# CHAPTER VI. SPATIAL INDICES FOR EVALUATING RECREATION RESOURCE IMPACTS

## Abstract

Many managers and scientists recognize that balanced evaluations of the magnitude of recreation resource impacts should be based on both the severity of impact and its spatial extent. Nevertheless, the scope of indicators and indices developed in the recreation ecology and recreation resource management literature have been mostly limited to quantifying the severity of impact, with little attempt made to capture spatial qualities. The purpose of this study is to expand the scope of indices used for evaluating recreation resource impacts. Two specific objectives are to synthesize the recreation ecology and recreation resource management literature on the use of spatially explicit indicators and indices, and to propose and apply selected spatial indices that are mostly lacking in the literature to empirical impact data sets.

Previous examinations of the spatial dimension of recreation resource impacts have been approached in at least three different ways, one of which being the application of descriptive spatial indices. The spatial indices that have been applied are, however, limited in scope and diversity. Based on a literature review, three spatial indices are proposed for their potential capabilities in quantifying and characterizing spatial distribution and association patterns. Each of these indices was applied to an empirical trail data set collected from Great Smoky Mountains National Park. Presented in tabular and graphic forms, the application results show that two of the proposed spatial indices are capable of characterizing spatial patterns of impact at trail and park scales, while the result of applying the impact association index is less promising. Lorenz curves and Gini coefficients reveal uneven distribution patterns of excessive tread widths, exposed roots, and wet soil among the surveyed trails. Furthermore, different impact problems exhibit different distribution patterns along trail routes, as indicated by the linear nearest-neighbor analysis and LR ratios. The potential uses of these indices in park and recreation resource management and research are discussed. Further studies are called for to examine the ecological and social importance, as well as management utility of these and other spatial indices in recreation impact evaluation.

**Key Words:** Spatial indices, descriptive spatial statistics, recreation impacts, trail degradation, impact evaluation, Great Smoky Mountains National Park.

## Introduction

Visitor impacts to natural and cultural resources in national parks, wildernesses, and other protected areas are of significant concern to managers, advocates, and visitors. Managers and scientists have developed methods to effectively and efficiently assess and evaluate the magnitude of recreation resource impacts and their temporal trends. Responding to such a need are recreation impact assessment and monitoring (IA&M) programs, which are becoming an integral part of contemporary management planning frameworks such as Limits of Acceptable Change (LAC) (Stankey et al. 1985), Visitor Impact Management (VIM) (Graefe et al. 1990), and Visitor Experience and Resource Protection (VERP) (NPS 1997). These frameworks share a common emphasis on the selection and measurement of biophysical and social indicators for establishing attainable management standards, evaluating and monitoring resource conditions, and providing feedback mechanisms on the effectiveness of management actions. Numerous indicators and indices have been adopted and proposed (Merigliano 1990a and 1990b, Watson and Cole 1992).

It has been recognized that the magnitude of recreation resource impacts consists of two integral components: the *severity or intensity* of impact, and the *spatial extent* of impact (Cole 1994). Previous recreation impact research, often referred to as recreation ecology (Cole 1989b), has accentuated the selection and measurement of indicators that quantify the severity of impact. In contrast, methods for quantifying and evaluating the spatial qualities of recreation resource impact, particularly the spatial distribution and association, are relatively undeveloped. Recreation resource managers are, however, concerned with spatial aspects of recreation resource impact. Expansion of campsite size and trail width and proliferation of campsites and informal trails, are perceived to be significant management problems by national park managers (Marion et al. 1993). From an ecological perspective, recreation resource impacts resulting from expansion of existing sites and proliferation of new sites in space appear to pose greater threats to the ecosystem health and aesthetic quality than increases in impact levels on established sites (Cole 1993, McEwen et al. 1996).

Analysis of the spatial distribution and association patterns of phenomena is a central issue in the discipline of geography (Hartshorne 1959, Berry and Marble 1968). Methods have been developed to identify, measure, and characterize these phenomena that encompass points, lines, and areas (Taylor 1977, Unwin 1981, Griffith and Amrhein 1991, Shaw and Wheeler 1994). Within the context of recreation resource management, geographers have made contributions to the understanding of spatial patterns of recreation impacts and to the spatial variation of factors relating to the susceptibility of ecological components to impact forces. In view of the lack of spatial knowledge in the field of recreation ecology, Cole (1989b) specifically noted the need for contributions from geographers to this applied field of study. The most fundamental contribution geographers could make, as he outlined, was an examination of the spatial distribution of impacts. Identifying and quantifying the spatial qualities of recreation resource impact permit more meaningful evaluations of impact patterns in space and a more comprehensive examination of impact-environment relationships.

The objectives of this study are two-fold. First, it seeks to provide a synthesis of the literature on the use of spatial indicators and indices for recreation impact assessment and evaluation. Second, this study seeks to propose, develop and test several spatial indices able to quantify and characterize recreation resource impacts with respect to their spatial distribution and association patterns. The proposed spatial indices are primarily adapted from the geography and ecology literature in which analysis of spatial data is a core component.

## Spatial Qualities of Recreation Resource Impacts

Recreational use and associated impacts are unevenly distributed in space, primarily determined by the uneven distribution of recreation resources, facilities, and visitor distribution patterns. These spatial inequalities cause concentrated impacts in certain areas. Spatial patterns of recreation resource impacts have been described by McEwen and Tocher (1976), Manning (1979), and Hammitt and Cole (1987). A standard pattern consists of lines and nodes of impact distributed over a recreational landscape. Linear features are trails and roads, nodes include facilities, attraction features, and day-use recreation sites or overnight campsites. Spatial patterns of impact are dynamic, responsive to changes in use, environmental, and managerial conditions.

