CHAPTER V. THE INFLUENCE OF SAMPLING INTERVAL ON THE ACCURACY OF TRAIL IMPACT ASSESSMENT

Abstract

Trail impact assessment and monitoring (IA&M) programs have been growing in importance and application in protected area recreation resource management. Census-based and sampling-based approaches have been developed, with systematic point sampling being the most common design in trail IA&M programs. This paper examines the influence of sampling interval on the accuracy of estimates for selected trail impact problems. A complete census of impact problems on 70 trails in Great Smoky Mountains National Park was utilized as the base data set for these analyses. Census data were resampled at increasing intervals to create a series of simulated point data sets. Estimates of frequency of occurrence and lineal extent for four impact problem types were compared with the census data set. The responses of accuracy loss on lineal extent estimates to increasing sampling intervals varied across different impact types, while responses for frequency of occurrence estimates were consistent, approximating an inverse asymptotic curve. These findings suggest that systematic point sampling is an appropriate method for estimating the lineal extent but not the frequency of trail impacts. A sample interval of less than 500 m appears to provide the reasonably accurate estimate for the four impact types evaluated. Further studies are needed in order to generalize these results to different environments and impact situations. The census-based trail survey and the resampling-simulation method developed in this study can be a valuable first step in

establishing long-term trail IA&M programs, in which an optimal sampling interval range with acceptable accuracy is determined before investing efforts in data collection.

Key Words: impact assessment, trails, sampling interval, accuracy, Great Smoky Mountains National Park.

Introduction

Trails in protected areas serve dual purposes of providing recreational access and opportunities, while protecting the resource by concentrating traffic on resistant trail treads. However, degraded trail conditions, manifested by different impact problems such as erosion and muddiness of trail treads, detract from their functional and recreational values, exacerbate their possible landscape ecological effects, and draw on meager protected area maintenance budgets (Cole 1983, Forman 1995). As trail impacts become a significant resource management issue, it is imperative that protected area managers base their management decisions on objective and reliable information, particularly the severity and extent of major types of trail impact. This information, coupled with visitation and environmental information, permits examination of factors that influence the type, severity, and extent of trail impact. When periodically collected as part of a monitoring program, such information can detect changes before impacts become severe or irreversible, identify trends, and evaluate the effectiveness of trail management actions.

These information needs require the development of efficient and reliable trail impact assessment and monitoring (IA&M) programs, which are increasingly employed in protected areas worldwide (Ruff and Maddison 1994, Hawes 1996), and incorporated into management planning and decision frameworks such as the U.S Forest Service's Limits of Acceptable Change (LAC) and the U.S. National Park Service's Visitor Experience and Resource Protection (VERP) models (Stankey et al. 1985, NPS 1997). Non-profit environmental organizations and outdoor clubs have also developed trail assessment programs to facilitate their volunteer maintenance efforts (ATC 1994). Previous trail-related studies have largely focused on the effects of human trampling and on factors that influence trail degradation (Leung and Marion 1996). Despite its importance, survey designs of trail IA&M programs have not been fully addressed by the trail research literature. Recognizing such a research gap, this paper was designed to investigate a fundamental issue in designing trail IA&M surveys: the choice of sampling interval.

Trail Impact Assessment and Monitoring Approaches

Previous trail IA&M programs have adopted either a *census-based* or *sampling-based* survey approach, with a few studies combining both (Table 5.1). Each of these approaches typically involves multiple indicators and measurements, and each can yield information useful to protected area managers (Cole 1983, Leung et al. 1997). The selection of survey approach is largely guided by management objectives and type of management standards in a particular protected area. Under the LAC or other standards-based management frameworks, for example, trail management standards may be stated as the following:

1. "The average tread width for any trail should not exceed 2 m"
2. "No more than 5% of a trail's length should have excessive tread incision, defined as segments where tread incision exceeding 30 cm in depth extends for more than 10 m in length"

The first type of management standard requires a characterization of tread width with reasonable levels of precision. Sampling-based approaches are most appropriate for

Table 5.1. A classification of different trail IA&M survey approaches and designs.

General Approach	Method	Implementation	Selected Examples	Trail Environments
Sampling-Based	Systematic point sampling	Observation points are placed at fixed distances along a trail	Cole (1983) Hall and Kuss (1989)	• wilderness trails in Montana, USA • national park trails in Virginia, USA
	Stratified point sampling	Sampling plans (intervals, types of measurement) vary across different strata	Summer (1980) Lajeunesse et al. (1997)	• national park trails in Colorado, USA • urban park trails in Montreal, Canada
Census-Based	Sectional evaluation	A trail is divided into sections of equal length and impact problems are made for each section	Bratton et al. (1979) Hawes (1996)	• national park trails in Tennessee/ North Carolina, USA • wilderness trails in Tasmania, Australia
	Problem census	Impact problems are predefined, followed by complete census of these impact problems	Marion (1994) Cole et al. (1997)	• national park trails in Tennessee/ North Carolina, USA • wilderness trails in Oregon and Washington, USA
Integrative		Combines the two approaches above in a single survey	Bayfield and Lloyd (1973)	• a long-distance hiking trail in England, UK

obtaining data that permits such a characterization. In contrast, the second type of management standard requires a reasonably accurate aggregate measure or estimate of trail segments exhibiting unacceptable problems. Census-based approaches are generally considered more appropriate for obtaining counts and dimension measurements of problem segments, although sampling-based approaches may also provide extent estimates (Cole 1983). The primary purpose of this paper is to define the role of sampling-based surveys for evaluating the second type of management standards.

