Evaluating Single-Pass Catch as a Tool for Identifying Spatial Pattern in Fish Distribution

Douglas S. Bateman
Oregon State University
Department of Forest Science
3200 SW Jefferson Way
Corvallis, OR 97331
doug_bateman@usgs.gov

Robert E. Gresswell
Northern Rocky Mountain Science Center
U.S. Geological Survey
229 AJM Johnson Hall
Bozeman, MT 59717
robert_gresswell@usgs.gov

Christian E. Torgersen
Forest and Rangeland Ecosystem Science Center
U.S. Geological Survey
3200 SW Jefferson Way
Corvallis, OR 97331
ctorgersen@usgs.gov

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ABSTRACT

We evaluate the efficacy of single-pass electrofishing without blocknets as a tool for collecting spatially continuous fish distribution data in headwater streams. We compare spatial patterns in abundance, sampling effort, and length-frequency distributions from single-pass sampling of coastal cutthroat trout (Oncorhynchus clarki clarki) to data obtained from a more precise multiple-pass removal electrofishing method in two mid-sized (500-1000 ha) forested watersheds in western Oregon. Abundance estimates from single- and multiple-pass removal electrofishing were positively correlated in both watersheds, $r = 0.99$ and 0.86. There were no significant trends in capture probabilities at the watershed scale ($P > 0.05$). Moreover, among-sample variation in fish abundance was higher than within-sample error in both streams indicating that increased precision of unit-scale abundance estimates would provide less information on patterns of abundance than increasing the fraction of habitat units sampled. In the two watersheds, respectively, single-pass electrofishing captured 78 and 74% of the estimated population of cutthroat trout with 7 and 10% of the effort. At the scale of intermediate-sized watersheds, single-pass electrofishing exhibited a sufficient level of precision to be effective in detecting spatial patterns of cutthroat trout abundance and may be a useful tool for providing the context for investigating fish-habitat relationships at multiple scales.

INTRODUCTION

The identification of repeated patterns is the foundation of ecological research (MacArthur 1972) and is sometimes useful in the examination of cause (Sale 1988). Because pattern may emerge at multiple spatial scales (Wiens 1989), establishing context based both on organism and environmental capacity (Warren and Liss 1980) is important for interpreting causal relationships. Fausch et al. (2002) argue that traditional sampling schemes and methods used by stream fish ecologists can be problematic because results are often considered outside the spatial and temporal context that gives them meaning. Although spatial and temporal context can be improved by increasing the extent at which studies are conducted, rare events in time and space can influence distribution and abundance of stream fishes (Torgersen et al. 1999, Baxter and Hauer 2000). Therefore, consideration of sampling grain (unit of observation; Wiens 1989) and sampling fraction (proportion of units actually sampled; Hankin 1984) are important in establishing spatial context. For a given extent, scope (the capacity to detect pattern) increases as grain size declines, and uncertainty is reduced by increasing sampling fraction (Schneider 1994, 2001). When little is known about the scales at which pattern may emerge, continuous sampling provides a conservative approach to establishing spatial context and, ultimately, understanding organism-habitat relationships.

Although spatially continuous sampling of stream fishes has been conducted (Duncan and Kubecka 1996), it is rarely applied at a watershed scale in mid-sized catchments (Torgersen et al. 2004). In part this is related to the expense of collecting continuous data and a failure to recognize the importance of spatial context in interpretation of results (Fausch et al. 2002). The expense of sampling can be reduced to some extent by decreasing the precision of individual sample unit estimates. Hankin and Reeves (1988) and Jones and Stockwell (1995) developed methods for generating population estimates for stream fishes using low-precision sampling methods. Although Thompson (2003) recently assessed the limitations and alternatives to the basin-scale approach for estimating fish abundance (Hankin and Reeves 1988), to date there have been no formal evaluations of low-precision sampling techniques with regard to detection of pattern. Here we evaluate the efficacy of single-pass electrofishing without blocknets as a tool for collecting spatially continuous data over intermediate scales by comparing patterns in abundance, sampling effort, and length-frequency distributions of coastal cutthroat trout (Oncorhynchus clarki clarki) to data obtained with a more precise multiple-pass removal electrofishing method in two mid-sized (500-1000 ha) forested watersheds in western Oregon

METHODS AND MATERIALS

Study basins were selected from a group of 40 watersheds located above barriers to anadromous fishes that were randomly selected for a study of coastal cutthroat trout in western Oregon (Gresswell et al. in press). Sample watersheds represented commonly occurring combinations of geology and ecoregion in this larger sample (Fig.1). Blowout Creek, a tributary to the North Santiam River, is in the Cascade Mountains ecoregion and has an igneous bedrock lithology. Slide Creek, a tributary to the Middle Fork Coquille River, is located in the Coast Range ecoregion and has a sedimentary bedrock lithology.