Spatial qualities of recreation resource impact may affect visitor perceptions of impact as well as the quality of recreational experiences. Previous studies have demonstrated that locations in which social encounters occur matter in determining the severity of perceived recreation conflict and perceived crowding (Manning 1985). The acceptability of recreation resource impacts has also been found to vary depending on the locations of undesirable impacts (Noe et al. 1997).

Spatial extent, distribution, and association of impacts are some under-explored situational variables that might affect visitor impact perceptions. For example, consider two environmentally similar trails each with 500 m of wet muddy tread. One trail might have 20 equally distributed occurrences of 25-m long muddy segments while the other trail might have only two occurrences of 250-m long muddy segments located at either end. Visitor perceptions of wet soil and its effect on their recreation experience might be quite different for these two trails. Hull and Stewart (1995) found that hikers tend to look at the ground more frequently than at other objects along the trail corridor. Although recreation-related nuisances such as litter was not found to influence the hiking experience, it is possible that frequent or continual encounters of certain impact problems or their association could capture hikers' attention and detract from their experience.

## The Index Approach

The term *index* has been defined differently in the environmental literature (Alberti and Parker 1991). Ott (1978:8), for instance, defines an index broadly as “a single number derived from two or more indicators”, while Inhaber (1976) restricts use of the term to a fraction comprising a measured value as a numerator, and a background or standard value as a denominator. This study adopts the broader definition in developing indices derived from spatially explicit indicators, including distance, size, and areal measures.

Environmental impact assessment programs typically involve numerous indicators, each of which is a measurable characteristic of the environment (Ott 1978); so do most recreation IA & M programs. Data collected from these programs are voluminous, even after data analyses have been conducted. Indices can reduce the volume of data into simple yet meaningful information to aid decision-making processes. Specifically, they offer three benefits: First, they *quantify* information on environmental conditions. Second, they *summarize* and *integrate* information, rendering it more comprehensible and useful to policy makers (House 1990). Third, these indices *simplify* and therefore *facilitate* communication among scientists, resource managers, and the public (O'Conner and Dewling 1986, Lindsey et al. 1997).

The use of indices can be found in many disciplines, including environmental sciences and the recreation and tourism fields. In recreation and tourism research, for example, indices have been developed to reflect demand for outdoor recreation and tourism (Backman et al. 1992), quality of recreational sites (Brunson 1996, Hamilton 1996), diversity of recreation facility supplies (Pikul et al. 1975, Saunders and Burnett 1983), perceived recreation resource impacts (Vaske et al. 1982), and severity of recreation-caused biophysical changes (Crowder 1983, Hall 1989, Cole and Bayfield 1993). Indices utilized in recreation impact studies can be classified into three types according to the phenomena they are designed to characterize. Vegetation indices are the first and most common type, originating in botany and plant ecology. They are designed to quantify change in vegetation cover (Cole 1978, Marion and Cole 1996), composition change (Cole 1978), diversity (Liddle 1975, Hall 1989), and resistance and resilience (Hall and Kuss 1989, Cole and Bayfield 1993). The second type are integrative indices that combine indicators of different aspects, including spatial measures of attributes.  Examples are erosion ratings (Bratton et al. 1979, Garland 1990), overall trail impact index (Welch and Churchill 1986), and recreational soil-loss index (Morgan and Kuss 1986).  While these impact indices focus on the severity of impact, spatial indices are designed to reflect some spatial quality of recreation resource impacts.

## Using Spatial Indices in Recreation Impact Evaluation

Spatial indices have been developed in physical and human geography (Cliff and Ord 1981, Shaw and Wheeler 1994) and landscape ecology (McGarigal and Marks 1995) for descriptive and modeling purposes.  This study restricts its focus to the use of descriptive spatial indices in recreation impact evaluation.  Some common descriptive spatial indices include mean center, median center, and standard distance (Shaw and Wheeler 1994).  More sophisticated indices include nearest neighbor ratios and spatial segregation indices (Morrill 1991, Wong 1993).  While non-spatial indices have been applied in recreation impact investigations, their spatial counterparts are less commonly utilized for impact evaluation.

A review of the literature suggests that there are generally three approaches in which indices have been used in examining the spatial qualities of recreation resource impacts.  The *first* and most common approach is to visualize spatially non-spatial indices using cartographic symbolization (Robinson et al. 1995).  A good example is the index-scale line symbols used by Calais and Kirkpatrick (1986) to indicate spatial variation of resource impacts on trails. Stohlgren and Parsons (1992), McEwen et al. (1996), and Cole et al. (1997) mapped surveyed campsites labeled with summary campsite impact index values.

The *second* approach is to develop summary impact indices that are partially based on spatially explicit indicators. A simple example of this approach is the Area of Vegetation Loss Index (Cole 1989c) which is derived by multiplying campsite size (a spatial indicator) and percent change in vegetation cover (a non-spatial indicator). In fact, many summary impact indices have some spatial elements. However, they are intended to provide an integrated characterization of the overall magnitude of recreation resource impacts. Once the spatial and non-spatial indicators are combined, it is difficult to disentangle the spatial qualities of the impact.

The *third* approach is to construct spatial indices that specifically characterize some spatial quality of recreation resource impact. These spatial indices can be descriptive or predictive. A simple descriptive example is the calculation of campsite density or trail density in a predefined zone (e.g., management units) or in unit area format (e.g., per ha). Many recreation impact studies employing spatial indices have provided spatial density indices for campsites (McEwen et al. 1996, Cole et al. 1997), damaged trees (Marion 1995), and felled trees (stumps) (Marion 1995). Moreover, of the 99 impact indicators reviewed by Watson and Cole (1992), only a few can be classified as spatial indices, and all are simple density measures indicative of spatial extent on a unitary basis. Orr (1971), on the other hand, developed a predictive spatial index called the Potential Pedestrian Impact Index. This index sought to estimate and quantify the evolution of recreation resource impacts in space. Specifically he provided an estimate of the potential social trail development at campgrounds based on the spatial configuration of campground facilities. Such indices are particularly relevant to recreation site and facility planning.

