BOREAL ENVIRONMENT RESEARCH 16: 218–228
ISSN 1239-6095 (print) ISSN 1797-2469 (online) Helsinki 30 June 2011

Estimating and modelling the resistance of nature to path erosion in Koli National Park, Finland

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Received 16 Dec. 2009, accepted 8 Oct. 2010 (Editor in charge of this article: Eeva-Stiina Tuittila)

Selkimäki, M. & Mola-Yudego, B. 2011: Estimating and modelling the resistance of nature to path erosion in Koli National Park, Finland. *Boreal Env. Res.* 16: 218–228.

We studied the resistance of nature to trampling and path erosion in Koli National Park. The data are based on 201 field measurements of paths together with digital datasets in order to identify the main factors affecting path erosion. Additionally, the resistance of different forest types to trampling was studied. Models for path erosion were constructed in order to predict the width and depth of a path. Slope of the path and the number of visitors were the two main factors explaining width and depth. The lowest resistance areas were identified in rocky-site forest located on the hilltops, while the deepest paths were on moraine soils. Paths on meadows were highly resistant to trampling and the most resistance forest type was *Oxalis–Myrtillus*. The results of this study can be applied in national park management and can be the basis for the design of measures to reduce path erosion. By mapping the most sensitive areas, the path network can be planned to be sustainable. Recreational pressure can be redirected to more resistant areas or structures such as duckboard and stairs can be built to protect the most sensitive areas. Developed models can be used for testing where to place new paths in order to minimize path erosion.

Introduction

According to the report of the Finnish Environmental Administration (2002), there is an increasing interest in recreational use of nature in Finland. During 2007, the number of visitors to Finnish national parks increased by 6% as compared with that in the previous year (Finnish Forest and Park Service 2008). In the near future, tourism is expected to grow even more, which creates the need for new development strategies: how to increase tourism without jeopardizing the protection needs of the national parks?

In fact, this flow of people to national parks has negative impacts that affect the natural conditions of the area. One of these impacts is on the surface terrain, since the utilization of forest paths increases erosion, however, with good planning and appropriate management, path erosion can be significantly reduced (Kellomäki 1977b, Jämbäck 1996, Hammitt and Cole 1998, Agate 2001). By studying the factors that are affecting the resistance of nature to erosion, the most sensitive areas can be mapped and outdoor activities can be directed to more resistant areas. Additionally, management actions can be undertaken, such as the redistribution of visitors and improvement of structures like stairs and duckboards to minimize path erosion.

The resistance of nature can be considered an ecological carrying capacity, which in terms of recreational use can be defined as the maximum number of people that can use a place without unacceptable changes in the physical environment as well as in the quality of recreational experience (Vuolanto and Tuhkanen 1982, Järviluoma 1994, Hemmi 1995, Hammitt and Cole 1998, Cole 2004). The resistance of nature is determined by the type of vegetation and soil, topography as well as the number of visitors, the type of activity and the time of activity (i.e. season) (Vuolanto and Tuhkanen 1982). Recreational activities are often channelled to paths, resting and camping areas where the effects of trampling can be seen as the wear and tear of the terrain (Kellomäki 1977b, Vuolanto and Tuhkanen 1982, Jämbäck 1996). Considerable damage to the vegetation and the soil are caused by horses, mountain bikes, motorcycles and snow mobiles, but they are often restricted to their own official tracks or are forbidden in national parks (Weaver and Dale 1978, Nenonen 1990, Törn *et al*. 2009).

Much research has been conducted on the resistance of vegetation to trampling by experimental trampling studies (Kellomäki 1973, 1977a, Kellomäki and Saastamoinen 1975, Weaver and Dale 1978, Emanuellson 1984, Cole and Bayfield 1993, Cole 1995, Littlemore and Baker 2001) or by measuring damage to the vegetation in worn out areas such as paths, fire places, camping areas and urban forest (Liddle 1975, Hoogesteger 1976, Nylund *et al*. 1979, 1980, Coleman 1981, Ukkola 1993, Karjalainen 1994, Rautio *et al*. 2001, Littlemore and Baker 2001, Andrés-Abellan *et al*. 2005, Malmivaara-Lämsä *et al*. 2008b, Törn *et al*. 2009). The results of these studies revealed a curvilinear relationship between the amount of trampling and the resistance of vegetation and that the resistance is often negatively correlated with resilience (Kellomäki 1973, Weaver and Dale 1978, Emanuelsson 1984, Cole 1995, Littlemore and Baker 2001). The resistance of vegetation is determined by the relationship between destruction and growth rate. The destruction depends on the type of wear, volume and timing of disturbance, whereas the growth rate depends on site characteristics (moisture and nutrient supply, light and thermal conditions) as well as biological characteristics of the vegetation (morphology, reproduction and species adaptation to local environment) (Kellomäki 1977a, Kellomäki and Lakka 1979, Nenonen 1990). Furthermore extreme climatic conditions, such as cold and dry winds and crown snow, reduce vegetation resistance (Nenonen 1990).

