

## Change in the Upper Extent of Fish Distribution in Eastern Washington Streams between 2001 and 2002

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*Abstract.*—The upper extent of fish distribution in streams has received increasing attention in recent years because fish-bearing streams in the Pacific Northwest receive greater protection from timber harvest than do non-fish-bearing waters. Significant amounts of time and funding have been spent surveying streams for the upper extent of fish distribution and, more recently, in developing models that predict where fish use ends in streams. The reliability of each approach rests in part on the assumption that the upper extent of fish distribution can be accurately determined by a single survey and that fish distribution boundaries (FDBs) do not shift appreciably through time. To examine changes in the upper extent of fish distribution, streams were surveyed throughout 10 forested watersheds in eastern Washington in the summers of 2001 and 2002. In 2002, 308 FDBs were resurveyed. Resurveys resulted in the establishment of 172 terminal boundaries (occurring mid-channel or at the confluence of two non-fish-bearing streams) and 136 lateral boundaries (occurring where a non-fish-bearing channel laterally intersects a fish-bearing channel). The number of terminal boundary changes was approximately evenly distributed among upstream shifts, no change, and downstream shifts. Excluding two relatively large downstream shifts, the mean distance between 2002 and 2001 terminal boundaries was  $-2.5$  m, which is not statistically or biologically significant. Terminal boundaries most often occurred immediately below small impasses created by large woody debris. Of the 136 streams occurring above lateral boundaries in 2001, 134 were again found to support no fish. The upper extent of fish distribution was similar between these 2 years, perhaps because of similar streamflows during the two sampling sessions. The number of terminal-to-lateral boundary shifts equaled the estimated number of lateral-to-terminal boundary shifts, indicating that no net change in the use of small tributaries occurred between the 2 years.

The upper extent of fish distribution in streams has received increasing attention by resource managers and aquatic scientists in recent years because fish-bearing streams in the Pacific Northwest receive greater protection from human disturbances than do non-fish-bearing waters. For example, in both Washington and Oregon, fish-bearing streams receive greater riparian protection for timber harvest activities than do non-fish-bearing streams. Therefore, the upper extent of fish distribution, as determined by the uppermost location of fish occurrence in a stream (herein referred to as the uppermost fish location), and how that location is determined have both ecological and economic importance. Development of models that predict boundaries of fish-bearing and non-fish-bearing waters has led to

increased efforts to collect field data for model validation (Conrad et al. 2003). The reliability of these models rests in part on the assumption that the upper extent of fish distribution can be accurately determined by a single survey and that fish distribution boundaries (FDBs) do not shift appreciably through time. Despite the ecological and economic importance of this assumption, the temporal variability of FDBs has gone unstudied.

The upper limit of fish distribution is thought to be determined by physical constraints (Kruse et al. 1997; Dunham et al. 1999), disturbance cycles (Reeves et al. 1995), and biological factors such as food resource limitations. Little work has been performed to understand what determines the upper extent of fish distribution in watersheds and how variation in physical and biological factors acts to expand or contract fish distribution. Physical constraints include stream gradients that are too steep and stream sizes that are too small to allow use of or passage through such

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TABLE 1.—Eastern Washington watersheds that were surveyed in 2001 and 2002 to determine the upper limits of fish distributions. Regions are northeast (NE), Southeast (SE), and Central (C).

Watershed	Region	Basin	Drainage area (ha)	Elevation range (m)	Precipitation range (cm)
Big Sheep Creek	NE	Columbia River	17,004	305–2,130	25–75
Upper Rattlesnake Creek	C	Naches River	14,401	915–2,440	100–200
Naneum Creek	C	Yakima River	22,267	790–1,490	40–65
Upper Cle Elum River—Cooper River	C	Yakima River	15,572	760–2,440	110–350
Deer Creek	NE	Colville River	12,747	580–1,525	40–50
North Fork Deep Creek	NE	Columbia River	12,315	640–1,430	65–100
LeClerc Creek	NE	Pend Oreille River	25,231	700–1,700	50–100
North Fork Touchet River	SE	Touchet River	11,597	700–1,670	50–100
Cabin Creek	C	Yakima River	9,533	760–1,670	125–250
Upper Taneum Creek	C	Yakima River	11,505	915–1,980	90–180

areas (Fausch 1989; Kruse et al. 1997; Watson and Hillman 1997; Latterell et al. 2003).