The scope and diversity of spatial indicators and indices applied in the recreation ecology and recreation resource management literature are summarized as a two-dimension matrix (Table 6.1). The first dimension of this matrix concerns the spatial quality which an index is designed to quantify. Three primary spatial qualities are extent, distribution, and association. It is evident that most of the spatial indices adopted in the recreation impact literature have focused on the spatial extent of impacts (Table 6.1). Spatial indices for characterizing spatial distribution and association patterns are less common, although such patterns may be qualitatively evaluated by mapping any impact indicators and indices.

The second dimension of the matrix concerns the spatial scale at which an index is derived. Previous studies have used spatial indices at the local/site and regional/landscape scales. Two cells in the matrix are empty, indicating that no spatial indices are identified in the literature. The lack of indices in these cells may be partly explained by the limited value of the index approach to understanding intra-site variation of impacts. Interests at this spatial scale can be more effectively addressed by obtaining detailed site maps and photographs (Boden 1977, Brewer and Berrier 1984).

The limited scope and diversity of spatial indicators and indices in recreation impacts is also evident from the variety of spatial indices proposed or suggested in the major protected area management planning frameworks, such as LAC (Stankey et al. 1985).

**Table 6.1.** Two dimensions of spatial indicators and indices and application examples for evaluating recreation resource impacts.[1]

| **SPATIAL SCALE** | **SPATIAL QUALITY** | | |
|---|---|---|---|
| | ***Extent*** | ***Distribution/Variation*** | ***Association*** |
| ***Local/ Site*** | Trails<br>**#** Trail width [a,c,e,n] [2, 3]<br>**!** Index of extent (IE) [a,e]<br>**!** Track damage index [m]<br>Campsites<br>**#** Campsite area [b,h,i,l]<br>**#** Devegetated area [b,h,i,l] | | |
| ***Intermediate/ Facility*** | Trails<br>**#** Impact extent measures [b,g]<br>**!** Trail area [k]<br>Campgrounds<br>**!** Potential pedestrian impact (PPI) [j] | Trails<br>**!** Linear nearest neighbor index **[this paper]** | Trails<br>**!** Impact association index (IAI) **[this paper]** |
| ***Regional/ Landscape*** | Trails<br>**#** Aggregate extent measures [b,g,l,n]<br>**!** Trail density [d,l,n]<br>Campsites<br>**#** Aggregate extent measures [b,h,i,l]<br>**!** Ratio of disturbance [o]<br>**!** Campsite density [h,l]<br>**!** Tree damage density [h]<br>**!** Felled tree density [h] | Trails<br>**!** Lorenz curve and Gini coefficient **[this paper]** | Trails<br>**!** Network connectivity and circuitry indices [f] |

[1] some of the studies included may not be directly related to recreation impacts, but they are judged to be directly applicable to recreation/tourism contexts.

[2] symbolization: **#** = indicator; **!** = index (combination of at least 2 variables or indicators)

[3] previous applications: [a] Bayfield and Lloyd (1973); [b] Cole et al. (1997); [c] Coleman (1981); [d] Harden (1992); [e] Lance et al. (1989); [f] Lewandowski and McLaughlin (1995); [g] Marion (1994); [h] Marion (1995); [i] McEwen et al. (1996); [j] Orr (1971); [k] Vogler and Butler (1996); [l] Watson and Cole (1992); [m] Calais and Kirkpatrick (1986); [n] Boorman and Fuller (1977); [o] Bratton et al. (1978).

Watson and Cole (1992) recently compiled a list of proposed LAC indicators. Some of the indicators are spatial or partially spatial, such as campsite size, and length of an impact problem on trails. With regard to indices that combine indicators, only a few are spatially explicit (Table 6.2). These spatial indices are only indicative of spatial extent of impacts at site or regional scales (Table 6.1).

## Proposed Spatial Indices

This literature review and synthesis suggest that the previous use of indices for evaluating recreation resource impacts is biased toward quantifying the severity of impacts. The spatial dimension of recreation resource impacts has been primarily evaluated qualitatively through the use of maps. The majority of integrative impact indices are constructed partially from spatial indicators. Spatially explicit indices that exist in the literature are typically density-related measures, such as ratios between number of campsites/trails or their areal extent and management unit size.

Based on this context several descriptive spatial indices were proposed and each was applied to an empirical data set from Great Smoky Mountains National Park. These proposed spatial indices were either adapted from the geography and ecology literature, or are developed by this author. These spatial indices were selected because they appear to meet most of the following criteria, some of which were derived from O'Connor and Dewling (1986):

**Table 6.2.** Spatial indices listed in Watson and Cole (1992) that have been or are being adopted in the Limits of Acceptable Change (LAC) management framework.

| Index Type | Spatial Scale | Description | Examples of Application [1] |
|---|---|---|---|
| ***Campsites*** | | | |
| Campsite density | Regional | Number of sites per unit area<br>Number of sites per river mile | LNF, NPNF<br>SNF |
| Devegetated area | Site | Devegetated area per unit area | AANF |
| ***Trails*** | | | |
| Trail density | Regional | Sum of trail length per square mile | WRNF |

[1] Indices were either recommended for or found in management plans of the cited protected area unit.
AANF: Apache-Aitgreaves National Forest (Mt. Baldy Wilderness), Arizona, USA
LNF: Lolo National Forest (Rattlesnake National Recreation Area and Wilderness), Montana, USA
NPNF: Nez PerceNational Forest (Selway-Bitterroot Wilderness), Idaho, USA
SNF: Sequoia National Forest (Kings River Special Management Area), California, USA
WRNF: White River National Forest, Colorado, USA