The characteristics of plants most resistant to trampling are, in general: small size, small leaf area, rosette or tussock growth habit, deep roots, fast growth and fast reproduction (Vuolanto and Tuhkanen 1982, Cole 1995, Jämbäck 1996). Cultural plant species, like meadow and pasture vegetation, are notably more resistant to trampling than are forest species (Hoogesterger 1976, Vuolanto and Tuhkanen 1982, Emanuelsson 1984). Plants most sensitive to trampling include mosses and lichens (Kellomäki 1977a, Törn *et al*. 2009). The resistance of individual species can change depending on the habitat type in which it is growing (Kellomäki and Saastamoinen 1975, Emanuelsson 1984). Therefore, it is meaningful to study the resistance of vegetation in different forest types. In Finland, the resistance of forest types in short term trampling experiments was found to be, in descending order, MT (*Myrtillys* type), OMT (*Oxalis–Myrtillys* type), VT (*Vaccinium* type), CT (*Calluna* type), ClT (*Cladonia* type) and rocky-site forest (Kellomäki and Saastamoinen 1975, Kellomäki 1977a). A study on the effects of long-term trampling showed similar results with one exception: OMT was more resistant than MT (Malmivaara-Lämsä *et al*. 2008b). The reason is thought to be the faster regeneration power of herbaceous plants which are dominant in OMT forests.

After vegetation has worn away and soil starts to compact under trampling, water begins to flow on top of the ground, instead of infiltrating into the ground, causing rill and gully erosion (Morgan 2005, Blanco and Lal 2008). Running water is a significant eroding factor, causing the detachment of soil particles. An increase in the slope of the terrain increases the ability of water to carry material (Brinker and Tufts 1995, Agate 2001, Morgan 2005). Soil erodibility is determined by the detachment and transportation of soil particles. This varies with soil texture, shear strength, aggregate stability, infiltration capability as well as the organic and chemical content of the soil (Morgan 2005, Blanco and Lal 2008). Many studies show that trampling also causes changes in soils nutrient and moisture contents, reduce its porosity, damage the mycocelial filaments as well as disturbs soil microbial communities and invertebrates (Liddle 1975, Weaver and Dale 1978, Coleman 1981, Littlemore and Baker 2001, Andrés-Abellan *et al*. 2005, Malmivaara-Lämsä *et al*. 2008a).

In path erosion studies (Coleman 1981, Ukkola 1993, Karjalainen 1994, Rautio *et al*. 1999, Törn *et al*. 2009), the most common factors measured are path width, depth, slope of the path, exposure of the stones and roots, number of visitors, aspect and the surrounding forest type. The resistance of vegetation to trampling and path erosion have been widely studied, however, little modeling (e.g. Coleman 1981) has been done. Although, in general, soil erosion is well studied, the most frequently used USLE model (Universal Soil Loss Equation) (Morgan 2005, Blanco and Lal 2008) cannot be directly applied to path erosion modelling, since path erosion is typically concentrated in narrow areas, while normal soil loss estimation has been done for larger areas.

This study focuses on path erosion in national parks, based on the measurements in Koli National Park in Finland. The aim is to provide tools and develop models that can contribute to a better understanding of the process of erosion on natural paths that can be used in the management of natural areas. The hypotheses are: (1) An increase in slope, number of visitors and elevation increase the probability of erosion. (2) Paths on bedrock are expected to be the widest and on moraine the deepest. (3) The meadow type is expected to be most resistant and the rocky sites most sensitive to trampling, while forest types are expected to be between these two. (4) Regarding the resistance of forest types, it is assumed that MT forest is the most resistant followed by OMT, VT and the rocky site forest (Kellomäki 1977a).