Owing to the potentially large temporal variation in stream discharge and accompanying changes that occur in wetted channel dimensions, available habitat, channel size, and location and impassability of transient barriers, the potential exists for large variation in the upper extent of fish distribution over temporal scales spanning weeks to years. Field surveys to determine FDBs are widely employed in forested watersheds of the Pacific Northwest, although we know of no published studies that have attempted to measure temporal variability in FDBs or relate the extent of any observed variation to physical, biological, or hydrological attributes. The primary purpose of this study was to begin to quantify temporal changes in FDBs. As a first step towards understanding temporal variability in the upper extent of fish distribution, FDBs were surveyed during 2001 and 2002 in 10 watersheds of eastern Washington State. We also performed more intensive sampling (multiple-pass rather than single-pass electrofishing) at a subset of FDBs to determine fish detection error rates and quantify the ability of the survey methodology to reliably locate the uppermost fish.

### Study Area

The 10 study watersheds occur in eastern Washington east of the Cascade Mountain crest. Drainage areas of these watersheds range from 9,533 to 25,231 ha (Table 1). Precipitation ranges from 25 to 350 cm among these watersheds, and elevation ranges from 305 to 2,440 m. Five watersheds are located in central Washington, four in northeastern Washington, and one in southeastern Washington. Surveyed areas within all of these watersheds occur on forested lands. Two survey areas occur within federally designated wilderness: the William O. Douglas Wilderness (Rattlesnake Creek watershed) and the Alpine Lakes Wilderness (Cooper River watershed).

### Methods

*Survey site selection.*—The upper extent of fish distribution was determined throughout 8 of the 10 study watersheds, while in two of the watersheds (Taneum and Cabin creeks) the FDB determinations were made only in a subset of streams where FDBs had been determined prior to 2001. Both terminal and lateral FDBs were established during the 2001 surveys. Terminal FDBs are those where the uppermost fish occurs at a point along the length of a fish-bearing channel or below the confluence of two non-fish-bearing channels. Lateral FDBs are those where a non-fish-bearing stream laterally intersects a fish-bearing channel (Figure 1).

Resurveys of all terminal boundaries and a random sample of 20% of the lateral boundaries established in 2001 were performed in 2002. Prior FDB data collected for stream typing surveys on the west side of the Cascade Mountains and the physical characteristics typically associated with each boundary type suggest that terminal boundary locations would probably show more temporal variation than would lateral boundaries. Terminal boundaries are often associated with subtle changes in channel conditions and transient barriers, such as debris jams, that are

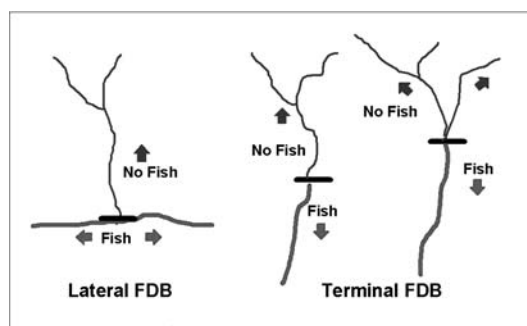


FIGURE 1.—Schematic illustrations of lateral and terminal fish distribution boundaries (FDBs) in eastern Washington streams, as applied in this study.

likely to influence distribution at the reach scale. In contrast, lateral boundaries are typically characterized by abrupt and sizable stream size or gradient changes that presumably offer little opportunity for changes in distribution to occur among years. We therefore chose to sample from only a subset of 20% of the lateral FDBs established in 2001, as a sample size of 136 lateral FDBs would allow sufficient estimates of the study parameters of interest.

To begin to quantify the error associated with determining FDBs, multiple-pass surveys (herein referred to as error distance surveys) were performed on a randomly selected subset of 28 streams in which the FDB occurred at a terminal location during 2002 resurveys.

*2001 FDB survey field methods.*—In 2001, FDB surveys were conducted from July 8 through September 12 to establish year-1 FDBs throughout the study area. The FDBs were determined based on standard protocols employed in Washington State to establish the upper limits of fish distribution in streams (FPB 2000). Establishment of an FDB via these protocols requires 400 m of stream to be electrofished upstream of the last fish detected without encountering another fish. Aside from these requirements and the 20% gradient, 0.6-m channel width exemption, the methods below are those we developed for this study.

The FDB surveys in 2001 began at or immediately below the confluence with known fish-bearing waters, as determined from Washington State records of fish distribution. Pools and other habitats suitable for holding resident salmonids were sampled periodically (about every 30 m) to ascertain fish presence. Once fish presence was established, the crew proceeded upstream while periodically electrofishing. If, during any periodic check, no fish were encountered for a distance of approximately 150 m, the crew reversed direction and electroshocked downstream until a fish was encountered, the location of which became the putative FDB. From this point, the crew electroshocked continuously while moving upstream. The survey continued upstream until 400 m of stream were surveyed without encountering a fish, unless stream gradient exceeded and remained above the 20% gradient threshold and channel width decreased to 0.6 m or less (in accordance with FPB 2000). If fish were again encountered, a new temporary FDB was established and the process of sampling 400 m was initiated upstream from that point.