1. They have been used, or are designed, for characterizing some spatial quality (e.g. area, distance) that is least represented in the recreation impact literature (refer to Table 6.1),
2. The spatial quality attributes addressed by these indices are important for an improved understanding of the spatial dimension of impact,
3. They are adaptable to the type of data common to recreation IA & M programs,
4. They are conceptually and computationally straightforward
5. The spatial scale of these indices is relevant to that of management decisions

While this review on spatial indices in the recreation impact literature is comprehensive, the following selection of spatial indices used for illustration is by no means exhaustive. This portion of the paper is of an exploratory nature. Further examination and testing are needed in order to fully establish the ecological, social, and managerial importance and relevance of these and other spatial indices. For this purpose an additional list of potentially useful descriptive spatial indices is provided and described in Appendix V.

Three spatial indices applicable to trail impacts are proposed:

(a) Lorenz Curve and the Gini Coefficient,
(b) Linear Nearest Neighbor Analysis and Index, and
(c) Impact Association Index.

### (a) *Lorenz Curve and the Gini Coefficient (LC-G)*

Lorenz curves (LCs) are a graphic means to characterize spatial or non-spatial distribution patterns, although quantitative indices can be derived from the same data on which LCs are constructed. LCs are commonly applied in geography for examining spatial inequality of social and economic phenomena, such as income and population (Griffith and Amrhein 1991). Its application to tourism contexts have also been explored (Smith 1995). In the outdoor recreation literature, LCs have also been employed to visualize the spatial concentration of recreational use within parks (Clawson and Knetsch 1971) and wilderness areas (Hendee et al. 1990).

The present study applies LCs to trail impact data to facilitate visualizing and quantifying the spatial distribution patterns of trail impacts at a landscape/regional scale. For each impact type, trails were first ranked by their respective lineal impact extent in terms of problem segments. Two cumulative percentage columns were then created: cumulative trail length for all surveyed trails and cumulative sum of lineal extent of impact across trails. These two columns were plotted as a line graph for each impact type. Based on the information available from the LC, the Gini Coefficient (G), or index of dissimilarity, of the impact type *j* is computed from the following formula (Griffith and Amrhein 1991):

$$G_j = \frac{\sum_{i=1}^{n} |X_{ij} - Y_{ij}|}{2} \qquad (1)$$

where $X_i$ is the percentage in the total trail length at the *i*-th (*i*=1,...,*n*) ranked trail, and $Y_i$ is the corresponding percentage in sum of problem segment length at the *i*-th ranked trail. G values can range from zero, when lineal extent of an impact type are proportionally distributed across park trails (i.e., match the diagonal line of equitable distribution), to 100 where all impacts occur on a single trail.

### (b) *Linear Nearest Neighbor Analysis and LR Ratio (LNNA-LR)*

Spatial distribution and variation of point data have been commonly examined by means of nearest neighbor analysis (NNA). However, conventional two-dimensional NNA is not suitable for analyzing patterns along linear features (Dacey 1960, Pinder and Witherick 1973). In the context of linear trail corridors, the extension of NNA by Pinder and Witherick (1973 and 1975) for linear features appear to be useful. Pinder and Witherick (1973 and 1975) developed LNNA in their study of distribution patterns of cities along the Mississippi River and of retailing shops along roads. The potential application of LNNA to tourism contexts is described by Smith (1995).

The present study adapts this spatial index to the linear trail corridor with discrete occurrences of problem segments in order to quantify the degree of spatial concentration or dispersion of problem segments along a trail corridor. The linear nearest-neighbor ratio or index (LR) is derived from the observed average inter-segment distance between two problem segments of the same impact type (or any impact type) divided by the expected or theoretical distance between two problem segments under a random distribution. As a problem segment has it own lineal extent, the total length of trail is adjusted by subtracting the sum of problem segment lengths from the total trail length. The modified formula for deriving the LR index is:

$$LR_j = \frac{\frac{1}{n-1}\sum_{i=1}^{n-1}\left[d(b)_{i+1,j} - d(e)_{ij}\right]}{\frac{1}{2}\left(\frac{L-l_j}{n-1}\right)} \qquad (2)$$

where $d(b)_{ij}$ and $d(e)_{ij}$ is the beginning distance reading of the $i+1$-th ($i$=1,...,$n$) problem segment of impact type $j$ along the trail, $d(e)_{ij}$ is the ending distance reading of the $i$-th problem segment, L is the total trail length, and $l_i$ is the sum of problem segment lengths. An overall LR index can also be produced for multiple impact types by calculating the inter-segment distance between two problem segments, regardless of impact type.

LR values can range from zero, when problem segments are clustered together, to about one when problem segments are distributed randomly, to a maximum of two, when all problem segments are spaced uniformly with equal intervals along a trail. A graphic means for evaluating the significance of LR values has been developed by Pinder and Witherick (1973, 1975).

### (c) *Impact Association Index (IAI)*

IAI was developed by the author, who identified no similar measures of segment-based spatial association along linear features in the geography or recreation literature, although there are association indices comparing spatial distribution patterns of two sets of points (Unwin 1981, Smith 1995). In the ecological literature, indices of association have also been developed for characterizing the coexistence of plant species (Mueller-Dombios and Ellenberg 1974). Knowledge of the spatial association of recreation resource impacts is, however, important to park managers for locating impact 'problem spots', understanding common causes that contribute to the coexistence of impacts, formulating targeted impact control strategies, and expediting management and maintenance efforts. The IAI can also be used as a correction factor for determining the proportion of a trail affected by impact problems to avoid repeated counting of multiple impact types at the localities where they co-exist.

