ABSTRACT

Meyer, Kristin Jennifer. An Evaluation of Methods for Estimating Ground Cover and Soil Compaction as Visitor Impact Indicators. (Chair of Committee: Dr. Yu-Fai Leung)

The purpose of this study was to perform an empirical comparison of several methods of data collection for two visitor impact indicators. This study is the result of a bigger carrying capacity research endeavor in which one of the goals was to come up with indicators to monitor visitor impacts at the Boston Harbor Islands National Park Area. Specifically, the two visitor impact indicators evaluated in this study were soil compaction and ground cover estimation. These indicators were measured on two high use and two low use plots on selected islands in the Boston Harbor Islands National Park Area in Boston, Massachusetts. Georges and Grape Islands had the accessibility to the public and the soil types found on the islands that are of interest. There were three data collection periods during the visitor use season: June (beginning of season), August (middle of season), and October (end of season). A sampling plot consisting of six radial transects and two quadrats was placed randomly on each transect. The first transect was placed randomly and then there was 60º between each transect. A penetrometer and a soil compaction tester were the two methods used to measure soil compaction. Four measurements from both methods were taken in each of the twelve quadrats. Eight control measurements were taken in nearby undisturbed areas. The pocket penetrometer measurements are more variable than those of the soil compaction tester, but the pocket penetrometer is easier to carry and easier for one person to take and record

readings. To estimate ground cover, specifically vegetation and bare soil, the following three methods were used: overall, quadrat, and transect. For the overall and quadrat methods the ground cover types were ranked based on a Daubenmire cover scale. The quadrat method was used as the reference method to be compared to the other methods because the quadrat method was used regularly in low herbaceous (grassy) areas. For the transect method, changes in principal cover type along the transect were recorded. The high use areas were found to have a higher percentage of bare soil cover than the low use areas. The transect method produced higher mean than did the quadrat method. The overall and quadrat methods indicated vegetation recovery from the middle to the end of the visitor use season on both islands. The transect method indicated a decrease in vegetation ground cover from the middle to the end of the visitor use season for Grape Island but not Georges Island. Researchers and managers may use the findings of this study to aid them in their data collection choices. This study contributes to the future management of BOHA by evaluating monitoring techniques of two potential visitor impact indicators. It is hopeful that through efficient monitoring of use and resource indicators and effective management BOHA will achieve a balance recreation provision and resource protection.

AN EVALUATION OF METHODS FOR ESTIMATING GROUND COVER AND SOIL COMPACTION AS VISITOR IMPACT INDICATORS

by
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North Carolina State University
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DEDICATION

I dedicate this thesis to my family for their love and support:

Fabián González Vásquez, my husband
Martín González-Meyer, my son
Karl Meyer, my dad
Barbara Meyer, my mom
Jeremy Meyer, my brother
&
To my new family in Chile

BIOGRAPHY

I, Kristin Meyer, was born in Tempe, Arizona, on January 3, 1976. I have since moved around so much I just simply call myself a citizen of the world, not knowing where to call my hometown. I have lived in Stamford, CT; Phoenix, AZ; Hampden, MA; Rancagua, Chile; Tempe, AZ; Santa Clara, CA; Boston, MA; and Raleigh, NC. I have spent at least one night in the following countries: Mexico, Canada, England, Chile, Argentina, Scotland, France, Holland, Germany, Italy, and Switzerland. I am fluent in Spanish thanks to my year-long study abroad experience in Chile during high school. I am who I am today because of that trip to Chile.

After I finished high school, I spent four years in beautiful Tempe, Arizona where I studied and chased the storms throughout the state. During May of 1998, I graduated Cum Laude from Arizona State University with a B.S. in Geography with an emphasis in Meteorology. The weekend I graduated I moved to California. I lived near Big Basin National Park where the beauty of the magnificent redwood trees changed my life forever.

The last past few years have been the best. January 2002, a university professor asked me to be his graduate student. On May 25, 2002, I got married to my Chilean sweetheart. On June 2, 2003, our first son was born. Now, summer 2004, I will be graduating with my Masters degree in Natural Resources in Outdoor Recreation and will start a summer internship with the U.S. Forest Service.

Playing the role of mom is my favorite new pastime. Luckily, my son and I share a love for walks in the park, my other favorite pastime activity. He really enjoys feeding the ducks and swinging on the swings.

My other favorite pastime is traveling. I get so motivated and inspired when learning and experiencing new places, people, and cultures. My husband, son, and I are continuously planning new adventures. Most of our trips, now, are to visit the relatives in New England or in Chile. Someday we will get to that exotic Caribbean Island or another foreign country. You never know when we may be knocking on your door.

ACKNOWLEDGEMENTS

If it were not for my parents, my husband, and my new son for their unfailing support, I would not be writing this thesis. Dr. Yu-Fai Leung, thank you for taking me in under your wing, I know it hasn't been easy. I do appreciate you more than you know. I would like to thank Fabián González, Martín González-Meyer, Pedro Robledo, Keith Johnson, Chrissie Ingle, Laura Lam, Karl Meyer, and Barbara Meyer for their field assistance. I thank North Carolina State University, especially the Parks, Recreation and Tourism Management Department, and the National Park Service for funding my Masters program. I want to thank everyone that gave me thesis advice, especially my committee members: Dr. Yu-Fai Leung, Dr. Gene Brothers, and Dr. Gary Blank. I would not have made it through the masters program without the help of all of my fellow graduate students, thank you to all!

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LIST OF SYMBOLS OR ABBREVIATIONS

BOHA	Boston Harbor Islands National Park Area
GMP	General Management Plan
LAC	Limits of Acceptable Change
NPS	US National Park Service
PP	Pocket Penetrometer
PR	Penetration Resistance
SCT	Soil Compaction Tester
SNG	Surface Nuclear Gauges
VAMP	Visitor Activities Management Process
VERP	Visitor Experience and Resource Protection
VIM	Visitor Impact Management

CHAPTER I: GENERAL INTRODUCTION

THE ISSUE OF VISITOR IMPACTS

Resource impacts caused by visitor use are an increasingly important issue in park and protected area management globally as park visitations continue to grow. Visitor use in parks usually causes some form of impact to the environment. Activities such as walking, hiking, horseback riding, snowmobiling, mountain biking and climbing may lead to soil compaction, soil erosion, vegetation loss, change in vegetation composition, tree damage, altered wildlife behavior, and reduced water quality. Many of these impacts have been studied and monitored in the USA and abroad, particularly on campsites and trails (Hammitt & Cole, 1998). Condition class ratings, rapid assessment, and quantitative measurements are some of the methods used to assess and monitor visitor impacts.

Management of visitor impacts is often referred to as a visitor carrying capacity issue. The concept of carrying capacity has long been a part of the natural resource professions. It started out in wildlife and range management and was defined as the quantity of animals of any species that can be supported by a given environment (NPS, 1997). This concept has since been applied to recreation and park management to help determine the appropriate amount and type of visitor use that can be maintained in a certain environment or place. A number of carrying capacity-based decision frameworks have been developed, including the U.S. Forest Service's Limits of Acceptable Change (LAC), National Park and Conservation Association's Visitor Impact Management (VIM) framework, Parks Canada's Visitor Activities Management Process (VAMP) framework, and the National Park Service's Visitor

Experience and Resource Protection (VERP). These frameworks share a lot in common, including the critical role of indicators, standards, and monitoring programs.

Mandated by the 1978 National Parks and Recreation Act (P.L. 95-625), each unit within the National Park System must address carrying capacity in their new or updated general management plans (GMP) (NPS, 2000). When the Boston Harbor Islands (BOHA) became a new unit of the National Park System in 1996 it was also required to address the carrying capacity issue in their first GMP through a VERP process. This study evaluated different methods for visitor impact monitoring as part of a large project that assisted this new national park unit in its VERP implementation.

THE VERP FRAMEWORK

There are nine steps in the VERP process to help managers determine what and where visitor and resource impacts are most prominent and how to manage and monitor them (VERP, 1997).

1. Assemble an interdisciplinary project team.
2. Develop a public involvement strategy.
3. Develop statements of park purpose, significance, and primary interpretive themes. Identify planning constraints.
4. Analyze park resources and the existing visitor use.
5. Describe a potential range of visitor experiences and resource conditions.
6. Allocate the potential zones to specific locations in the park (Prescriptive management zoning).

7. Select indicators and specify standards for each zone. Develop a monitoring plan.
8. Monitor resource and social indicators.
9. Take Management Action.

Steps one through six are required parts of a GMP. The first two steps guide the managers on how to put together a planning group and get the public involved. Step three is when the managers have to determine the park's different purposes, significances, themes and constraints. Steps four and five analyze current and potential ranges of resource and visitor impacts. It is only through step four that a carrying capacity study is needed. Step six allocates the themes to areas of the park that are appropriately based on the findings in step five.

Individual park units implement steps seven through nine somewhat differently. This is because each park has a different set of indicators and standards to monitor. Through these steps managers are informed about what impacts, indicators, and standards currently exist in their parks and are offered guidance on ways to monitor and manage the impacts. In the end, park managers will determine how monitoring of impacts is implemented.

VERP was first applied in Arches National Park, Utah in the early 1990s. Some of the other parks that are currently going through or have finished the VERP process are Kenai Fjords National Park, Alaska; Arcadia National Park, Maine; Yosemite National Park, California; and Canyonlands National Park, Utah. After completing their carrying capacity study, Arches National Park suggested a VERP process with only five components (Selleck, 2000). He also noted three weaknesses of the VERP plan, which include the need for lead-time to do research on habitats, staff expertise, and their constraints in both time and money . As more studies are being conducted, the VERP process will be continuously improved and enhanced by the National Park Service (NPS, 1997).

INDICATOR DEVELOPMENT

The selection of indicators for a monitoring program is step seven in the VERP process. Indicators are specific and measurable variables reflecting the overall physical, ecological, and social aspects of management zones. Good indicators are easy to measure, easy to train observers for monitoring, cost effective, and the variability of the measurement techniques are relatively low (NPS, 1997). Some examples are the extent and condition of social trails, the conditions of official trails, the conditions of recreation sites (official and unofficial), facility proximity to sensitive resources, trash or human waste, vandalism, tree damage, soil quality, and vegetation quality. These indicators are broad categories that can be further broken down and measured in many ways. Most of these indicators were assessed in the BOHA carrying capacity study.

This thesis research focused on two common indicators: ground cover and soil compaction. These two indicators have ecological and social significance. Ecologically, vegetative ground cover is essential in protecting the soil from water and wind erosion. Vegetative ground cover loss can be a direct result of visitor use. Degraded soil quality inhibits plant and vegetative growth, creating bare soil exposure. Bare soil and soil compaction are evidence of overuse, which may potentially affect the visitor experience (Liddle, 1997).

Ground cover estimates (vegetation and bare soil) are some of the most common indicators in recreation ecology and for impact monitoring programs (Liddle, 1997). Like cover estimates, frequency counts and density measurements are two other types of quantitative parameters related to the abundance of vegetation. Vegetation density measurements and frequency counts are time consuming. Vegetation density measures are evaluated by counting all plant individuals in sampling plots. Vegetation frequency counts measure the number of times a species occurs in a given number of repeatedly placed plots or points. A good working knowledge of plant taxonomy is essential for density and frequency because they are dependent on species or individual plants. For cover, though, knowledge of plant taxonomy is helpful, but only needed if doing an in-depth and detailed coverage study. Sampling, whether for density, frequency, or cover, can be inaccurate depending on the areas and dispersion of the coverage. Compared to density and frequency, cover estimates are relatively easy to measure. Ground cover estimates along with vegetation height measures plant biomass, an important measure in forest inventory studies. The biggest advantage for cover estimates is that all ground cover types can be evaluated in comparable terms (Mueller-Dombois & Ellenberg, 1974). This cannot be done with density or frequency.

Soil compaction is also an important visitor impact indicator. When using the same method to measure soil compaction, measures can compare the change in soil volume over time. A decrease in soil volume is typical in recreational areas because of visitor use. Soil compaction is one way of describing the overall soil quality, which is very important to the organic forms living in the soil, the water quality, and the plants growing on the surface (Brady& Weil, 2002).

THE BOSTON HARBOR ISLANDS

The Boston Harbor has been an essential part of the history and culture of the Boston, Massachusetts, since even before European settlers arrived to the east coast of the USA. The islands are mostly drumlins created by glaciers (Figure 1.1). The Native Americans found the islands a great place to hunt and fish from early spring to late autumn (BOHA, 2003b). As explorers and settlers came new stories, myths, and legends were created. By the mid-1900's, the harbor waters became polluted and the islands neglected because the Bostonians were forgetting about the significant history and culture of the islands. There was one person who was very important in the idea of preserving and cherishing the harbor by creating a park. Edward Rowe Snow beckoned and warned the people of Boston not to neglect the islands nor forget about the natural treasures on and around them (Snow, 2002).

The Commonwealth of Massachusetts heeded Snow's advice and took action in the 1970s by acquiring islands and cleaning up the harbor. It was not until 1996 that the Boston Harbor Islands National Recreation Area (BOHA) was formed as a unit of the National Park System (Figure 1.1). The name was changed to Boston Harbor Islands, a National Park Area because the Native Americans were opposed to the idea of people recreating upon their ancestors' places of social and ceremonial activities. In 2000, BOHA implemented the Visitor Experience Resource Protection (VERP) planning framework to aid in the preparation of the park's first general management plan to address the visitor capacity issue. The partners of BOHA are concerned about ever-increasing visitation to the islands and potential effects on the natural resources, especially since a population of 40 million people lives within 400 kilometers (250 miles) of the park (BOHA, 2003b).

