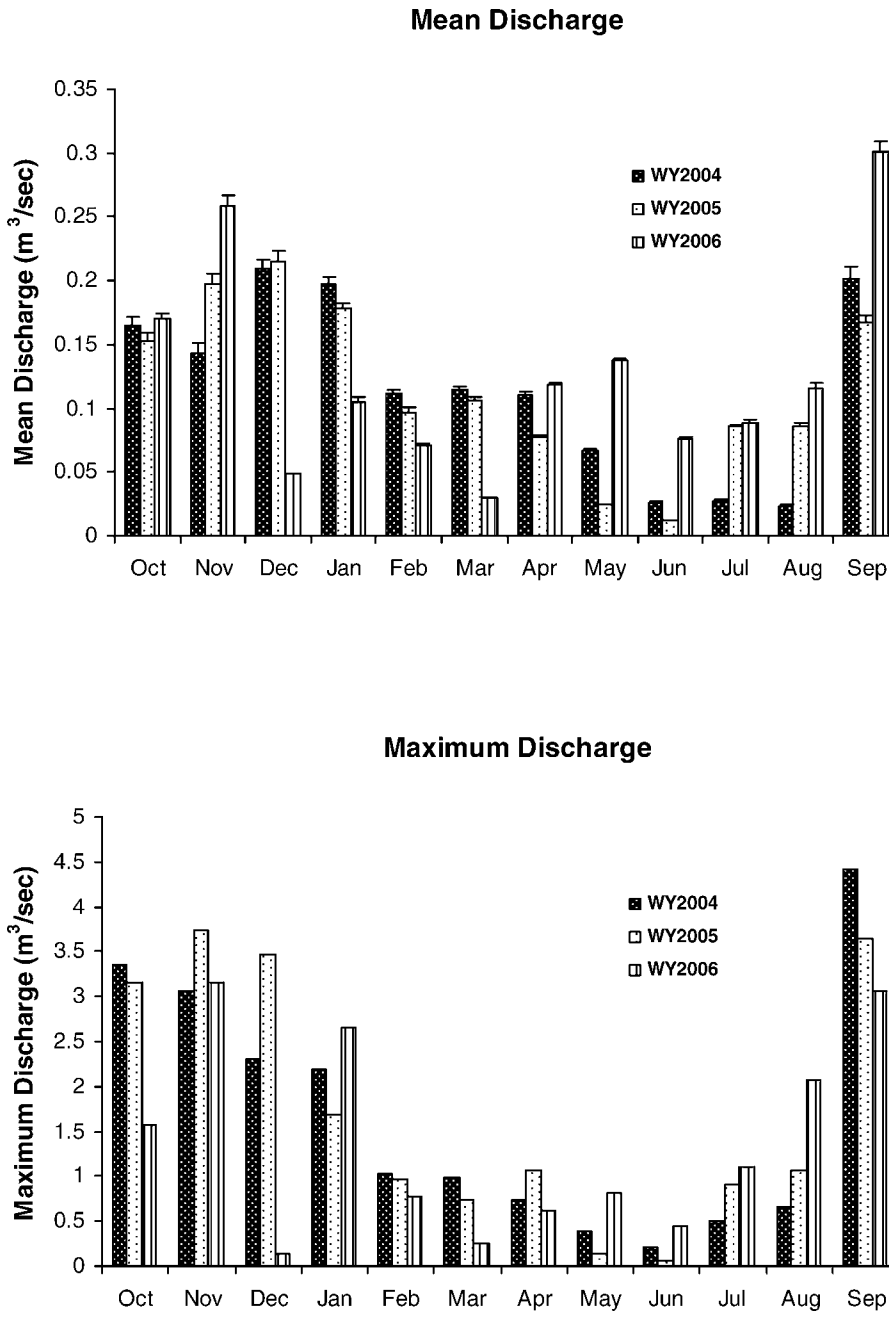

FIGURE 5.—Monthly mean (+SE) discharge (m^3/s; upper panel) and maximum discharge (lower panel) measured on Hobo Creek, Alaska, for water years (WY) 2004–2006 (e.g., WY2004 = October 2003–September 2004).