This paper develops and applies this new spatial index specifically for quantifying the extent of spatial overlaps between two or more different impact types ($j = 2,\ldots, k$) along a trail corridor using a problem census method (Cole 1983). The IAI value is derived from the following formula:

$$IAI_k = \frac{\sum_{a=1}^{m} cl_{a,[j=2,\ldots,k]}}{\sum_{j=1}^{k}\sum_{i=1}^{n} l_{ij}} \qquad (3)$$

where $l_{ij}$ is segment length of the $i$-th ($i$=1,...,$n$) occurrence of impact types $j$, and $cl_{a,[j=2,\ldots,k]}$ is segment length of the $a$-th ($a$=1,...,$m$) occurrence of associated segment where two or more impact types coexist (any combination among the $k$ impact types). To give an example, in a simple situation when only 2 impact types exist, each has 10 occurrences of 100-m long problem segments (20 segments in total). These segments of two impact types coexist at 5 locations (associated segments), each of which measures 75 m in length, the IAI value would be:

$$IAI = (5 \times 75)/(10 \times 100 + 10 \times 100) = 0.19$$

The possible range of IAI values fall between zero, when problem segments of all impact types do not overlap with each other, to a maximum of one when all problem segments of all impact types coexist entirely in space.

## Illustrative Examples

### Procedures

To demonstrate the properties and potential utility of these three spatial indices they were applied to an empirical trail survey data set. This data set was collected from a parkwide trail impact assessment in Great Smoky Mountains National Park (GSMNP), located in Tennessee and North Carolina. Seventy-two backcountry trails, totaling 520 km (35% of the park's total trail system length), were assessed. A complete census of six impact problems was conducted for each of the surveyed trails. A distance-measuring wheel (1.2-m circumference) was used by trained field staff to record distances from each trail’s starting point to the starting and ending distances of all problem segments longer than 3.3 m (10 ft) in length, defined as the observation unit size of this study. This method yielded data on location and problem segment length (lineal extent) of six impact types:

1. *tread incision* - the erosional loss of the trail tread of more than 30 cm (1 ft),
2. *wet soil* - wet 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,
5. *excessive tread widths* - trail tread widths extend more than 1 m (3 ft) beyond the tread width typical of that trail,
6. *running water* - existence of running water on the trail treads, excluding stream crossings.

Data from all surveyed trails were utilized for constructing each spatial index. For interpretation and discussion purposes, however, only selected trails and impact types are presented to demonstrate the types of information yielded from these indices. Tabular and graphic formats are employed to illustrate results. The utility of each proposed spatial index was judged by two criteria described by O'Neill et al. (1988): discriminant ability and independency. No quantitative evaluation was made on Gini coefficients due to their small sample size. For another two indices (LR and IAI), the discriminant ability criterion was evaluated by examining the range and distribution of index values. As the data set contains a diversity of environmental and impact situations, a good spatial index should also reflect such diversity with a wide range of possible values. The one-sample Kolmogorov-Smirnov test was used to determine the normality of LR and IAI values. To examine the independency criterion, Spearman rank-order correlation coefficients between the two spatial indices were computed to test the null hypothesis that the two indices are independent from each other. All computational and statistical analyses were conducted in SPSS for Windows (ver. 7.5), and graphs produced in SigmaPlot for Windows (ver. 3.0).

## Results

### (a) *Lorenz Curve and the Gini Coefficient (LC-G)*

The distribution patterns of all six trail impact types are depicted by six Lorenz curves, respectively (Figure 6.1). Based on the degree of deviation of the curve from the diagonal line it is evident that problem segments with running water, multiple treads and tread incision are more evenly distributed than the other three impact types. In contrast, problem segments with wet soil, exposed roots and excessive tread width tend to be concentrated on smaller numbers of trails, as indicated by the greater departures of their curves from the diagonal. For example, 20% of the total lineal extent of wet soil exists on a single park trail, and 10 trails account for nearly 80% of the total lineal extent. The Gini coefficient for each impact type is also shown in Figure 6.1. G values range from 44 for multiple treads to 67 for excessive tread widths. When the possible range of G values of 0 - 100 is considered, the observed G values seem to indicate a moderate degree of distributional inequality or spatial concentration of trail impacts. The differences in G values among impact types appear to be commensurate with the differences in line patterns shown in Figure 6.1.

### (b) *Linear Nearest Neighbor Analysis and LR Ratio (LNNA-LR)*

Results of the application of LNNA-LR are summarized in Table 6.3. Problem segments, regardless of impact type, are spaced an average of 521 m apart. The overall LR values for 59 GSMNP trails have an average of 1.28 and a range from 0.01 (highly clustered)

