Multidisciplinary assessments of trail degradation for framing future trail management: examination in Shei-Pa National Park, Taiwan

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Abstract

This study aims to develop the basis for the framework of future trail management in mountain protected areas. For this aim, we conducted three kinds of field surveys on the 10.9 km trail in Shei-Pa National Park, Taiwan. A rapid trail-condition assessment revealed that the total length of 4,808 m faces problems, showing root exposure to be the greatest. Repeat cross-sectional area measurements of the trail surface identified the spatial distribution of severe soil erosion. A geophysical sounding showed that the average depth of the surface deposits was 98 cm (range: 4–271 cm), which indicates an average depth to be eroded in the future.

Keywords: erosion, mountain national park management, multidisciplinary assessment approach, Shei-Pa National Park, trail degradation

1 Introduction

Impacts on trails caused by visitations have been described earliest in the 1920s (Leung & Marion 2000). Since then, trail degradation (especially, trail erosion) has been one of the main target issues studied mainly in the western world. Such studies in mountainous countries of Asia, on the other hand, started only recently although much precipitation could cause heavy soil erosion. In Japan, trail erosion has been monitored especially in Daisetsuzan National Park (Watanabe & Ono 1996; Yoda & Watanabe 2000; Watanabe 2002). In the high mountain areas of the Republic of China (hereafter, Taiwan), extremely heavy precipitation is most likely to cause severe erosion. The national park authority of Taiwan recognizes the importance of recreational impacts such as trail degradation on the mountain environments. Nevertheless, Taiwan's mountain national parks have no studies on trail impact by recreational use so far.

Developing a rapid assessment method of trail conditions without special equipment and large funding is important for park managers. However, that method does not enable the prediction of future trail degradation. Researchers tend to use special equipment to obtain accurate data. Developing a combined multidisciplinary approach is preferable for future mountain protected area management because no studies have tried to do so and because it can bridge a gap between park managers and researchers. This study aims to understand the current trail conditions in a mountain protected area, and to develop a multidisciplinary assessment approach for future trail management in mountain protected areas. For these aims, this study selected Shei-Pa National Park, located in central Taiwan.

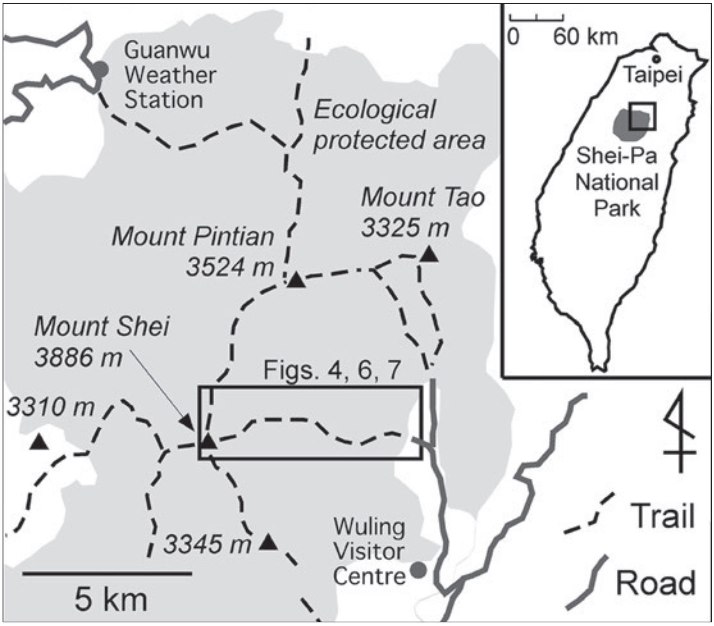

Figure 1: The location of Shei-Pa National Park and study area.

2 Study area

Shei-Pa National Park (Figure 1) is a mountain national park with 51 peaks over 3,000 m high. The studied trail, 'Shei-shan (Syue Mountain) Trail', is located in the eastern part of the national park. The trail is 10.9 km long, starting from the trailhead (2,155 m a. s. l.) to the summit of Mount Shei (3,886 m a. s. l.), the second highest peak in Taiwan. The trail is one of the most heavily visited trails in Taiwan.