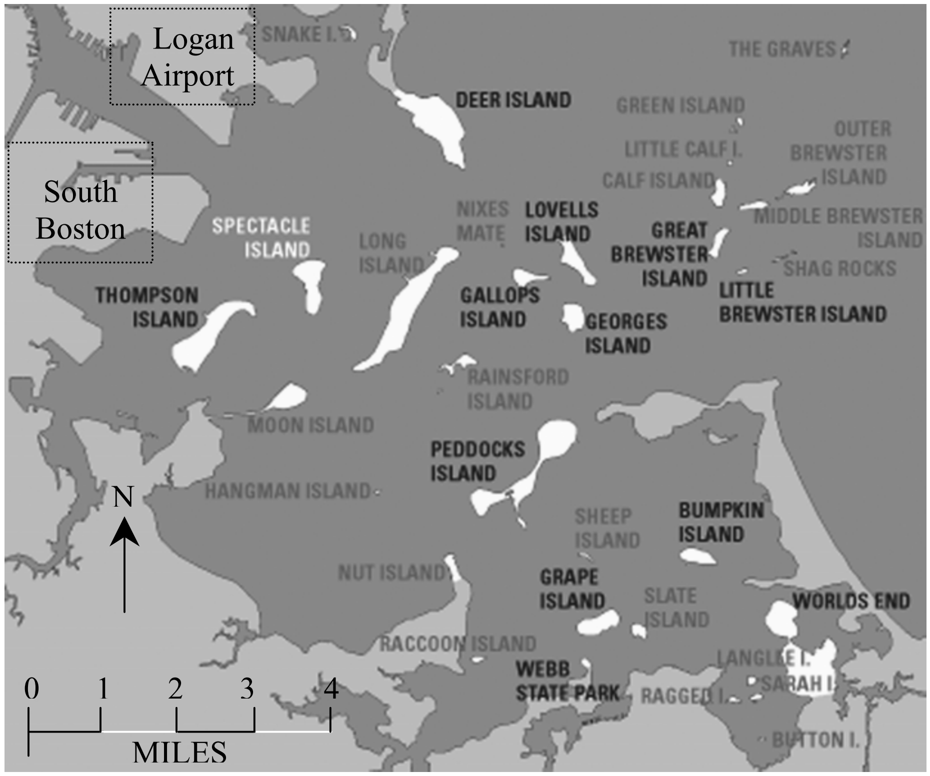

Figure 1.1. Map of the Boston Harbor Islands National Park Area

Notes. The Boston Harbor Islands National Park Area includes the areas in white. The island names with black lettering are open conditionally or unconditionally to the public. The island names with grey lettering are not open to the public. The island names with white lettering will be open to the public in 2004. Adapted from http://www.bostonharborislands.com.

At present, 34 islands and peninsulas (formerly islands) are part of BOHA (Figure 1.1). The islands include 1,600 acres at high tide and 3,100 acres at low tide with over 35 miles of undeveloped coastline. They extend 11 miles eastward of downtown Boston. The sizes of the islands range from less than 1 acre to greater than 274 acres (BOHA, 2003b). These islands are unlike most NPS units because BOHA is managed by a unique partnership of 13 members consisting of the National Park Service, state agencies, municipal agencies, and island owners (BOHA, 2003b). The mission of the BOHA Partnership is to "...protect the islands as a resource of national significance and to make the island system an integral part of the life of the surrounding communities and region, while improving public knowledge and access for education, recreation, and tranquility within an urban area (NPS, 2002)."

RESEARCH OBJECTIVES

The overall goal of this research is to contribute to the process of VERP indicator development in BOHA by examining alternative indicator measurement techniques. Specific objectives are to:

1) Evaluate three common methods of estimating extent of vegetative and bare ground cover.
2) Evaluate two portable instruments for measuring soil compaction (penetration resistance).
3) Develop recommendations on selecting monitoring methods in VERP implementation.

THE STRUCTURE OF THESIS

This thesis adopted a journal-manuscript format with four chapters. The first chapter provides background information about visitor impact issue, VERP, and the study area. Chapters 2 and 3 address study objectives 1 and 2, respectively. The final chapter integrates findings from the two main chapters and discusses overall recommendations and implications.

CHAPTER II: GROUND COVER

Estimating Vegetative and Bare Ground Cover as Visitor Impact Indicators: An Evaluation of Three Methods

ABSTRACT

As visitations to the Boston Harbor Islands National Park Area (BOHA) continue to increase, there is also a growing concern about groundcover loss due to visitor use. This issue is being addressed by the implementation of the Visitor Experience and Resource Protection (VERP) planning framework. This chapter reports results of an empirical study to evaluate three methods for estimating vegetative ground cover and bare soil cover. Also reported are advantages and disadvantages of each method based on field application in 2002. The evaluation results indicate that different assessment methods may produce different results in vegetative ground cover estimates. For example, a low use site on Georges Island evaluated in August indicated a statistically significant difference between the quadrat and transect methods. The transect mean percent value was much higher (93.9%) than that of the quadrat (64.3%). For estimating the bare soil cover type, different assessment methods appear to produce comparable estimates. Research and management implications are discussed.

INTRODUCTION

Changes in the amount and composition of ground cover are a common type of resource impact resulting from visitor use in parks and recreation areas. Park visitors who stand, walk, run, bike, horseback ride, or drive vehicles on or off trails and recreation sites can impact ground cover. Managers expect and plan for some of these impacts within use areas as an inevitable outcome of visitor use. However, they are more concerned when ground cover impacts are caused when visitors go off the trails or recreation areas to take pictures, to take shortcuts, or for any other reason. To minimize ground cover impacts managers often encourage or require visitors to stay on resistant or hardened trails and recreation sites through design, regulations and education (Hammitt & Cole, 1998).

A change in ground cover on recreation sites typically shows a trend of decreasing vegetative ground cover and increasing bare soil exposure (Liddle, 1997). Socially, reduced vegetation coverage may degrade aesthetic quality and visitor experiences. Ecologically, reduced vegetation ground cover and increased bare ground would likely accelerate erosion by water and wind. Accordingly ground cover estimates using a variety of field measures are commonly used as indicators in visitor impact research and monitoring.

The purpose of this paper is to apply three types of ground cover estimation methods at the Boston Harbor Islands National Park Area (BOHA) to evaluate their functionality and data variability as potential impact indicators for the park's Visitor Experience and Resource Protection (VERP) implementation plan. This paper reports results for two major ground cover types, namely vegetative cover and bare soil cover.

METHODS FOR MEASURING GROUND COVER

Various methods have been developed to estimate ground cover. Point (overall), line (transect), and area (quadrat) assessment methods are three major methodological approaches in previous recreation impact studies (Hammitt & Cole, 1998). The study areas for this project were primarily low herbaceous (grassy) picnic areas where the quadrat method has commonly been applied (Mueller-Dombois & Ellenberg, 1974). On the other hand, it is common to find the transect method used in desert environments and the point method used on trails (De Soyza, Whitford, & Herrick, 1997; Deng, Qiang, Walker, & Zhang, 2003). A combination of methods is often found in recreation impact studies (Table 2.1). For this study, the quadrat assessment approach will serve as the reference method against which the overall and transect methods are compared. The following is a concise review of each method.

Assessing a location using the point method means that one general observation for the entire site is recorded for each variable. The point method can be approached in two ways. First, the area is observed without a border. Second, the area is observed with a border. The advantage of having a border around the area being studied is that it decreases observer subjectivity. Border or no border, most study plots are too large that the far side of the site will be distorted to the observer. Due to the small sample size of one estimate at a site, parametric statistical tests of significance may not be appropriate. It is rare to see a study design using only the point assessment method without some use of the quadrat or transect methods as seen in Table 2.1. From a practical perspective, it is easy to just take one observation estimate for a site, especially if a site border has to be erected. However, this method is statistically weaker due to the limited number of data taken. A visitor impact study in China used a point method to quickly describe a number of spots along a trail. At some of these points they used a transect to determine a more detailed and accurate estimate of the ground cover (Deng, Qiang, Walker, & Zhang, 2003).

Table 2.1. Assessment Methods used in Some Previous Recreation Studies.

Study Area (Author (s), Year)	**Type of Study** Trail (T) Grassy (G)	**Methods used**		
		Overall (Point)	**Quadrat** (Area)	**Transect** (Line)
Delaware Water Gap NRA (Marion and Cole, 1996)	T, G		X	X
Salisbury Plain Training Area (SPTA), a UK Military Area. (Hirst, Pywell, Marrs, & Putwain, 2003)	G	__	X	__
Costa Rica and Belize, Eight protected areas (Farrell & Marion, 2002)	T, G	X	__	X
Zhangjiajie National Forest Park, China (Deng, Qiang, Walker, & Zhang, 2003)	T	X	X	__
Riparian Forests of the Eastern US (Cole, & Marion, 1988)	T, G	__	X	X
Torres Del Paine National Park, Chile (Farrell & Marion, 2001)	T	X	__	X
Warren National Park, Western Australia. (Smith, & Newsome, 2002)	T, G	__	X	X

Note. Grassy (G) includes mowed and/or unmowed low herbaceous grasses and weeks.

Quadrats are framed areas within the study site that are used to form manageable sample areas. Accuracy usually increases with an increased number of quadrats (sample size). The size and shape of the quadrats are dependent on the type of vegetation, statistical precision, and logistical considerations. Field testing of quadrat samples is the most accurate way to find the optimal size and shape quadrats. Of the various sizes and shapes, a long, rectangular quadrat provides statistical precision, and smaller more uniform shapes tend to increase the accuracy in the observer's perspective (Elzinga, Salzer, & Willoughby, 1998). Larger quadrats are required for measuring tree and shrub stands, while smaller quadrats are often sufficient for measuring grasses and herbaceous ground cover. Either way, quadrats are a way to provide data suitable for statistical testing. Using quadrats is a popular cover estimation technique because of the ease and speed at which data can be collected (Elzinga, Salzer, & Willoughby, 1998). In a campsite study at the Eagle Cap Wilderness in Oregon, USA, 15 quadrats each 1m by 1m were used to evaluate ground cover percentages (Cole, 1982).

The continuous line transect is an assessment method to randomly and systematically get data at a site. Transects in circular plots radiate from the center. Transects in square or rectangular plots connect two randomly chosen spots on opposing sides of the plot. There can be one or many data values per plot, depending on the number of vegetation changes. Whenever the vegetation type changes, a distance from the beginning of the transect is recorded. Data are collected in a slightly different manner than in the overall and quadrat methods. This method is based on lengths rather than a rank scale. This method has been used frequently in sparsely vegetated environments such as deserts (DeSoyza, Witford, Herrick, Van Zee, & Havstad, 1998). This method is also used to inventory trees in forests (Mueller-Dombois, & Ellenberg, 1974). For statistical purposes this is a very useful method, especially since an actual and reliable length scale is being used. Although, from a practical perspective, there are many factors that introduce subjectivity in field decisions. One of these factors has to do with the season the study is being conducted. In winter the deciduous trees lose their leaves, which may cause a logistical problem. It has to be pre-determined which trees to measure depending if any part of the tree has to actually touch the transect or be within the aerial area of the tree. It is harder to determine the aerial area of the tree without leaves. Another factor is determining the coverage area of the vegetation type, or a lack thereof, to know when to mark a change (Elzinga, Slazer, & Willoughby, 1998). The coverage area is easy to determine for a Christmas tree or piece of trash since they are normally dense and contained. On the contrary, the coverage area for a Palo Verde tree (*Cercidium floridum* or *Cercidium microphyllum*) with slim branches going in all directions, like grasses, is hard to determine. A third factor in deciding to use a transect is whether or not to have an observation zone around the tape measure. An observation zone gives a better chance of including more vegetation types (Mueller-Dombois, & Ellenberg, 1974). In a visitor impact study, Farrell and Marion (2002) used the transect methods to determine the percent of ground cover types on trails and recreational areas within eight protected areas of Belize and Costa Rica..

METHODOLOGY

Study Area

BOHA consists of 34 islands and peninsulas in Boston Harbor amounting to 650 hectares (1600 acres) in total size. Due to proximity to population centers this new park receives ever-increasing visitation, with 262,000 recreational visits recorded in 2002 (BOHA, 2003a). BOHA is managed by a 13-member partnership that includes the National Park Service, federal, state and municipal agencies, and island owners.

Three islands were initially selected for this study based on their environmental characteristics and accessibility. Of the 34 islands only five were open and accessible by public ferries (Georges, Peddocks, Grape, Bumpkin, and Lovells Islands). Georges Island was chosen because it has the highest volume of visitors with the greatest amount of visitor impact. Two of the islands had very similar soil type and visitor use levels (Bumpkin and Grape). We chose to collect data on Grape Island for efficiency reasons. Peddocks Island was also selected but field data collection was incomplete due to weather and logistical constraints. This paper therefore reports results from Georges and Grape Islands only. Georges Island is a heavily used island with Fort Warren taking up a majority of the island. There are many grassy trails and recreation areas. There are a few unmowed bushy areas with some scattering of trees. Grape Island possesses a more vegetative setting with lots of trees and bushes. All the trails, campsites, and picnic areas are grassy.

Field Procedures

BOHA is open from May to October and is closed during the winter months. We collected data at the beginning (June), middle (August), and end (October) of the visitor use season to evaluate a seasonal trend in ground cover. Unfortunately, during the summer of 2002, Boston was experiencing drought conditions, which may have affected our August results.

It took three observers, on average, 45 minutes to complete one sampling plot. This could be less if the same three people always did the data collection. It would take between

10 and 15 minutes to set up the plot. It would take between 15 and 40 minutes to record ground cover over the transect, depending on the amount of cover changes. During this time the overall method (one minute) and quadrat method (15 minute) estimates can be recorded. Between the working hours of ten o'clock in the morning to five o'clock in the evening, there was a total of approximately 5 hours a day to perform data collections on Georges Island and 4 hours on Grape Island. These limited hours were due to corresponding ferry schedules.

