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Journal of Freshwater Ecology
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tjfe20

The Value of Using Permanent Sites When Evaluating Stream Attributes at the Reach Scale

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Published online: 06 Jan 2011.

To cite this article: Brett B. Roper, Jeffery L. Kershner & Richard C. Henderson (2003) The Value of Using Permanent Sites When Evaluating Stream Attributes at the Reach Scale, Journal of Freshwater Ecology, 18:4, 585-592, DOI: 10.1080/02705060.2003.9663999

To link to this article: http://dx.doi.org/10.1080/02705060.2003.9663999

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ABSTRACT

We evaluated two questions related to the use of permanent sites in evaluating stream attributes at the reach scale. 1) Are permanent sites more efficient than temporary sites in determining a change or trend? 2) How exact must permanent sites be relocated to improve sampling efficiency? We found that sample sizes necessary to detect a significant change for 13 of the 14 attributes were reduced by at least 40% if the sample design is based on permanent rather than temporary sites. The value of permanent sites increased with the increased precision of relocating that site.

INTRODUCTION

Natural and anthropogenic disturbances within watersheds alter physical processes resulting in the modification of stream channel dimensions and characteristics (MacDonald et al. 1991, Reeves et al. 1995, Magilligan and McDowell 1997). A goal of many aquatic monitoring projects has been to quantify these relationships (Ralph et al. 1993, Dose and Roper 1994, Wood-Smith and Buffington 1996). While aspects of monitoring streams with physical attributes have been criticized (Roper and Scarnecchia 1995, Poole et al. 1997, Bauer and Ralph 2001), physical stream survey protocols continue to improve thereby increasing the ability to detect the effects of watershed disturbance on aquatic system status and trend (Kaufman et al. 1999, Roper et al. 2002).

Sampling designs have also evolved so as to better understand the effect sample allocation has on the evaluation of an attributes status and trend (Urquhart et al. 1998, Larsen et al. 2001). This work has suggested repeat surveys at permanent sites should increase power to detect trends when compared to a sampling scheme that randomly chooses new sample sites each year. The increased power associated with use of permanent sites is due to the reduction of total variance when values collected at permanent sites are correlated (Larsen et al. 2001). When an attribute value collected at permanent sites in one year has low or no correlation with values collected at another time, however, permanent sites offer no advantage over random sites (Elzingia et al. 1998).

Poor relationships among values collected at the same locations can be due to a variety of factors. The most obvious is when measured attributes change quickly over a short time period. Examples of parameters with high variability at the stream reach scale (100's of meters stream length) include fish populations (Gibbs et al. 1998) and sediment loads (Benda and Dunne 1997). Other reasons for low correlations between time periods include observer variation in protocol application, different survey times, and failure to exactly relocate sample sites among years (Larsen et al. 2001). Attributes with a high year-to-year process variability will require additional samples or time in order to evaluate status and trend. In contrast, other components of variability can be controlled

by changing sample design or reducing observer variability. For example, operational definitions of stream attributes in combination with considerable training can minimize observer variation of some variables (Roper et al. 2002).

A common technique used to reduce site variability is ensuring resurveys of reaches occur in the same locations (Harrelson et al. 1994). While resurveying the same reach through time should reduce variance due to the site, little effort has been expended exploring the precision with which permanent sites must be relocated. If processes within watersheds (Hicks 1989), valley segments (Frissell et al. 1986), and/or reaches (Rosgen 1994, Montgomery and Buffington 1997) are similar, then high correlations should be expected by simply sampling a similar reach type within a particular valley segment or watershed. If such a relationship could be demonstrated, then minimal effort would be needed to ensure the exact relocation of a monitoring site. Conversely, if attributes vary in a less predictable manner within a valley segment or reach or change abruptly over short distances, extra effort must be expended in the exact relocation of the sites so as to ensure variance is reduced.