The annual precipitation attains 3,190 mm at the Guanwu (Kuan Wu) Weather Station, 2,000 m a.s.l. The precipitations fluctuate depending on the degree of the influence by typhoons, which concentrate in July-October. Ground temperatures at the depth of 5 cm on the trail were recorded at three altitudes from November 2006 to April 2007: the number of freeze-thaw cycles for the period was zero at 2,733 m, 13 times at 3,180 m, and 115 times at 3,550 m.

Geology of the eastern end of the trail below 2,800 m a. s. l. is mainly slate and fine-grained sandstone of the Jiayang Formation, and that at the higher altitudes is coarse sandstone of the Baileng Formation (Liu et al. 2001).

Vegetation in central Taiwan represents altitudinal zoning (Lee 2001). Quercus zone lies between 1,500 and 2,500 m, with Fagaceae family dominated by Arishan Oak (*Cyclobalanopsis stenophylloides*), Taiwan red pine (*Pinus taiwanensis*) and Formosan alder (*Alnus formosana*). Montane coniferous forest zone with Chinese hemlock (*Tsuga chinensis*) and Morrison spruce (*Picea morrison*) lies between 2,500 and 3,100 m. The sub-alpine coniferous forest zone is composed of Kawakami fir (*Abies kawakamii*) between 3,100 and 3,600 m, and high mountain juniper (*Juniperus squamata*) in the upper part of this zone. Above 3,600 m is the alpine vegetation zone.

All hikers who use the trail have to obtain two types of permits (park entry permit and mountain entry permit) from the national park authority, and are requested to register at the trailhead service station. The number of hikers was 6,938 in 1998 and 15,703 in 2008 with the maximum number of 20,316 in 2005.

3 Method

This study used the following three methods: (1) rapid trail-condition assessment, (2) measurement of soil erosion rates, and (3) estimation of future erodable deposit depth based on geophysical sounding.

A rapid trail-condition assessment is a kind of so-called census method, described in the previous studies (Cole 1983, 1991; Leung & Marion 1999a, 1999b; Marion 1994; Hammitt & Cole 1998). An appropriate method needs to be developed depending on the local environmental conditions. First, a reconnaissance field visit was conducted in 2006 to identify the major problems of the trail. The following seven trail impact problems were recorded in the field: gully erosion, sheet erosion, wet/muddy tread, surface water, multiple trail, trail expansion, and root exposure. Tread surface was divided into three types: fines (sand and silt), gravels, and exposed bedrock. Measures to cope with the problems such as stone steps and wood steps, together with bridges and other installations, were also recorded in the field. Moreover, dominant species of trailside vegetation were recorded. The detailed assessment of the trail of the entire 10.9 km section was conducted in 2007. All data that were taken for the entire 10.9 km trail were recorded on the notebook when a minimum lineal distance with the pre-defined trail problem(s) exceeds 5 m.

The soil erosion rate was estimated by the most widely used method worldwide, i.e., repeat measurement of cross-sectional profiles of the trail surface (Cole 1983; Hammitt & Cole 1998). In this study, soil is defined as surface soft materials including A–C horizons. The first and second measurements were conducted at 51 sites on 3–6 December 2007 and 21–23 November 2008. Change over time in the cross-sectional area of the trail shows either erosion or deposition.

In order to estimate the depth of soil from the trail surface to be potentially eroded in the future, application of geophysical approach is proposed (Yoda & Watanabe 2008). We utilized a hand-held dynamic cone penetrometer (PANDA 2), originally designed to measure soil compaction. This method is a non-destructive way of the trail surface, so it is appropriate to be applied in a protected area. The sounding was carried out at 73 sites on 8–11 May 2009, which cover the sites where the cross-sectional measurement was conducted.

In this study, a measured and recorded site is expressed by the horizontal distance from the trailhead, starting from the 0.00 km site to the 10.90 km site.