Sampling occurred between 19 September and 22 September 2001 in Blowout Creek and between 22 May and 13 June 2001 in Slide Creek. Each stream was divided into segments (Frissell et al. 1986, Moore et al. 1998), geomorphic reach types (Montgomery and Buffington 1997), and pool, riffle-rapid, cascade, and vertical step habitat-unit types (Bisson et al. 1982). For each of the 204 and 634 habitat units in Blowout Creek and Slide Creek, respectively, estimates of wetted width, length, active channel and valley floor widths, dominant and subdominant substrate were recorded (Moore et al. 1998). In habitat units where both single- and multiple-pass removal methods were used, the number of unembedded boulders was recorded. Wetted surface area covered by woody debris and undercut banks were measured when woody debris prevented electrofishing in an area of wetted channel \$0.5 m^2 or when any portions of undercut banks exceeded 0.5 m in depth.

After initial habitat assessment, single-pass electrofishing was used to collect fish in all pools and cascades in each watershed, and then all cascades and every third pool were sampled a second time using multiple-pass electrofishing. For this part of the study, the first pool to be sampled was selected randomly from the first three pools upstream from the start location in each watershed. A minimum of six and a maximum of 24 hours separated single- and multiple-pass sampling events in each habitat unit. If this time period was exceeded, units were discarded and replaced as follows: (a) if the unit was a pool, a new random draw was made from the next three available pools, or (b) if the unit was a cascade, sampling resumed at the next available cascade.

Electrofishing was conducted with a pulsed-DC electrofisher set at 40 Hz, 200-300 V, with a 4-6 milliseconds fixed pulse width. All captured fish were removed from the unit, weighed to ± 0.1 g, and measured to ± 1 mm (fork length). After recovery, and once sampling was completed, all fish were returned to the habitat unit in which they were captured. All fish > 70 mm that were collected during single-pass sampling were marked with a fin clip. In Blowout Creek, fish received a combination of fin clips unique to the habitat unit from which they were collected. In Slide Creek, only the adipose fin was removed. Because sampling extended through the period of fry emergence, statistical analyses were limited to individuals $ 70 mm (i.e., presumed $ age 1).

Single-pass electrofishing always occurred prior to multiple-pass electrofishing. Blocknets were not employed during single-pass electrofishing. A single-pass event in pool habitat began at the downstream end of the unit, proceeded upstream to the geomorphic channel unit boundary, and then returned downstream to the point where electrofishing began. In cascade habitats, a single-pass event began at the downstream boundary of the unit and proceeded upstream to the upper boundary of the unit. Pocket pools within each cascade were sampled as described above, receiving both upstream and downstream passes.

During multiple-pass electrofishing, 6-mm mesh blocknets were set at the downstream and upstream boundaries of each habitat unit prior to sampling. Electrofishing proceeded from the downstream blocknet to the upstream blocknet, then back to the downstream blocknet. The same pattern was followed in both cascade and pool habitat units.

At each habitat unit, a timer on the electrofishing unit was used to measure sampling effort, and in the case of multiple-passes, time measurements were used to insure equal effort among passes. Because the timer was activated by a switch on the anode, only the number of seconds of active electrofishing were tallied. To compare effort/cost between methods, we calculated total sampling effort for single-pass estimates as the number of seconds recorded on the timer(s). For multiple-pass estimates, we recorded the elapsed time and then added 30 min. per habitat unit for setting, checking and removing blocknets. We used tables from Connolly (1996) to predict 10% confidence intervals around unit estimates in the field. Multiple-pass removal ceased in Blowout Creek when a 10% confidence interval was achieved and a minimum of three passes had been performed. Multiple-pass removal sampling ceased in Slide Creek when a 10% confidence interval was achieved and a minimum of two passes had been performed or no fish were captured in a pass.

Population estimates were generated for two, three, and greater than three-pass sampling events as follows: (1) the Seber and LeCren (1967) two-pass estimator for small sample sizes, (2) the Junge and Libosvarsky (1965) explicit solution of Zippin (1956) maximum likelihood estimator for the three-pass events following Cowx (1983), and (3) the computer program Capture (White et al. 1982) for greater than three-passes.

Paired t-tests were used to compare the mean number of cutthroat captured during single-pass versus the first-pass of removal sampling. In Slide Creek, the abundance estimator failed to meet normality assumptions; therefore, the Wilcoxon signed-rank test was used to compare medians. The relationship between single-pass catch and multiple-pass removal population estimates was described for each stream by calculating the Pearson correlation coefficient.