Ideally, a complete enumeration or census of all impact incidents (or problem segments) regarding their location, dimension, and severity would satisfy all information needs for evaluating most management standards. Such a census-based approach, however, is time consuming and costly, and requires expertise in consistently identifying and measuring each impact incident in the field. As a result, few census-based trail IA&M programs have been developed, and those that have use coarse levels of measurement (Mortensen 1989, Marion 1994, Cole et al. 1997).

More often, protected area managers employ a sampling-based approach for designing trail IA & M surveys, as sampling designs reduce field time or permit more detailed measurements of impact indicators and environmental site characteristics at sampling points (Cole 1983). However, the utility of sampling-based approach is hinged on the assumption that a representative sample is achievable to provide accurate and precise estimates of trail impact conditions that would approximate the results from a complete census. In order to provide management guidelines for developing optimal sampling schemes that yield such a representative sample, the viability of this assumption needs to be examined.

The Sampling Issue

There are three levels of sampling questions involved in any trail IA&M survey design. At the *broad or landscape scale*, the primary sampling question concerns the selection of an objective and representative sample of trails or trail segments in a protected area for assessment and monitoring. The selection process at this level, however, is often non-random and biased towards trails that have substantial impact problems.

At the *local or site scale*, the primary sampling question concerns the selection of measurements or observations at individual sampling points along a trail. Procedures applied to assess trail surface (tread) conditions at a sampling point include trail width, maximum tread incision, and muddiness. Research studies often add procedures to precisely profile a cross-section of the tread (Leonard and Whitney 1977) or to document and evaluate changes in vegetation cover and composition (Dale and Weaver 1974, Hall and Kuss 1989). Most previous studies have employed established ecological methods for vegetation sampling using line transects or quadrats at a series of locations arranged in a gradient away from the trail tread.

Subsequent to the selection of trails or trail segments to be assessed, and prior to collecting data at specific sampling points, one must decide how frequently and where the sampling points should be located. This paper is concerned with spatial sampling questions at this *intermediate or trail scale*. There are two general consequences associated with suboptimal spatial sampling at this scale. First, oversampling should yield an accurate characterization of the magnitude of trail impacts, but is inefficient and too costly. In contrast, undersampling provides an inadequate sample size to accurately estimate the magnitude of impact problems. Management decisions based on such undersampled data are unreliable and misleading.

Systematic point sampling is probably the most common trail IA&M survey design due to its simplicity of implementation (Table 5.1). This sampling approach is most effective when the phenomenon of interest exists randomly in space, or when there is no periodicity or regularity in distributional patterns. The choice of sampling interval in most previous surveys utilizing a systematic sampling scheme, however, has been arbitrary, ranging from 50-500 m for assessing trail tread conditions (Cole 1983, Lemky 1996). A few approaches for determining sampling intervals have been documented. For example, Adkison and Jackson (1996) selected a desired number of sampling points, then divided the length of each trail by this number to determine the sampling interval. Alternatively the sampling interval can be fixed, with the number of samples determined by trail length (Parikesit et al. 1995). Lance et al. (1989) employed a statistically-based approach to determine the minimal sampling interval. They conducted a pilot survey and used variability in trail width measurements to determine the minimum sample size needed to obtain a specified confidence level. The sampling interval was derived by dividing trail length by the minimal sample size (Lance et al. 1989).

Spatial sampling is an important issue in disciplines such as geography, ecology, and natural resource sciences, which strive to understand the spatial distribution and variation of phenomena. The effects of sampling interval and sampling intensity on the accuracy of digital elevation models (DEMs) and derived topographic attributes have been investigated (Balce 1987, Li 1992, Gao 1997). Their results indicate that accuracy tends to decrease with increasing sampling intervals, and that greater accuracy loss seems to be associated with more complex terrains (Balce 1987, Gao 1997). Ecologists have also been concerned with the effects of sampling methods and sample intensity on the accuracy of population estimates. Complete census surveys (Etchberger and Krausman 1997) and computer simulations (Dale et al. 1991) have been used to provide 'ground truth' data sets for comparing against alternative sampling schemes.