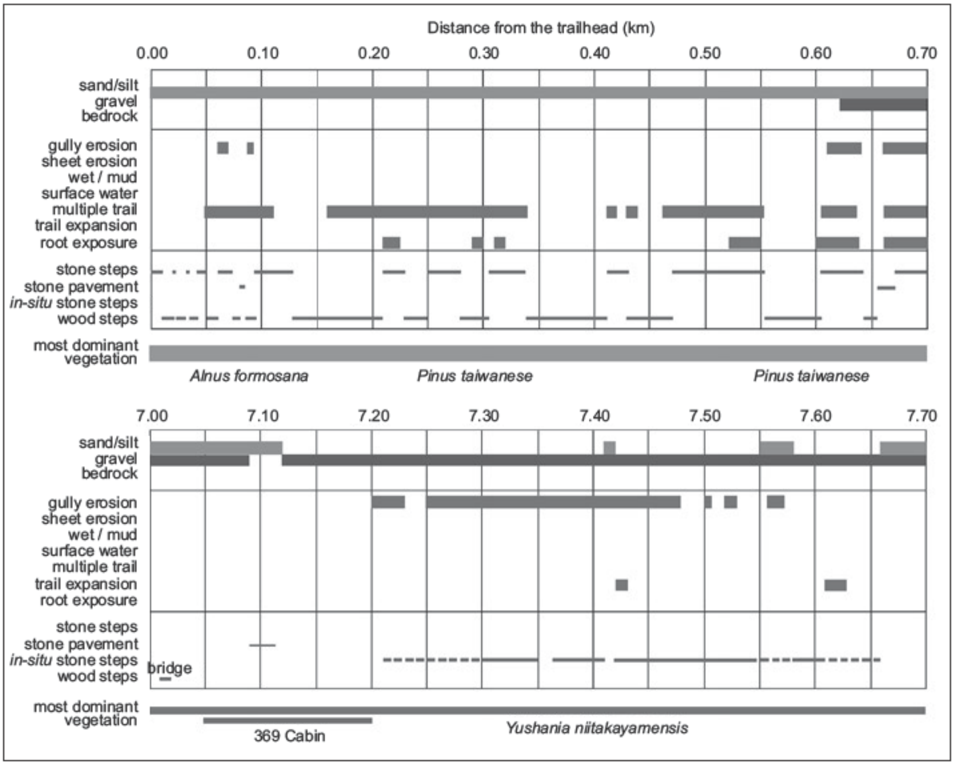

Figure 2: Summary diagram showing the characteristics and problems of the trail by the rapid trail-condition assessment method. Top: 0.00–0.70 km section, bottom: 7.00–7.70 km section.

4 Results

This study shows brief results of the three methods due to the constraints of the limited page number: their details will be discussed elsewhere.

4.1 Rapid trail-condition assessment

Figure 2 is an example of the summary diagram showing the characteristics and problems of the trail in the representative two short sections (0.00–0.07 km and 7.00–7.70 km). The same summary diagram was drawn for the entire 10.9 km trail. Out of the 10.9 km trail, the total length of 6,709 m had no impact problems on its tread, and the rest of 4,191 m had problems. Although heavy precipitation could cause severe trail degradation associated with water, root exposure was the largest problem. The length of the trails with the root exposure attained 2,630 m out of the entire 10.9 km trail (24.1%), followed by multiple trail (8.8%) and gully erosion (6.8%) as shown in Table 1. The root exposure contributed to 54.70% of the entire problems (2,630 m/4,808 m), and those three major problems attained 89.99% of the entire problems (Table 1).

Table 1: The section length with the problems and percentage of the length.

Problems	Total length, L (m)	Problem section, L/109 (m/100 m)	Proportion each problem/overall total length, L/4808*100 (%)
root exposure	2,630	24.1	54.70
multiple trail	956	8.8	19.88
gulley erosion	741	6.8	15.41
wet/muddy tread	246	2.3	5.12
trail expansion	170	1.6	3.53
sheet erosion	45	0.4	0.94
running water	20	0.2	0.42
overall total	4,808	44.2	100.00

Table 2: Type classification of the trail for future management based on a combination of the existing measures and problems.