*2002 terminal boundary resurvey field methods.*—Resurveys occurred between July 2 and September 24, 2002. All terminal boundaries established in 2001 ( $n = 172$ ) were resurveyed in 2002. To avoid introducing variation owing to possible seasonal changes in fish locations, 2002 resurveys of each watershed were

conducted in the same sequence as and within 2–3 weeks of 2001 surveys. To begin each resurvey, the crew first located the 2001 FDB in the field from maps, notes, and field tags and flagging. The crew commenced electrofishing immediately downstream (within 5–10 m) of this location, working in an upstream direction and sampling only the more suitable habitat (pools and other habitat suitable for holding resident salmonids) to ascertain fish presence. If no fish were encountered after 150 m, the crew reversed direction and began shocking downstream in the same manner until a fish was captured. When fish presence was confirmed through periodic sampling as described above, the crew began to sample continuously in an upstream direction by means of the same methods employed in 2001. After locating the 2002 FDB, surveyors permanently marked the FDB location with a plastic tag nailed to a live tree within 10 m of the bank-full channel and measured the channel distance with a hip chain between 2001 and 2002 FDBs when these locations differed. Distance upstream from the 2001 boundary was recorded as a positive number; distance downstream was recorded as a negative number.

At each FDB, the feature apparently precluding upstream fish use was identified. The FDB features were classified into broad categories, including small stream size (i.e., where an abrupt change in stream size or gradient occurred, most often associated with lateral FDBs), large woody debris jams (apparent temporary barriers), permanent barriers (bedrock or boulder waterfalls and cascades), impassable culverts, and natural ends (i.e., where a noticeable reduction in streamflow or channel dimensions occurred). Under some circumstances, no feature was evident and this was noted. When the FDB occurred below an apparent barrier (waterfall, chute, log jam, culvert, etc.), the length, height, and gradient of the impediment were measured. Debris jams with minimum heights of greater than 20 cm and in immediate association with the uppermost fish location were classified as apparent temporary barriers. A minimum height of 20 cm was selected because this height corresponds closely with Oregon and Washington's fish passage blockage criteria (maximum culvert outlet drops of 15.24 and 22.86 cm [6 and 9 in], respectively). Instantaneous water temperature and conductivity also were measured at the 2002 boundary by use of a YSI model 85 multiparameter water quality meter.

Habitat characteristics were measured over a minimum distance of 100 m above and below the 2002 boundary to characterize channel conditions above and below the FDB. When the distance between the 2001 and 2002 boundaries exceeded 100 m, physical habitat was measured over the entire distance between the two

points, as well as over the 100-m distance in the opposite direction. Measurements included mean channel gradient, bank-full and wetted channel widths, pool count, and dominant substrate.

Wetted and bank-full channel widths were measured at transects spaced 20 m apart ( $\pm 0.1$  m). All quiet-water areas that appeared to be suitable for fish holding and resting were tallied, and residual pool depths were measured. Dominant substrate was visually characterized ( $< 0.25$  cm = silt and sand; 0.26–7.5 cm = gravel; 7.6–30 cm = rubble;  $> 30$  cm = boulders/bedrock) at five evenly spaced points across each transect. Channel gradient was measured at least every 20 m (i.e., between each survey transect) and at significant changes in slope by use of a clinometer.

*Lateral boundary resurveys.*—In 2002, resurveys of 136 lateral boundaries were performed. When streams above lateral boundaries held insufficient water for sampling, no electrofishing was performed and only physical conditions were measured, as described above, in the first 100 m above the confluence with the fish-bearing stream. Resurveys of lateral boundaries with defined channels and surface water commenced at the confluence of the non-fish-bearing and fish-bearing streams (i.e., at the lateral point) following the same protocols and by use of the same survey effort criteria as described above, except with the following modifications.

Because fish were known to occur in the fish-bearing stream intersecting the non-fish-bearing stream at the lateral boundary, a continuous electrofishing survey was performed from this point upstream through the stream deemed to be non-fish-bearing in 2001 (i.e., sampling was not merely performed periodically to ascertain fish presence). If fish were located in the channel in question above the 2001 lateral boundary, the survey continued and followed protocols as described above. If no fish were encountered (i.e., the point remained a lateral boundary), the stream was flagged at the confluence with the fish-bearing stream as a 2002 lateral FDB. Physical measurements then were taken in the 100-m reach of the non-fish-bearing channel above the confluence with the fish-bearing channel; no physical data were collected from the fish-bearing channel below.