We address two objectives related to the use of permanent sites in aquatic monitoring programs. Our first objective was to compare the variance associated with physical stream attributes collected at permanent versus temporary sites. Our second objective explored how variance changes when data is collected from sites located within the same valley segment or similar reach types within the watershed.

METHODS AND MATERIALS

Data for this study were collected throughout the Interior Columbia River Basin in conjunction with a large-scale monitoring effort to evaluate the effects of federal land management on stream conditions. Evaluations were conducted at the scale of a stream reach (≅20 bankfull widths in length, Frissell et al. 1986). All evaluated stream reaches were wadeable (1.5-11 m bankfull width) and had gradients less than 3%. The initial determination of sample reaches was based on a random selection of a watershed in the region, then sampling the downstream most, low gradient reach on federally managed land. All total over 300 sample reaches were selected and evaluated for the large-scale effort. We collected additional data from 56 of these reaches (Fig. 1). Thirty-six were randomly selected to be evaluated a second time; 24 were selected to have a co-located reach in the same stream. Four streams occurred in both the revisit and co-located sample.

We used global positioning systems (GPS) in combination with topographic maps, site maps, and digital photographs to relocate the start point of permanent reaches. As a result the starting points of our permanent sites were relocated within the tolerances of these tools – 0 to 10 meters. Crews conducting the resurveys were provided with the reach length surveyed by the original crew to insure variations among revisits were not due to differences in evaluated length.

Observers evaluated a total of 14 physical stream attributes. These attributes were gradient, sinuosity, bankfull width, width-to-depth ratio, pool percentage, residual pool depth, bank stability, bank angle, undercut percentage, undercut depth, percent fines (< 6 mm) in riffles, median particle size in riffles (D_{50}), riffle particle size in which 84% of the sampled substrate was smaller (D_{84}), and the amount of large wood (>10-cm diameter by 3-m in length). Survey protocols generally followed standard published approaches (Platts et al. 1987, Harrelson et al. 1994). A complete description of protocols can be found in the appendix of Kershner et al. (2003). Observers received 10 days of training prior to conducting surveys to improve consistency in the use of protocols among crews. Training consisted of acquainting the crews with the attributes and methods to be used, demonstration of those methods, and several days of evaluation in field situations to ensure different crews came to similar conclusions. Estimate of observer and stream variability for most attributes evaluated within this paper can be found within Roper et al. 2002.

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Data necessary to evaluate variance associated with permanent and temporary sites were collected from 36 stream reaches (Fig. 1). Observers visited each stream during the summers of 2000 and 2001. Crews were arbitrarily assigned to evaluate reaches. A total of 17 different survey crews collected data from these reaches. No streams were resurveyed with the same crews. Other than reach length, results of the 2000 survey were not provided to observers conducting the 2001 survey. In the years these surveys were conducted, most basins had below average precipitation. This suggests stream channels were unlikely altered by low probability, high-energy spates between surveys.

We compared the efficiency of sampling at permanent sites to temporary sites by evaluating the sample sizes needed to detect a predetermined change in the value of each stream attribute. Samples sizes were used in these comparisons because reach surveys have a fixed cost independent of whether they were done at temporary or permanent sites. As such, the smaller the sample size used to detect change the less expensive the sampling design. Sample size (n) estimates followed the iterative process outlined by Zar (1996):

$$n \geq \frac{2s_p^2}{d^2}(t_{\alpha(2),v} + t_{\beta(1),v})^2$$

where s_p^2 is the pooled estimate of the variance, v is the degrees of freedom (2(n-1)) for s_p^2, $t_{\alpha(2),v}$ is the two-tailed t-value with v degrees of freedom and a type-I error rate of α, $t_{\beta(1),v}$ is the one-tailed t-value with v degrees of freedom and a type-II error rate of β, and d is the minimum difference to be detected. For all attributes we set d to 20% of the mean attribute value, and both $\alpha(2)$ and $\beta(1)$ equal to 0.1. This equation calculates the number of samples needed from each population assuming equal sample sizes and equal variances. When n exceeded 30, z-values were used instead of t-values because differences were minimal. We used the sample variance of the first visit to the 36 streams as an estimate of s_p^2. This variance estimate was used to calculate sample sizes needed for a sample design based on temporary sites.