Each site provides a number of ground cover data. There are twelve quadrats that provide a total of twelve ground cover quadrat observations. There is one observation from the overall ground cover assessment method. For the transect method, the number of observations depends on the number of changes in vegetation. There was a range of 17 to 59 changes in vegetation per site.

The selection of two high use and two low use sites on each island was based on soil type and visitor use level. There were two predominant soil types that made up the majority of the islands open to the public. Georges Island is made up of primarily the Udorthents, Loamy (Ud) soil type. The Ud soil is predominately fine sandy loam good for recreation fields and parks. A slow runoff rate is the main concern for managers, because puddles will form after intense rains (USDA, 1989). Newport silt loam (NpC) and Pittstown silt loam (PtB) soils dominate Grape Island. They are reported herein as a combined soil type (NpC/PtB). These soil types have the same soil properties; the only difference is in slope. Between the two soil types a slope of two to fifteen percent is covered. The NpC/PtB soil is predominately silt loam good for parks and playgrounds. Erosion is the main concern for managers, so vegetation cover is very important (USDA, 1989).

The visitor use levels (high use and low use) were based on each individual island. For example, a high use area on Grape Island would not be comparable to a high use area on Georges Island. There were a total of 83,829 visitors to Georges Island during the 2002 season while there were only 4,905 visitors to Grape Island (BOHA, 2003a). Georges Island, as a whole, is well used, but there were a few areas of very concentrated visitor use. Many people including school and organization groups use the four large picnic areas around the island. We chose two of these high use areas to be our high use sampling plots. We chose one close to the pier, which is almost always occupied. The other large picnic area we chose is on the southwest part of the island (approximately a 1/4-mile from the pier) and includes a large area where children run around and play games.

The selection of low use sites was more difficult than the high use sites. On Georges Island few places are not walked or played on. On the backside of the island, there were a few areas on some trails that did not seem to be used as much as on the pier side of the island. We chose two of these areas on the trails for our study sites: one that is right next to the Fort and another closer to the coastline. From two summers of observations we found that these areas received lower use compared to the two high use areas.

On Grape Island the majority of concentrated use is in two picnic areas close to the pier and from there the use is then dispersed to the other parts of the island. In each of these areas we were able to determine high use and low use areas based on field observations of use patterns.

Sampling Plot Design

At each study site a circular sampling plot was laid out (Figure 2.1). A circular plot design was adopted, as most of the sites being studied are oddly shaped or small. From the center, our transects went out as far as six meters or until the mowed recreation area ended. This method seemed to be less time consuming than laying out square plots. With square plots we would have had to trudge through brush to find beginning and ending points for the transects. Another advantage of the circular plot is all of the transects start at one point and the end points are all the same distance. The first transect is found randomly. This center of the circular plot is found randomly by throwing any object into the pre-determined study area. A metal nut was buried into the ground at that point so that we could be certain that we relocated the exact site location for the mid and end of season data collection.

Once the center was determined, the transects were then measured out six meters. A stake at the center point stabilized the tape measure. The first transect was chosen randomly using the random operation on the calculator ((.nnn) * 1000). The number 360 was subtracted from the random number until the resulting number was between 0-360º (the number of degrees in a circle). If the number is between 0 and 360, no subtraction is necessary. For example, a random number of 0.590 would give a direction of 230º for the first subtransect. This number would become 230º by multiplying the random number by 1000 to get 590. Then, 590 less 360 is equal to 230º. The transects are evenly spaced every 60º going clockwise around the plot.

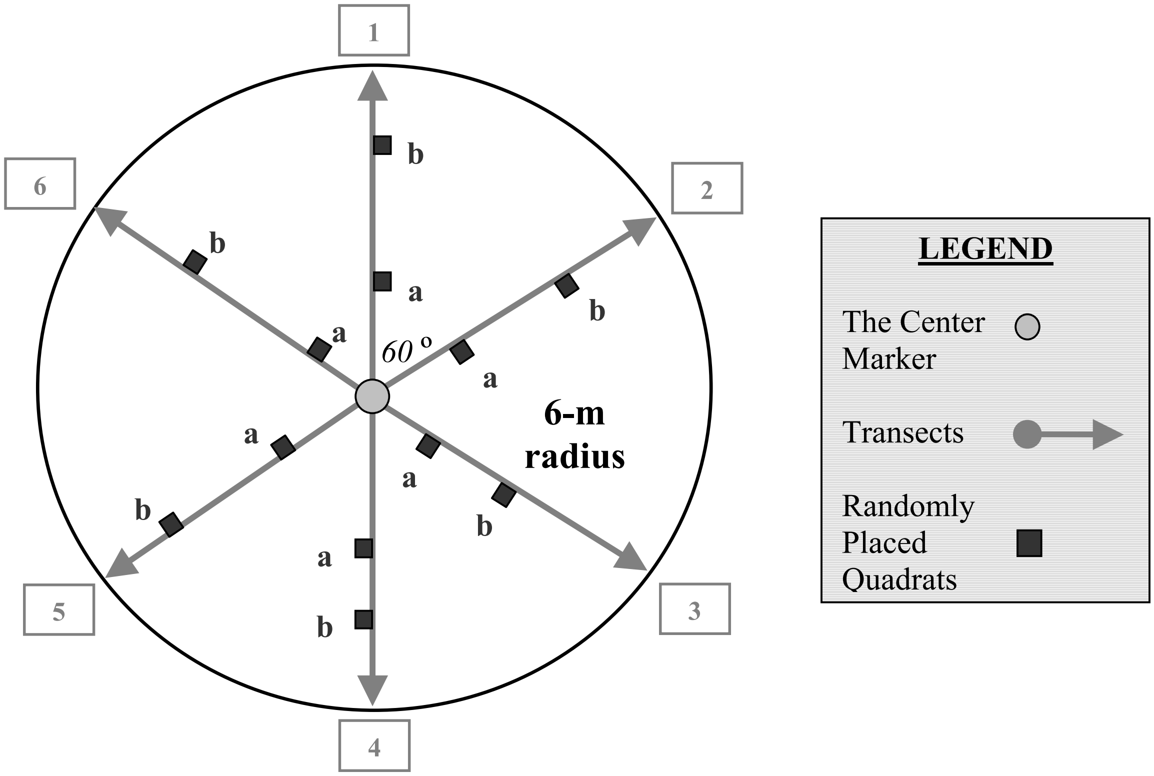

Figure 2.1. The Sampling Plot Design.

Two quadrats, made out of plastic piping forming a 25cm by 25cm square, were randomly placed along each of the transects. The location of the quadrats along the transects was calculated using the random operation on the calculator (.nnn) then multiplying that decimal by 6. For example, the random number 0.847 is multiplied by 6 giving a result of 5.082. This number is rounded to 5.1 meters. Since random numbers can range from .000 to .999 when multiplied by 6 it gives the range of 0.0 meters to 6 meters (when rounded). Using this method, quadrats had equal chance of being located along any part of all the transects.

On the data collection forms, to be consistent, the quadrat closer to the center point is listed before the farther away quadrat.

Ground Cover Methods Selected

Ground cover composition was estimated using three different methods: point method assessment, quadrat assessment, and continuous line transect assessment. In this study, the terms overall, quadrat, and transect will be used to represent the point, quadrat, and continuous line transect assessment methods, respectively. All ground cover measures for the overall and quadrat assessment techniques were measured in percents using a zero to six cover scale adapted from the Daubenmire cover scale (Table 2.2; Mueller-Dombois, & Ellenberg, 1974). This similar scale was used in Leung and Marion's (1999) camping impacts study in the Great Smoky Mountains. The categories of ground cover types estimated for each method in this study are in Table 2.3. In this study, only mowed areas are included in the vegetation ground cover analysis. Unmowed areas are not considered to be visitor use areas.

Table 2.2. Ground Cover Assessment Scale

Class	Range of Cover %	Class Midpoints %
0	0	0
1	0 – 5	2.5
2	5 – 25	15
3	25 – 50	37.5
4	50 – 75	62.5
5	75 – 95	85
6	95 – 100	97.5

Adapted from Mueller-Dombois, D., & Ellenberg, 1974.

The first two methods, point method assessment and quadrat assessment, both use the same ground cover ranking scale to measure ground cover. To help the observers be consistent in using the given scale, a laminated 8.5x11 inch reference sheet with visual representations of respective ground cover was available (Figure A1). For the point method, the entire site is estimated in one observation. For the overall method, each ground cover type is estimated for the entire site. The quadrat placement was dependent on the transect layout. The ground cover in each of the 12 quadrats was estimated using the ranking scale in Table 2.2. The quadrats gave 12 values for each site.

Table 2.3.Ground Cover Data: Analysis of Data from the Field.

Ground Cover Categories and Methods Used				
Observed Ground Cover Types	Simplified Ground Cover Categories	Methods used to estimate the ground cover types.		
		OVERALL Method	QUADRAT Method	TRANSECT Method
Grass	Vegetation	X	X	X
Weed	Vegetation	X	X	X
Plant litter	Other	--	X	X
Bare soil	Bare Soil	--	X	X
Trash	Other	X	X	X
Moss/Lichen	Vegetation	--	X	X
Pebbles/soil	Bare Soil	--	--	X
Pebbles	Bare Soil	--	--	X
Unmowed*	Other	--	--	X
Rock	Other	--	--	X
Vegetation	Vegetation	--	--	X
Unmowed grasses*	Other	--	--	X
Unmowed weeds*	Other	--	--	X
Mowed	Vegetation	--	--	X
Cement	Other	--	--	X
Animal waste/ bird Droppings	Other	--	--	X
Plant litter/ dry grass	Other	--	--	X
Dry grass	Vegetation	--	--	X
Tree sapling	Vegetation	--	X	X
Root	Vegetation	--	--	X
Fern	Vegetation	--	--	X
Other	Other	X	X	--

* Ground cover type is beyond the visitor use areas as defined by this study, so it is not included as vegetation.

The continuous line transect estimations were performed by observers who started at the center of each sampling plot and walked the length of each 6-m transect. Measurements of ground cover were estimated as the principal type of ground cover along the transect changed, to the closest decimeter (10 cm). There was a 10-cm observation zone along each transect so that a principal ground cover type could be determine more accurately. A beginning and end distance was recorded for each change in principal ground cover type. The amount of values to estimate ground cover depended on the amount of ground cover changes. There would be a minimum of six values for each site if all the transects reported one ground cover type. For example, if the area was principally grass, a transect may have just one value, 6 meters for grass.

Analysis

The data were entered into and analyzed in SPSS for Windows. Data were split, sorted, or aggregated to get into the formats needed for doing either the descriptive statistics or the statistical significance tests. Table 2.3 illustrates how the ground cover data were simplified into three different categories: vegetation, soil, and other. Descriptive statistics and the independent samples t-tests with unequal variances were used to assess the statistical significance of the difference in cover estimates. T-tests were applied only between the quadrat and transect methods. The scatter plots graphs of the ground cover trends in figures 2.3 and 2.4 were created in Excel 2000.

RESULTS

Georges Island

Table 2.4 highlights the means, standard deviations, and the coefficient of variations for the ground cover estimates for the overall method on Georges Island. Due to the small sample size the overall results cannot be directly compared to the transect and quadrat results through significance tests. As expected, the low use sites have a higher amount of vegetation cover (95%) than the high use sites (77%). The high use sites have a greater percent (15.1%) of bare soil than low use sites (less than 1%). Measuring vegetative ground cover has a CV range of 0.07 to 0.25, which is lower than that of bare ground cover range of 0.93 to 2.60.

For the overall method, the high use sites show an indication of recovery with a vegetation increase of 86% to 91% and a bare soil decrease of 10% to 8% between June and October (Table B1). Low use sites had more cover in the 'other' category because vegetative ground cover decreased from 100% in June to 96%, but bare soil remained at 0%. There is 0% bare ground in October for both use levels.

Table 2.4. Overall Ground Cover Estimation Results: Georges Island (All months combined)

Groundcover Type/ Use Level		Overall Ground Cover Estimates			
		N	Mean (%)	Standard Deviation (%)	Coefficient of Variation (%)
Vegetative Ground Cover					
	High Use	12	76.6	19.5	0.25
	Low Use	12	95.1	7.1	0.07
Difference between High and Low Use (Mann-Whitney U Significance)			0.065		
	Combined Use	24	85.9	17.0	0.20
Bare Ground (Exposed Soil)					
	High Use	12	15.1	14.1	0.93
	Low Use	12	0.5	1.3	2.60
Difference between High and Low Use (Mann-Whitney U Significance)			0.015*		
	Combined Use	24	7.8	12.2	1.6

* Significant: $p < 0.05$. ** **Significant**: $p < 0.01$.

Table 2.5 highlights results of the quadrat and transect estimation methods for Georges Island. With all three months combined, the quadrat and transect methods of evaluating vegetation on the low use sites were found to have a statistically significant difference of 11%. When evaluated by month, the data collected in August was found to make this comparison statistically significant with a difference of 30% (Table B2). The combined use for both the August data and the data for all three months show that it is important which evaluation method is chosen. This result may be directly related to August's low use data, because the high use data for vegetation does not significant differ for any month. No other months were found to have statistically significant differences between the two methods on the low use or high use sites. The difference that was found to be statistically significant in August may have been the result of plant litter on the ground because the area had been recently mowed.

Table 2.5.Georges Island Ground Cover Estimates: Comparison of the Quadrat and Transect Methods (All months combined)

Groundcover Type/ Use Level		**Ground Cover Estimates**		**Difference between Quadrat Vs. Transect Methods** *(T-test significance)*
		Quadrat Method *Mean (S.E.)* (%)	**Line Transect Method** *Mean (S.E.)* (%)	
Vegetative Ground Cover				
	High Use	71.6 (3.4) n = 72	77.0 (4.5) n=36	0.347
	Low Use	81.7 (2.5) n = 72	92.5 (2.5) n=36	**0.003****
Difference between High and Low Use (T-test significance)		0.019*	**0.004****	
	Combined Use	76.7 (2.1) n = 144	84.8 (2.7) n=72	0.021*
Bare Ground (Exposed Soil)				
	High Use	3.8 (1.5) n = 72	6.3 (1.3) n=36	0.212
	Low Use	0.9 (0.3) n = 72	0.3 (0.1) n=36	0.082
Difference between High and Low Use (T-test significance)		0.068	**0.000****	
	Combined Use	2.3 (0.8) n = 144	3.3 (0.7) n=72	0.375

* Significant: $p < 0.05$. ** **Significant**: $p < 0.01$.