Type	Existing measures	Existing trail problems	# of the 100-m sections with problems	Percentage of occurrence	Future treatment priority	Future monitoring priority
1	yes	great	24	22.02	2	1
2	yes	minor	36	33.03	3	2
3	no	great	20	18.35	1	1
4	no	minor	29	26.60	3	1
Total	-	-	109	100.00	-	-

Priority values: 1 (highest) – 3 (lowest).

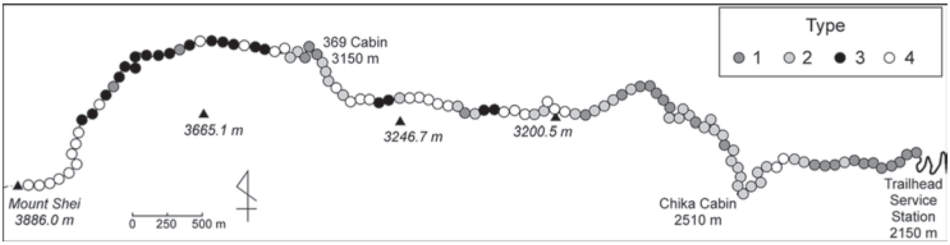

Figure 3: Distribution of the trail types. The altitude of the trail is lower in the east (towards the trailhead) and higher in the west (towards the summit of Mount Shei).

Table 2 shows the classification of the trail types based on the rapid trail-condition assessment method. The trail types were classified into four by a combination of the existing measures and problems. The sections with the total length of the problems more than 50 m per 100-m section were regarded as 'great', and those with the shorter length of the problems as 'minor' (Table 2). The sections of type 1 tended to occur near the trailhead, or at the lower altitudes (Figure 3). The sections of types 3 and 4 occurred at the higher altitudes.

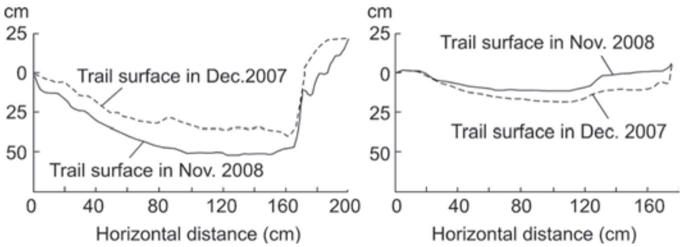

Figure 4: Examples of the cross sectional profiles showing the soil erosion and depostion on the Shei-shan Trail from 2007 to 2008. Left: the 9.35 km site, right: the 1.55 km site.

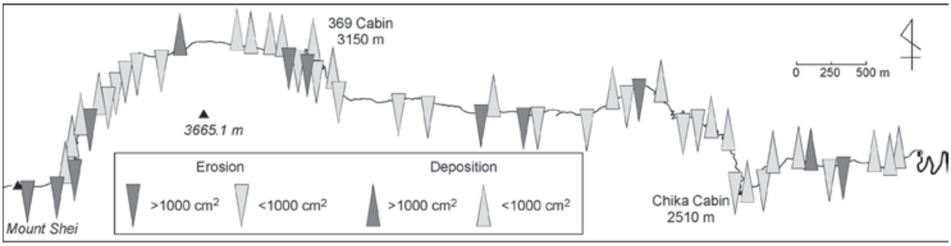

Figure 5: Spatial distribution of the soil erosion and deposition from 2007 to 2008.

4.2 Soil erosion rates

Figure 4 exemplifies the cross-sectional profiles, and Figure 5 shows the spatial distribution of the amount of the erosion and deposition on the trail for the one-year period from 3–6 December 2007 to 21–23 November 2008. The 9.35 km site (Figure 4, left) is one of the most severely eroded sites, where the average erosion depth was 13.8 cm for the one-year period. The 1.55 km site (Figure 4, right) is an example showing the deposition, where the average deposition was 6.1 cm for the same period.