Gregory 1989; Rosenfeld et al. 2002). The Dolly Varden was the dominant species in high-gradient reaches in a set of small streams in the Maybeso Creek watershed, Prince of Wales Island (Bryant et al. 2004). Resident and anadromous cutthroat trout and resident Dolly Varden may also use headwater streams for spawning (Armstrong 1971). Dolly Varden in spawning condition were observed in the highest reaches of the Maybeso Creek tributaries (Bryant et al. 2004). Dolly Varden and cutthroat trout were captured and

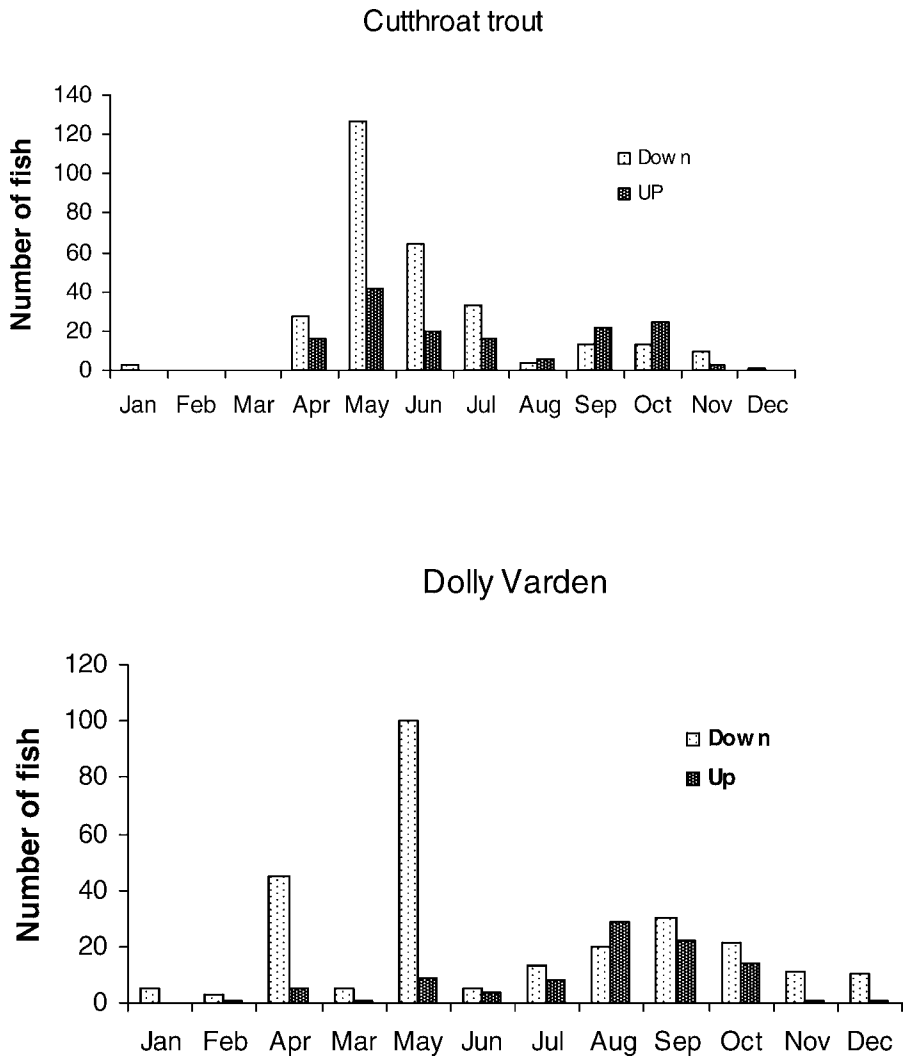

FIGURE 6.—Number of cutthroat trout (upper panel) and Dolly Varden (lower panel) detected (all antenna pairs pooled) as moving more than 20 m upstream or downstream from their last identified location in Hobo Creek, Alaska, 2004–2006.

tagged over the length of Hobo Creek, including the upper reaches of the study section. Furthermore, both species moved over the length of the 1,150-m study reach in the stream.