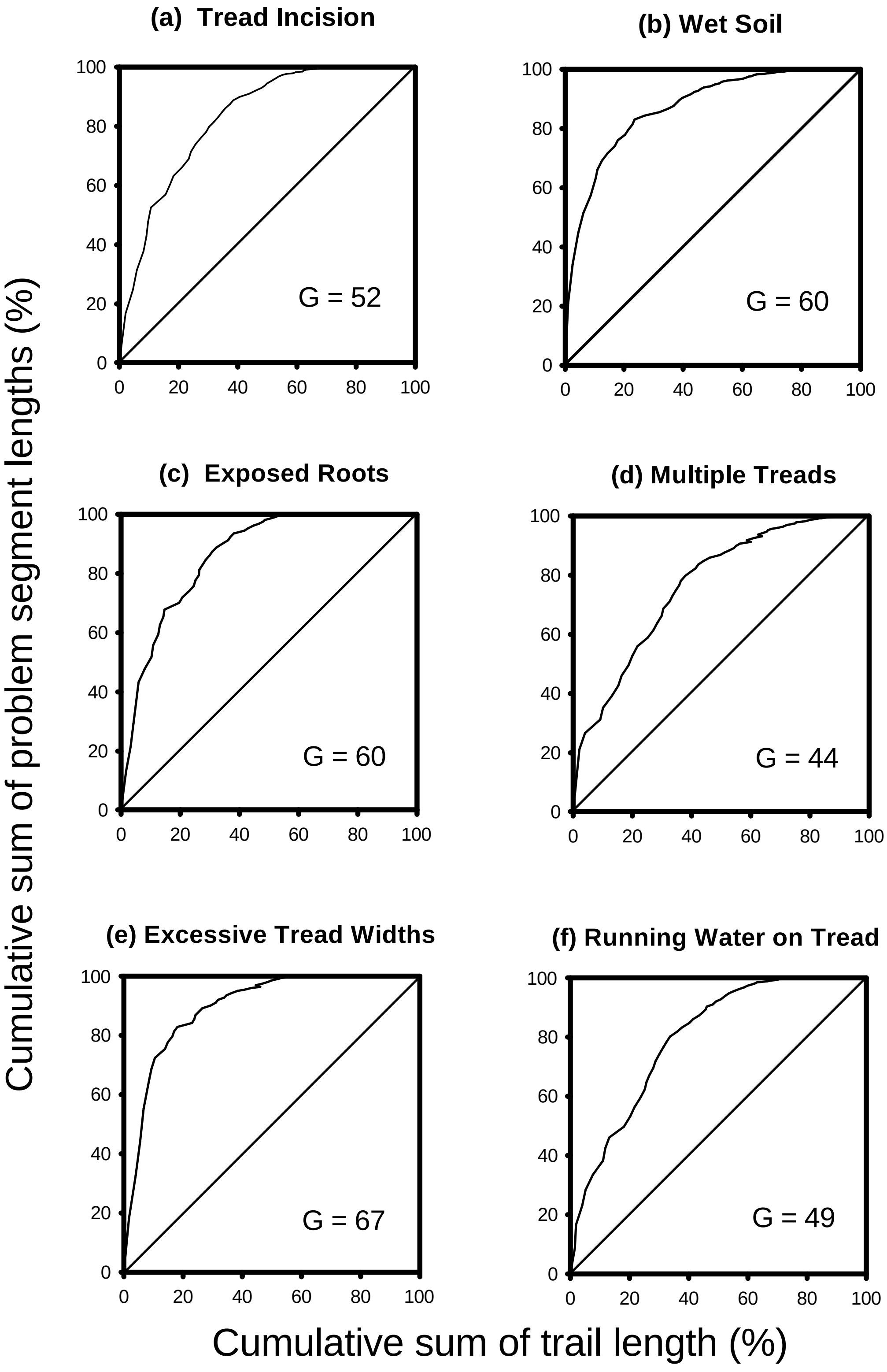

**Figure 6.1.** Lorenz curves and Gini (G) coefficients for six trail impact types (n=70). (based on cumulative sums of trail length and problem segment length). [Note: Higher G values and greater departure of a curve from its diagonal indicate greater spatial concentration]

**Table 6.3.** Results of applying the linear nearest neighbor analysis and LR ratio to GSMNP trail impact assessment data.

| **Impact Type** | **LR Value (no unit)** | | | | **Inter-Segment Distance (m)** | |
|---|---|---|---|---|---|---|
| | Mean | Std. Dev. | Range | Skewness[1] | Mean | Range |
| *Overall (n=59)* | 1.28 | 0.48 | 0.01-1.94 | -0.97(ns) | 521 | 15-2,325 |
| *Wet Soil (n=47)* | 0.82 | 0.50 | 0.01-1.82 | 0.21(ns) | 454 | 18-2,414 |
| *Tread Incision (n=46)* | 0.84 | 0.58 | 0.01-1.93 | 0.19(ns) | 379 | 15-3,166 |

[1] Based on one-sample Kolmogorov-Smirnov test (ns: not significant at $p = 0.05$ level)

to 1.94 (highly uniform) (Table 6.3). By examining the histogram of LR values it is noted that the data are slightly negatively skewed, although the result of a Kolmogorov-Smirnov test shows no statistically significant deviation from the normal distribution.

Results for wet soil and tread incision are also included in Table 6.3 for comparison. Problem segments of wet soil, for example, are spaced about 455 m apart, while problem segments of tread incision are spaced about 379 m apart. However, the LR values of these two impact types are similar with respect to mean, range, and symmetry.

The variation in LR values can be visualized when individual problem segments are plotted against distance from trailheads. An example is provided as Figure 6.2. The spatial distribution patterns of wet soil and tread incision on the Panther Creek Trail are substantially different. While problem segments of wet soil exist extensively along the entire trail, problem segments of tread incision are concentrated within 1200 m from the trailhead. The LR values appear to reflect such a difference, with the wet soil LR value of 1.69, indicating a uniform distribution, and the tread incision LR value of 0.22, indicating a clustered distribution.