This study attempts to address several spatial sampling questions in trail IA&M surveys, with a focus on the issue of sampling interval as it affects the accuracy of trail impact problem estimates. Answers to these questions provide guidance for researchers and managers in developing efficient and reliable trail IA&M programs and in selecting appropriate sampling strategies. Four specific research questions are:

1. What is the general magnitude of loss of estimate accuracy within the range of sampling intervals commonly adopted by trail IA&M surveys?
2. What is the magnitude and direction of loss in estimate accuracy in response to increasing sampling intervals?
3. To what extent do the response patterns of the four impact types vary from each other?
4. What is the variability in the accuracy loss among trails, and to what extent is this variability related to topographic complexity, trail length, and impact characteristics?

Study Area

Data for this study were collected as part of a comprehensive recreation impact assessment project conducted in Great Smoky Mountains National Park (GSMNP) (Marion 1994, Marion and Leung 1997). Seventy-two backcountry trails totaling 520 km (35% of the park's total trail mileage) were surveyed using a census-based problem assessment method. The surveyed trails were selected by managers, including low to high use trails, though a disproportionate number were highly impacted. However, the sample size is considerable and includes a broad cross-section of trails from all areas of the park and a diversity of topographic positions and vegetation types (Marion 1994).

Located between the states of Tennessee and North Carolina, GSMNP is the most heavily visited park in the U.S. National Park System, reporting 8.6 million recreation visits in 1994 (NPS 1994). A considerable number of visitors engage in day hiking and overnight backcountry activities. This heavy visitation places considerable pressure on the park's 1470 km trail system, two-thirds of which are also open to horse use. The problem of trail impacts was previously addressed by a parkwide trail survey conducted by Bratton et al. (1979) in the 1970s. Trail erosion and muddiness problems were extensive in their study. No program for monitoring trail conditions currently exists in the park, although such work is identified as a critical need in a revised Backcountry Management Plan (GSMNP 1995). Trail maintenance is performed by park crews and volunteers. Funding and staffing for this work is limited, however, and budget cuts over the past decade have greatly reduced the extent and effectiveness of these efforts. The diversity of the park's environment, such as a large elevation range and steep topography, as well as the extensiveness of trail impact problems, provide a diverse data set of trail conditions.

Methods

This study was designed to examine the effects of changing sampling intervals on the accuracy of sampling-based trail IA&M surveys in estimating (1) the frequency of occurrence, and (2) the lineal extent of impact problems. *Accuracy* is herein defined as the extent to which an estimate mirrors the true value of a quality (Avery and Burkhart 1994). It should be distinguished from the related concept of *precision*, which refers to the clustering of sampling values about their own average, regardless of whether the average is the true value or not. Sampling error is referred to as a *loss of estimate accuracy*, manifested as the deviation of an estimated value from its true value due to increasing sampling intervals (distance along a trail) between which observations are made.

The selected trails in GSMNP were assessed by a complete census of six predefined impact problem types. These impact types were determined in consultation with park staff, and were considered to be significant with respect to their negative effects on various trail values, including functional, safety, aesthetic, recreational, and ecological elements. This paper is restricted to four of these six impact types used to define the trail problem segments reported in this paper:

1. *tread incision* - the erosional lowering of the trail tread of more than 30 cm (1 ft),
2. *wet soil* - wet or muddy soils covering more than half the width of the trail tread,

3. *exposed roots* - tops and sides of many tree roots exposed on the trail tread,

4. *multiple treads* - two or more parallel trail treads within the same trail corridor.

A trail measuring wheel (1.2-m, or 4-ft circumference) was pushed by field staff to record the distance from each trail's starting point to the beginning and end points of all problem segments longer than 3.3 m (10 ft) in length, the observation unit size in this study. This method yielded data on location, type, and length (lineal extent) of problem segments. Other trail attributes, such as width and incision depth, were not measured. This census data set represents the 'ground truth' or reference data set in this paper. The quality, in terms of both accuracy and precision, of this census data set was recognized as an important issue in itself, and was enhanced by the use of a comprehensive procedural manual and careful training of field staff. Accuracy and precision levels of this census data set, however, are not critical for this study, as the census data set is simply utilized as the reference for evaluating the reproducibility of reference values from systematic point sampling with varying intervals. The use of empirical census data, as compared to computer-generated data, has the advantage of reflecting the actual range and complexity of impact and environmental conditions on trails.

A resampling-simulation approach was implemented on the census data to generate a series of simulated point data sets at varying sampling intervals. Similar approaches have also been used by geographers and landscape ecologists for investigating spatial scale effects on ecological relationships (Turner et al. 1989, Bian and Walsh 1993) and the accuracy of topographic parameters extracted from DEMs (Gao 1997). Two trails were excluded from the analysis as they had no occurrences of any of the four impact types. For each of the remaining 70 trails, a 3.3-m (10-ft) interval point data set was first created to represent the census data set in a point format (the base-level point data set). A series of 20 simulated point data sets were subsequently extracted by resampling the base-level data set at 30-m (100-ft) increments, with the minimum sampling interval set at 30 m and the maximum at 606 m (2000 ft). This range of sampling intervals reflects common choices in previous trail IA&M surveys (Cole 1983).