*Detection error distance surveys.*—Detection error distance (DED) surveys were performed on 28 streams that were randomly selected from the pool of 2001 terminal sites without waterfalls or other significant barriers. Streams that had fish passage barriers, in our judgment, at or immediately above 2001 FDBs were omitted from our selection pool. The FDB was first determined by means of the standard protocols described earlier. A block net was placed just below (within 5 m of) the 2002 boundary immediately after

the point was found, and a second block net was placed at the upstream end of the DED survey reach (400 m) to prevent fish from moving above the reach. Three additional electrofishing passes through the 400-m survey reach were made with equal effort to determine sampling error. The distance from the 2002 last-fish points to any fish encountered in subsequent passes was measured with a hip chain and recorded. All fish sampled during the DED survey were identified, counted, measured, and then released after the DED survey was complete. A DED survey continued until 400 m of stream were sampled four times without detecting a fish.

*Data analysis.*—Summary statistics (means, frequencies, ranges, and SDs) were produced to characterize the relationships between 2001 and 2002 last-fish points and to relate last-fish feature types to 2002 last-fish points. A one-sample *t*-test was used to test the hypothesis that the distance between 2001 and 2002 points was different from zero.

## Results

### *Differences between 2001 and 2002 Fish Distribution Boundaries*

Of the 172 resurveyed streams within which terminal boundaries occurred in 2001, 162 were found to be fish bearing again in 2002, while 10 no longer held fish. One stream sampled in 2001 was not resampled in 2002 because conditions prevented effective sampling with electrofishing equipment. The mean ( $\pm$ SD) distance between 2001 and 2002 terminal FDBs was  $-11.7 \pm 118$  m (range =  $-943$  to 400 m). Excluding the two largest downstream shifts of 664 and 943 m, the mean distance between 2001 and 2002 terminal FDBs was  $-2.5 \pm 80$  m. Differences between 2001 and 2002 FDBs were approximately evenly distributed among upstream shifts ( $n = 59$  observations), no change ( $n = 51$ ), and downstream shifts ( $n = 63$ ) (Figure 2) from 2001 terminal points.

A *t*-test of the hypothesis that the mean distance between 2001 and 2002 FDBs did not equal zero was not significant ( $P = 0.195$ ,  $n = 172$ ; the two largest distances were retained in the data set), indicating that no net upstream or downstream movement occurred in 2002 relative to terminal boundaries established in 2001. The FDBs did not change from 2001 to 2002 at 51 of 172 locations. When movement did occur (in either direction), FDBs shifted by 25 m or less at 61 locations. Boundaries shifted by more than 100 m in either direction at 17 locations and changed by more than 200 m at eight locations. The FDBs shifted by more than 500 m at only three locations, all of which had shifts in the downstream direction.