Causal mechanisms for movement include spawning, environmental factors (which may include a suite of interrelated factors such as temperature, amount of daylight, and discharge), and competitive interactions (Cederholm and Scarett 1983; Hughes and Reynolds 1994; Brown 1999; David and Closs 2005; Schrank and Rahel 2006). In some cases, movement may be associated with higher growth as fish locate better habitat conditions (Kahler et al. 2001). Cutthroat trout tend to move as discharge and temperature increase (Schmetterling 2001; Zurstadt and Stephen 2004). Movement of cutthroat trout and Dolly in Hobo Creek coincided with spawning periods for cutthroat trout (spring) and Dolly Varden (fall). However, we were unable to determine whether fish were mature or whether movement was associated with spawning. As is true of other life history aspects, size at maturity is not well documented for resident cutthroat trout and Dolly Varden in southeast Alaska streams, and differences between resident and anadromous forms are often difficult to identify in small (<150-mm) fish. Smithson and Johnson (1999) observed a pattern of movement, which they described as exploratory, by sunfishes *Lepomis* spp., creek chub *Semotilus atroma-*

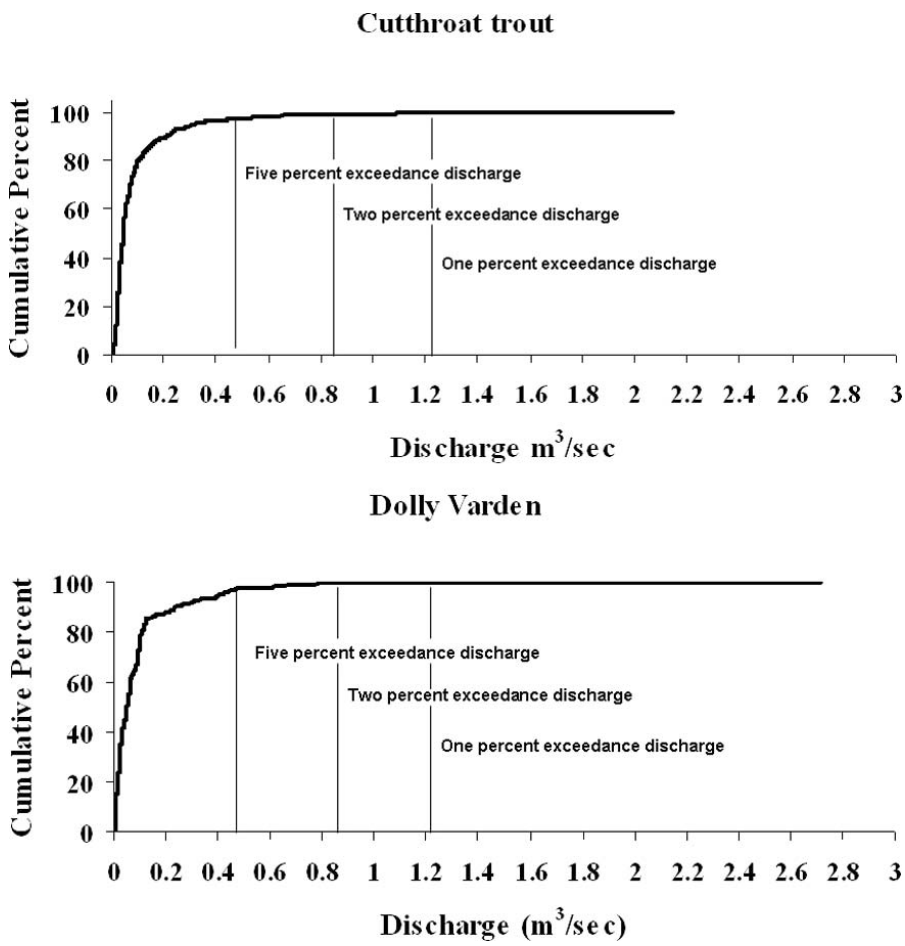

FIGURE 7.—Cumulative percentage of cutthroat trout (upper panel) and Dolly Varden (lower panel) that were detected as moving upstream through antennas (all antennas combined) at various discharge levels during 2004–2006 in Hobo Creek, Alaska (5% exceedance discharge = 0.49 m^3/s; 2% exceedance discharge = 0.85 m^3/s; 1% exceedance discharge = 1.24 m^3/s).

culatus, and blackspotted topminnow *Fundulus olivaceus* among pools within a small stream. Dolly Varden and cutthroat trout that moved short distances in Hobo Creek may also have been exhibiting exploratory movements.

In larger watersheds, cutthroat trout may move long distances (Schmetterling 2001; Zurstadt and Stephen 2004). However, even in these systems, a large percentage of fish remain within a relatively short segment of the stream, at least for the short term. Many cutthroat trout and Dolly Varden in Hobo Creek either did not move or moved less than 50 m from their tagging location. A few moved considerable distances. For example, two cutthroat trout (116 and 106 mm) that were marked in September 2001 were captured 520 m upstream from the site of tagging. Two days later, the same two fish were detected as returning downstream. During spring through fall, at least 20% of the cutthroat trout and Dolly Varden that were recaptured had moved from one location to another. Furthermore, those that were recaptured in the same place may have moved during the intervening period. Although many of the Dolly Varden and cutthroat trout in this study were detected as moving a relatively short distance, they may move considerable distances at some point in their life history.