Material and methods

Study area

Koli National Park (63°05´47´´N, 29°48´20´´E), located in North Karelia, eastern Finland, covers 3000 ha and contains over 60 km of paths, both man-made and natural. Paths classified as man-made include crushed stone coated paths, paths on old forest roads and paths on the ski slopes, whereas the rest were classified as natural paths. The relatively large differences in elevation, calciferous rock and small streams as well as human activities such as slash-and-burn cultivation and grazing on meadows have created very diverse habitats for plants and animals. The Koli area hosts many rare and endangered animal and plant species (Hakalisto 2000). The altitude ranges from 94 m a.s.l. (Lake Pielinen) to a peak of 347 m a.s.l. in the park. The growing season is 10–12 days shorter on the hilltops than in the lower areas. Koli is the southernmost place in Finland where crown snow load occurs, which shortens the growing season as well as lowers the vegetation resistance to trampling (Nenonen 1990, Norokorpi 2000). Snow cover is typically about 90 cm on the top of hills and about 70 cm on the shores of Lake Pielinen (Kullberg and Lovén 2006). During spring, the snowmelt on the inclined paths is carrying material and causing erosion in natural as well as in man-made paths.

Data measurements

A path inventory was conducted in the autumn of 2005, as part of the NEST-Koli project (the Northern Environment for Sustainable Tourism). The inventory method had to be fast and simple due to the extensive path network and the fact that no previous information about the condition of the paths was available. This was the first path inventory made in the park, and it aimed to collect information regarding the condition of the paths (both man-made and natural), to define level of erosion as well as to suggest actions to repair the problems or damages found (e.g. repairing duckboards, building ditches). In this study we used 201 measurement points of natural paths from this path inventory data.

There was no previous information on the paths' conditions, therefore, based on visual estimation of roots and stone exposure and soil loss [a method modified from Jewell and Hammitt (2000)], every natural path was divided into sections based on the erosion criteria, according to the classification presented in Table 1. In addition to this classification, a new section was added based on the following criteria: change in the slope of more than 7°, visually evident change in the rate of erosion (width or depth), and a noticeable change in the terrain/vegetation type. The resulting sections were considered homogeneous, and measurements were then taken for each of the sections defined in each path. At least one measurement was taken for each section, and in case of long sections, several measurements were taken. The information collected per section were: erosion class, vegetation type, terrain type, and possible action to be taken to fix damages (e.g. building stairs). Inside the sections, at each measurement point measurements of the paths width, depth and slope were performed. Each measurement point was marked on the path map along with its distance from the beginning of the path. A wire gauge measure was used to calculate the distances and base maps (1:20 000) were used as a background reference.

The path width was measured to the disturbed edges of the path, while the path depth was measured at the deepest point of the path at the measurement point. Slope was the general slope of the path close to the measurement point, and the vegetation types were recorded around the path. The forest site types follow Cajander's (1949) classification. In general, paths were located in the forest types OMT (*Oxalis–Myrtillus* type, includes groves), MT (*Myrtillus* type), and VT (*Vaccinium* type). Forest on bedrock areas were classified as rocky-site forest. Paths crossed also other vegetation types, such as meadows and slash-and-burn areas, which were combined for the analysis given the small amount of measurements and the similar characteristics between them (both are resulting from human influence and covered by wide grass vegetation). Estimations on the number of visitors on different paths were based on long-term observations by the park administrators. The number of visitors was estimated per year. For natural paths, the estimation varied from 300 to 7000 visitors per year. Except for the two new paths, information of how long the paths have been in use was not available.

Digital data

For the topography of the terrain, a digital terrain model (DTM) with a 2.5-m resolution was used. The DTM provided the elevation of each measurement point, using the spatial analysis tools of ArcGis 9.2. To obtain soil types, the geological map of soils 1:20 000 (Huttunen *et al.* 2003) was scanned, geo-referenced and digitized. The resulting soil information was combined with the path database based on spatial location. According to the soil map, paths were on three different soil types: moraine, bedrock and thin soils.

Statistical methods

The width and depth of the paths were used as predicted variables of erosion. Simple correlations were performed for the continuous variables (slope, elevation, number of visitors) *versus* the predicted variables. The variable number of visitors was transformed using the square root in order to adjust it for the linear model. Mean comparisons, based on ANOVA were performed for the categorical variables. Post-hoc analyses were performed for the width of the path, to identify which of the classes, from each nominal variable, were different. Due to the heterogeneous variances reported in the first ANOVA tests (Table 2), Tamhane's test was used to determine the actual differences between the groups.