Both the quadrat and transect methods can be used to evaluate bare soil ground cover (Table 2.5). No months or use levels that were found to have a statistically significant difference. For all months combined, a range of significant values of 0.08 to 0.37 occurred.

When the quadrat and the transect methods are compared, all but one transect mean were higher than that of the quadrat method. In the case of low use levels on bare ground, the transect estimates were slightly lower than that of the quadrat method.

Table 2.5 included the statistically significant difference values for the comparison between high use and low use sites for each method. The quadrat method has a statistically significant difference for vegetation ground cover between high and low use sites, but not a statistically significant difference for bare soil ground cover. The transect method has a highly statistically significant difference for both vegetation and bare soil ground cover types between high and low use sites.

Figure 2.2 shows the seasonal trend on Georges Island by comparing transect and quadrat methods over the three months with combined use averages. Soil stays relatively low and linear. Soil seems to be independent of vegetation and 'other' estimates. Vegetation appears to have an inverse relationship with the 'other' cover category. As one goes up, the other goes down relatively proportionally. The overall trend though shows that the beginning and end of the season values are relatively similar. This indicates that there is minimal damage caused by increased visitor use and drought conditions during the middle of the summer.

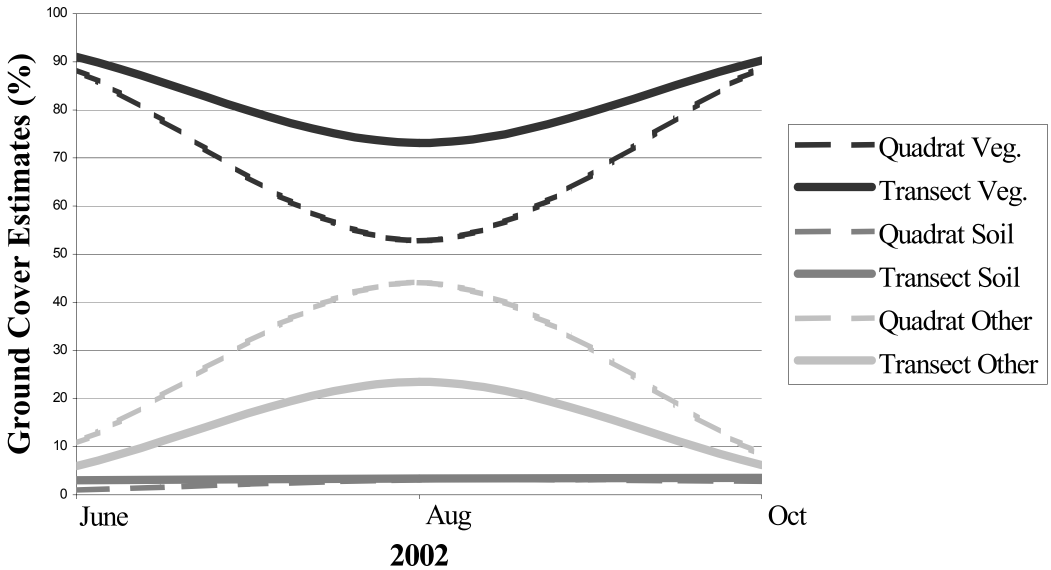

Figure 2.2. Georges Island: Comparison of Two Ground Cover Estimation Methods over Time (high and low use sites combined).

Grape Island

Table 2.6 highlights the means, standard deviations, and the coefficient of variations for the ground cover estimates for the overall method on Grape Island. The low use sites have a higher percentage (99%) than the high use sites (92%). The high use sites have a greater amount of vegetation cover (6.5%) than of bare soil than low use sites (>1%). Measuring vegetative ground cover has a CV range of 0.02 to .83, which is lower than that of bare ground cover, 1.48 to 2.33. The trends on the high use sites over the three months indicate recovery, with vegetation percentage increasing from 93% to 100%. Likewise, soil percentages are decreasing from 5.5% to no visible bare soil (Table B1). For the low use sites vegetation is at 100% with no bare soil for June and October (Table B1). Data were collected on only two of the four sites on Grape Island, one high use site and one low use site.

Table 2.6. Overall Ground Cover Estimation Results: Grape Island (All months combined)

Groundcover Type/ Use Level		Overall Ground Cover Estimates			
		n	Mean (%)	Standard Deviation (%)	Coefficient of Variation (%)
Vegetative Ground Cover					
	High Use	10	91.8	10.3	0.11
	Low Use	10	98.9	1.5	0.02
Difference between High and Low Use (Mann-Whitney U Significance)			0.222		
	Combined Use	20	95.4	7.9	0.83
Bare Ground (Exposed Soil)					
	High Use	10	6.5	9.6	1.48
	Low Use	10	0.6	1.4	2.33
Difference between High and Low Use (Mann-Whitney U Significance)			0.548		
	Combined Use	20	3.55	7.2	2.03

* Significant: $p < 0.05$. ** **Significant**: $p < 0.01$.

Table 2.7 highlights the significance of the quadrat and transect ground cover estimation methods for Grape Island. With all three months combined, the quadrat and transect methods of evaluating vegetation on the low use sites were found to have a statistically significant difference of 12.5% for low use and 12% for high use sites. When evaluated by month, the data collected in August was found to make the high use comparison statistically significant with a difference between methods of 25% (Table B3). The combined use for both the August data and the data for all months combined indicates an importance in which evaluation method is applied. This result may be directly related to the August high use data, because no other vegetation data indicates a statistically significant difference between methods. The statistically significant difference that was found in August may have been the result of the difficulty determining between dry grass and plant litter as the drought had made much of the grass yellow.

Table 2.7.Grape Island Ground Cover Estimates Comparison of the Quadrat and Transect Methods (All months combined)

Groundcover Type/ Use Level		**Ground Cover Estimates**		**Difference between Quadrat Vs. Transect Methods** *(T-test significance)*
		Quadrat Method *Mean (S.E.)* (%)	**Line Transect Method** *Mean (S.E.)* (%)	
Vegetative Ground Cover				
	High Use	76.0 (3.2) n = 60	88.2 (2.3) n=30	**0.003****
	Low Use	93.9 (1.3) n = 60	81.4 (3.9) n=29	**0.005****
Difference between High and Low Use (T-test significance)		**0.000****	0.143	
	Combined Use	84.9 (1.9) n = 120	84.8 (2.3) n=59	0.969
Bare Ground (Exposed Soil)				
	High Use	6.7 (1.9) n = 60	4.9 (1.3) n=30	0.443
	Low Use	0.1 (0.1) n = 60	0.7 (0.4) n=29	0.160
Difference between High and Low Use (T-test significance)		**0.001****	**0.005****	
	Combined Use	3.4 (1.0) n = 120	2.9 (0.7) n=59	0.655

* Significant: $p < 0.05$. ** **Significant**: $p < 0.01$.

Both the quadrat and transect methods can be used to evaluate bare soil ground cover (Table 2.7). No months or use levels were found to have a statistically significant difference. For all months combined, there was a range of significance values of 0.16 to 0.66 occurred.

There was no distinct pattern found when comparing the quadrat method to the transect method. Three is not enough evidence to support the conclusion that either the quadrat or transect has higher average means. There were two transect means that were higher than the quadrat means. There was one comparison that was about the same. There were three transect means lower than the quadrat means.

Table 2.7 included the significance values for the comparison between high use and low use sites for each method. The quadrat method has a very statistically significant difference for both vegetation and bare soil ground cover types between high and low use sites. The transect method has a statistically significant difference for bare soil ground cover between high and low use sites, but not a statistically significant difference for vegetation ground cover.

Figure 2.3 shows the seasonal trend on Grape Island by comparing the transect and quadrat method over the three months. The combined use values are used for this figure. Soil stays relatively low and linear. Soil seems to be independent of vegetation and other estimates. Vegetation and the ‘other’ category exhibited an apparent inverse relationship. As one goes up, the other goes down relatively proportionally. There is an obvious trend difference between the methods, the quadrat method shows an improvement trend after the middle of the season, whereas the transect shows a degradation trend over the season. This does not follow the patterns that overall and quadrat share.

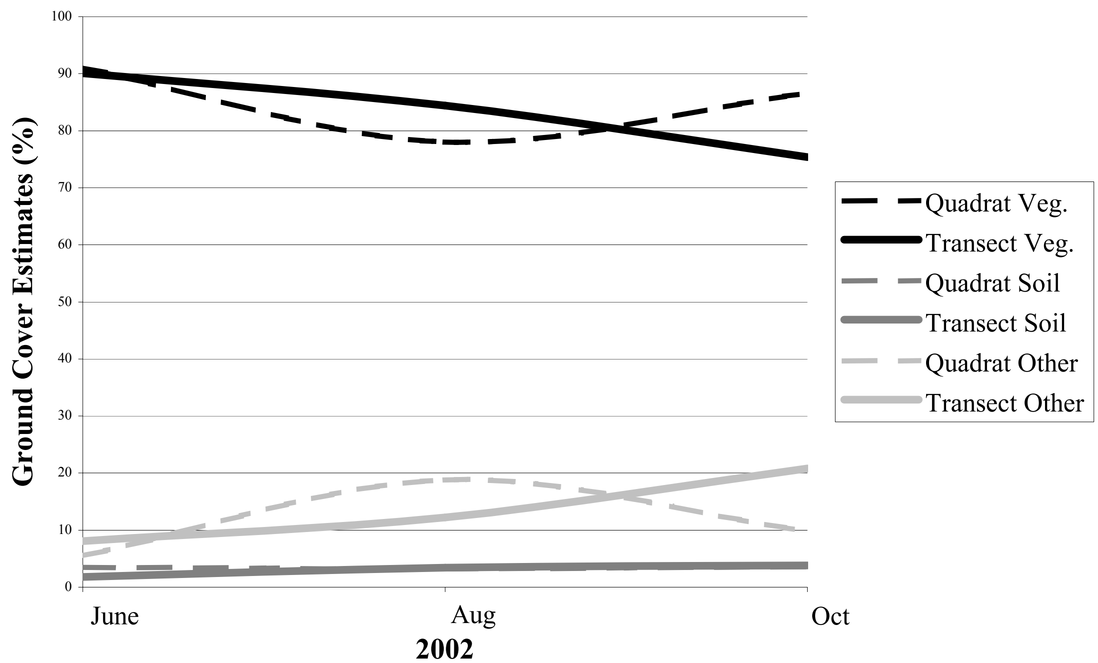

Figure 2.3. Grape Island: Comparison of Three Ground Cover Estimation Methods Over Time (high and low use sites combined).

DISCUSSION AND IMPLICATIONS

The study results suggest that it may be more important to choose an appropriate method for vegetative groundcover estimates than for bare groundcover estimates. In other words, no statistically significant difference arose between transect or quadrat methods in estimating bare ground cover. The significance of the overall method is not known, but the variability of the bare ground estimates is more than that of the vegetation estimates. This was the case only for the middle of the summer data in August when Boston, Massachusetts, was experiencing an above the average dry spell (drought).

These findings may have implications for research and monitoring. For example, the selection of a field monitoring method may be more important for ground vegetation cover than for bare soil cover. A combination of assessment methods, such as quadrats and transects, should be used along with control data in park or recreation areas that have a great emphasis on conservation, restoration, enhancement, or preservation of one or more types of vegetation types. This may be the case for areas that are interested in opening a new area to recreation. Control areas as well as pre-recreation data can be used to get a better idea if the area is being over-used.

For open recreation areas where the vegetation cover is being lost and there is the chance of runoff or erosion, depending on soil type, management action should be taken. If the vegetation is trampled to the point of being non-existent, there will be no protection for the topsoil. This would allow further recreation, as well as natural factors, to erode the topsoil. Before the vegetation is trampled to the point of being eliminated, managers can both close the site temporarily or permanently and promote recreation on another site. If all of the vegetation is to the point of being eliminated, managers should close the site permanently. They may have to aide in the speedy recovery of new vegetation by putting down seeds or planting new grass (Hammitt & Cole, 1998).

There are some advantages and disadvantages to the overall assessment method for estimating ground cover. The advantage to the overall method is that it was quick, one minute or less, and could be done by any person. The disadvantages of this method were that the far side of the site is distorted and could not be incorporated into significance tests with the other methods. Although the overall method was not that strong for statistical purposes, it may be the best method if the management does not need detailed statistics. An overall assessment of a site with a photograph of the area may be all that a manager needs to assess vegetation changes from one year to the next. This may be the case for an area that is well vegetated and shows signs of natural regeneration. Some difference year to year should be accounted, if various volunteers are taking the estimations.

There are some advantages and disadvantages to the quadrat method for estimating ground cover. The advantage of the small and uniform quadrats is that there is no distortion when observing the whole area within the quadrat. It also takes very little time to estimate the ground cover within a quadrat, approximately one minute or less per quadrat. The disadvantage is the possibility that not all cover types are correctly represented. Although it was not tested in this study, using quadrats may not give the most representative data, but using this method an observer can get some satisfaction of obtaining good data. Quadrats seemed to be relatively easy and manageable. Managers could use this method if they need to compare their ground cover estimations to a strict standard. This may be the case if they feel they are getting close to the limits set through the carrying capacity study.