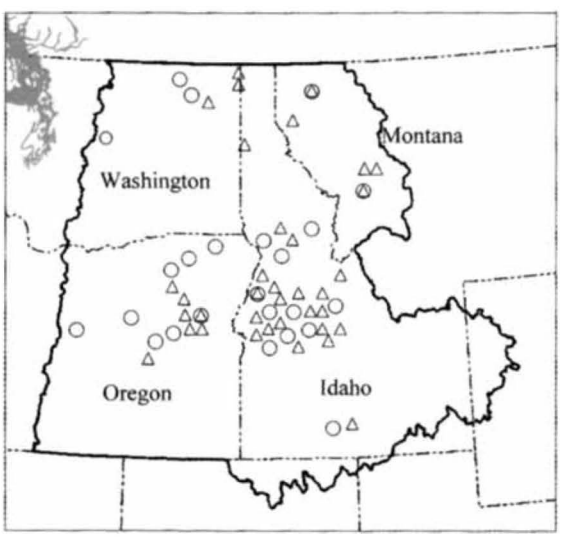

Figure 1. Locations of the stream reaches evaluated within the Interior Columbia Basin (dark line). The triangles indicate stream reaches that were precisely relocated and resurveyed. The circles indicate streams in which two closely co-located reaches were evaluated.

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In order to calculate sample sizes for permanent sites we used the modification for estimating the standard deviation suggested by Elzinga et al. (1998):

$$s_{diff} = s_p \sqrt{2(1 - r_{diff})}$$

where s_{diff} is the standard deviation that incorporates the relationship between the paired samples, s_p is the standard deviation among sampling units in the first time period, and r_{diff} is the correlation coefficient for each attribute between years at the 36 permanent sampling sites. For this estimate to be useful for comparing temporary and permanent sample sizes we had to assume no significant difference in the sample variance of the first and second visit. The assumption proved tenable for all the stream attributes we evaluated (variance ratio test, Zar 1996, $p>0.1$).

Correlation coefficients for data collected at permanent sites were <1 due to changes in stream condition and variation among evaluations. For a comparison of sample sizes, s^2_{diff} was substituted for s^2_p to estimate sample sizes at permanent sites. Because permanent sites are paired, the degrees of freedom used in these calculations are n-1 instead of 2(n-1). The value of s_{diff} will be less than s_p when the correlation coefficient between the two visits exceeds 0.5. In these cases sample sizes will be reduced by using permanent sites.

In order to determine how precisely permanent sites needed to be relocated we sampled paired low gradient reaches within the same stream in 24 watersheds (Fig. 1). These visits occurred over a four-year time frame from 1999 to 2002. Distances between the members of the paired reaches ranged from 0.1 km to 10 km. Surveys were conducted in the same manner as for the previous exercise. Correlation coefficients were calculated for two groups of stream distances: 1) those between 0.1 km and 1 km apart (n=10) and 2) those between 1 km and 10 km apart (n=14). Correlations were always evaluated by relating the downstream reach to the upstream reach.

For all analyses we assumed attributes had normal distributions. Our assumption of normality was justified by the central limit theorem not the underlying distribution of the individual indicator values (Urquhart et al. 1998).

Table 1. Mean values of the first visit to permanent site and the correlation coefficients between visits at 36 revisited stream reaches. The column entitled r is the correlation coefficient. Sample sizes for both temporary and permanent sample designs are determined for detecting a difference of 20%, and a type I and type II error rate of 0.1. Numbers listed in sample size columns are the number of samples required in each time period. All correlation coefficients are significant at the $\alpha \leq 0.1$.