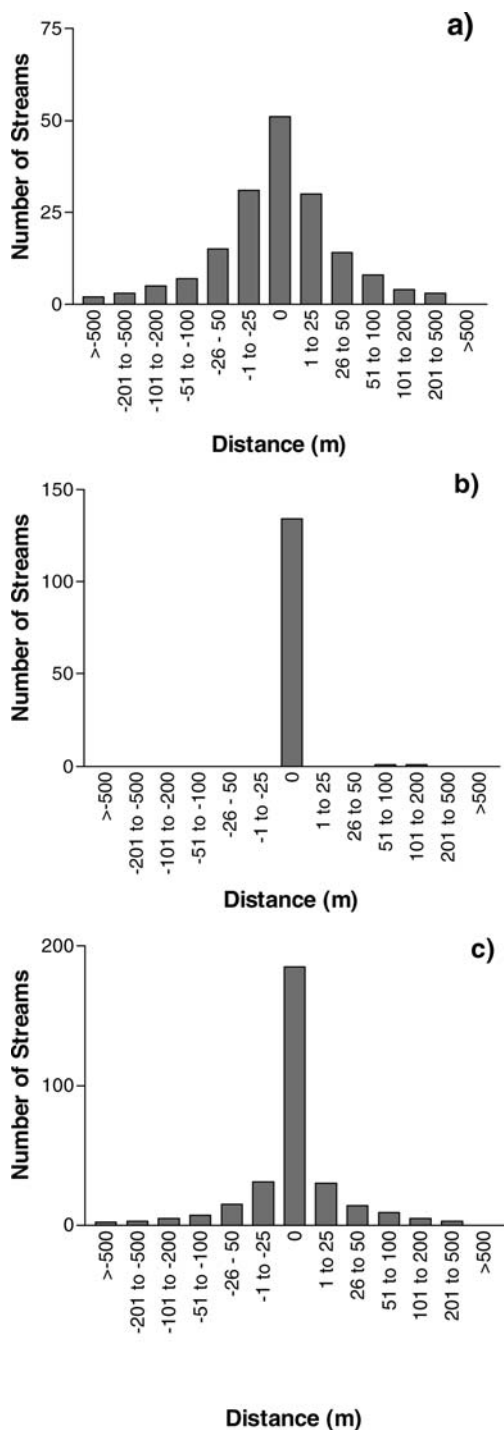


FIGURE 2.—Distribution of distances between (a) terminal ( $n = 172$ ), (b) lateral ( $n = 136$ ), and (c) all ( $n = 308$ ) fish distribution boundaries established in eastern Washington streams in 2001 and those resurveyed in 2002.

Ten terminal FDBs in 2001 shifted downstream to lateral FDBs in 2002, as no fish were present in these 10 tributaries. The distance between 2002 and 2001 boundaries in these streams ranged from  $-5$  to  $-450$  m and averaged  $-75.2$  m. When the  $-450$ -m distance was excluded, the mean distance between these 2001 terminal boundaries and 2002 lateral boundaries was  $-28.4$  m. Of the 136 streams resurveyed above lateral boundaries, 134 remained lateral boundaries (i.e., supported no fish) and 2 were found to hold fish (Figure 2). In 2002, fish were detected 60 and 107 m upstream in the two streams that were found not to support fish in 2001.

The FDBs did not change at 150 of 309 terminal and lateral boundaries. Moreover, 94% of the boundaries shifted by 50 m or less (Figure 2). To account for subsampling from 2001 lateral boundaries and to produce estimates of fish distribution changes throughout the study area, we weighted the lateral FDB data in proportion to the subsampling effort. Weighting the subsample of lateral boundaries to estimate shifts throughout the study area resulted in an estimate that no changes in annual FDBs occurred from 2001 to 2002 at 78% of these locations. Additionally, given that two streams classified as non-fish-bearing in 2001 were fish bearing in 2002 and that approximately 20% of the 2001 lateral boundaries were revisited in 2002, we can estimate that across the entire study area, 10 streams that lacked fish in 2001 subsequently contained fish in 2002. If so, the estimated upstream fish movement into 10 channels above 2001 lateral boundaries would equal the downstream movement of fish out of 10 fish-bearing channels between 2001 and 2002.

Across all resurveyed terminal and lateral sites, the mean ( $\pm$ SD) absolute (i.e., irrespective of direction moved) FDB distance between the 2 years was  $25.5 \pm 85.2$  m. The absolute FDB shift distance was  $43.0 \pm 108.1$  m at 2002 terminal boundaries and  $5.8 \pm 39.9$  m at 2002 lateral boundaries.

#### 2002 Last-Fish Point Features across All Sites

Across all FDBs (terminal and lateral combined), an abrupt change in stream size was the most common feature associated with FDBs, occurring at 159 of 308 locations (Figure 3). Such abrupt changes in stream size most often occurred at tributary junctions where a non-fish-bearing channel intersected a fish-bearing channel; the FDB feature was classified as this type at 143 of 146 lateral boundaries. Transient barriers were recorded as the FDB feature at 26% of all locations (2 lateral and 78 terminal boundaries), while waterfalls and cascades occurred at 16% of all FDBs (Figure 3).

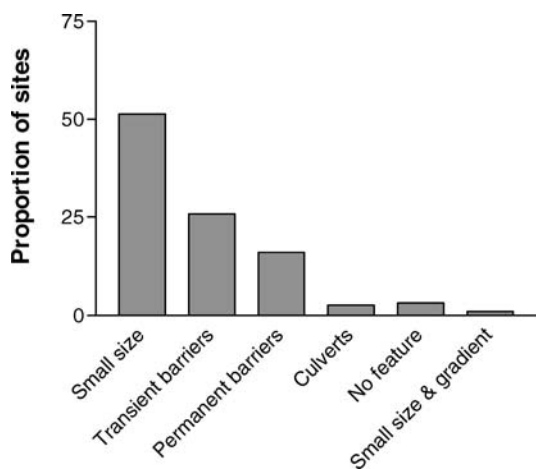


FIGURE 3.—Frequency of occurrence of fish distribution boundary (FDB) feature types across all 2002 resurveyed stream sites in eastern Washington (terminal and lateral FDB sites combined;  $n = 308$ ).

#### Features Associated with 2002 Terminal Boundaries

Terminal boundaries most often occurred immediately below small apparent impasses created by woody debris, as such conditions occurred immediately above 78 of 164 (48%) terminal boundaries established in 2002. These woody debris jams ranged from 0.2 to 3.0 m high, averaged 0.9 m high, and most often produced a nearly vertical obstruction to upstream fish movement.