There are a few advantages and disadvantages to the transect method for estimating ground cover. The advantage to the transect method was in the scale used. Measuring the changes in ground cover, based on a standard length scale, made both the data analysis and comparisons easier to understand and visualize. The disadvantage in this method was in determining exactly where one cover type begins and the next starts. The total amount of time, 15 to 45 minutes, to complete a sampling plot depends on the amount of ground cover changes. The exact types of ground cover prior to starting data collections were not predetermined. The observation sheet was left open to make the most representative data of the ground cover types that actually existed. With this much subjectivity, it was difficult to be confident in the data. With all types of covers recorded, a total of 21 different groundcover categories emerged. This method is recommended to managers who need to do a detailed and professional ground cover inventory. Either ground cover types need to be predetermined, or trained scientists or permanent staff should use the transect method to evaluate ground cover. This may be the case for well-used sites with a mixture of cover types.

LIMITATIONS AND CONCLUSIONS

There were many limitations to this study that should be known. First, it was decided at the beginning to minimally disturb the site. This meant that we did not rake or move any plant litter, trash, or type of cover not connected to the ground. Second, it was not always clear how to record some ground covers, especially if they occurred after the pretest sample sites were evaluated. In August, for example, it was hard to determine the difference between the dry grass and the plant litter. Third, we did not always have the same people estimating the ground covers. Fourth, there were times that the quadrats were not put on the correct side of the transect. Fifth, no control data were taken, so there is no basis to say which estimation method is right. Sixth, the sample size and data were limited due to logistical constraints. The sample size would have been larger with more sampling plots or if more islands were studied. Seventh, some ground cover types were unexpected and thus were not taken into account from the beginning of the study. For example in August there was dry grass due to the drought that was hard to place into a category. It was easily confused with plant litter. For analysis, dry grass was incorporated into the vegetation ground cover category. Finally, we were only interested in sites that were mowed and had the classification of a picnic area, trail, or both. In a few cases, though, our sampling plots extended outside the mowed area into shrubs and bushes. From the very first incident we classified these areas as ‘unmowed’. With the linear transect method of recording the distances where the changes in ground cover occur, the extent of the unmowed area is known.

Although there are many limitations, this study is very important for the Boston Harbor Islands National Park Area. This study will inform managers on existing conditions on the given islands. This may give them ideas about how to manage for future impacts on the two islands that were analyzed and may prompt interest in doing ground cover evaluations on other islands, especially the one that will be opening to the public this year.

Based on the evidence in this study, there are a few ways of managing the recreation areas of the islands. Most areas that are accessible to the public for recreation activities are covered in grass, but there are a few patches of bare soil. It would be good strategic planning for the future to start building some record of the extent of vegetation ground cover. This could be as simple as taking a picture of a big picnic or recreation area. This picture can be recorded with some observational data, such as, an overall ranking assessment and the amount and approximate size of bare soil patches. This picture can be taken from the same spot every year by recording the direction and distance to a reference point. This can be done once every year in September, right after the amount of visitor use peaks. Along with the overall area photos, the patches of bare soil can be recorded and evaluated using the quadrat method as described in this paper. All bare patches should be taken seriously. Soil erosion and soil loss are two conditions that should be watched for and prevented.

For the National Park Service this is one more park that has been through a carrying capacity study. The NPS officials can refer park managers who will be starting future carrying capacity studies to this study to compare the methods used. There are National Parks in all parts of the country, even in deserts, for which we have found data. Most of our data would be relevant for islands and parks with low herbaceous vegetation, though. Scientific research will benefit because of the ability to compare the results to other related studies. Eventually there could be a new relationship found between groundcover types as well as new standards by which these methods are used or compared.

There are many opportunities and needs for further research. First, standards and comparisons are only as helpful as there are studies. The more studies or reviews conducted on these methods, the better future studies will be. Second, these methods can be compared again with a more complete evaluation of the actual sites' cover percentages, so that the method closest to the actual conditions can be determined. Third, more islands can be evaluated. Fourth, there were only two high use and two low use sampling plots used in this study, other studies can incorporate more use sites. Fifth, the type of plants and grass on and near the sites, native and invasive, were not part of this study. It may be wise to get an idea of the plants around the recreation sites, especially poison ivy. There is poison ivy on the islands and there may be the need to warn parents and children, so that their experiences on the island do not end up unsatisfied due to itchy rashes. Sixth, the size of the recreation areas may need to be measured to see if there are any trends in the movement of the mowed recreational areas. If areas get worn from use, visitors may use different areas of the site or create new areas. Finally, the actual visitor use level on each site can be linked to the ground cover estimates to give a better idea of how much use causes certain amounts of vegetation loss.

CHAPTER III: SOIL COMPACTION

Estimating Soil Compaction as A Visitor Impact Indicator: An Evaluation of Two Methods

ABSTRACT

As visitations to the Boston Harbor Islands National Park Area (BOHA) continue to increase, there is also a growing concern about soil compaction due to visitor use. This issue is being addressed by the implementation of the Visitor Experience and Resource Protection (VERP) planning framework. In this paper we report the results of an empirical study to compare two methods for estimating soil compaction through penetration resistance measurements. Also reported is a comparison of soil compaction measurement approaches. The evaluation results indicate that a soil compaction tester is less variable than a pocket penetrometer and that a pocket penetrometer is easier to use by one person. The best penetrometer for a study depends on the site's characteristics (e.g. soil type and use), the number and type of people involved, and the study's budget.

INTRODUCTION

One of the most common ecological changes induced by recreational use is soil compaction, a process in which individual soil particles within the soil matrix are forced to rearrange themselves into closer proximity (Liddle, 1997). Some common forces of soil compaction in recreation settings include trampling by foot and vehicular traffic on recreation sites and trails, though soil compaction can also occur from natural causes such as drying and wetting. Soil compaction typically results in reduced amount and size of pore space and total soil volume, which in turn lead to decreased infiltration capacity and increased surface runoff, standing water and erosion (Brady & Weil, 2002). These changes represent site degradation and may have a detrimental effect on vegetation and soil resources.

The purpose of this paper is to evaluate soil compaction through two types of penetration resistance methods in the Boston Harbor Islands National Park Area (BOHA). Each method will be evaluated for its functionality and data variability as potential impact indicators for this park's carrying capacity study. This paper reports results from two penetration resistance instruments, namely the pocket penetrometer and the cone penetrometer.

MEASURING SOIL COMPACTION

Four approaches have been developed in agriculture and related natural resource disciplines to measure soil compaction, including penetrometry, bulk density, conductivity/permeability and radiation (Freitag, 1971). Table 3.1 provides a concise description about these four approaches.

Table 3.1. A Comparison of the Four Different Approaches to Measuring Soil Compaction.

Comparison	**Approach**			
	Penetrometry	*Bulk Density*	*Conductivity/ Permeability*	*Radiation*
*Definition**	Records the force necessary to drive a rod of known length into the ground	A direct measure of soil density (weight to volume ratio)	A measure of how rapidly water permeates the soil	A measure of soil density based on penetration of gamma rays or neutrons
Types of Instruments	Pocket or cone penetrometer	Soil sampler, oven, balance	Metal ring, cylinder	Surface nuclear gauges (SNG)
Depth of Measure	0-6.4 mm (pocket) or 0-27 inches (cone)	3-10 cm (typical)	Near surface	Measures moisture 15 cm (2-6 inches) from the instrument
Work Setting	Field oriented	Field and lab oriented	Field oriented	Field oriented
Advantages	Easy to operate; gives immediate readings; relatively economical	Standardized method; consistent results	Easy to operate	Can use in stony soils; gives immediate readings
Disadvantages	Does not work in stony soils; varies with moisture content	Does not work in stony soils; disturbance to the soil by digging; soil samples needs to be evaluated in a laboratory	Field time and distilled water needed in the field; disturbs vegetation	Expensive; nuclear radiation; need a license to operate; influence of organic material

* Based on Hammitt and Cole (1998) and Randrup and Lichter (2001).

Penetrometry or soil strength measures the resistance of soil surface to vertical force by poking a rod or penetrometer into the soil. There are many types of penetrometers ranging in sizes and technology. Both pocket penetrometers and cone penetrometers are common instruments used in this approach. A pocket penetrometer is a small handheld instrument that just takes surface data. The U.S. Forest Service has determined that the pocket penetrometer should be included in their phase three inventory procedures because it quantifies the soil quality indicator (Amacher & O'Neill, 2004). A basic cone penetrometer is operated manually by pushing long rod into the ground while observing a gauge at predetermined increments. Some cone penetrometers have the technology to automatically record data at the predetermined depth increments. The greatest advantage in using a penetrometer is that it is easy to use and does not disturb the soil like bulk density does (Chacalo, 2000). The greatest disadvantage is that soil moisture is needed to get very accurate results. In a recent study by Hurst, Pywell, Marrs, and Putwain (2003) the penetration resistance of grasslands to military vehicles was measured by a manual penetrometer. Both a 4-ton truck and a 1-ton land rovers caused statistically significant soil compaction, even after only one pass.

Like penetrometry, bulk density is also a very common approach in recreation ecology studies (Liddle, 1997). Bulk density is determined by the weight of oven-dried solid per unit volume. This approach requires collection of soil samples and oven-drying in a laboratory (Lowery & Morrison, 2002). The greatest advantage with bulk density is the ability to attain consistent and repeatable data. The greatest disadvantage is that soil is disturbed through both digging and the need to take soil samples to a laboratory.

Some previous studies incorporated both penetration resistance and bulk density. In a campsite impact study, Marion and Cole (1996) documented a 460% relative change in penetration resistance between 29 campsites and undisturbed control areas and a relative change of only 18.9% in bulk density. In an earlier campsite study, Cole and Marion (1988) compared both penetration resistance and bulk density between high and low use campsites. Based on the absolute differences, the penetration resistance had a relative change of 52.6% and bulk density had a relative change of 3.8%. In a Hawaiian trail study by Sutherland, Bussen, Plondke, Evans, and Ziegler (2000) the relative change for penetration resistance was 118.2% and only 29.3 for bulk density between on trail and off trail sites. Finally, Smith and Newsome (2002) also recently conducted a campsite study in Australia that found that the relative change between the designated area and control area means for penetration resistance and bulk density were 550% and 80.5%, respectively.

Conductivity/permeability evaluates the rate at which water or air permeates through soil. A common technique in this category is infiltration capacity, which requires the availability of field time and distilled water. This process is performed by carrying out five steps: firm the soil, line the ring with plastic wrap, add water, remove wrap and record the time, then finally repeating these steps a second time for dry soil. Cole and Fischtler (1983) did a study in three different locations and using both penetration resistance and infiltration found similar results. Thy both concluded that the less use a site gets the more significant the penetration resistance and infiltration rates will be.

Radiation methods, such as surface nuclear gauges (SNG), measure soil density instantly based on penetration of gamma rays or neutrons. This approach requires expensive equipment and licensed users. Radiation methods are used more in construction areas than recreation areas. Randrup and Lichter (2001) compared a surface nuclear gauge with bulk density and found that the SNG was on average higher than bulk density. The differences between bulk density and the SNG ranged from –2.4% to 18.66%. There were no visitor impact studies that used the radiation method approach.

METHODOLOGY

Study Area

BOHA consists of 34 islands and peninsulas in Boston Harbor with 650 hectares in total size. Due to proximity to population centers this new park receives ever-increasing visitation, with 262,000 recreational visits recorded in 2002 (BOHA, 2003a). BOHA is managed by a 13-member partnership that includes the National Park Service, federal, state and municipal agencies, and island owners.

Three islands were initially selected for this study based on their environmental characteristics and accessibility. Of the 34 islands only five were open and accessible by public ferries (Georges, Peddocks, Grape, Bumpkin, and Lovells Islands). Georges Island was chosen because it has the highest volume of visitors with the greatest amount of visitor impact. Two of the islands had very similar soil type and visitor use levels (Bumpkin and Grape). We chose to collect data on Grape Island for efficiency reasons. Peddocks Island was also selected but field data collection was incomplete due to weather and logistical constraints. We did not have time to collect data on Lovells Island. Georges Island is a heavily used island with Fort Warren taking up a majority of the island. There are many grassy trails and recreation areas. There are a few unmowed bushy areas with some scattering of trees. Grape Island possesses a more vegetative setting with lots of trees and bushes. All the trails, campsites, and picnic areas are grassy.

Georges Island is a heavily-used island with Udorthents (Ud) loamy soil as the dominant soil type. The Ud soil is predominately fine sandy loam good for recreation fields and parks. A slow runoff rate is the main concern for managers, because puddles will form after intense rains. There is a moderate to slow permeability rate to a depth of 3.05 meters for this soil type. Also, there is a low or moderate water capacity available (USDA, 1989).

Grape Island possesses a more natural setting with less visitor use. Newport silt loam (NpC) and Pittstown silt loam (PtB) soils dominate Grape Island. They are reported herein as a combined soil type (NpC/PtB). These soil types have the same soil properties; the only difference is in slope. Between the two soil types a slope of 2 to 15 percent is covered. The NpC/PtB soil is predominately silt loam good for parks and playgrounds. Erosion is the main concern for managers, so vegetation cover is very important. There is moderate soil permeability in the surface and subsoil layers. The available water capacity is moderate. Finally, the distance to the seasonal high water table is only 0.45 to .76 meter (USDA, 1989).

Field Procedures

In June 2002, a total of 12 circular plots (6-m radius) were established on Georges and Grape Islands. On each island 2 plots were randomly located within high-use zones (close to pier) while another 2 were randomly located in low-use zones. Within each plot 12 quadrats (25cm x 25cm) were randomly located along 6 radial transects that are 60^{o} apart. In each quadrat 4 penetration resistance (PR) readings were taken randomly using pocket penetrometer (PP), and 4 pairs of PR measurements were taken using the Soil Compaction Tester (SCT) at the depth of 7.6 cm and 15.2 cm. Hence, the maximum numbers of PP and SCT readings for each plot were 48 and 96, respectively. Only the SCT readings at the 7.6-

cm level are compared with PP readings. Due to rocks, roots, and compaction not all SCT measurements could be taken at their intended depths, resulting in reduced number of SCT readings in some cases. Eight background PR measurements were taken with two penetrometers, respectively, at adjacent environmentally similar control areas outside each plot. All measurements of a single plot were completed on the same day.