Simple linear regression was used to determine whether significant trends in capture probabilities were present at the watershed scale. Capture probabilities from each habitat unit were regressed against cumulative distance from the origin of sampling in that watershed. Due to evidence of heteroscedasticity, a percentile bootstrap method was used to estimate the slope and intercept parameters and their associated 95% confidence limits. All statistical analyses were performed using NCSS 2001 (Hintze 2001).

To evaluate the influence of sampling method on observed patterns of relative abundance at larger spatial scales, abundance estimates for individual habitat units were plotted by sampling method versus distance upstream as if data had been collected from contiguous habitat units. This yielded four hypothetical distributions of fish, one for each sampling method for each watershed. Each distribution was analyzed with locally weighted scatterplot smoothing (LOESS; SAS ver. 8.0), a regression line and corresponding 95% confidence interval were generated for each distribution. The smoothing factors for Blowout and Slide creeks were 0.7 and 0.16, respectively.

Fish $ 70 mm were placed in 10-mm length classes based on fork length. The proportion of total catch accounted for by each 10-mm length class was plotted for each sampling method in each stream to provide a comparison of fish length- frequency distribution between sampling methods by stream.

RESULTS

The spatial extent of coastal cutthroat trout distribution differed in the two study watersheds (Fig.1). At the watershed scale, streams were similar in many respects but differed in gradient profiles (Table 1), but median values for most habitat unit parameters were lower in Slide Creek (Table 2). Step-pool reaches were the most common reach type in both streams; however, habitat was more diverse in Slide Creek, where cascade, plane-bed, pool-riffle, and bedrock reach types were also present. In contrast, only cascade and bedrock reach types were found in Blowout Creek. Woody debris and undercut banks in quantities sufficient to influence sampling efficiency were rare in both streams.

Single-pass catch and multiple-pass removal population estimates were positively correlated in both Blowout Creek and Slide Creek $r = 0.99$ and 0.86, respectively (Fig. 2). Capture probabilities for individual habitat units ranged from 0.58 to 1.00 in Blowout Creek and 0.22 to 1.00 in Slide Creek. The mean and coefficient of variation were 0.82 and 16% and 90 and 19%, for Blowout Creek and Slide Creek, respectively. The null hypothesis that capture probabilities did not vary significantly over the extent of sampling could not be rejected in either watershed ($P > 0.05$). In contrast to capture probabilities, total catch from multiple-pass removal sampling was highly variable among habitat units: mean and coefficient of variation were 7 and 113% for Blowout Creek and 3 and 134%

for Slide Creek, respectively.

The difference in the number of cutthroat trout captured during single-pass sampling and the first pass from the multiple-pass removal estimate was generally not different from zero in either stream, (*P* = 0.1 and 0.8 for Blowout Creek and Slide Creek, respectively). Length-frequency distributions for cutthroat trout obtained from single- and multiple-pass removal electrofishing were similar in both streams (Fig. 3).

In Blowout Creek, a total of 127 cutthroat trout were given unique sets of fin clips corresponding to the habitat unit in which they were captured during single-pass sampling. During multiple-pass removal sampling, a total of 86% of these marked fish were recaptured, with 74% of marked fish recaptured in the habitat unit in which they were originally marked, 12% recaptured in a different habitat unit, and 14% not recaptured. For marked fish recaptured in locations other than the site where they were original tagged, 77% were within two habitat units.

In Slide Creek, only the adipose fin was clipped and it was therefore not possible to determine whether fish were captured in the same location during both sampling events. Seventy-six percent of the 238 marked fish were recaptured. During multiple-removal sampling we collected more adipose- clipped fish than were initially marked in 11 of 94 (12%) habitat units. In a similar comparison using data from Blowout Creek, only 1 of 21 (5%) of habitat units yielded more marked fish than were initially marked.

Patterns of relative fish abundance were similar for both sampling methods in each watershed (Fig. 4). In Blowout Creek, a very simple linear pattern was observed, and abundance steadily declined with distance upstream. In Slide Creek, patterns of fish abundance were more complex; both sample methods yielded a sharp initial increase in abundance with distance in the upstream direction. Numbers then declined gradually with localized peaks and troughs in abundance.

Single-pass catch in Blowout Creek accounted for 78% of the estimated population of fish with 7% of the effort. Single-pass sampling required an average of 7 min. per habitat unit compared to 70 and 98 min. per habitat unit for two-pass and three-pass removals. In Slide Creek, a comparison of single-pass catch to two-pass electrofishing suggests that single-pass sampling captured 74% as many fish with 10% of the effort. Average sampling time by method was similar to sampling times in Blowout Creek, with 7 and 74 minutes per habitat unit for single-pass and two-pass sampling, respectively.