Terminal FDBs coincided with permanent barriers at 49 (30%) of 164 locations. Most of these barriers were bedrock or boulder waterfalls or cascades. At 8 of these 49 locations, however, FDBs were associated with an increase in stream gradient without the presence of an obvious obstruction. The vertical height of these waterfall and cascade obstructions ranged from 0.4 to 30.0 m, averaged 5.4 m, and varied widely in length and gradient characteristics.

Terminal FDBs coincided with streamflow cessation at 16 of 164 locations, defined as areas where streamflow ceased or became intermittent to the extent that it precluded further upstream fish movement by fragmenting usable habitat. At 11 locations, the FDB could not be related to any particular changes in channel or flow characteristics. Terminal FDBs were associated with road crossings at 7 of 164 locations. Terminal FDBs associated with permanent barriers (e.g., waterfalls and cascades) often coincided with 2001 boundaries, as 57% percent of the FDBs associated with permanent barriers occurred at the same location in both 2001 and 2002. Only 7 of 49 (14%) 2002 FDBs associated with permanent barriers

occurred below 2001 FDBs; four of these occurred within 10 m of the 2001 boundary, and only one of the seven locations was a prominent waterfall.

Terminal boundaries associated with woody debris jams, natural ends, and sites where FDB features were not immediately apparent were more variable in 2002 than in 2001. Only 20% of 2002 FDBs occurring below woody debris jams coincided with 2001 FDBs; fish had moved upstream or downstream at 43% and 37% of these locations, respectively. Few (6%) terminal boundaries associated with natural ends in 2002 coincided with 2001 FDBs. Upstream and downstream shifts of FDBs associated with natural ends occurred at 50% and 44% of these locations, respectively. Hence, there was no apparent upstream or downstream trend in the direction of change. Likewise, 2002 boundaries coincided with 2001 FDBs at only 20% of locations where FDB features were not readily identifiable.

#### Habitat Characteristics at Terminal Boundaries

Habitat characteristics varied widely among 2002 terminal boundaries; stream bank-full and wetted widths within 100 m upstream of the boundary ranged from 0.6 to 11.0 m and from 0.2 to 10.4 m, respectively. The average stream gradient increased from 10.7% below terminal boundaries to 14.6% above terminal boundaries. Terminal FDBs most frequently occurred at bank-full and wetted widths ranging from less than 1 to 2 m and at gradients ranging from 10% to 20% (Figure 4).

#### Habitat Characteristics at Lateral Boundaries

Lateral FDBs occurred almost exclusively at abrupt changes in stream size and/or gradient. Physical features above lateral boundaries typically were characterized by small channel dimensions, particularly wetted channel widths (Figure 5), steep channel gradients, or a combination of these two features.

#### Fish Detection Error Distance

On 27 of 28 DED surveys, fish were not observed upstream from the boundary established by the first pass. During one DED survey, one fish was observed during the second pass 0.5 m upstream of the uppermost fish established during the first pass, and one fish was observed during the third pass 14 m upstream of the uppermost fish established during the first pass. The DED was 0 m (i.e., no fish were encountered during subsequent passes upstream of the FDB established on the first pass) on 27 of 28 streams and 14 m on one stream. The mean DED across all streams was 0.5 m.