The same plots and quadrats were relocated and remeasured in August and October 2002 to evaluate temporal changes. The August data were collected during a severe drought, resulting in extremely high PR readings under unusual soil moisture regimes. For comparability purposes only data in June and October 2002 representing the beginning and end of a visitor use season are presented.

It could take approximately 30 minutes for three people to complete one sampling plot when collecting only soil compaction data. This could be less if the same three people always did the data collection. Two people could take 10 to 15 minutes to set up the plot, while during this time the third person is collecting the control data. It would then take between 10 and 20 minutes for two people to collect the SCT data, while the third person is collecting the PP data. Between the working hours of 10AM to 5PM, there was a total of approximately 5 hours a day to perform data collections on Georges Island and 4 hours on Grape Island. These limited hours were due to corresponding ferry schedules.

Sampling Plot Design

At each study site a circular sampling plot was assembled. (Figure 2.1) We decided on a circular plot because some of the recreation sites being studied are oddly shaped or small in size. From the center our transects went out as far as six meters or until the mowed recreation area ended. In our opinion, this method was less time consuming than square plots. With square plots we would have had to trudge through brush to find beginning and ending points for the transects. Another advantage of the circular plot is all of the transects start at one point and the end points are all the same distance. It is easy to randomly chose the direction of the transect. This center of the circular plot is found randomly by throwing an object into the pre-determined study area. A nut was buried into the ground at that point so that we could be certain that we relocated the exact site location for the mid and end of season data collection.

Once the center was determined, the transects were then measured out six meters. A stake at the center point stabilized the tape measure. After the first transect is randomly determined, five more transects are radially placed 60º apart, clockwise around the plot. Two 25cm by 25cm square quadrats were then placed randomly along each of the transects. On the data collection forms, to be consistent, the quadrat closer to the center point is listed before the quadrat farther away.

Penetrometers Selected

This study adopted penetrometry as the soil compaction measure due to its minimal ground disturbance as required by park regulations and its efficiency in island settings. Two different types of portable penetrometers were chosen to measure penetration resistance as an indicator of soil compaction. The pocket penetrometer (SOILTEST, Inc.) is a spring-loaded instrument with 15.2 cm in length and 1.9 cm in diameter. The instrument measures penetration resistance by pressing the 6.4 mm-diameter round tip 6.4 mm into the soil. When pushed into the ground a metal ring is pushed up the scale, marking the penetration resistance value in kg/cm^2. The Soil Compaction Tester (DICKEY-john Co.) is a portable cone penetrometer of 93 cm in total length with a dial on top to immediately read the soil compaction value (pounds per in^2). An angled cone attachment of 12.7 mm (½ in) or 19.1 mm (¾ in) is screwed onto the other end of the 70-cm rod that is pushed into the ground. The rod is marked every 7.6 cm (3 in) to enable measurement of soil compaction at 7.6 cm increments (up to 45.7 cm or18 in).

Analysis

The data were entered into and analyzed in SPSS for Windows. Data in its original form were split, sorted, or aggregated to get into the formats needed for doing the descriptive statistics and the relative change. For each island the soil compaction data was analyzed for June, October, and for each penetrometer. The tables in this study were created in Excel 2000.

PR readings from two plots representing the same use level were combined. Relative PR change of each plot was calculated by the difference between mean plot and control PR values divided by the control mean PR value. Relative changes are valid for comparison among sites with varied background PR levels. Data variability was evaluated by the coefficient of variation (CV) (standard deviation as the percentage of the mean). The percentage of successful SCT penetration to each depth level in each plot was reported as penetration depth. All SCT-PR readings were converted to kg/cm^2 for analysis and reporting.

RESULTS

Each island was evaluated separately due to the differences in the use and soil type. There were two patterns, though, that seemed consistent for both island and both months. First, there was a pattern in the Ud soil type where high use sites exhibited less variability in the pattern than in the low use sites. This was the opposite for the NpC/PtB soil type where it was found that the low use sites are less variable. Secondly, PP measurement showed a higher degree of measurement variability than the SCT measurements.

Georges Island

On Georges Island (Ud soil), high use plots started with higher PR values in June. The mean PP-PR was 3.0 kg/cm^2 for high use plots and 2.1 kg/cm^2 for low use plots (Table 3.2). The relative PR change based on PP was 54.3% for high use plots and 53.0% for low use plots (Table 3.3). On the other hand, the mean SCT-PR was 31.6 kg/cm^2 for high use plots and 18.8 kg/cm^2 for low use plots. The relative PR change based on SCT readings was 66.4% for the high use area and –0.05% for low use area, indicating essentially the same PR level between use and control sites in the latter case (Table 3.3).

All Georges Island plots were reassessed in October 2002. Consistent with June data, high PR values were recorded on high use sites based on both penetrometers. The PP mean was 2.3 kg/cm^2 for high use plots and 1.6 kg/cm^2 for low use plots, both of which were lower than the beginning of season (Table 3.2). The relative PR changes based on PP were 35.4% and 60.9% for high and low use plots (Table 3.3). The SCT-PR mean for the high use plot was 23.7 kg/cm^2 and 24.5 kg/cm^2 for the low use plot. The relative PR changes were 21.3% and 25.9% for high and low use plots (Table 3.3).

Table 3.2. Penetration Resistance Measurements on Georges Island (Ud Soil) Using Two Types of Penetrometers.

Penetrometer / Use Level		June 2002				October 2002			
		Mean (kg/cm^2)	Std. Dev. (kg/cm^2)	Coeff. of Var. (%)	N	Mean (kg/cm^2)	Std. Dev. (kg/cm^2)	Coeff. of Var. (%)	N
Pocket Penetrometer (PP)									
	High Use	3.0	0.8	25.8	96	2.3	0.9	37.9	96
	Low Use	2.1	0.8	37.1	96	1.5	0.8	51.7	96
Difference between High and Low Use (T-test significance)		0.00***				**0.00*** **			
Soil Compaction Tester (SCT) @ 7.6 cm									
	High Use	31.6	7.3	23.1	80*	23.7	6.2	26.0	47*
	Low Use	18.8	5.2	27.8	92*	24.5	7.2	29.5	60*
Difference between High and Low Use (T-test significance)		**0.00*** **				0.53			

* Some readings were unable to be obtained due to failure of the equipment to penetrate to the required depth. *** **Significant**: $p < 0.01$.

Table 3.2 shows the statistical significance of the penetration resistance value differences between the high and low uses. In both June and October for the PP, high use sites indicate more soil compaction than the low use sites. These values are statistically significant. The soil compaction tester indicated higher amounts of soil compaction on high use sites in June, only. This value is statistically significant. In October, the values were not statistically significant, indicating that they were relatively the same. This means that the there was not more soil compaction on high use than low use sites. In October, the penetration depth of 7.6 cm was reached more on the low use sites than the high use sites, but in both cases many values are missing.

Table 3.3. Relative Changes in Penetration Resistance on George Island (Ud Soil).

Penetrometer/ Use Level		**June 2002**	**October 2002**
Pocket Penetrometer (PP)			
	High Use	54.3*	35.4
	Low Use	53.0	60.9
Soil Compaction Tester (SCT) @ 7.6 cm			
	High Use	66.4	21.3
	Low Use	-0.1	25.9

* All values in percent.

Grape Island

PR values as measured by both penetrometers were lower on Grape Island (NpC/PtB soil). For example, the mean PP-PR was 2.0 kg/cm^2 for high use plots and 1.5 kg/cm^2 for low use plots. According to the relative PR difference, use sites actually had more substantial compaction change as compared to their off-site controls. For example, relative PR changes for PP were 85.9% and 143.5% for high and low use plots respectively, while those for SCT were 111.7% and 53.5% (Table 3.5).

Table 3.4 shows the statistical significance of the penetration resistance value differences between the high and low uses. All high use sites indicate more soil compaction than the low use sites. These values are all statistically significant.

Table 3.4. Penetration Resistance Measures on Grape Island (NpC/PtB Soil) Using Two Types of Penetrometers.

Penetrometer / Use Level		**June 2002**				**October 2002***			
		Mean (kg/cm^2)	Std. Dev. (kg/cm^2)	Coeff. of Var. (%)	n	Mean (kg/cm^2)	Std. Dev. (kg/cm^2)	Coeff. of Var. (%)	n
Pocket Penetrometer (PP)									
	High Use	2.0	0.9	42.1	96	2.4	0.8	35.9	46**
	Low Use	1.5	0.6	37.2	96	1.8	0.4	22.2	48
Difference between High and Low Use (T-test significance)		**0.00***				**0.00***			
Soil Compaction Tester (SCT) @ 7.6 cm									
	High Use	16.6	5.9	35.2	96	22.5	4.6	20.6	38**
	Low Use	10.4	3.2	31.2	96	12.9	2.3	17.5	47**
Difference between High and Low Use (T-test significance)		**0.00***				**0.00***			

* Only one plot was measured for each use level in October due to logistical constraints. **Some readings were unable to obtain due to failure of the equipment to penetrate to the required depth. *** **Statistical significance**: $P < 0.01$

Due to inclement weather conditions, only one high use plot and one low use plot were remeasured on Grape Island, resulting in less number of readings. The PP-PR mean was 2.4 kg/cm^2 for the high use plot and 1.8 kg/cm^2 for the low use plot. These values were higher than the June values (Table 3.4). The relative PR changes based on PP were 34.8% and 42.7% for the high and low use plots, which were much lower than the June values (Table 3.5). The SCT results showed similar patterns on this island.

Table 3.5. Relative Changes in Penetration Resistance on Grape Island (NpC/PtB Soil).

Penetrometer/ Use Level		**June 2002**	**October 2002**
Pocket Penetrometer (PP)			
	High Use	85.9*	34.8
	Low Use	143.5	42.7
Soil Compaction Tester (SCT) @ 7.6 cm			
	High Use	111.7	37.8
	Low Use	53.5	25.7

* All values in percent.

Penetration Depths

These measurements were applicable to only SCT. The results suggest that soil was generally less penetrable on high use sites and on Georges Island (Ud), on which most of the SCT measurements were not able to reach the depth of 15.6 cm. At the 7.6 cm level there was a decreasing trend in penetration depth from the beginning of use season (83.3-95.8%) to the end of season (68.8-79.2%). Soil was more penetrable on Grape Island (NpC/PtB soil). Twenty-four percent to 46% of SCT measurements reached the penetration depth of 15.6 cm. The soil was less penetrable at the 7.6cm level in October, with the percent penetrated decreased from 100% to 85% on the high use site.

DISCUSSION AND IMPLICATIONS

It should be noted that the PR values of two penetrometers cannot be directly compared due to differences in their measurement depth and mechanism. However, they may be comparatively evaluated based on their utility and data variability. The PP is less expensive (≈$60) and is very efficient to operate with one person. The ring attached to the penetrometer holds the PR reading until it is reset. PP measurements also create less ground disturbance. The PP is more efficient than the SCT in three ways: time, people needed, and size (portability). The SCT is more expensive (≈$250), is harder to carry, and requires 2 people to operate it effectively. One person must be dedicated to taking the dial reading as it changes constantly. Another person must keep track of rod markings to ensure that reading is taken at each desirable penetration depth. As a result, the inter-rater variability could be higher. This aspect of measurement error, however, was not assessed in this study. Furthermore, the two sizes of cone tip and corresponding scales on the dial gauge could create confusion.

On the other hand, the PP readings contain a higher degree of variability in its measurements based on coefficient of variation as shown in the results. This may be due to the short penetration depth of this equipment. Irregularities of soil surface, such as rocks, stones, plant litter, and tree or grass roots, are more likely to interfere with the PP readings. Since SCT measures compaction at a deeper level, it is less influenced by surface conditions. The SCT is also capable of measuring compaction at various depths.

Choosing the right penetrometer, cone or pocket, depends on the factors of each individual study and criteria. There are pros and cons to each penetrometer, as there are with all instruments and methods. In a study being done by just one person on a limited budget and in a remote area with stable soils, a PP would be recommended. A SCT would be recommended for a detailed study with more than one person, a decent budget, and where the topsoil was unstable. The important part with either of these methods is to be consistent.

Park managers and scientists have three considerations in choosing an instrument to be used their studies. First, they have to decide if this is just a one time study or a long-term study involving monitoring. In a one time study, it is easier to have consistency in the way the data are collected. Planning for inter-user validity is needed if different people, especially volunteers, will be collecting data over time, in the case of a long-term study or monitoring program. Secondly, the use of volunteers, staff, or scientists to do the data collection needs to be determined. Volunteers of varied backgrounds may introduce inconsistency in measurements. Therefore adequate training is often needed. Paid scientists will probably be more consistent in applying the procedures but they are more costly. Thirdly, current site conditions and characteristics are very important. Soil types and characteristics do play a part in choosing instrumentation. Once these three issues are contemplated, only then can the pros and cons of each penetrometer used in this study can be examined. Through this study, it should be realistic to assume that a park manager can choose a soil compaction instrument that would suit the needs of their park or recreation area

There are several observations from this study. First, the relative PR changes in this study were much lower than those reported in Marion and Cole (1996). This may be related to generally higher PR levels on both use and control areas in BOHA as compared to campsites in Delaware Water Gap (Marion & Cole, 1996). Sutherland et al's (2001) study of on trail and off trail PR showed a relative difference of 118.2%. This difference between on trail and off trail values is greater than the values found in this study, except for one value. Secondly, the PR level of Georges Island was generally higher than that of Grape Island. A number of factors, such as soil type, amount of use (higher visitation on Georges Island), may have contributed to this variation. Thirdly, the high use plots on Georges Island (Ud soil) showed less data variability for both penetrometers, whereas less data variability were found on the low use areas on Grape Island (NpC/PtB soil). In other words, data variability of PR readings appeared to increase with amount of use at low use areas, while such data variability decreases with the amount of use at high-use areas. A possible explanation is that soil strength could become more uniform in already compacted soil. Finally, the relative PR changes were found to decrease in most cases from June to October, indicating the closing gap of PR between use and control areas. Both decreasing on-site PR values and/or increasing control PR values may have caused this effect.