After the preliminary analysis, models for erosion were constructed. The criteria to include

Table 1. Erosion intensity classification used for defining the path condition.

Erosion class	Estimation of the intensity of erosion on a natural path
0	Path barely distinguishable: minimal disturbance of vegetation, over grown path
1	Path obvious: vegetation worn away, minimal disturbance of organic litter
2	Vegetation cover lost, soil visible
3	Soil erosion evident, stones and tree roots exposed, gullying

the variables were to represent the erosion features, aiming at identifying the main factors affecting path width and depth, to contribute to a higher model's predictive value and to be significant at the 0.05 level. The models were made using ordinary least squares.

Results

The path erosion inventory resulted in 51 natural paths, whose length varied from 40 to 2700 m (mean 636 m). These paths were divided into 92 sections (1–8 sections per path) for which the erosion class was defined, and 201 measurement points of the path width and depth were taken (Table 3). The least eroded paths in the park located on meadows, where the mean width and depth of the paths were 33 cm and 2 cm, respectively. The most eroded paths were on rocky sites, where the mean width varied from 30 to 300 cm, the average being 140 cm.

The widest (up to 300 cm) natural paths having an estimated 7000 visitors per year were located on the top of the hills. Additionally, on the hill tops there were many short side paths to viewpoints. The deepest point (42 cm) of all the natural paths was measured on a 25° slope, on moraine soil and the OMT forest type, where the number of visitors was estimated to be only 1000 per year. This path was located straight along the slope, which allowed the water to flow along the path,

Table 2. One-way ANOVA means and significances (p) for different vegetation and soil classes for path's width and depth (top section) and results of post-hoc Tamhane's test (bottom section) for the path's width.

Variable	Mean square between groups	F	p
Soil type (width)	55411.42	25.95	< 0.001
Soil type (depth)	39.33	1.28	0.281
Vegetation types (width)	32102.61	15.53	< 0.001
Vegetation types (depth)	42.64	1.39	0.237

	OMT	MT	VT	Meadow
MT	5.07 (p = 0.999)			
VT	25.77 (p = 0.023)	20.70 (p = 0.041)		
Meadow	–36.07 (p < 0.001)	–41.14 (p < 0.001)	–61.84 (p < 0.001)	
Rocky	70.90 (p = 0.001)	65.82 (p = 0.002)	45.13 (p = 0.078)	106.96 (p < 0.001)

Table 3. Distribution of erosion classes and maximum, minimum and mean values for each class width and depth on natural paths, and number of measurement points and maximum, minimum and mean values of path width and depth in different vegetation types in Koli.

	No. of sections	Measurement points	Width (cm)			Depth (cm)		
			min	max	mean	min	max	mean
Erosion class								
0	9	11	20	40	31.36	0	7	1.27
1	36	81	30	135	58.40	0	12	3.95
2	36	84	30	240	107.29	0	17	5.98
3	11	25	65	300	131.60	0	42	13.44
Vegetation type								
OMT	11	28	30	170	69.82	0	42	5.75
MT	41	91	20	180	74.89	0	30	5.81
VT	20	46	50	200	95.59	0	22	6.85
Rocky forest	15	28	30	300	140.71	0	20	5.39
Meadow	6	8	25	40	33.75	0	7	2.00