At each sampling interval level, sampling points were regularly spaced along the trail, beginning from the trailhead or a random starting point as described below. The presence or absence of each impact type was noted for each sampling point. Specifically, if a sampling point fell within any part of a problem segment in the census data, a positive response, or 'hit' was recorded. For problem segments with lengths greater than the sampling interval, multiple hits were recorded. For each of the four impact types, two estimates, the frequency of occurrence (FO), and the lineal extent (LE), were obtained for each trail at each sampling interval. Both parameters were measured on a unitary (per km) basis so that they can be compared across trails of different lengths.

From the census data set, FO (# occurrences/km) for impact type j was determined by the following formula:

$$FO_j = \frac{\sum_{i=1}^{n} O_{ij}}{L_T} \qquad (1)$$

where O_{ij} is the i-th (i = 1, 2, ..., n) occurrence of impact type j, and L_T is the total length of the trail (km).

LE for impact type j (m/km) was calculated by:

$$LE_j = \frac{\sum_{i=1}^{n} L_{ij}}{L_T} \qquad (2)$$

where L_{ij} is the problem segment length of the i-th (i = 1, 2, ..., n) occurrence of impact type j, and L_T is the total length of the trail (km).

From the simulated point data sets, the FO estimate for impact type j, or $E(FO_j)$, was determined by:

$$E(FO_j) = \frac{\sum_{i=1}^{n} I_{ij}}{L_T} \qquad (3)$$

where I_{ij} is the *i*-th (i = 1, 2, ..., n) incident of impact type j. Multiple continuous hits of a single problem segment were assigned as one impact incident.

The lineal extent estimate (m/km) of each impact type was determined by:

$$E(LE)_j = \frac{\sum_{i=1}^{n} H_{ij}}{H_T} \times 1000 \qquad (4)$$

where H_{ij} is the i-th (i = 1, 2, ..., n) hit of impact type j, and H_T is the total number of possible sampling points on the trail, determined by dividing trail length with sampling interval.

The possible effect of alternate starting points on the results, as described by Li

(1992), was controlled by implementing six different runs with varying starting points. The starting points in five runs were chosen at random between 0 and 30 m (0-100 ft), with the remaining one started at zero, which was generally at the trailhead signpost. Results from these six runs were averaged for reporting the results, since no significant differences were found on the estimates among these six runs (with one exception at the 121-m (400 ft) interval level).

To address the research questions, the difference between an impact estimate value, E(FO) or E(LE), from simulated data sets and its corresponding values from the census was calculated and examined with respect to their magnitude of deviation at each sampling interval level. This difference was expressed as *percentage loss of estimate accuracy* from the census value. This relative measure permits valid comparison among trails with varying impact extents. It was expected that the loss of estimate accuracy would increase with augmented sampling intervals. The overall magnitude of accuracy loss within the common interval range was evaluated by categorizing the results into three interval-level groups and by comparing between these groups in terms of average conditions and the intra-group variability. One-way ANOVAs and Duncan's multiple range tests were used to test the null hypothesis that mean accuracy losses in impact estimates are not different among these three groups. Variations in response patterns, including the magnitude, rate, and direction of accuracy loss, among the four impact types were evaluated through the use of graphs. Variations in the magnitude of accuracy loss among different trails were related to their differences in topographic complexity, trail length, and impact characteristics. The former two factors were chosen because previous studies have suggested that complex terrains are likely to be sensitive to spatial sampling error (Balce 1987, Gao 1997). Also, longer trails provide larger sample sizes at a given sampling interval, which might reduce the magnitude of accuracy loss. At each sampling interval level, a stepwise multiple regression was performed to determine the relative importance of these factors. Input data and regression residuals were checked for normality and equal variance assumptions. All simulations and analyses were conducted in SPSS for Windows (ver. 7.5).

Results

The Actual Extent of Trail Impacts

Table 5.2 summarizes the extent of trail impact problems for the 70 GSMNP trails based on the census data. Tread incision and wet soil are the two most common impact types with respect to both aggregate and unitary measures. There are, for example, 734 occurrences of tread incision on 52 trails, contributing to a sum of 23.5 km or 4.6% of total assessed trail length. Wet soil exhibits a similar number of occurrences (752) but less lineal extent (18.1 km). In contrast, exposed roots and multiple treads are much less pronounced in both occurrence and lineal extent, although the problem of multiple treads was observed on more trails (61) than the other three impact types.

Table 5.2. Results from the census data for aggregate and unit measures of four impact problem types along 70 trails within Great Smoky Mountains National Park.