For the BOHA managers, soil compaction may not be a visible condition directly, but should be very important to include in their monitoring plan. Soil compaction is a result of too much use and will prevent grasses from growing. Although it is not proven that visitors prefer grassy areas to bare soil recreation areas, grassy areas improve the aesthetics of the islands and prevent both soil erosion and soil loss. The pocket penetrometer can be used if only one person is monitoring the soil compaction conditions. The cone penetrometer can be used if more than one person is monitoring the soil compaction conditions. One advantage of the cone penetrometer is that the depth of the soil can be estimated. To establish and maintain a general record, measurements by either instrument can be used as long as they are taken consistently. Various locations around the islands should be measured and recorded with reference points so that they can be re-evaluated every year. This is so that trends can be identified. In recreation areas that already have bare soil patches, a pocket penetrometer used with the quadrat setup as explained in this paper would be sufficient to record and evaluate soil compaction.

There are some options for managers if they have a site with a soil compaction problem. Some of these options have to do with implementing changes to the resources and some to the visitors. First, the site can be restricted to more resistant areas by zoning (Hammitt & Cole, 1998; VERP, 1997). This would mean that the current area would be zoned for limited or no use and other areas that can better withstand visitor use will be promotes. Second, areas may have to be created so that when one area is limited there are others to meet visitor demand (VERP, 1997). Third, the durability of the site can be increased by maintaining or rehabilitating the resource (Hammitt & Cole, 1998; VERP, 1997). Trails and campsites can be maintained or rehabilitated through surfacing, water bars, steps, bridges, outsloping, and drainage dips. Outsloping and drainage dips are the least costly and very helpful to reduce erosion. They can also be artificially restored through means such as aeration. Aeration is the breaking up of the compacted soil to help to increase seed germination and root growth (Hammitt & Cole, 1998). Finally, elements of the visitor experience can be altered. These elements include attitudes, expectations, and behavior (VERP, 1997).

For the BOHA managers, soil compaction may not be a visible condition directly, but should be very important to include in their monitoring plan. Soil compaction is a result of too much use and will prevent grasses from growing. Although it is not proven that visitors prefer grassy areas to bare soil recreation areas, grassy areas improve the aesthetics of the islands and prevent both soil erosion and soil loss. The pocket penetrometer can be used if only one person is monitoring the soil compaction conditions. The cone penetrometer can be used if more than one person is monitoring the soil compaction conditions. One advantage of the cone penetrometer is that the depth of the soil can be estimated. To establish and maintain a general record, measurements by either instrument can be used as long as they are taken consistently. Various locations around the islands should be measured and recorded with reference points so that they can be re-evaluated every year. This is so that trends can be identified. In recreation areas that already have bare soil patches, a pocket penetrometer used with the quadrat setup as explained in this paper would be sufficient to record and evaluate soil compaction.

LIMITATIONS AND CONCLUSIONS

There are a number of limitations in this study. Only two islands and two penetrometer types were involved. Bulk density and soil moisture were unavailable to provide more comprehensive comparison. The control areas are not entirely free of human influence and may be subject to limited foot traffic. The full limitations of each instrument are important in comparing data from one study to another (Chacalo, 2000).

While soil compaction has been excluded from the final list of resource indicators for BOHA VERP implementation, this study has provided the park with baseline PR data on three different islands (data on Peddocks Island were not presented here). It seems useful to conduct similar measurements on selected sites that show signs of growing degradation. The PR data can inform management of the need for visitor and/or site management actions to reduce soil compaction and increase soil quality of recreation sites.

There are only a few studies that compare soil compaction methods, especially for penetration resistance, and there is none that compared penetrometers in parks and recreation areas. As indicated there are studies that may use two different types of approaches, such as penetration resistance and bulk density. This study compared two measures of the same approach, penetration resistance, for consideration in a monitoring program. As there is an increase in the desire and need to conduct carrying capacity studies in the United States and other countries, studies such as this one will inform other researchers of the utility and variety of different measurement tools so that they can make an informed choice of equipment in future studies.

There are a few recommendations for further research. Future studies may include bulk density, a larger sample size, or more years to detect temporal trends. Unfortunately, due to strict NPS requirements on soil sampling, bulk density may not be possible. Secondly, it would be advantageous to have more sampling plots to get a better representation of soil compaction. Thirdly, a study that includes two or more years will allow a better conclusion about how soil compaction recuperates during the winter. With the inclusion of data collection over a few summers, a seasonal trend as well as a long-term yearly trend could be better determined. Fourth, there needs to be more actual visitor use data taken within the plots so that the penetration resistance values can be linked to use. Finally, more research is also needed to evaluate the efficiency of using each instrument, especially taking into account the amount of people and time needed.

CHAPTER IV: GENERAL CONCLUSIONS

The purpose of this thesis was to contribute to the process of VERP implementation at the Boston Harbor Islands National Park Area (BOHA) by examining two potential resource indicators, ground cover and soil compaction, through alternative measurement techniques. Soil degradation, or the loss of utility of soil to serve its functions, is one of the main management concerns about BOHA as the soil layer is very thin. Both ground cover and soil compaction are measures indicative of potential soil degradation. Vegetative and bare ground cover was evaluated by three alternative techniques: overall observation, quadrats and line transects. On the other hand, soil compaction was assessed using two portable penetration resistance instruments: a pocket penetrometer and a cone penetrometer.

Both ground cover and soil compaction are measures that can indicate potential soil loss. Soil loss is one of the main problems at BOHA. Soil is like a natural filter because the nutrients in the soil can cleanse the water to increase water quality. Without soil there will be rocky or sandy areas where no plants will grow, except for maybe only limited types of plants, such as lichens, mosses, and algae. Soil loss occurs naturally and by recreational activities on the BOHA islands. Big storms and hurricanes wash away coastlines. Nix Mate Island, a 4.8 hectare (12 acre) island in the 1630s, is now only a buoy at high tide (Snow, 2002). The soils that were sampled for this study are good for recreation areas, but still have to be managed accordingly for visitor use and natural causes. On Georges Island there is the good chance for the formation of puddles after intense rains. The need for non-compacted soil is very important on Georges Island. If the soil is compact the water will not be able to soak into the ground and will flow to other soils or locations that will soak up the water. This will prevent the growth of vegetation. On Grape Island there is a high chance of soil erosion if there is a great amount of vegetation loss. An important finding from the penetration resistance study was that there were many cases on both islands that the cone penetrometer could not be pushed to a depth of 7.6cm. This means that the soil is very compacted or that there are rocks or roots very near the surface. No soil loss can be afforded on either island, since there may not a limited supply.

Just like there are natural erosion processes, there are natural aerating processes. Frost heaves, a natural abiotic process during the winter, can potentially help lessen the soil compaction and allow for more plant growth the next spring (Hirst, Pywell, Marrs, & Putwain, 2003). BOHA, like most of the parks in the northeast of the United States, is closed for the winter. The combination of minimal visitor use and the natural aeration of the soil through frost heaves during winter months many have contributed to well vegetated areas at the beginning of the season.

The ground cover assessment techniques were found to be mostly comparable for use in the BOHA. For June and October, the use of transects or quadrats were not found to have a statistically significant difference in estimating vegetative ground cover. A combination of elevated visitor use and a dry spell can be possible causes for the month of August to produce these statistically significant differences. Either technique can be used to evaluate bare ground cover. The comparisons between quadrat and transect techniques for estimating bare ground cover were not found to have a difference that was statistically significant for either island nor during any months. There was a similar seasonal trend between the overall and quadrat techniques. Both techniques showed a loss of vegetation for the month of August and improvement by October. For Georges Island, the transect method showed the same trend. On Grape Island, though, the transect method showed a vegetation loss in August with October conditions worsening. Bare ground cover was relatively similar for all three months on both islands.

The soil compaction and ground cover assessment methods indicate that each island had a different seasonal trend. The penetration resistance values on Georges Island indicate that from June to October the soil compaction values were decreasing, except on the low use sites using the soil compaction tester. At the same time the ground cover estimates in October were shown to be similar to those in June. This decrease in soil compaction and resilience of the vegetation cover could indicate that the area is being managed well and that there is potential to increase the visitor numbers. The opposite trend was found on Grape Island. The penetration resistance values for both instruments showed an increase in soil compaction and decrease in vegetation ground cover from June to October. This may indicate that the island needs to improve managed for the current amount of visitors before allowing an increase in visitation numbers. The creation and proper signage to a new picnic area with a view of the harbor may relieve some of the use from the two picnic areas that currently exist.

A total of nine people collected data during the three data collection periods. In June, it took four days for three people to complete six sites and two people to finish the last two sites. In August, it took two days to complete data collections. Two people completed the four sites on Grape Island on one day. On the next day, three to five people finished the sites on Georges Island. In October, there were four people who were able to finish two sites on

Grape Island. It took five people to finish all four sites on Georges Island. Due to bad weather conditions we were not able to finish the last two sites on Grape Island.

When collecting data separately, the ground cover data collection takes more time than the soil compaction data collection. Ground cover data collection by all three methods would take three people approximately 45 minutes. Soil compaction data collection by both methods would take three people approximately 30 minutes. If both types of data collection were done together, with all methods, it would not add any time to the 45 minutes it would take to collect the ground cover data. The transect method is costly in time and the soil compaction tester needs two people. If these two methods were not used, both ground cover and soil compaction data collection can be done faster and more efficiently. Two people could probably complete the site with the overall, quadrat, and pocket penetrometer assessment methods in approximately 20 to 30 minutes.

The trends for the three main categories are compared by the quadrat and transect methods for the visitor use season trends. The 'other' and vegetation categories seem to be inversely related. As one goes up, the other goes down. This is not the case for soil, which seems to have an independent relationship being nearly constant during the three months. This may mean that further analysis may have to be done in future studies. Unfortunately in this study, because of the limited number of pre-selected ground cover types for the overall and quadrat methods, no further breakdown was possible

The soil compaction indicator methods for penetration resistance were found to be harder to compare to each other because of the differences in measurement depths and mechanisms. The data can only be compared by method and month. The utility, cost effectiveness, and data variability can be compared for both islands and all months, though. The pocket penetrometer costs less than the cone penetrometer by about $200. For any person or agency on a tight budget this may be a big factor. For more accuracy, two people are needed to take the cone penetrometry readings. Only one person is needed to record the pocket penetrometer. The pocket penetrometer is advantageous on an island setting where the instruments have to be hand carried on boats and on long paths. The pocket penetrometer did display more variation in the measurement values on both islands. On Georges Island, the picket penetrometer had coefficients of variations ranging from 25% to 52%. The soil compaction tester for Georges Island had coefficients of variations ranging from 23% to 30%.

Table 4.1. Evaluation of Methods Using the Good Indicator Criteria

Criteria / Indicator	**Penetration Resistance**		**Ground Cover**		
Method	Cone	Pocket	Overall	Quadrat	Transect
Ease of Measurement	Lower	Higher	Middle	Highest	Lowest
Ease to Train	Lower	Higher	Highest	Middle	Lowest
Cost Effective	Less	More	Most	Least	Middle
Impacts to environment	Higher	Lower	Lowest	Middle	Highest
Variability of measurement values	Lower	Higher	Soil higher than vegetation	Mean % is lower than transect	Mean % is higher than quadrat

The three ground cover and two soil compaction indicator methods were compared to the VERP guidelines for choosing a good indicator (Table 4.1; NPS, 1997). The requirements state that good indicators are easy to measure, easy to train for monitoring, cost effective, cause low impacts to the environment, and the variability of the measure is relatively low. The PR methods were rated higher or lower for all criteria except for the cost effectiveness that was rated more or less. The ground cover assessment methods were ranked lowest, middle, and highest for ease of measuring and ease of training. Cost effectiveness was ranked least, middle, and most. Variability of measurements for the overall method cannot be directly compared to the variability of the measurements for the quadrat and transect methods. For the ease of measurement the overall method is more difficult than the quadrat method because of its large size. The variability of the bare soil measurements were much more than that of the vegetation measurements in the quadrat method. The overall trend in the mean percentages was looked at, although the variability of measurements between the quadrat and transect methods were not directly evaluated. The transect method showed slightly higher mean percent values more often than did the quadrat method.

There are recommendations for further research in ground cover and soil compaction. First, the amount of visitor use needs to be linked to the indicator data. Sites may have to be monitored or observed to see their actual use levels and how they are distributed spatially. Second, a longer period of time is needed to detect trends between visitor use seasons. These trends will identify if ground cover or compaction is increasing or decreasing year to year. Third, recovery of vegetation over the closed winter months is also a necessary long-term study. Finally, a study with more sampling plots or a larger sample size will generate data to give a better representation of the actual amount of ground cover or soil compaction. Permanent plots may be needed to gather baseline data and start keeping records of both the social and biophysical changes in the park.

While research on indicator development such as this study informs park managers of current conditions and the utility of alternative indicator measures, the managers will have to choose indicators and associated standards (minimum acceptable conditions) based on their priorities and constraints. Although the two indicators examined in this thesis were not chosen for the final monitoring program, it is important to realize that any knowledge of the history of the land use, climate, degree of ecosystem health and impact conditions is beneficial to park managers in detecting changes in resource conditions and probable causes (DeSoyza, Whitford, Herrick, Van Zee, & Havstad, 1998). The results of this study provide park management with baseline data and recommendations on selecting methods for long-term monitoring of visitor impacts.