### (c) *Impact Association Index (IAI)*

Spatial associations between different impact types from the GSMNP data are shown in Table 6.4. Fifty-three or 76% of all surveyed trails have at least one problem segment where two or more impact types are associated. In total there are 446 problem segments involving two or more impact types. Of these, 42 problem segments have 3 or more impact

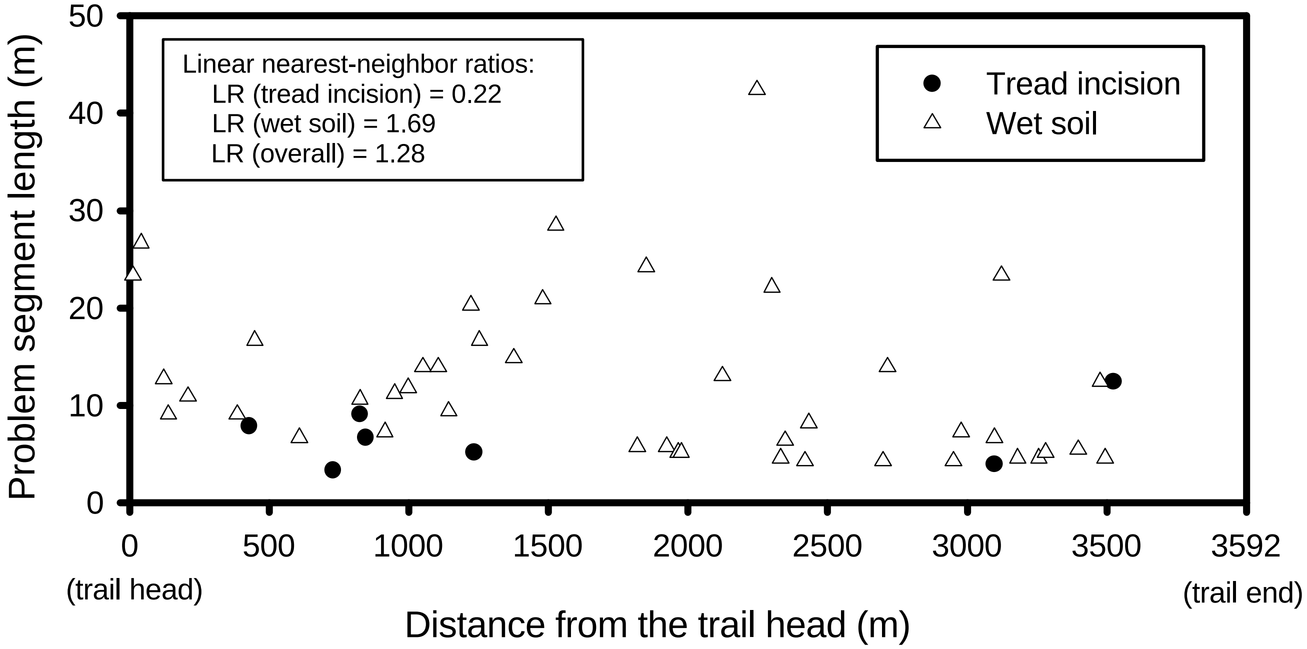

**Figure 6.2.** Spatial distribution of two impact types along Panther Creek Trail, Great Smoky Mountains National Park.

**Table 6.4.** Spatial association among different impact types for the surveyed GSMNP trails that have impact occurrences (n=53). Table values refer to the number of incidents where two or more impact types occur simultaneously.

| **Impact Type** | **Impact Type** | | | | | | **Row Total** |
|---|---|---|---|---|---|---|---|
| | *Tread Incision* | *Multiple Treads* | *Exposed Roots* | *Excessive Width* | *Wet Soil* | *Running Water* | |
| *Tread Incision* | -- | 55 | 24 | 10 | 48 | 6 | 143 |
| *Multiple Treads* | 55 | -- | 24 | 12 | 32 | 7 | 130 |
| *Exposed Roots* | 24 | 24 | -- | 3 | 9 | 1 | 61 |
| *Excessive Width* | 10 | 12 | 3 | -- | 92 | 7 | 124 |
| *Wet Soil* | 48 | 32 | 9 | 92 | -- | 1 | 182 |
| *Running Water* | 6 | 7 | 1 | 7 | 1 | -- | 22 |

types. These multiple impact segments might be considered 'critical spots' that require immediate management attention.

Wet soil has the highest degree of association with other impact types (182 occurrences), primarily with excessive widths. Tread incision and multiple treads are also commonly associated with each other (55 occurrences). The close spatial association between wet soil and excessive width is likely due to trail users trying to circumvent muddy soil, resulting in trail widening (Bayfield 1973).

Besides the nature of spatial association presented in Table 6.4, the degree of association among impact types was quantified using the impact association index (IAI). As no spatial association of impact types was found on 17 trails (i.e., IAI = 0), they were excluded from summary statistic computations shown in Table 6.5. IAI values range from 0.01 (minimal association) to a maximum of 0.49. Only twenty-five of the trails have an index of greater than 0.13. The index values are positively skewed, although the result of a Kolmogorov-Smirnov test shows no statistically significant deviation from the normal distribution (Table 6.5). Considering the possible range of index values from zero to one, the narrow range of IAI values obtained from the GSMNP data set implies a modest discriminant ability for this index.

Correlations between IAI and trail environmental attributes reveal a strong negative correlation coefficient between IAI and elevation change (m/km) ($r = -0.36$, $p<0.01$), suggesting that in steep terrains trail impacts tend to be solitary in location, while in flat terrains trail impacts are more likely to be co-located. The relationship between the LR and

**Table 6.5.** Results of applying the impact association index (IAI) to GSMNP trail impact assessment data (n=53).

| IAI Index | Statistic | | | | |
|---|---|---|---|---|---|
| | Mean | Median | Std. Dev. | Range | Skewness[1] |
| value (no unit) | 0.12 | 0.09 | 0.11 | 0.01 - 0.49 | 1.38 (ns) |

[1] Based on one-sample Kolmogorov-Smirnov test (ns: not significant at p = 0.05 level)

IAI indices was tested using a Spearman rank-order correlation. The result was not statistically significant ($r_s = -0.07$, $p = 0.62$) and failed to reject the null hypothesis of independence between the two indices.