Movement of both species was seasonal. Upstream movement of Dolly Varden and cutthroat trout coincided with periods of high discharge in September and October. All fish moved at less than bank-full conditions, and most were detected as moving at relatively low discharges (<0.28 m^3/s). Movement during the summer decreased and coincided with low flows as well as higher temperatures. As temperatures

decreased below 4°C beginning in November, which is typical for southeast Alaska, movement decreased and was negligible during the winter.

Fish were detected as moving at a wide range of discharges; however, most moved within a relatively narrow range. The cumulative number of fish detected as moving decreased rapidly after discharges reached about 0.5 m^3/s. Discharges above this level were exceeded 5% of the time, and more than 97% of the fish were detected as moving at lower discharges. Although most fish were detected at discharges considerably below the maximum observed in Hobo Creek, a few were detected at discharges greater than 1.42 m^3/s. The results from this study suggest that fish movement decreases as discharge increases above 0.5 m^3/s and that fish do not move upstream above bank-full discharge (2.88 m^3/s for Hobo Creek). However, resident Dolly Varden and cutthroat trout can and do move at close to bank-full conditions in Hobo Creek.

The ability of fish to move at high discharge levels is not a measure of their ability to swim against a given flow velocity. Measurements of the swimming ability of fish (i.e., maximum and sustained swimming speeds) are best determined in stream tank experiments (e.g., Brett 1964; Puckett and Dill 1984) and were beyond the scope of this study. Such information is important, but fish movement is more complex. Fish moving upstream will select avenues of low velocity within the stream cross section, and stream channel roughness will strongly influence the ability of fish of all sizes to move at a given discharge. In a study of the ability of juvenile coho salmon (50–120 mm) to move up a baffled culvert, Bryant (1981) observed that fish used turbulent flow patterns to navigate up the culvert, which was set at a 10% gradient. Upstream movement at increasing water velocities also increases metabolic output, with accompanying survival disadvantages (Brett 1964); therefore, small fish like those in this study would tend to avoid moving at high stream discharges and would instead reside in areas of low velocity in streams.

Connectivity within headwater reaches and between headwater and downstream reaches is an important part of the life history of both resident and anadromous salmonids. Dolly Varden and cutthroat trout moved throughout Hobo Creek over a range of discharges for various reasons that may be critical for survival, such as spawning, feeding, or refuge. Maintaining connectivity at road crossings is an important management issue. Fragmentation and isolation of stream reaches usually adversely affect fish populations and at extreme levels can increase the risk of extinction within the isolated reach (Horan et al. 2000; Hilderbrand 2003; Young et al. 2004; Hastings 2005).

Integration of hydrological requirements (i.e., culvert size required to pass water at peak discharges) and biological requirements is critical in the design of culverts on forest roads. In addition, it is equally important that culverts be designed to accommodate flood discharges without failure. In some cases, culverts designed to accommodate peak discharges may be sufficient for fish passage. An important element in the biological component is an understanding of when fish move within the natural discharge regime of the stream. Most Dolly Varden moved upstream during the fall; cutthroat trout moved upstream during the spring. Cutthroat trout spawn in the spring, and Dolly Varden spawn in the fall. Some of the highest discharge events occur during the fall; however, Dolly Varden and cutthroat do not necessarily move during peak discharge events. In this study, 97% of the fish moved upstream at discharges that occurred 95% of the time. A greater understanding of when fish move and what stream stages (discharges) are associated with movement will contribute to the design of road crossings to ensure connectivity throughout a watershed.

Acknowledgments

Don Cornelius, Suzanne Hebert, Bob Zorich, and Travis Bower assisted in the day-to-day operation of the fish detection system, which was critical to the success of the study. Brenda Wright, Brian Davies, Aaron Trusdell, and numerous seasonal technicians provided valuable assistance in various aspects of field sampling. Russ Thynes and Marc Novik provided expertise with various electronic issues. We appreciate the thorough and constructive manuscript review by Gayle Zydlewski. Funding was provided by the USFS Tongass National Forest. The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

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