			Sample Size	
Attribute	Mean	r	Temporary	Permanent
Gradient (%)	0.96	0.92	211	34
Sinuosity	1.43	0.91	27	7
Bankfull width (m)	5.58	0.86	47	15
Width-to-depth ratio	17.88	0.75	60	32
% Pool	57.63	0.86	53	17
Residual pool depth (m)	0.37	0.92	102	19
Bank stability	83.52	0.60	20	17
% undercut	34.33	0.72	101	57
Undercut depth (m)	0.09	0.86	157	46
Bank angle (°)	101.14	0.81	20	9
Percent fines	30.06	0.91	333	61
D_{50} (mm)	30.70	0.84	271	87
D_{84} (mm)	65.03	0.89	170	38
Large wood (#/100 m)	7.27	0.86	587	165

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RESULTS

All 14 of the attributes we surveyed at permanent sites had correlation coefficients exceeding 0.5. These data indicate sample variance and therefore sample size would be reduced if the sample designs evaluating these attributes utilized permanent sample reaches instead of randomly selected reaches (Elzinga et al. 1998). Correlation coefficients ranged from a high of 0.92 for gradient to a low of 0.60 for bank stability (Table 1). Sample sizes needed to detect 20% changes in attributes were 15 to 84% lower if permanent sites were used instead of temporary sites.

Correlation coefficients (r) estimated from neighboring reaches within the same watershed were generally lower than the relationships derived from revisiting the same site (Table 2). The strength of the relationship declined as reaches became farther apart. Half the attributes had correlation coefficients exceeding 0.5 when distances between sites were between 0.1 and 1 km. At distances of between 1 and 10 km, five attributes still had correlation coefficients exceeding 0.5. Three of the 14 attributes — bankfull width, residual pool depth, and undercut depth — had correlation coefficients exceeding 0.5 at all distances.

Table 2. Correlation coefficients determined from multiple sampled reaches within a watershed. Ten reaches between 0.1 and ≤1 km apart and 14 for reaches 1 km to <10 km apart sampled. A * indicates the correlation coefficient significant at $\alpha \leq 0.10$.

	Correlation Coefficent (r)	
Attribute	0.1 km to ≤ 1 km	>1 km to 10 km
Gradient (%)	0.82*	0.20
Sinuosity	0.04	0.29
Bankfull width (m)	0.90*	0.76*
Width-to-depth ratio	0.27	0.10
% Pool	0.80*	0.38
Residual pool depth (m)	0.84*	0.70*
Bank stability	0.48	0.19
% Undercut	0.28	0.50*
Undercut depth (m)	0.53*	0.51*
Bank angle (°)	0.32	0.61*
Percent fines	0.56*	0.48*
D_{50} (mm)	0.37	0.34
D_{84} (mm)	0.68*	0.06
Large wood (#/100 m)	0.42	0.31

DISCUSSION

These analyses document the clear advantage of using permanent sites in assessing commonly evaluated stream attributes. Sample sizes necessary to detect a change for all attributes we evaluated except one (bank stability) were reduced by at least 40% when using permanent instead of temporary sites. These data support complementary work on sample designs that suggested the use of permanent sites can result in the more rapid trend detection (Urquhart and Kincaid 1999).

Although sample sizes for all attributes were reduced through the use of permanent sites, the attributes describing substrate and large wood benefited the most from this sampling strategy. Sample sizes necessary to detect a 20% change in the three substrate measures were reduced by at least 130 (>66%) when using permanent instead of temporary sites. The reduction in the number of samples was even more dramatic for large wood, where samples required for permanent sites were 422 (72%) fewer than temporary sites. The large drop in the required sample sizes to detect pre-specified differences indicates that these attributes have high variability among sites which can be

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effectively controlled for by resurveying permanent sites (Larsen et al. 2001).