DISCUSSION

The field of stream ecology has been slow to embrace the notion of spatial hierarchies and the role scale may play in interpretation of observed phenomena (Fausch et al. 2002). Fisheries biologists commonly sample individual habitat units or short, arbitrarily defined lengths of stream and think about parameters of interest at these small spatial scales. However, when the scale of measurement of a variable changes, its variance changes. This is an important concept with regard to using low-precision estimators over a large spatial extent. When grain size (sample unit) remains fixed, increasing extent results in increasing heterogeneity or variance between sample units

(Wiens 1989). As variance between sample units increases, the value of precise estimates of the parameter of interest at the unit or grain scale declines because within-unit variance explains less and less of the total variation. Thus, it becomes advantageous to increase sampling fraction within the extent of the survey rather than the precision of individual sample unit estimates. This is essentially the argument made by Hankin (1984) and applied by Hankin and Reeves (1988) with regard to generating population estimates of fishes in small watersheds. Based on this fundamental scaling principle, it is inevitable that at some extent, a low-precision sampling technique such as single-pass electrofishing will produce accurate estimates of pattern in relative abundance at a given grain size. This has not been tested empirically at intermediate scales, and therefore it would be useful to determine the spatial extent at which between-unit variance exceeds within-unit error for a sampling technique of a given precision.

Within-sample-unit error is directly related to capture efficiency, which can vary with changes in habitat (Bayley and Peterson 2001) and sampling technique (i.e., open and closed; Thompson 2003). We observed a sizeable range in capture probabilities within our study sites; however, at the watershed scale this source of variation exhibited no trends in either stream. This lack of trend in capture probabilities and the fact that between-habitat-unit variation in abundance was much greater than variation in capture probabilities suggests that the survey extent represented by our watersheds was sufficient to give an accurate depiction of relative abundance at that scale.

Multiple-pass removal estimates have been shown, in some cases, to underestimate the true population size (Peterson and Cederholm 1984, Rodgers et al. 1992). This suggests possible inflation of capture probabilities. In our study, fish were marked during a census of pools and cascades, returned to the unit of capture, and given 6-24 hours to recover before resampling. During this period, fish were free to move among habitat units. With multiple-pass removal sampling, only a subset of units were sampled a second time. All marked fish that moved to an adjacent riffle or pool were unavailable for recapture. If we assume that 20-30% of coastal cutthroat trout would typically be somewhere outside their unit of first capture at any point in time (Hendricks 2002), the calculated capture probabilities closely reflect true probabilities. This is because we recaptured 86% of the marked fish when it was highly unlikely that all marked fish were susceptible to capture.

In our streams, we found a strong positive correlation between single-pass catch and multiple-pass removal population estimates, and this indicates a general agreement between the two sampling methods with regard to abundance. Patterns of abundance that were generated by treating sampled units in both streams as continuous distributions differed between methods primarily in the magnitude of fish abundance at any given location, not in the slope of the abundance trend line or in locations of inflection points along the trend line. This suggests that although multiple-pass removal population estimates provide a more accurate estimate of true abundance relative to single-pass catch, this method provided little if any additional information on distributional pattern. In addition, single-pass catch provided an accurate depiction of length-frequency distributions and an opportunity to collect scale samples and gather fish length and weight data in a cost effective manner. Using single-pass electrofishing, we were able to survey habitat and conduct a census of fish in pools and cascades in up to 20 intermediate-sized watersheds (500-1000 ha) in a single field season with a 13-person crew. This allowed us to provide spatial context at a variety of spatial scales (Gresswell et al., in press) and identify potential habitat relationships that are not usually apparent when a site-based approach is used. In this study, streams were selected in an arbitrary fashion and do not represent a statistically valid sample. We recommend that researchers perform a site-specific evaluation to determine the relative magnitude of among- and within-sample unit variance before implementing single-pass removal sampling to detect spatial pattern in fish abundance.

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Figure 1. Map of western Oregon showing study site locations. The watersheds have been delineated and bold lines depict cutthroat trout distribution upstream from the sampling initiation points, a tributary junction in Blowout Creek and a waterfall in Slide Creek.

Figure 2. Relationship between single-pass catch and mutliple-pass population estimates of cutthroat trout for 21 and 90 habitat units in Blowout and Slide creek, respectively. Solid line represents a 1:1 slope.

Figure 3. Comparison of the proportion of cutthroat trout captured in 10 mm size classes during single-pass (without blocknets) and multiple-pass (with blocknets) sampling events.

Figure 4. Locally weighted scatterplot-smoothing (LOESS) function applied to habitat-unit abundance estimates for cutthroat trout from single- and multiple- pass sampling. The x-axis represents the cumulative length of all double-sampled habitat units in each watershed. Fish abundance estimates are plotted versus cumulative distance corresponding to their respective habitat unit. Abundance estimates by stream and sampling method are shown as follows: a) Blowout Creek, single-pass catch, b) Blowout Creek, multiple-pass removal, c) Slide Creek, single-pass catch, d) Slide Creek, multiple-pass removal.