Impact Type	n [1]	Aggregate Measure		Unitary Measure [2]		
		Total Occurrence (no.)	Total Lineal Extent (km)	Frequency of Occurrence (no./km)	Lineal Extent (m/km)	Problem Segment Length (m)
Tread Incision	52	734	23.5	4.9 ± 0.6	63 ± 13	26 ± 3
Wet Soil	55	752	18.1	4.7 ± 0.8	46 ± 14	21 ± 3
Exposed Roots	41	365	5.2	4.4 ± 0.8	18 ± 3	11 ± 1
Multiple Treads	61	470	9.4	2.8 ± 0.5	22 ± 4	22 ± 3

[1] number of trails where the impact type exists.
[2] mean ± 1 standard error.

More valid comparisons among the four impact types are made with unitary measures, which account for differences in number of trails and their lengths (Table 5.2). On a per km basis, tread incision and wet soil remain high in frequency of occurrence and lineal extent. Individual problem segments associated with tread incision and wet soil average 26 and 21 m, respectively. Exposed roots also exhibit a high frequency of occurrence (4.4 occurrences/km) on the 41 trails where this impact type was observed. This same impact type, however, has the lowest average lineal extent (18 m/km), primarily due to shorter lengths of individual problem segments.

Effects of Changing Sampling Interval

The Magnitude of Accuracy Loss

The magnitude of accuracy loss of lineal extent (LE) and occurrence (FO) estimates within the common interval choice range (30-606 m) may be evaluated by categorizing the 20 sampling intervals into three interval groups of similar range. *Absolute* accuracy loss values were averaged to provide the magnitude of loss for each trail within each group. The direction of accuracy loss was not important in this evaluation and will be discussed in the next section.

The results summarized in Table 5.3 show that for the short interval group (30-182 m), the magnitude of accuracy loss of LE estimates ranges from a mean of 51% for wet soil to a mean of 58% for exposed roots. The magnitude of accuracy loss of FO estimates are more substantial, ranging from a mean of 72% for tread incision to a mean of 85% for exposed

Table 5.3. Average losses of estimate accuracy on linear extent and frequency of occurrence of four impact types among three sampling interval groups.

Impact Type and Estimate [1]	Sampling Interval Group [2]		
	Short (30 - 182 m)	***Medium (212 - 394 m)***	***Long (424 - 606 m)***
***Tread incision** (52)*[3]			
LE	56±11%(a) [4]	100±15%(b)	108±10%(b)
FO	72±1.8%(a)	93±0.5%(b)	97±0.3%(b)
***Wet soil** (55)*			
LE	51±6%(a)	105±12%(b)	110±10%(b)
FO	79±1.6%(a)	95±0.7%(b)	97±0.3%(b)
***Exposed roots** (41)*			
LE	58±5%(a)	108±10%(b)	125±10%(b)
FO	85±1.2%(a)	96±0.6%(b)	98±0.3%(b)
***Multiple treads** (61)*			
LE	53±5%(a)	106±9%(b)	133±17%(b)
FO	76±1.9%(a)	95±0.7%(b)	97±0.5%(b)

[1] Estimate of trail impact problem: LE: lineal extent; FO: frequency of occurrence.
[2] Interval groups in feet: short (100-600ft), medium (700-1300ft), long (1400-2000ft).
[3] Number of observations (trails)
[4] Mean ± 1 standard error. All inter-group differences are significant at p=0.001 level (One-way ANOVA). Values followed by different letters are significantly different (Duncan's multiple range post-hoc test, $\alpha = 0.05$)

roots. Smaller standard errors of the FO values in Table 5.3 are indicative of little variability across trails. These data indicate that GSMNP trail surveys with sampling intervals less than 182 m would have about a 55% accuracy loss in LE estimates of impact problems, though the magnitude of loss would vary from trail to trail. FO estimates of impact problems along most trails are likely to have a higher accuracy loss. Such a magnitude of accuracy loss may be illustrated by a hypothetical example: For 30 trails that have an identical lineal extent of tread incision (e.g., 100 m/km), the simulation results suggest that systematic point sampling using an interval between 30-182 m could yield LE estimates that deviate 56% from the true value, from an underestimate of 44m/km to an overestimate of 156 m/km. The magnitude of accuracy loss is less pronounced for wet soil and multiple treads.

Table 5.3 also exhibits an increasing trend on the magnitude of accuracy loss from the short interval group to the medium (212-394 m) and long (424-606 m) interval groups, in which accuracy loss on LE estimates exceeds 100% for all impact types. The difference of mean LE and FO values between the short and medium groups are statistically significant ($p<0.001$), but differences between the medium and long interval groups are not. This result indicates that regardless of direction of accuracy loss (underestimate vs. overestimate), the magnitude of accuracy loss changes more substantially at shorter intervals, but tends to stabilize at longer intervals. This implies that the choice of sampling interval may have greater effect on the resulting estimate accuracy when shorter intervals are under consideration.