Previous studies have suggested that high stream-to-stream variability coupled with observer inconsistency results in difficulty when using stream attributes to assess changes in aquatic systems (Roper and Scarnecchia 1995, Poole et al. 1997, Bauer and Ralph 2001). Roper et al. (2002), however, suggested that numerous stream attributes could be used to evaluate changes in stream conditions if they were part of a large-scale well funded monitoring effort. The findings of this study suggest that a less extensive stream monitoring program using a specific suite of characteristics may succeed, as long the evaluation is based on stream attributes measured at permanent sites. For nine of the 14 attributes we evaluated, a stream monitoring program with less than 40 permanent sites would likely detect a significant difference (α=0.1) when a 20% change in the attributes mean value occurred between two sampling periods. Permanent sites for smaller scale studies can also use more powerful paired designs to analyze change. Non-parametric tests such as the Wilcoxon sign rank test can be used to detect the general direction of change with smaller sample sizes and without specifically stating the exact amount the attribute has changed (Hollander and Wolfe 1973).

Permanent sites should be relocated as precisely as possible. Correlations at sites measured in the same place were high, and these values tended to decline quickly when resurveys were located any distance away. Eleven attributes had correlations exceeding 0.80 when measurements between years were taken in the same reach. Gradient, bankfull width, percent pool and residual pool depth had correlation which remained above 0.80 when survey reaches were located between 0.1 and 1 km apart. No attributes we evaluated had correlation in excess of 0.80 when distances between reaches exceeded 1 km. While correlations diminished with distance, values for many attributes still suggested advantages to measuring stream reaches in the same gradient class within the same watershed rather than randomly sampling new stream reaches in a different watershed.

One potential shortcoming of this study is that it was conducted over a short time frame (< four years) in watersheds that had not been subject to low probability disturbances (i.e., flood or fires). Under circumstances evaluated in this study, correlations < 1 primarily represented variation among observers, within reach, and/or within the summer sampling window – not actual changes in the attributes. If measurements had been separated by more time or by a larger disturbance, sites may have changed markedly (Lyons and Bestha 1983, Reeves et al. 1995) thereby reducing between visit correlations. Reduced correlations would result in higher sample sizes. But given the strength of the correlation we observed in this study, even after a major disturbance, survey designs based on permanent location are still likely to be significantly less costly than those based on temporary sites.

Identifying the time period that correlations between visits remain high is an important aspect of sample design using permanent sites (Urquhart et al. 1993). Longer time intervals (5-20 years) may be sufficient for characteristics such as gradient, sinuosity and bankfull widths which are primarily determined by geology, geomorphology, and precipitation pattern. These attributes likely change slowly over the time scale of a decade or after low probability events (Leopold and Wolman 1957, Knighton 1974, Frissel et al. 1986). In contrast, other attributes we measured such as bank shape, habitat composition, habitat complexity, large wood, and substrate composition have been shown to change over short-time periods or following disturbances (Hicks et al. 1991, Benda and Dunne 1997). In order to use permanent sites to detect changes in these attributes a more intensive revisit cycle of two to five years may be necessary.

The primary disadvantage of permanent sites is their reduced ability to describe status. Given a constrained sample effort (for example 30 sites a year), the total number of unique sites visited using a sample design based on permanent sites will be smaller than one based on temporary sites. A larger number of unique sites can permit a more precise estimate of an attributes overall average (status). The use of temporary sites,

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however, greatly increases among stream variability (Urquhart et al. 1993). This increases the likelihood of Type II errors -- accepting the null hypotheses (no difference) when there is a difference in the true condition. The lack of power associated with temporary sites amplifies the uncertainty associated with decisions based on these data (Peterman 1990, Ludwig et al. 1993). Therefore, a sample design relying on temporary sites must be used with caution when sample sizes are small.

ACKNOWLEDGEMENTS

We thank Eric Archer for overseeing the Forest Service field efforts that collected and summarized these data as well as reviewing an early draft of this document. Regions 1, 4, and 6 of the USDA Forest Service and USDI Bureau of Land Management state offices of Oregon/Washington and Idaho provided funding for this project.

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Received: 1 April 2003 Accepted: 9 July 2003