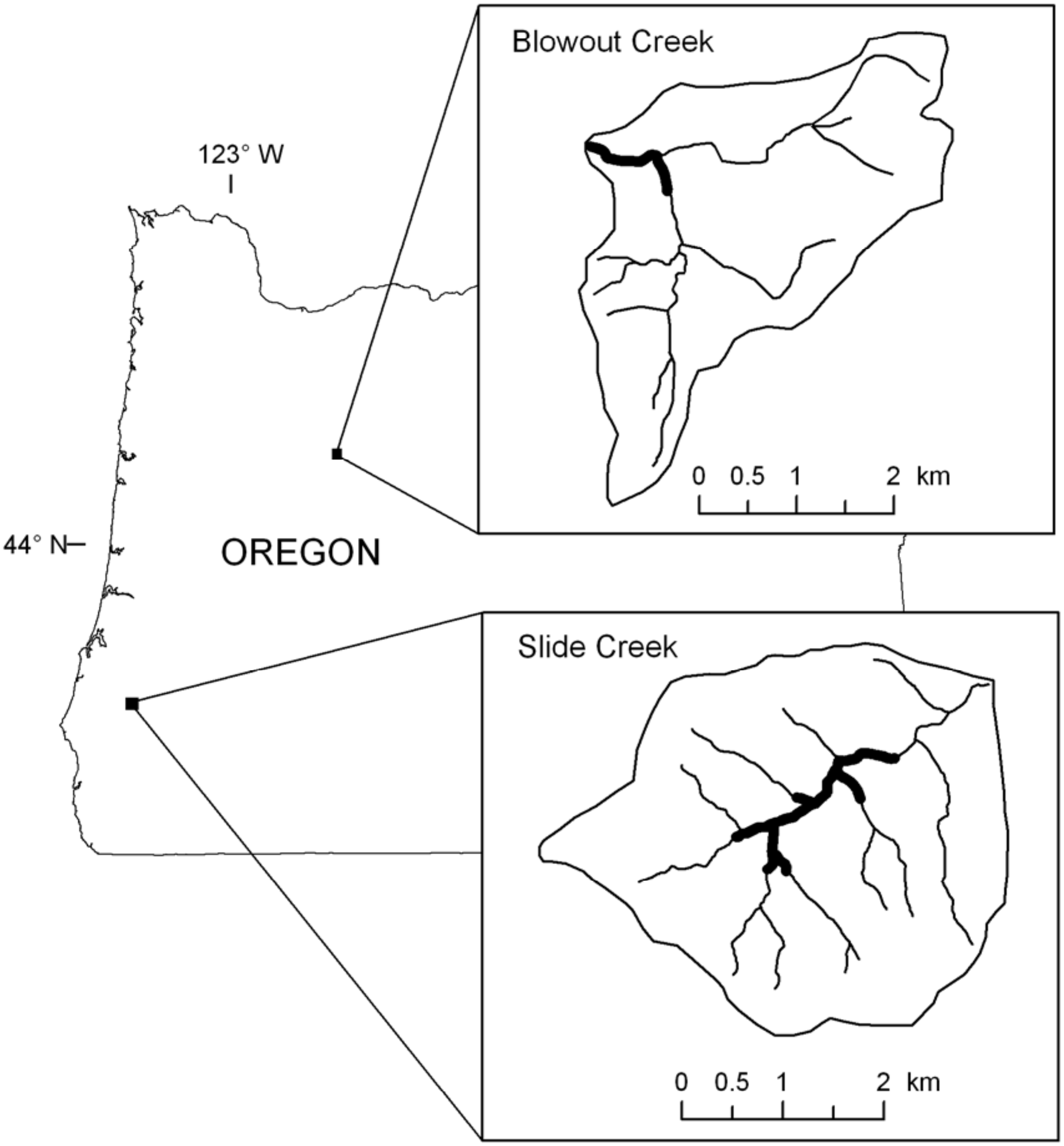

Figure 1

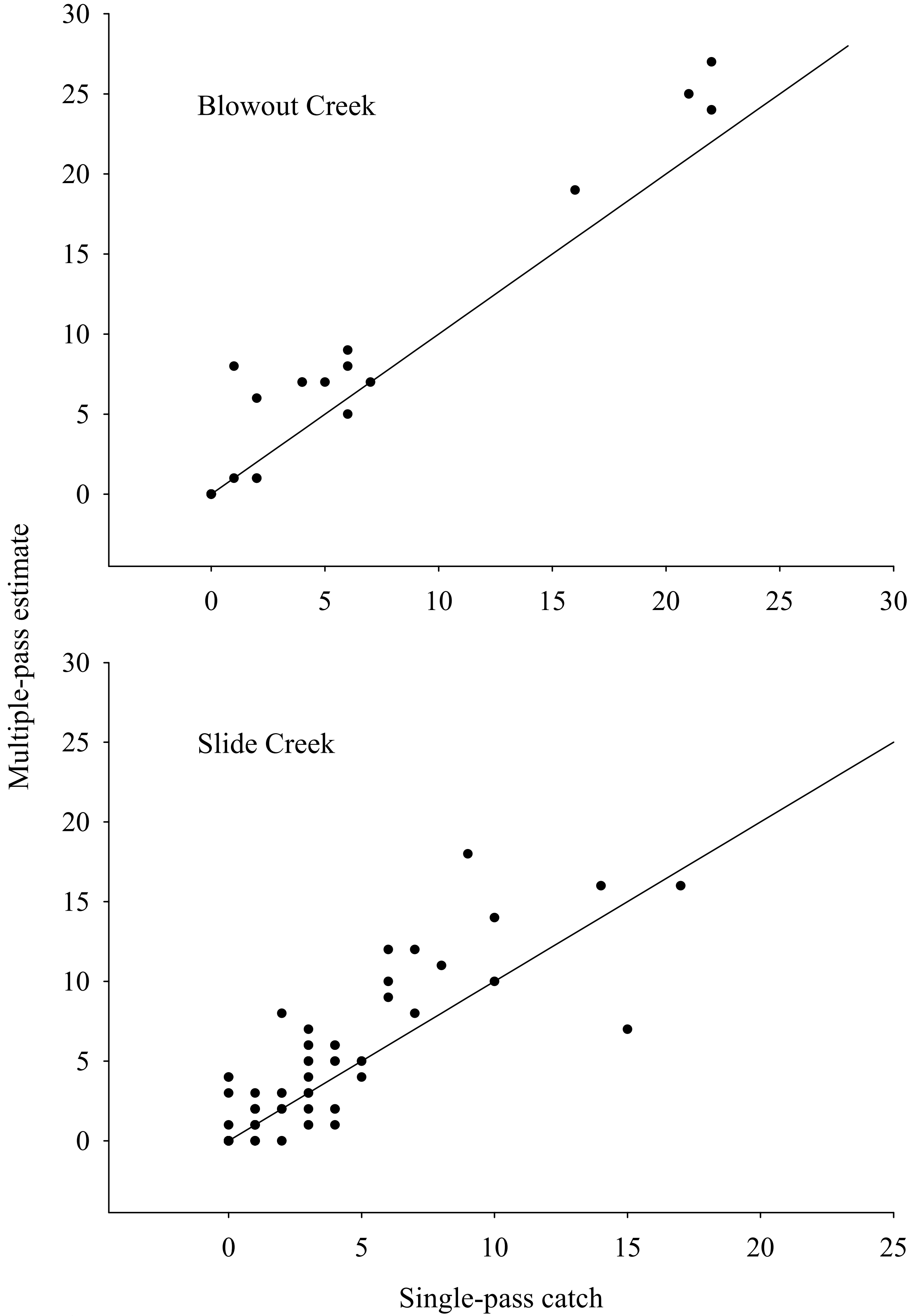
Blowout Creek
Slide Creek
Multiple-pass estimate
Single-pass catch
0
5
10
15
20
25
30