A higher deviation in LE estimates between systematic sampling and problem census methods has been reported by Cole (1983). Using a systematic sampling interval of 320 m, he obtained an LE estimate of 17% (equivalent to 170 m/km) for wet soil, which was 1,600% higher than 1% (10 m/km) determined by a problem census on the same trail in his study. This 1,600% overestimate in LE is much greater than the average accuracy loss of 107% for wet soil (LE) at the similar 333 m interval in the present study. However, this comparison may not be entirely appropriate due to differences in wet soil definitions and in the observation unit size for recording wet soil incidents.

Response Patterns Among Impact Types

While the accuracy loss evaluation provides some insight into the overall magnitude and trend of accuracy loss, specific response patterns for each impact type to changing sampling intervals permit a more detailed analysis of the relationship between sampling interval and loss of estimate accuracy. Specific response patterns for each impact type to increasing sampling intervals are depicted in Figure 5.1 (a) to (d). For visualization purposes, each series of data is fitted by a polynomial regression curve. For the LE estimates, the degree of deviation of each solid line from zero represents the magnitude of accuracy loss. Likewise, the degree of deviation of each dashed line from zero represents the magnitude of accuracy loss for FO estimates. The dispersion of values at each sampling interval level, as indicated by vertical error bars, represents the inter-trail variability in the loss of estimate accuracy.

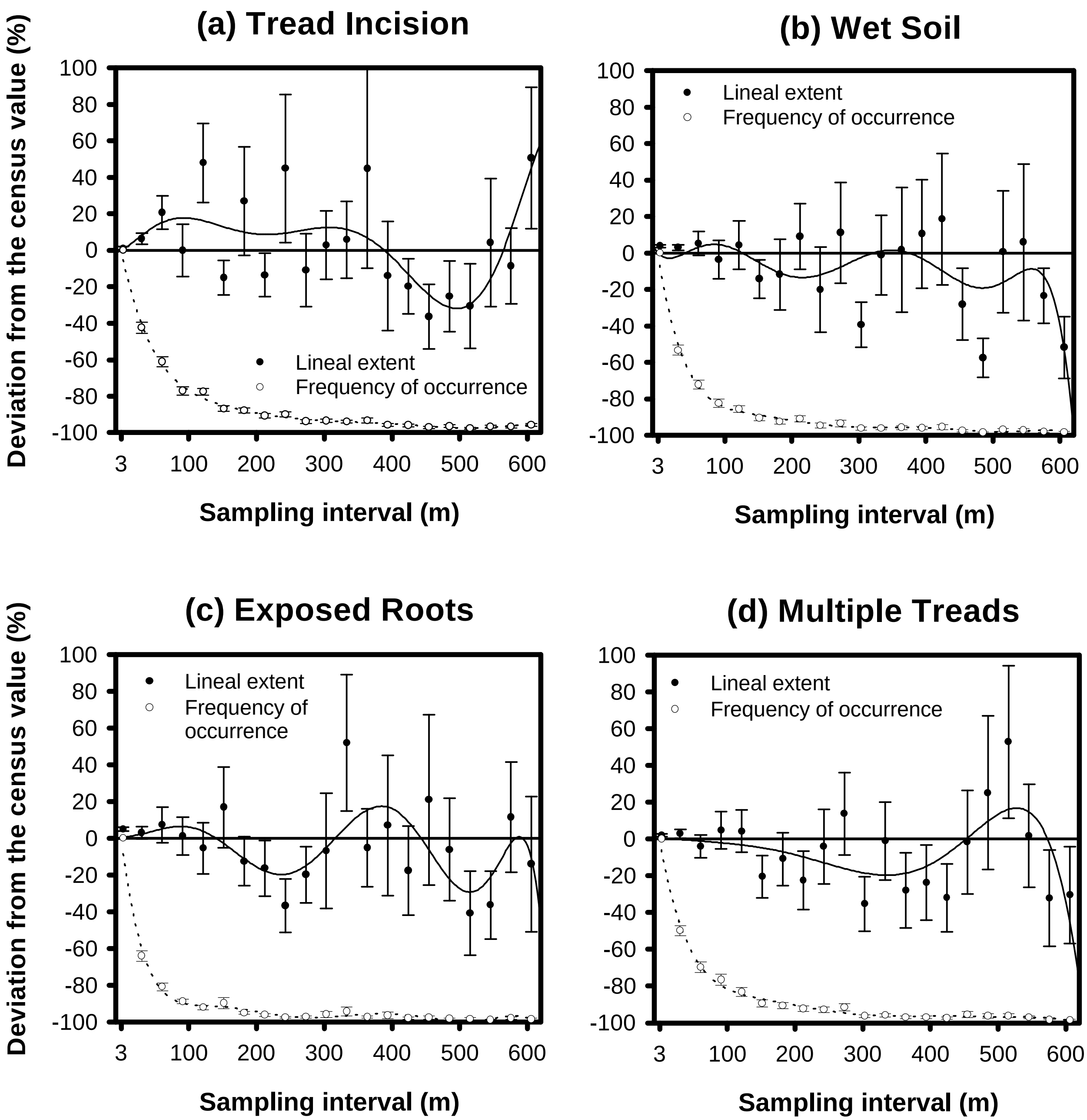

Figure 5.1. Deviations of lineal extent (LE) and frequency of occurrence (FO) estimates from the census values with increasing sampling intervals (mean +/- 1 Std. Err.).