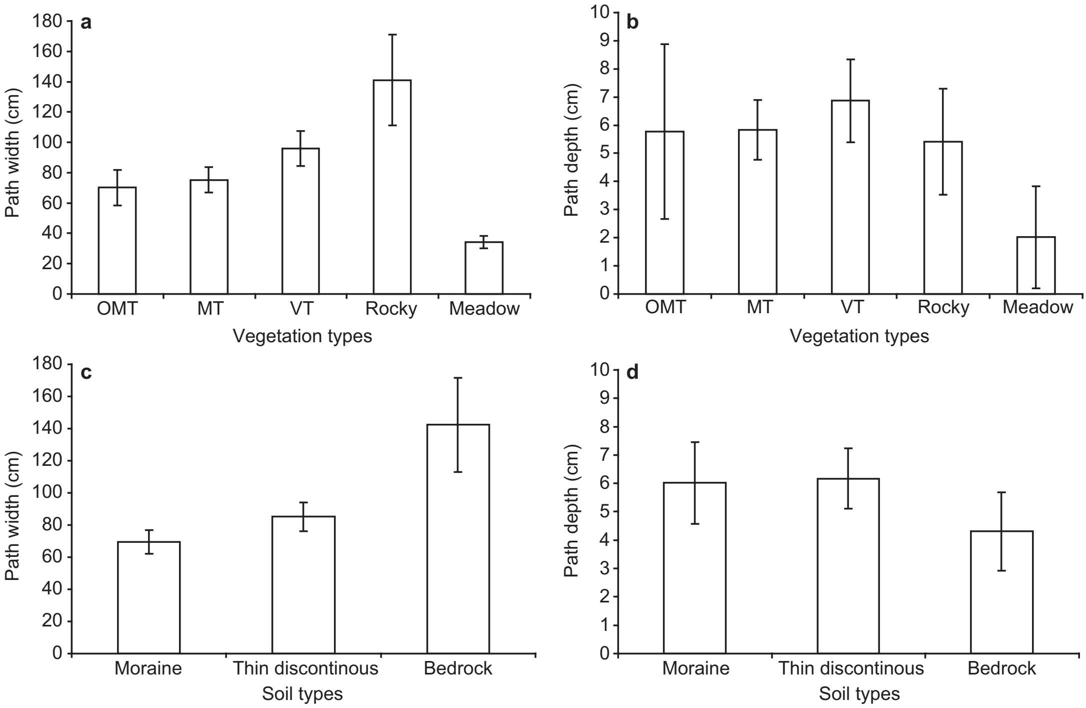

Fig. 1. Average path width (**a** and **c**) and depth (**b** and **d**) according to vegetation types (**a** and **b**) and soil types (**c** and **d**). The error bars are 95% confidence intervals.

working as a ditch. There was a clear evidence of water induced erosion observed on the path.

According to the calculated correlations, slope, elevation and number of visitors affected significantly the path's width (Table 4). In the case of depth, elevation was not significant, and the correlation coefficients were lower. Paths on meadow were significantly narrower as compared with paths in the forest. The paths' were narrowest in the OMT forest and widest in rocky-site forests. Additionally, the paths were narrowest on moraine soil and widest on bedrock (Fig. 1 and Table 3). According to the ANOVA test, there are significant differences in path width in different forest types and soil types, but differences in depth are not significant (Table 2). Based on this, the resistance of forest types would decrease in the order OMT, MT, VT with rocky-site forest being the least resistant.

These results indicated significant differences in width among the soil and forest types. These two variables are not independent from each other, as soil type determines, to a certain extent, the vegetation of the area (Vuolanto and Tuhkanen 1982). Therefore, two models for path width were created: the first (Eq. 1) was based on soil types, and the second (Eq. 2) on forest types: The path-depth model was based on soil types (Eq. 3). The models are as follows:

$$\begin{aligned}\text{width}_i = \beta_0 + \beta_1\text{SLOPE}_i + \beta_2\text{ELEVATION}_i \\ + \beta_3\text{VISITOR}_i + \beta_4\text{MOR}_i + \beta_5\text{THIN}_i + \varepsilon_i\end{aligned} \quad (1)$$

$$\begin{aligned}\text{width}_i = \beta_0 + \beta_1\text{SLOPE}_i + \beta_2\text{ELEVATION}_i \\ + \beta_3\text{VISITOR}_i + \beta_6\text{MEADOW}_i \\ + \beta_7\text{OMT}_i + \beta_8\text{MT}_i + \beta_9\text{VT}_i + \varepsilon_i\end{aligned} \quad (2)$$

Table 4. Pearson's *r* and significance (*p*) in the regressions for slope, elevation and visitors, *versus* width and depth on natural paths.

Parameters	Width		Depth	
	r	*p*	*r*	*p*
Slope	0.536	< 0.001	0.329	< 0.001
Elevation	0.327	< 0.001	0.032	0.701
Square root of visitors	0.416	< 0.001	0.176	0.012

$$\text{depth}_i = \beta_0 + \beta_1\text{SLOPE}_i + \beta_3\text{VISITOR}_i + \beta_4\text{MOR}_i + \beta_5\text{THIN}_i + \varepsilon_i \quad (3)$$

where 'width' is the width (cm) and 'depth' is the depth (cm) of the natural path at point i, SLOPE is the slope (in degrees) measured in the field along the path at point i, ELEVATION is the elevation of the path at point i (expressed in m a.s.l.), VISITOR is the square root of the number of visitors at point i, MOR (moraine) and THIN (thin and discontinuous soils) are dummy variables for soil types as defined by the soil map (Huttunen *et al*. 2003) at point i. MEADOW, OMT, MT and VT are the different vegetation types, taken rocky site forest as a reference value since it had the widest paths. These variables were treated as dummies, at point i. Parameters β_0–β_9 (Eqs. 1–3) are the estimates of the parameters for each variable (Table 5), ε is the between-measurement error term, normally distributed, and with mean = 0 and variance σ_i.