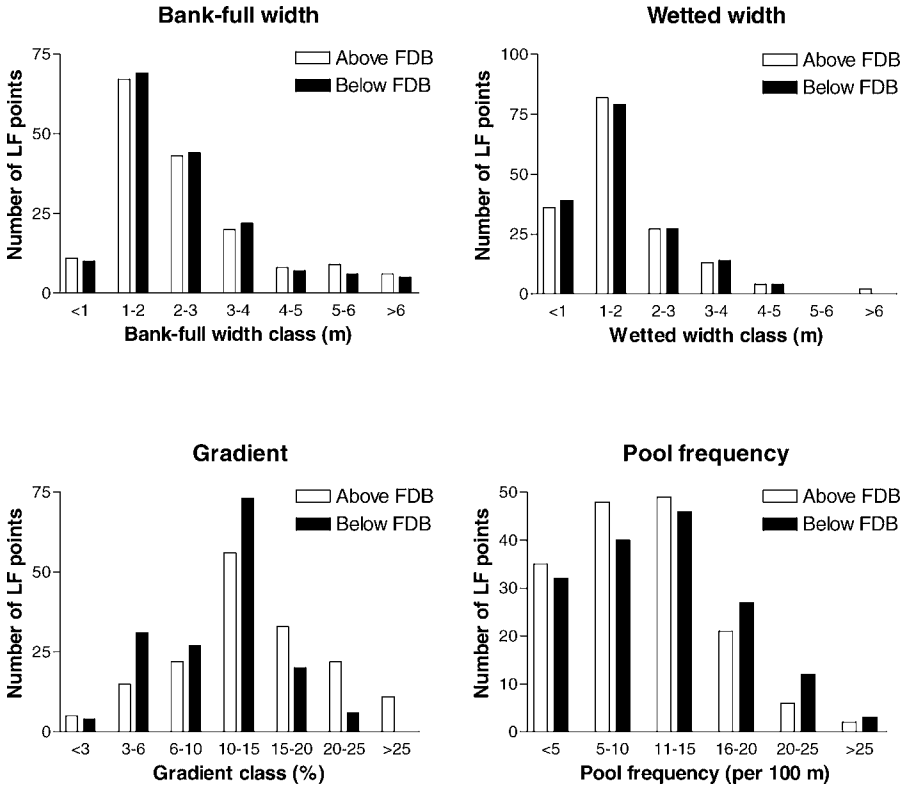


FIGURE 4.—Frequency of occurrence of habitat characteristics above and below fish distribution boundaries (FDBs) surveyed in eastern Washington in 2002 (n = 164; an LF point = the most upstream point at which the last fish was sampled).

Species Encountered

Four fish taxa were observed as the uppermost fish during 2002 resurveys, including cutthroat trout *Oncorhynchus clarkii*, brook trout *Salvelinus fontinalis*, bull trout *S. confluentus*, and redband trout *O. mykiss*. Across all watersheds, cutthroat trout were the most frequently encountered fish, occurring in 8 of 10 watersheds. Brook trout occurred in five watersheds and were the most frequently encountered uppermost fish in the Big Sheep Creek and Deer Creek drainages. Cutthroat trout were the uppermost fish at 74% of all terminal FDBs, while brook trout were the uppermost fish at 21% of all terminal FDBs.

Discussion

Fish distribution boundaries did not change appreciably between 2001 and 2002 across the study area. With few exceptions, most changes in FDBs were restricted to distances of less than 50 m, indicating that the changes that do occur may often be limited in distance. These short-term (months to years) changes in the upper limits of fish distribution at the reach scale appear to be influenced by the formation and de-

struction of transient barriers (e.g., debris jams) and/or changes in streamflow that facilitate passage around these smaller barriers. Only 20% of the 2002 boundaries associated with these transient barriers occurred in the same locations as 2001 boundaries.

Investigating the reliability with which FDBs could be determined by electrofishing is warranted because electrofishing can produce low fish detection rates under some sampling conditions (Peterson et al. 2004). Our data indicate that the survey effort employed was sufficient to accurately identify FDBs. The DED surveys for this study were performed almost entirely above relatively distinct habitat breaks, below which sampling efficiently revealed fish presence and above which (where the DED survey was performed) fish almost never occurred. Sampling for this study was performed under ideal conditions, including low streamflows with good clarity and sampling from small habitats where fish could not easily escape above or below the two-person crews. These optimal sampling conditions contributed to the ability of crews to reliably locate last-fish points. In these small streams, fish rarely escaped capture by passing downstream of the survey crew; rather, they were