Simulation results demonstrate that increasing sampling intervals are associated with an overall increase in accuracy loss (% deviation from the reference level) of LE and FO estimates. The direction of change in accuracy loss for LE estimates is mixed throughout the range of sampling intervals. The mix in direction (i.e., signs) of accuracy loss results in a relatively low average accuracy loss as shown by the plotted points in Figure 5.1. However, as discussed in the preceding section, the magnitude of accuracy loss is greater for LE estimates when the direction of deviation is not considered.

Accuracy loss of LE estimates is within 10% from the census values for all impact types at sampling intervals of 100 m and below, but range up to 50% at intervals of about 400 m to 500 m, depending on the impact type. Accuracy losses appear to diverge more substantially from the reference line for sampling intervals greater than 500 m for all but exposed roots (Figure 5.1). FO estimates, in contrast, are consistently and substantially underestimated. Their responses are inversely asymptotic in form, with substantial reductions in accuracy occurring at three initial intervals (30, 61, and 91 m) and near-maximum values reached at intervals greater than 100 to 300 m, depending on the impact type (Figure 5.1). FO estimates for exposed roots exhibit the most substantial decline of more than 60% with the first interval change (3 to 30 m).

With regard to inter-trail variability indicated by the error bars in Figure 5.1, the general response pattern of LE estimates seems to be one of increased variability with increasing sampling intervals. Such a pattern, however, is most consistent for multiple treads. The inter-trail variation is more variable for tread incision, wet soil, and exposed roots.

Despite the wide range of inter-trail variation in LE estimates, standard errors for FO estimates are very small at all sampling interval levels for all impact types, implying high precision (*not accuracy*) or predictability on the estimate of accuracy loss at any sampling interval regardless of differences among surveyed trails.

Potential Sources of Variation

The fourth research question concerns the extent to which differences in estimate accuracy loss among trails can be explained by topographic complexity, trail length, or impact characteristics. A series of stepwise multiple regression models were run at each sampling interval on four independent variables: (1) elevation change (m/km), (2) trail length (m), (3) mean problem segment length (m), and (4) sum of problem segment lengths for a trail (m). The percentage accuracy loss of LE and FO estimates for each impact type are dependent variables.

Stepwide multiple regression results summarized in Table 5.4 show that these four independent variables explain little of the variation in accuracy loss of LE estimates, with only a few statistically significant regression models identified for tread incision and exposed roots. No significant models were identified for wet soil and multiple treads. Although they are statistically significant, adjusted coefficients of determination (adj. R^2) for these models are generally low, ranging from 0.08-0.29. Of the significant independent variables for tread incision, mean problem segment length was negative in effect, while elevation change was positive at two higher interval levels. No patterns can be identified for LE estimates of

Table 5.4. Results of stepwise multiple regression analysis on the relationship between accuracy loss (% deviation from the census value) of *lineal extent* (LE) and *frequency of occurrence* (FO) estimates on four trail impact problems and four selected impact and environmental factors: elevation change (▲), trail length (**O**), mean problem segment length (**M**), and sum of problem segment lengths (♦). [**Note:** symbols in black indicate significant (p(t value) <0.05) positive betas (standardized regression coefficients), while symbols in white indicate significant negative betas; values in parentheses are the adjusted coefficients of determination (adj. R^2)].

Interval (m)*	***Tread Incision***		***Wet Soil***		***Exposed Roots***		***Multiple Treads***	
	LE	**FO**	**LE**	**FO**	**LE**	**FO**	**LE**	**FO**
30		**M** (0.68)		**M**, ◇ (0.45)		**M** (0.90)		**M**, ▲ (0.53)
61	**F** (0.12)	**M** (0.65)		**M**, ◇ (0.53)		**M** (0.33)		**M** (0.66)
91		**M** (0.53)		**M** (0.37)	**G** (0.08)	♦ (0.13)		**M** (0.45)
121	**F** (0.11)	**M** (0.32)		**M** (0.29)		♦ (0.11)		**M** (0.55)
152		**M** (0.48)		**M** (0.30)	**M** (0.11)	♦, **M** (0.52)		**M** (0.09)
182		**M** (0.17)		**M** (0.28)	♦ (0.09)	♦ (0.25)		**M** (0.17)
212		**M** (0.29)		**M** (0.19)				**M** (0.10)
242				**M** (0.06)		♦ (0.10)		**M** (0.06)
273	**F**, ▲ (0.20)	▲ (0.18)				♦ (0.10)		
303				**M** (0.19)		**M** (0.07)		**M** (0.12)
333				♦ (0.11)		**M** (0.35)		
364						♦ (0.11)		
394		**M** (0.18)		♦, ▲, **O** (0.20)				
424		**M** (0.14)						
455		**M** (0.10)		♦ (0.07)				
485				♦ (0.15)				
515		◆ (0.14)			**O** (0.29)	**O** (0.40)		
545	▲ (0.09)	▲ (0.15)						
576						**O** (0.21)		
606				**M** (0.09)				

* Sampling interval in meters (converted from 100-2000 feet).

exposed roots.