The coefficients of determination were 0.51 (Eq. 1), 0.47 (Eq. 2) and 0.16 (Eq. 3). The best model for width (Eq. 1) included slope, elevation, square root of the number of visitors and soil types. Vegetation types classification made in the field was giving significant results as well. Different estimations were made using the models (Eqs. 1 and 2) in order to simulate nature's resistant to recreational pressure (number of visitors). The predictions are showing the estimated development of path width on different sites (Fig. 2). In the models slope was set to 7° and elevation to 200 m. Large differences in predicted path widths were noticed, depending on the soil and vegetation types or the path slope whereas smaller differences are revealed for different elevations.

Discussion

In this study, we analysed path erosion in national parks, using measurements from the Koli National Park in Finland. We found path slope, number of visitors, elevation and soil types as well as vegetation types to be variables affecting path erosion. The path's slope was the strongest variable explaining both width (27.8%) and depth (10.7%) of the paths, which was also found by Coleman (1981). We found meadows to be most resistant to path erosion; there paths were the narrowest as well as the shallowest. The widest paths were at rocky sites and the deepest in VT forests and on moraine soil. Our results regarding the forest type resistance were similar to previous studies (e.g. Kellomäki and Saastamoinen 1975, Kellomäki 1977a, Malmivaara-Lämsä *et al*. 2008b): VT and rocky forest seem to be less resistant than more fertile site types, where no clear difference between the OMT and MT forest types was found. The means of paths' width (OMT 69.82 cm and MT 74.89 cm) suggest that probably OMT could be more resistant than MT, which could be due to herbaceous plants having stronger growth rates with

Table 5. Estimates, standard errors (SE) and significances (p) for the parameters of the models for predicting path width (Eqs. 1 and 2) and path depth (Eq. 3).

	Eq. 1			Eq. 2			Eq. 3		
Parameters	Estimate	SE	p	Estimate	SE	p	Estimate	SE	p
β_0	26.311	16.517	0.113	22.194	20.147	0.272	–1.952	1.599	0.224
β_1	3.666	0.439	< 0.001	3.800	0.461	< 0.001	0.299	0.061	< 0.001
β_2	0.135	0.064	0.035	0.167	0.069	0.017			
β_3	0.730	0.168	< 0.001	0.483	0.184	0.009	0.047	0.022	0.031
β_4	–46.453	8.930	< 0.001				3.091	1.141	0.007
β_5	–38.585	8.049	< 0.001				2.996	1.130	0.009
β_6				–44.225	16.642	0.009			
β_7				–38.068	12.586	0.003			
β_8				–34.242	9.415	< 0.001			
β_9				–25.198	10.081	0.013			
σ_i	1302.396	129.915	< 0.001	1391.020	138.756	< 0.001	25.902	2.584	< 0.001