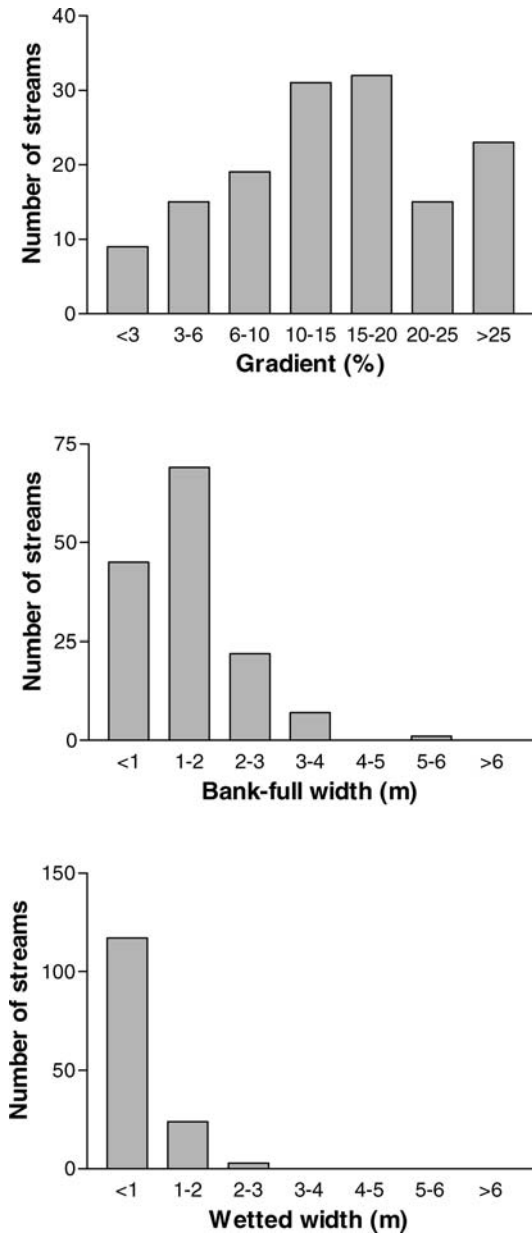


FIGURE 5.—Frequency of occurrence of habitat characteristics occurring above lateral fish distribution boundaries established in eastern Washington in 2002 ( $n = 136$ ).

observed seeking cover within the habitat unit, most often passing underneath or into the interstitial spaces of larger substrate (cobble and larger).

This work suggests that FDBs are frequently associated with debris jams. Such impasses appear to influence fish distribution at small spatial scales and short time scales. The nearly equal occurrence of

upstream and downstream shifts of FDBs associated with debris jams from 2001 to 2002 suggests that these features present only temporary barriers, perhaps only seasonal in some cases (depending on the size and other physical characteristics of the feature), as changes in streamflow may allow passage through or around the feature. During our surveys, we found fish above many temporary debris jams that were seemingly impassable to fish at the time of the survey but above which populations of fish persisted. The FDBs are likely to occur at debris jams when these obstructions are in close proximity to the upper limit of fish-bearing habitat, as determined by more permanent constraints such as stream size, gradient, and food resource limitations. We suspect that the formation and destruction of transient barriers, acting in concert with hydrologic extremes and biological forces such as competition for food resources or space, largely govern localized variability in the upper extent of fish distribution in many of the study streams.

Streamflows, particularly seasonal high and low flows, probably influence the upper extent of fish distribution in streams. The results of this study, when considered in the context of the similarity of summer streamflows between the 2 years, suggest that the lack of differences in FDB locations between the years may be related to the similarity in 2001 and 2002 streamflows. Summertime discharge data from the region encompassing the study area indicate that streamflows were similar between the 2 years. For example, August discharge in the Kettle River (U.S. Geological Survey [USGS] gauge number 12404500), located in northeastern Washington near Big Sheep Creek, was  $13.5 \text{ m}^3/\text{s}$  in 2001 and  $10.8 \text{ m}^3/\text{s}$  in 2002; both discharge values were lower than the 75-year August average at this station ( $23.3 \text{ m}^3/\text{s}$ ). Similarly, August discharge in the American River (USGS 12488500), located north of the Rattlesnake Creek drainage, was  $2.2 \text{ m}^3/\text{s}$  in 2001 and  $1.5 \text{ m}^3/\text{s}$  in 2002, both of which were lower than the 79-year August average at this station ( $2.7 \text{ m}^3/\text{s}$ ). Moreover, average discharge from each of these two gauge stations was similar between 2001 and 2002 and was lower than the long-term averages at these locations.

Biological factors potentially affecting the upper limits of fish distribution include competition for food and space and selection for sedentary genotypes that remain in the same location over time. Competition for food and space would probably be largely regulated by natural fluctuations in fish abundance, which are known to be as large as four- to sixfold in stream trout populations of the Pacific Northwest (P. A. Bisson, S. L. Gregory, and T. E. Nickelsen, paper presented at the 1994 annual meeting, American Fisheries Society, North Pacific Chapter; House 1995).

Temporal variability in FDBs may be explained by the relative influence of (1) environmental extremes that induce mortality or force downstream movement or displacement, (2) competitive pressures to move upstream in search of unoccupied habitat, and (3) the locations, sizes, numbers, and permanency of barriers. Currently, little is known about how FDB locations vary over time in forested watersheds (Latterell et al. 2003). Our 2 years of data indicate that changes can be relatively minimal over a larger geographic area, at least when flows are similar between years. Longer-term studies that include sampling over a wider range of streamflows and that occur after catastrophic environmental events may further characterize variability in the upper limits of fish distribution. Also, the large seasonal variability in discharge exhibited by forested streams of the Pacific Northwest warrants the investigation of potential seasonal patterns in fish distribution changes. Seasonal expansion and contraction of habitats resulting from extreme seasonal variation in streamflow may play an important, yet-unmeasured role in producing reoccurring shifts in FDBs.

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