Figure 2

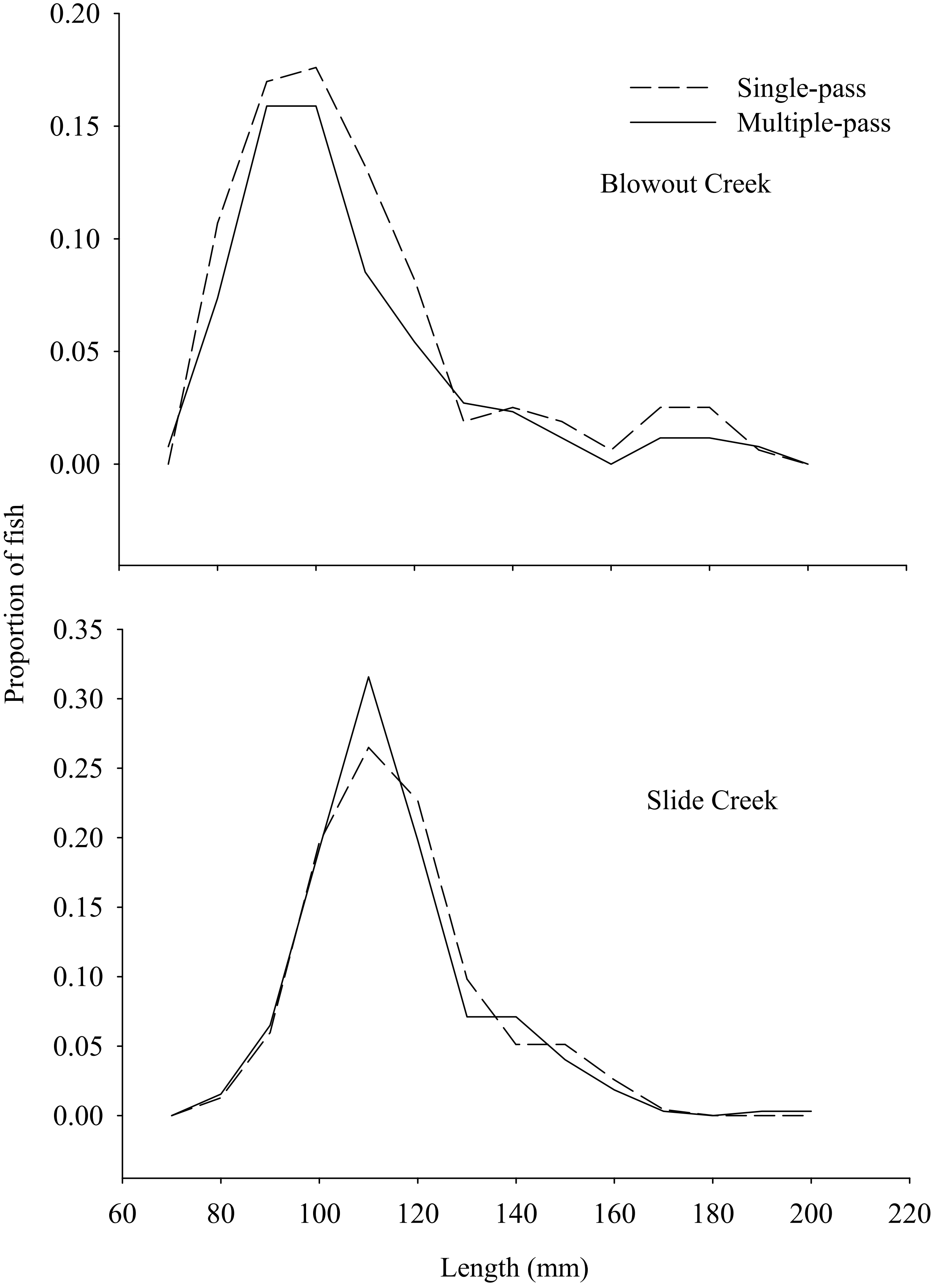
0.20
0.15
0.10
0.05
0.00
Single-pass
Multiple-pass
Blowout Creek
Proportion of fish
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Slide Creek
60
80
100
120
140
160
180
200
220
Length (mm)