Regression results for FO estimates are more significant. Variations in FO estimates are strongly associated with mean problem segment length in a positive direction, especially at fine interval levels. Sum of segment lengths is also a significant explanatory variable for exposed roots at six intermediate interval levels. Adj. R^2 values for these models are high at fine interval levels, and decrease with increasing sampling intervals (Table 5.4).

Discussion and Implications

If trail IA&M programs are to generate reliable information for management decision making, the sampling issues involved in their development and application must be addressed. This paper investigated the influence of sampling interval on the accuracy of impact estimates by means of a resampling-simulation approach using empirical data. A primary objective was to evaluate to what extent the more common sampling-based trail IA&M approach can be utilized to evaluate maximum-condition management standards that are an integral part of LAC and other management frameworks.

In general, the findings suggest that using systematic point sampling for estimating the lineal extent of trail impact problems can achieve an excellent level of estimate accuracy (around 10% accuracy loss) for most impact types examined at sampling intervals of less than 100 m, and reasonably good estimates (around 50% accuracy loss) at intervals between 100 and 500 m. However, accuracy loss values are probably higher if the directions of losses are not considered. As the lineal extent of an impact problem is often of greater ecological and management relevance than its frequency of occurrence, systematic point sampling seems to be a reliable trail IA&M method for estimating the lineal extent of impact problems, in addition to its more conventional use in assessing and monitoring trail condition indicators such as tread width and incision depth (Lance et al. 1989).

Using systematic point sampling for estimating the frequency of occurrence of trail impact problems is not advised, as gross underestimates were consistently revealed by these analyses, even at fine sampling intervals. The high sensitivity of FO estimates to increasing sampling interval is likely explained by the problem of missing large numbers of short problem segments. Larger intervals result in fewer sampling points which proportionally miss more of these small segments. Predictions of number of occurrences are thus poor, particularly for impact types such as exposed roots, whose mean problem segment lengths are very short. However, when impact incidents, especially the major ones, are defined clearly, they can be efficiently tallied by field staff, who have to walk through all surveyed trails. Furthermore, since short problem segments apparently do not contribute substantially to the total lineal extent of these impact problems, estimates of total lineal extent at longer sampling intervals remain more accurate.

The observation unit size, or what constitutes a 'problem' segment or impact 'incident' (3 m in this study), must be defined prior to field work. The findings of this study could vary depending on the observation unit size, although 3 m was considered to be typical and reasonably fine in resolution. For example, these analyses suggest that accuracy loss of FO estimates could be reduced substantially by increasing the observation unit size to 10 m. The appropriateness of such an increase, however, is essentially a management question. The complex relationships among observation unit size, sampling interval, accuracy, and precision therefore warrant further investigations.

The sources of variation that might contribute to the response of impact estimates to increasing sampling intervals were examined by multiple regression. Results revealed no or weak relationships between the accuracy loss of LE estimates and the four independent variables. One implication of these analyses is that longer sampling intervals might not be justified on longer trails. At a fixed sampling interval, LE estimates were not more accurate for longer trails than for shorter trails. The determination of sampling intervals, then, might be more greatly influenced by the characteristics of different impact types. For example, strong relationships were identified for accuracy loss of FO estimates and two independent variables: mean problem segment length and sum of problem segment lengths. However, the positive relationships between mean and sum of problem segment lengths and FO estimates are counterintuitive. Additional examinations of these relationships are needed to refine sampling design guideline further.

Conclusions

This study was designed to examine the influence of sampling interval on the accuracy of point-based trail IA&M surveys in estimating impact extent and occurrence. Results suggest that reasonably accurate estimates of lineal extent for four major impact types (tread incision, wet soil, exposed roots, and multiple treads) can be achieved by systematic point sampling. A sampling interval of less than 100 m yields the most accurate estimates of lineal extent, although such small intervals would generally be viewed as inefficient due to the time required for field assessments. Sampling intervals of between 100 and 500 m are therefore recommended to achieve an appropriate balance between estimate accuracy and efficiency of field work.

The resampling-simulation approach adopted in this study provides a method that can be replicated in other environmental types and impact situations to examine and verify the consistency of relationships identified by these analyses. Other issues in need of further study include: (1) examining sources of variation in different trail IA&M survey designs, (2) interrater precision, an important issue for monitoring purposes (Berry and Baker 1968), and (3) survey design guidelines for improving the accuracy, reliability and efficiency of trail IA&M programs.