Figure 5 also shows that both erosion and deposition occurred on the trail. Erosion dominated at 28 sites, and deposition dominated at 23 sites with the overall surplus of erosion: over the year, a total of 28,854 cm^2 of soil was eroded away, and 7,897 cm^2 was deposited. The deposited materials, however, are unconsolidated, and hence are easily washed away.

4.3 Potential depth of soil to be eroded

The potential depth to be eroded in the future that was measured by the dynamic penetrometer ranged from 4 cm (3.72 km site) to 271 cm (1.90 km site) with the average depth of 98 cm (Figure 6). The depth is in general larger near the trailhead. This section with deep soil (0.00–2.90 km) approximately corresponds to the area of slate and fine-grained sandstone.

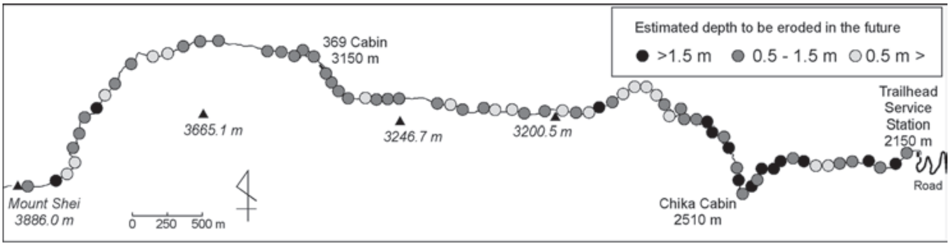

Figure 6: Spatial distribution of the soil depth to be potentially eroded in the future.

5 Discussion

5.1 Current status and future prediction of the trail degradations

The problems on the Shei-shan Trail are serious in terms of both their magnitude and frequency. For example, a similar assessment conducted on the trails in the Great Smokey Mountains National Park shows that wet soil occurred most extensively with 194 m/km (average) and 20% of the trail length (Leung & Marion 1999a). All other problems were largely infrequent (0.0–5.3%) there.

The problems of the Shei-shan Trail are characterized by the dominance of the root exposure (Table 1). The exposed roots are often slippery, so safety for hikers is not ensured there. Root exposure is also harmful to the trees. Measures to minimize further root exposure are needed to conserve the forests in the Shei-shan Trail area, especially in the 7.80–9.70 km section.

Among the four types of the trail (Table 2, Figure 4), the total length of the type 3 sections (with great problems but no measures) attained 2,000 m (18.35% of the entire trail). The type 3 sections have the first priority to be treated as well as to be monitored (Table 2). The sections of type 1 (total length: 2,400 m, 22.02% of the entire trail) suggest that the measures are not necessarily effective: many sites experience new problems that occurred after the application of the measures such as stone/wood steps. This type of the sections, therefore, needs some improvement and maintenance of the existing measures. The type 2 sections with the minor problems and measures (total length: 3,600 m, 33.03%) have less priority over other types in terms of the future management treatment and monitoring (Table 2). Also, the type 4 sections with the minor problems and no measures (total length: 2,900 m, 26.60%) have less priority of the future management treatment.

Figure 7 shows the maximum erosion depth at each site from 2007 to 2008, which was calculated from the cross-sectional profiles. The total number of the sites with the large erosion depth exceeding 20 cm attains 8 out of 51 (Figure 7). With these data and the data derived from the dynamic penetrometer sounding (Figure 6), future prediction of further soil erosion became possible. For example, at the 9.35 km site (Figure 4, left), the maximum and mean erosion depths for the one-year period were 28 cm and 13.8 cm, respectively. The soil thickness at the site was 72 cm, so that the 72 cm deep soil would be eroded away by 2011 (at the maximum rate) and

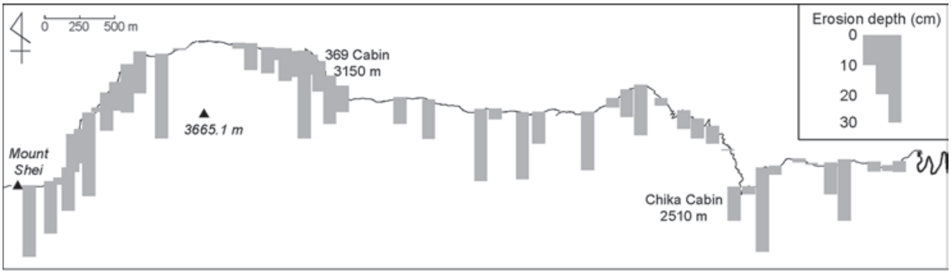

Figure 7: The maximum soil erosion depth from 2007 to 2008.

by 2014 (at the average rate). In the same way, future soil erosion can be understood for all measured sites.