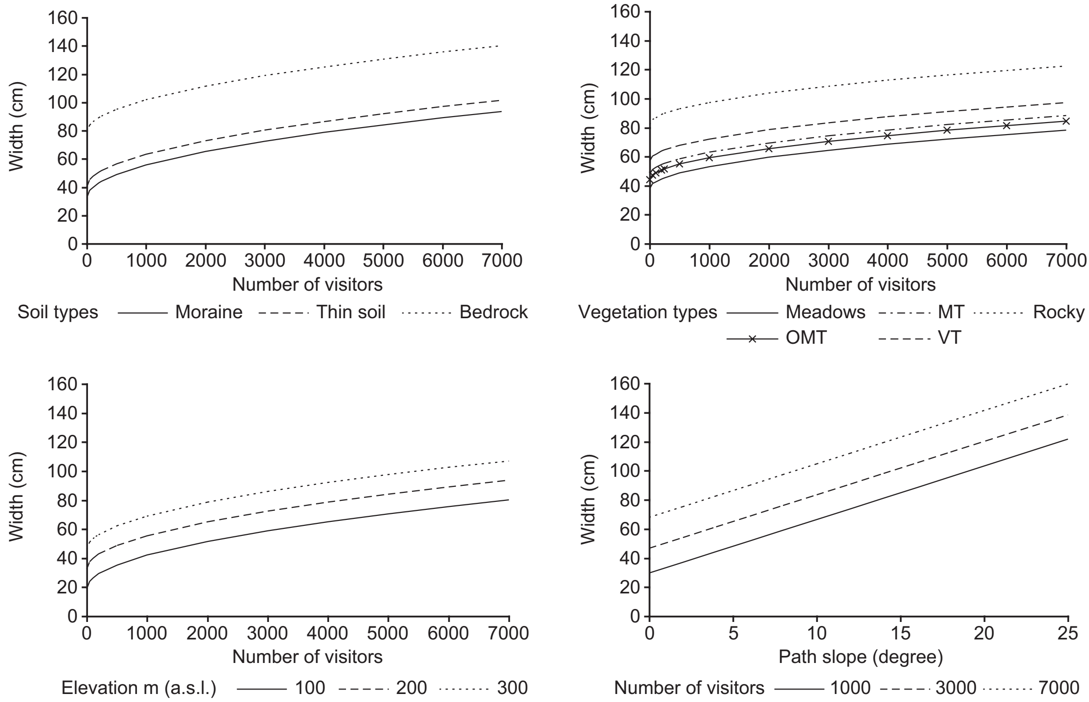

Fig. 2. Predicted widths of natural paths predicted by the models (Eqs. 1 and 2), for different numbers of visitors on the paths, for different soil and vegetation types, elevation, and path slope.

higher resilience (Vuolanto and Tuhkanen 1982, Emanuelsson 1984, Cole 1995, Malmivaara-Lämsä *et al*. 2008b). However, this is only evident in long-term trampling experiments, since in short term trampling experiments, the OMT forest type was not the most resistant (Kellomäki and Saastamoinen 1975, Kellomäki 1977a).

Soil types were all significantly different in path width. Stony and rocky soils have excellent resistance to erosion but on the other hand, vegetation in these areas is worn away extremely easily (Vuolanto and Tuhkanen 1982, Jämbäck 1996) leading to the widening of the paths. In Koli the widest paths were located on the bedrock areas of the hill tops. As soil types are also partly explained by elevation; bedrock and rocky sites are on the hilltops whereas moraine is dispersed at lower elevations between the hilltops. In the soil map, the bedrock areas and the rocky forest site are basically the same, both located on the tops of the hills, where lichen and dwarf shrubs grow, which are very sensitive to trampling (Vuolanto and Tuhkanen 1982, Törn *et al*. 2009). Elevation explains more the path width in the model with vegetation types, which could be a result of the vegetation resistance being lower in the higher areas where the growing season is shorter. Vegetation types were not correlated with elevation as clearly as soil types. Although the model performed better with soil types as a predictor, we think that vegetation types can be of higher utility as a predictor.

Based on our study, path erosion can be modelled, although models are better for predicting width of the path than its depth. Both width models had quite high R^2 (0.51 and 0.47, respectively) whereas the depth model explained only 16% of the variation. The low explanatory power suggests that there are other factors affecting the paths' depth which were not included in our study. For instance, running water is a powerful eroding factor (Coleman 1981, Brinker and Tufts 1995, Morgan 2005), and some studies show strong correlation between path erosion and precipitation (Garland 1987). In Koli, most of the deepest paths were at the bottom of steep slopes, and in many places water-caused erosion was evident. Paths going directly across steep slopes are likely to channel water from surroundings. The steeper the slope, the higher the velocity of water and its capacity to carry material becomes (Brinker and Tufts 1995, Morgan 2005). In future, a more detailed study of path deepening would require the establishment of a field experiment to measure the amount of soil particles carried by overland flow (Morgan 2005, Blanco and Lal 2008) or inclusion of precipitation variables in the model. Management action to prevent water-caused deepening of paths can include water barriers and ditches (Agate 2001, Morgan 2005) which were also suggested in the path inventory report of Koli National Park.