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APPENDICES

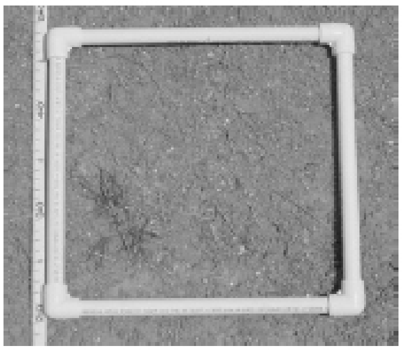
APPENDIX A: FIELD DATA COLLECTION FORMS AND HANDOUTS

GROUND VEGETATION COVER CLASSES (0-6)
Photo Examples

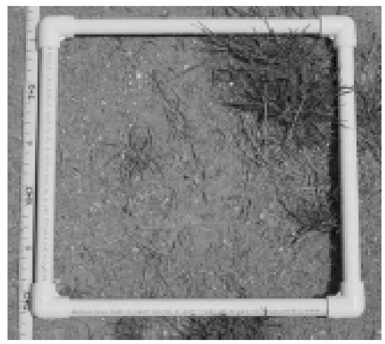
Live, non-woody vegetative ground cover (including herbs and grasses; excluding mosses)

Class 0 = Not Present

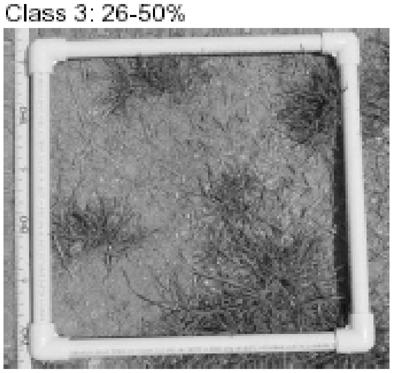
Class 1: minimal amount-5%



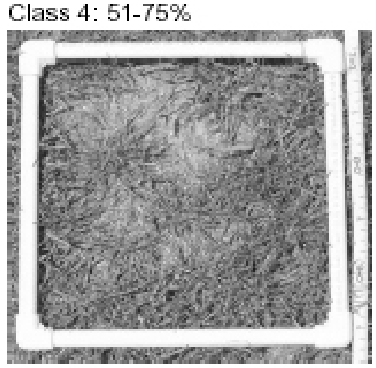
Class 2: 6-25%



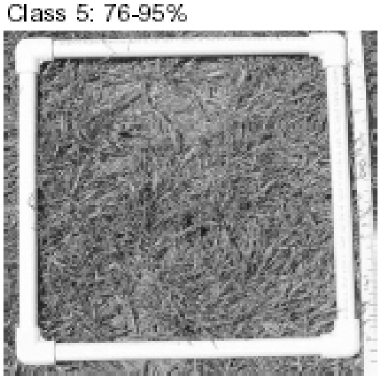
Class 3: 26-50%



Class 4: 51-75%



Class 5: 76-95%



Class 6: 96-100%

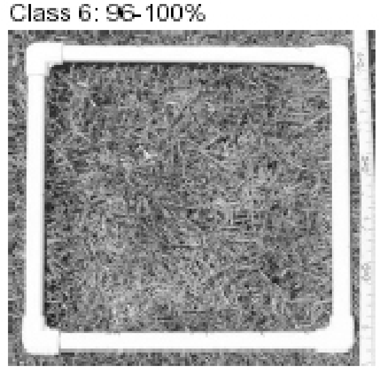


Figure A1: Ground Cover Vegetation Assessment Handout

FORM A - SAMPLING PLOT AND QUADRAT-BASED MEASUREMENTS

Date: ______________Start Time: _____(am/pm)End Time: _______ (am/pm) Island: ________
Start Weather: _________End Weather: _________Staff:______ **SAMPLING PLOT No:** ___________
Center Point Location: Description:_________________________________ Garmin GPS (UTM): ________________ Photo:__ Nut:__
Reference Point: Object Description:__________________________________ Distance from center point (m):_______ Bearing: _______
General Plot Data: Slope____ Aspect____ Canopy (0-6)__ Grass (0-6)__ Weed (0-6)__ Trash (0-6)__ Erosion (0-5):___ Write comments on back -->

Transect No. _______________ Sub-Transect A Bearing: ___________ Sub-Transect B Bearing: ___________

Quad No.	Distance from center point (m)	Surface Composition (class 0-6) [0=None;1=min.-5%;2=6-25%;3=26-50%;4=51-75%;5=76-95%;6=96-100%]								Penetration Resistance (Pocket)				Penetration Resistance (Cone)								Soil Tests Selected (check 1)
		grass	weed (+type)	tree seedl.	moss/ lichen	plant litter	bare soil	trash	Other (____)	#1	#2	#3	#4	#1		#2		#3		#4		
														3in	6in	3in	6in	3in	6in	3in	6in	

Transect No. _______________ Sub-Transect A Bearing: ___________ Sub-Transect B Bearing: ___________

Quad No.	Distance from center point (m)	Surface Composition (class 0-6) [0=None;1=min.-5%;2=6-25%;3=26-50%;4=51-75%;5=76-95%;6=96-100%]								Penetration Resistance (Pocket)				Penetration Resistance (Cone)								Soil Tests Selected (check 1)
		grass	weed (+type)	tree seedl.	moss/ lichen	plant litter	bare soil	trash	Other (____)	#1	#2	#3	#4	#1		#2		#3		#4		
														3in	6in	3in	6in	3in	6in	3in	6in	

Transect No. _______________ Sub-Transect A Bearing: ___________ Sub-Transect B Bearing: ___________

Quad No.	Distance from center point (m)	Surface Composition (class 0-6) [0=None;1=min.-5%;2=6-25%;3=26-50%;4=51-75%;5=76-95%;6=96-100%]								Penetration Resistance (Pocket)				Penetration Resistance (Cone)								Soil Tests Selected (check 1)
		grass	weed (+type)	tree seedl.	moss/ lichen	plant litter	bare soil	trash	Other (____)	#1	#2	#3	#4	#1		#2		#3		#4		
														3in	6in	3in	6in	3in	6in	3in	6in	

Figure A2: FORM A: Sampling Plot and Quadrat-Based Measurements

FORM A1 – Penetration Resistance at Controls

SAMPLING PLOT NO.___________ Date________ Time______(am/pm) Staff __________

Penetration Resistance (Pocket)		Penetration Resistance (Cone)		
Point	Reading (kg/cm^2)	Point	Reading ($pounds/in^2$)	
			0-3 inches	3-6 inches
#1		#1		
#2		#2		
#3		#3		
#4		#4		
#5		#5		
#6		#6		
#7		#7		
#8		#8		

Figure A3: FORM A1: Penetration Resistance at Controls

Page ____ of ____

FORM B – LINE TRANSECT CONTINUOUS ASSESSMENT AND SOILTESTS

Date: _________ Start Time: ______(am/pm) End Time: ________ (am/pm) Island: _________
Start Weather: __________ End Weather: __________ Staff:______________________

SAMPLING PLOT No: _______________

I. LINE TRANSECT CONTINUOUS ASSESSMENT

Transect No.	Begin distance (m)	End distance (m)	Surface type	Transect No.	Begin distance (m)	End distance (m)	Surface type

Continue on back (y/n)?___

II. SOIL TESTS

Transect No.	Quad-rat	Soil Texture	Slake Test								
			Individual Slake Ratings								*Average Rating*

Figure A4: FORM B: Line Transect Continuous Assessment and Soil Tests

Transect No.	Begin distance (m)	End distance (m)	Surface type	Transect No.	Begin distance (m)	End distance (m)	Surface type

Comments:

Figure A5: FORM B1: Continuation of Line Transect Continuous Assessment

APPENDIX B: SUPPLEMENTAL TABLES AND FIGURES

Table B1. Results for the Overall Estimation Method

Island	Use	Date	Groundcover type	N	Mean (%)	Standard Deviation	Coefficient of Variation
Georges	High	June	Vegetation	2	86.4	6.9	0.08
			Soil	2	10.1	8.1	0.80
		August	Vegetation	2	52.8	5.6	0.11
			Soil	2	27.2	18.8	0.69
		October	Vegetation	2	90.7	9.7	0.11
			Soil	2	8.1	11.5	1.42
	Low	June	Vegetation	2	100.0	0.0	0.00
			Soil	2	0.0	0.0	NA*
		August	Vegetation	2	89.0	11.2	0.13
			Soil	2	1.6	2.2	1.38
		October	Vegetation	2	96.4	1.6	0.02
			Soil	2	0.0	0.0	NA*
Grape	High	June	Vegetation	2	93.3	6.0	0.06
			Soil	2	5.5	7.7	1.4
		August	Vegetation	2	86.3	16.0	0.19
			Soil	2	10.7	15.2	1.42
		October	Vegetation	1	100.0	NA	NA
			Soil	1	0.0	NA	NA
	Low	June	Vegetation	2	100.0	0.0	0.00
			Soil	2	0.0	0.0	NA*
		August	Vegetation	2	97.2	0.5	0.05
			Soil	2	1.6	2.2	1.38
		October	Vegetation	1	100.0	NA	NA
			Soil	1	0.0	NA	NA

* Values are undefined when divided by 0.

Table B2. Georges Island Ground Cover Estimates: Comparison of the Quadrat and Transect Methods for August

Groundcover Type/ Use Level		**Ground Cover Estimates** Quadrat Method *Mean (S.E.)* (%)	**Line Transect Method** *Mean (S.E.)* (%)	**Difference between Quadrat Vs. Transect Methods** *(T-test significance)*
Vegetative Ground Cover				
	High Use	41.2 (5.0) n=24	52.2 (10.0) n=12	0.327
	Low Use	64.3 (4.5) n=24	93.9 (3.4) n=12	**0.000****
Difference between High and Low Use (T-test significance)		**0.001****	**0.001****	
	Combined Use	52.8 (3.7) n=48	73.1 (6.6) n=24	0.011**
Bare Ground (Exposed Soil)				
	High Use	5.4 (3.8) n=24	6.7 (2.5) n=12	0.781
	Low Use	0.8 (3.0) n=24	0.1 (0.1) 0.2 n=12	0.280
Difference between High and Low Use (T-test significance)		0.243	0.023*	
	Combined Use	3.1 (1.9) n=48	3.4 (1.4) n=24	0.900

* Significant: $p < 0.05$. ** **Significant:** $p < 0.01$.

Table B3. Grape Island Ground Cover Estimates: Comparison of the Quadrat and Transect Methods for August

Groundcover Type/ Use Level		**Ground Cover Estimates**		**Difference between Quadrat Vs. Transect Methods** *(T-test significance)*
		Quadrat Method *Mean (S.E.)*	**Line Transect Method** *Mean (S.E.)*	
Vegetative Ground Cover				
	High Use	63.3 (5.6) n=24	88.1 (3.4) n=12	**0.001****
	Low Use	92.7 (1.9) n=24	80.8 (5.4) n=12	0.058
Difference between High and Low Use (T-test significance)		**0.000****	0.274	
	Combined Use	78.0 (3.6) n=48	84.4 (3.2) n=24	0.191
Bare Ground (Exposed Soil)				
	High Use	6.2 (3.0) n=24	6.8 (2.8) n=12	0.892
	Low Use	0.2 (0.2) n=24	0.0 (0.0) n=12	0.328
Difference between High and Low Use (T-test significance)		0.054	0.036*	
	Combined Use	3.2 (1.5) n=48	3.4 (1.6) n=24	0.938

* Significant: $p < 0.05$. ** **Significant:** $p < 0.01$.

APPENDIX C: RELATED CONFERENCES AND PUBLICATIONS

CONFERENCES

Meyer, K., & Leung, Y. (2004). *Estimating Vegetative and Bare Ground Cover as Visitor Impact Indicators: An Evaluation of Three Methods.* Oral presentation at the 2004 Southeast Recreation Research Conference, Charleston, SC.

Meyer, K., & Leung, Y. (2003). *Evaluating Soil Compaction and Ground Cover Indicator Measures for Visitor Use Planning on the Boston Harbor Islands*. Poster presented at the 2003 Boston Harbor Islands Science Symposium, Boston, MA.Leung, Y., & Meyer, K. (2003). *Soil Compaction as Indicated by Penetration Resistance: A Comparison of Two Types of Penetrometers*. Paper presented at the 12th George Wright Society Conference on Resource Management in Parks and on Public Lands; April 14-18, 2003. San Diego, CA.

Leung, Y.-F., K. Johnson, and K. Meyer. (2003). Developing visitor impact monitoring indicators and procedures for Boston Harbor Islands National Park Area. Paper presented at the 12th George Wright Society Conference on Resource Management in Parks and on Public Lands; April 14-18, 2003. San Diego, CA.

Holden, T., Ingle, M.C., & Meyer, K.J., (2003). The effectiveness of two sign design types at Lake Johnson Metro Park, Raleigh, North Carolina [Poster signs preferred over footprints, but both reduce social trail use]. Poster presented at the 2003 Southeast Recreation Research Conference, Asheville, NC.

PUBLICATIONS

Leung, Y.-F. and K. Meyer. 2004. Developing Resource Indicators and Standards for Implementation of the Visitor Experience and Resource Protection (VERP) Framework on Boston Harbor Islands. Final report submitted to USDI National Park Service.

Leung, Y., & Meyer, K. (2003). *Soil Compaction as Indicated by Penetration Resistance: A Comparison of Two Types of Penetrometers*. In: Harmon, D., Kilgore, B.M., & Vietzke, G.E. (2004). *Protecting our diverse heritage: The role of parks, protected areas, and cultural sites – Proceedings of the George Wright Society/National Park Service joint conference; April 14-18, 2003; San Diego CA* (pp. 370-375). Hancock, MI: George Wright Society.