5.2 Multidisciplinary assessments and stakeholders

This study suggests that the methods described above should be used under a single management framework because each method produces different output. A rapid trail-condition assessment used in this study is a replicable method over time. Not only park managers but also citizens can use the method. This study employed a 5 m segment as a minimum lineal distance with a trail problem to record.

However, as Leung & Marion (1999a) pointed out, surveyors need to judge in determining where each problem segment begins and ends. Repeat measurement of cross-sectional profiles is also replicable, although it is time-consuming in the field (Jewell & Hammitt 2000). The method is very simple, although Jewell & Hammitt (2000) state that it requires specific training: anyone would be able to conduct the measurement after some training. More importantly, the method requires long-term measurements. It is well known that annual values of cross-sectional area and depth of soil erosion greatly vary over time (Watanabe 2008). These two methods require no special equipment.

The third method of geophysical sounding, on the other hand, needs special equipment, which may not be available in a national park office. Therefore, a collaboration with a research institute such as a university is suggested. The dynamic penetrometer (PANDA 2) can be used without special training, on the contrary other types of geophysical soundings such as electric resistivity sounding and seismic sounding (Yoda & Watanabe 2008) need considerable training.

Researchers tend to spend more time to obtain data sets as accurately as possible, whereas park managers prefer fast assessment approach. However, they should not limit their approach. The fast trail-condition assessment method used in this study provides the spatial characteristics of the problems. This fast trail-condition assessment method allows different researchers and park managers repeatability over time.

Trail degradation not only decreases the natural and recreational values but also increases budget for repair (Hawes et al. 2006). For example, the Japanese mountain national parks have spent enormous amount of money for the maintenance of trails, because the most measures are of countermeasures after the occurrence of the extremely severe degradation. To minimize repair cost in future, it is important to establish a management framework of early detection of trail impact problems and early treatment of the problems. Developing the multidisciplinary assessment approach would serve as the basis for building a mechanism for securing involvement of park managers, researchers and citizens.

6 Conclusions

This study, as an early stage towards the final goal to bridge a gap between park managers and researchers, presented the results from the three kinds of field surveys in Shei-Pa National Park in Taiwan.

First, a rapid trail-condition assessment method was developed for the 10.9 km long Shei-shan Trail. The results revealed that the total length of 4,808 m faces impact problems, i. e., root exposure, multiple trail, gully erosion, wet/muddy tread, trail expansion, sheet erosion, and surface running water. This study clarified the spatial characteristics of the problems, identifying root exposure to be the greatest (root exposure: 2,630 m long in total). The trail was classified into four types, so that the priority sections to future management treatment were identified. The type 3 sections (2,000 m in total), which are defined to be sections with great problems but lacking measures, are given the first priority to be treated and monitored.

The second method adopted was repeat measurement of cross-sectional area of the trail surface to estimate the actual erosion/deposition rates for the period from 2007 to 2008. The results demonstrated that erosion dominated at 28 sites and deposition dominated at 23 sites with the overall surplus of erosion.

The third method is a dynamic cone penetrometer sounding to detect soil thickness at 73 sites, by which the magnitude of future soil erosion can be estimated. The average depth of the soil was 98 cm (range: 4–271 cm), which indicates an average depth to be eroded in future.

The first and second methods above allow park managers and researchers repeatability over time. The third method requires special and expensive equipment. Park managers will be appreciated the overall multidisciplinary assessment approaches to result in an integrated future management of mountain trails.

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