Figure 3

Figure 4

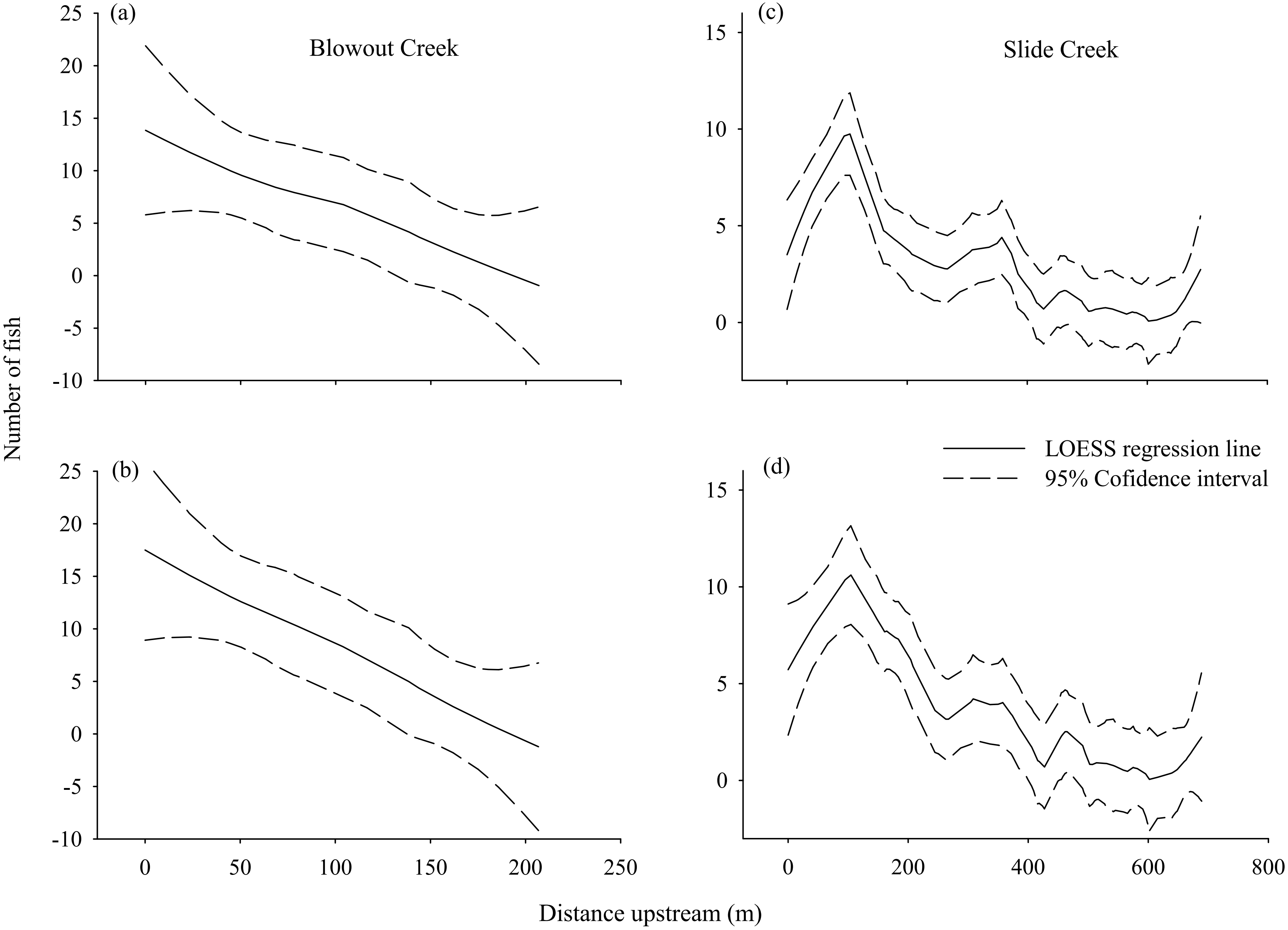
(a)
Blowout Creek
(b)
(c)
Slide Creek
(d)
Number of fish
Distance upstream (m)
25
20
15
10
5
0
-5
-10
0
50
100
150
200
250
0
200
400
600
800
LOESS regression line
95% Cofidence interval

Table 1. Watershed characteristics for two western Oregon streams.

	Blowout Creek	Slide Creek
Basin Area (ha)	918	889
Discharge (m^3/s)	0.01	0.04
Conductivity (FS)	35-37	74-90
Water Temperature (^{B}C)	9-11	9-15
Gradient (Mainstem) (%)	7.0	2.9
Gradient (Tributaries) (%)		9.2
Active Channel Width (m)	7.5 (3-14)[a]	2.5 (1-10)[a]
Number of Pools	93/12[b]	265/59[b]
Number of Cascades	14/9[b]	36/31[b]

[a] Median and range

[b] First value represents total number of habitat units of this type in the watershed; second value represents the number of units sampled by both single- and multiple-pass removal electrofishing.

Table 2. Habitat unit characteristics for two western Oregon streams.

	Blowout Creek	Slide Creek
	Median (Range)	Median (Range)
Wetted Width (m)		
Pools	3.9 (2-9)	1.7 (1-5)
Cascades	4 (2-8)	1.7 (1-8)
Length (m)		
Pools	5 (2-19)	3 (1-18)
Cascades	13.3 (6-30)	10 (3-25)
Woody Debris[a]		
Pools	0 (0-3)	0 (0-4)
Cascades	0 (0-1)	0 (0-3)
Unembedded Boulders[a]		
Pools	14 (0-42)	3 (0-25)
Cascades	68 (7-108)	21 (2-183)
Undercut Bank[a]		
Pools	0 (0-1)	0.0 (0-3.5)
Cascades	0 (0)	0.0 (0)
Maximum Depth (m)		
Pools	0.5 (0.3-1.7)	0.35 (0.2-1.3)

[a] Data were collected for these factors only in habitat units that were sampled with both single- and multiple-pass removal electrofishing.

Table 3. Comparison of sampling effort (in seconds) and the proportion of estimated population accounted for by single-pass removal and multiple-pass removal estimates for cutthroat trout in two western Oregon streams.

Stream	Number of passes	Effort (sec)	% of removal population estimate	% of total effort
Blowout Creek	1	8705	78	7
	2[a]	87930	93	71
	3[a]	123249	100	100
Slide Creek	1	24810	74	10
	2[a]	256600	100	100

[a] Blocknets