The number of visitors was an important factor in determining the level of erosion. However, a main limitation in modelling erosion caused by visitors is that there is no extensive information about how long paths have been in use by hikers and the exact number of visitors in different areas and during different periods. Koli has been a destination for tourists for more than a hundred years and people have been living in Koli area since the 17th century (Martikainen *et al*. 2006) so it is difficult to evaluate the paths age. Often it is impossible to determine the number of visitor passing, except in controlled trampling experiments (Kellomäki 1973, 1977a, Kellomäki and Saastamoinen 1975, Weaver and Dale 1978, Emanuellson 1984, Cole and Bayfield 1993, Cole 1995, Littlemore and Baker 2001). In many studies, numbers of visitors are based on yearly estimates made by park workers (e.g. Törn *et al*. 2009) or estimation is based on the number of resident's around the study area (Malmivaara-Lämsä 2008b). At the time of this study, two paths in the park had visitor calculators since their establishment (for two years) which could be used in future for assessing the impact of visitors. The method used in this study can provide adequate estimates, and the analysis indicates that the obtained numbers of visitors explained the path width and depth significantly, which supports the claim that the estimates are probably indicative of the real values.

This study presents tools to understand and evaluate the process of erosion on natural paths, based on measurements combined with digital data. The combination of different sources of data demands many steps and processes where errors could have occurred. We acknowledge that these errors could affect soil type and elevation variables, which were taken from the digital data sets. However, the results show strong effects of the variables studied on path erosion. The methodology applied here has been shown to be an easy tool for evaluating condition of paths and hence it can be used in future studies.

In addition to the variables analysed here, a number of other factors (e.g. precipitation, type of recreational activity, etc.) can affect the rate of path erosion and deterioration of the vegetation (Weaver and Dale 1978, Coleman 1981, Jämbäck 1996, Agate 2001, Törn *et al*. 2009). When studied separately, effects of each factor can be shown, but the combination of the different effects is a difficult issue to study. Furthermore, there is a significant lack of measurement-based literature that would suggest proper approaches to path erosion modelling (Coleman 1981), although many methodologies to measure eroded areas have been developed (Hoogesteger 1976, Cole and Bayfield 1993, Karjalainen 1994, Rautio *et al*. 1999, Jewell and Hammitt 2000). In our study, the combination of different factors, created by models, clearly helps to identify main factors affecting path erosion, and how strongly they influence the rate of erosion.

Conclusions

The location of paths is important, especially in national parks when considering the effect of trampling. Koli National Park has an important status in the national landscape, where lakes, forest and hills and meadows attract hikers. The studying of path erosion is, therefore, fundamental for managing the National Park. The number of visitors is not the only factor that explains why some places are more eroded than others, since the same amount of visitors have different effects, depending on the resistance of nature to trampling.

This study offers a detailed inventory of the paths in Koli, as well as tools to study and quantify the evolution of erosion on those paths. Findings of this study show that many paths on the hilltops are badly worn out, most of the vegetation has disappeared and bedrock is exposed. The most resistant places are courtyards and meadows where the narrowest and shallowest paths were identified. In addition, slash-and-burn areas would probably be good places for paths, since they are also attractive to tourist and, at the same time, are highly resistant to trampling. Slope is affecting vegetation resistance, both because of the impact of hikers, and because of other factors such as water erosion. In general, slope was the main factor indentified as the one explaining variations in path width and depth in Koli National Park.

Careful planning of the location of paths on steep slopes is vital in order to prevent future path erosion, for both minimizing erosion and to increase the safety of future potential visitors. These problems can be addressed by e.g. constructing fences and stairs. Elevation affects the rate of crown snow occurrence and shortening the growing season. This makes vegetation more sensitive to trampling, which explains the wide paths in those areas. Vegetation recovery from trampling at higher elevations takes more time, yet these higher areas are attractive to hikers because of their landscape views.

It is difficult to predict in which areas paths are likely to be eroded, since there are many factors involved. However, the modelling approach presented in this study is a good tool to estimate erosion, and to understand the natural processes involved. Although our models cannot fully explain all factors related to the erosion of the paths, they may serve as an indication of what ought to be done, and can help the planning of corrective measures in order to minimize erosion and to improve the management of conservation areas. In addition the models can be used to make predictions of path erosion in order to construct erosion maps, which can be used as a tool to evaluate possible risks and to help the future planning of the path networks.

Acknowledgements: Financial support and facilities for this project was provided by the Finnish Forest Research Institute (METLA) and the Onnenmäki Foundation. The path erosion measurement was part of the sustainable tourism NEST-Koli project, financed by the Northern Periphery Program. We thank the National Park's former director Mr. Lasse Lovén and co-workers, who helped in the data collection, Dr. Alfred Colpaert and Dr. José Ramón González Olabarria as well as the anonymous reviewers for their valuable comments, and Dr. David Gritten for the linguistic revision of the manuscript.

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