## Evaluation

The results of applying three spatial indices suggest that the Lorenz curves and associated Gini coefficients, and the linear nearest neighbor analysis and LR ratio, are capable of discerning spatial distribution patterns of trail impacts at two spatial scales: trail (intermediate) and park (landscape) levels. The diversity contained in the GRSM trail data set seems to be effectively captured by these two indices. The use of these indices can aid in evaluations of the overall magnitude of recreation resource impacts, thereby informing management decisions. However, results for the impact association index are less promising. Further studies are therefore needed to refine this index, or explore alternative indices and ways to effectively quantify the degree of spatial association among impact types, as well as between visitation and impact patterns.

The application of Lorenz curves and Gini coefficients to the GSMNP trail impact data demonstrates their capabilities for characterizing the magnitude of distribution inequality of impact problems within the park's trail system. Variation in the magnitude of inequality among different impact types can be compared qualitatively through examination of their respective line patterns and quantitatively based on their Gini coefficients. This method is adaptable to other impact assessment data for trails and campsites. The information provided by a Lorenz curve, however, is limited in its link between distribution inequality and locational information. For example, from the Lorenz curve we might discover that five out of fifty trails are responsible for 100% of all occurrences of an impact type. We still would not know anything about the spatial relationships of these highly impacted trails. Quite often, specific locational information is important for formulating management strategies and allocating maintenance priorities. One option to increase the management utility of Lorenz curves and Gini coefficients is to label graphs with trail names or codes. Another important limitation of the Lorenz curve is its sensitivity to the change of observation unit size, also known as the Modifiable Unit Area Problem (Taylor 1977, Unwin 1981). In the present application the effect of this problem is minimal, unless there are substantial modifications in the length of individual trails. However, this problem could be substantial if comparisons are made on two sets of data collected by different methods and/or over a long period of time during which considerable trail rerouting or closures occur.

Application of the linear nearest neighbor analysis and LR index has also demonstrated its capability in quantifying the spatial distribution of impact problems and their variation along trails. The management utility of this LR index lies in its simplicity and apparent discriminant ability. This method is readily adaptable to other linear features in recreational environments, such as waterways, greenways and roads. However, Pinder and Witherick (1975) caution that the LR index could be sensitive to changes in the placement of the two end points under consideration. In an example given by Pinder and Witherick (1975) the LR value was increased by 0.3 by altering the endpoints of a line. This problem could also exist in trail environments when the trail heads and ends are ill-defined.

The IAI index was designed to quantify the degree of spatial association among segment-based features along trails. The performance of this index suggests that further testing and refinement are needed to improve its discriminating ability. The utility of this index, however, is limited due to its high specificity in data requirements and relatively complex computational procedures.

In summary, among the three spatial indices tested, the LR index seems to be more spatially explicit and have the best performance when applied to an empirical data set. The Lorenz curves and Gini coefficients may also be useful for application at larger spatial scales. Spatial association indices applicable to recreation IA&M data are still needed, but the proposed IAI index requires further refinement. All three indices may be adapted to data collected from other trail impact assessment methods (refer to Table 6.1) or other recreation IA&M programs, such as campsites and recreational roads.

## Management Implications and Conclusions

The two goals of this study have been to synthesize the literature on the use of spatial indices for evaluating recreation resource impacts, and to propose, develop and apply several spatial indices that were considered to be capable of discerning spatial distribution and association patterns. A thorough review of recreation ecology and recreation resource management literature revealed that while spatial patterns of recreation impacts are well recognized, little work has been done to quantify such information in a way that is useful for evaluation and management decisions. The existing spatial indicators and indices are primarily designed to quantify the spatial extent of impacts. Methods developed for capturing other spatial qualities, such as spatial distribution and association patterns of impacts, are very limited.

The matrix shown in Figure 6.1 may be useful for researchers and managers to identify significant knowledge gaps in the use of spatial indicators and indices in recreation impact evaluation. Researchers can also benefit from the matrix by establishing the ecological, social and managerial importance of each cell in the matrix in the overall magnitude of recreation resource impacts.

Three spatial indices were proposed in this paper as the first step towards strengthening the spatial knowledge in recreation ecology and recreation impact evaluation. Each of these proposed indices captures spatial qualities of recreation impacts. These indices may be used:

1. As indicators in management planning frameworks such as LAC,
2. As a means for quantitative comparison among recreation resources and protected area units,
3. As features to be mapped and visualized in order to aid impact evaluations,
4. As weighting factors for established severity indicators and indices,
5. As new situational variables to be examined in recreation social science literature.

This paper has explored only selected spatial indices that are believed to be most lacking in the literature yet are useful to recreation resource managers. The application was restricted to one empirical dataset. As previously mentioned, there are other spatial indices that may be useful to reveal other aspects of spatial information (see Appendix V for examples). Further studies are needed to systematically examine the properties, importance (ecological, social), and management utility of these and other spatial indices. The proposed and other spatial indices should also be applied to other protected area types and for other impact attributes to determine performance consistencies in different contexts. Spatial indices proven to be particularly useful should be communicated in the literature and among managers. Such efforts can accumulate a collection of spatial indices for recreation impact evaluation which, together with non-spatial indices, form a repertoire of indices that serve as a recreation resource planning and management tool.

Recent advancements in geographic information systems (GIS) provide an effective platform on which both spatial and non-spatial indices can be generated, analyzed and visualized. The use of GIS should facilitate the management utility of these indices and aid in the decision-making process. Another important step is the conceptual development of spatial indices that fit into the nature of recreation impact assessment data. The knowledge and training of geographers are particularly helpful to either or both aspects of methodological development (Cole 1989b). Such work would contribute to recreation ecology as a systematic field of study, to controlling visitor impacts as a protected area management objective, and to the preservation of natural environments as a societal goal.