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TRAMPLING TOLERANCE OF FOREST VEGETATION

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Seppo Kellomäki and Varpu-Leena Saastamoinen

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SEPPO KELLOMÄKI AND VARPU-LEENA SAASTAMOINEN

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PREFACE

This work is part of a larger study in which an attempt has been made to clarify the ecological effects of recreation on terrestial ecosystems. The study has been carried out under the guidance of professor Antti Haapanen, Head of the Department of Environmental Conservation, Helsinki University.

The effects of recreation on ground vegetation of different types of forest stands have been dealt with in this study. The study was carried out at the Forest Training Station of Helsinki University with the permission of Dr. Juhani Sarasto, the Head of the Station. Professor Antti Haapanen has suggested many beneficial changes and modifications to the manuscript. The study has been financed with scholarships awarded by the Council of Man and Biosphere of the Finnish Academy and the Foundation for Research of Natural Resources in Finland. The translation from Finnish into English was carried out by John Derome, B. Sc.

We wish to thank all those who have assisted us.

Helsinki 1975

THE AUTHORS

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INTRODUCTION

Deterioration and destruction of the ground vegetation is perhaps the most visually evident change caused by the recreational use of natural areas (e.g. Frissel & Duncan 1965; LaPage 1967). Ground cover which has deteriorated reduces the biological attractiveness of a recreation area and lowers its aesthetic value (e.g. Goldsmith & al. 1970). A deteriorated ground cover also indicates that ecological changes have taken place in the soil. In the case of a forested area they can be reflected for instance in tree growth (Düggeli 1937; Lutz 1945; LaPage 1962; Settergren & Cole 1970).

Different types of natural and managed areas are able to withstand recreational use to a varying degree and in this sense have a different ecological capacity (e.g. Holmström 1970). The ecological capasity refers to the physical and biological ability of the recreation environment to withstand recreational use. The ecological capacity restricts the amount and the type of recreation use for which an area intended for recreation can be used. It forms one of the premises of prime importance in the planning and management of recreation areas (cf. e.g. Wagar 1964; Jacsman 1971).

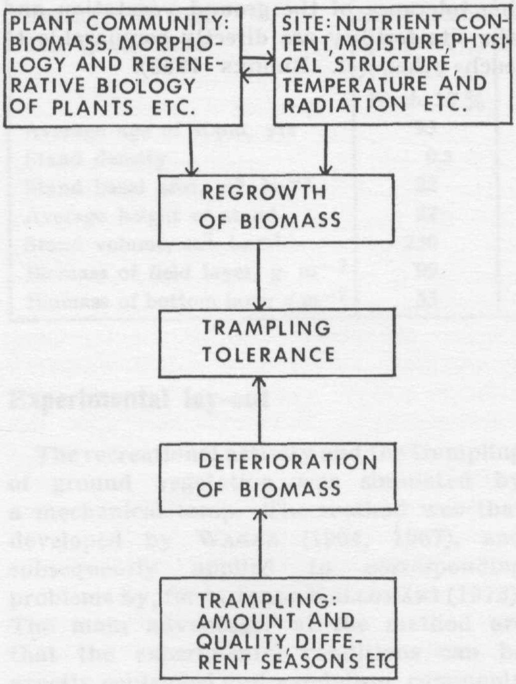

Figure 1. Factors effecting on the trampling tolerance of ground vegetation.

Trampling tolerance of the ground vegetation, i. e. its ecological capacity, is a dynamic concept determined by a variety of different factors. The factors which have the greatest effect on the trampling tolerance of the ground vegetation are depicted in the following model (Fig. 1). According to the model, there are two main factors involved in the deterioration of ground vegetation; on one hand, the destruction of biomass resulting from trampling, and on the other hand the regeneration of biomass (e.g. Holmström 1970; Kellomäki 1973). The dynamic relationship between deterioration and regeneration is affected for instance by the quality and the quantity of the trampling and its seasonal time pattern. The regeneration of the biomass is affected by many site factors, the most important ones being the nutrient level, moisture content and structure of the soil, and the light and temperature conditions of the site (e.g. Bates 1935; Wagar 1964; Holmström 1970). The most important biotic factors connected with the plant community subjected to trampling, are the morphological, organological and reproductive characteristics of the individual plant species, and the total biomass of the ground vegetation (Bates 1935; LaPage 1967).

It has been found that the coverage and biomass of ground vegetation subjected to trampling shows a curvilinear decrease with an increase in the amount of trampling (cf. Wagar 1964; Frissel & Duncan 1965; Kellomäki 1973). LaPage (1967) observed that the deterioration of ground vegetation is usually at its greatest during the initial stage of the deterioration process (cf. also Hoogesteger 1974). When elucidating the trampling tolerance of ground vegetation in areas which have been in recreational use for a number of years, it has been found that the rates of destruction and regeneration of biomass gradually reach a state of equilibrium in which resistant secondary species adapted to the special conditions have replaced the original vegetation (e.g. Bates 1935; LaPage 1967). The number of different species in the new ecological system which develops is usually smaller than in the original plant community (George 1965).

In particular, many species of grasses (e.g. LaPage 1967; Holmström 1970) and also some herbaceous plants, for instance *Trifolium sp.*, *Plantago sp.* and *Taraxacum sp.* (cf. Steinbrenner 1951) have proved to be resistant to trampling and able to take the place of the original vegetation. Bates (1935) emphasises the significance of the morphological and reproductive factors associated with these species when giving an explanation for the varying trampling tolerances of different plant species. In general however, herbaceous plants as well as lichens have proved to be sensitive even to small amounts of trampling (LaPage 1967; Burden & Randersson 1970; Goldsmith & al. 1970; Holmström 1970; Willard & Marr 1970). In addition, the moss and dwarf shrub vegetation in forest areas is prone to such damage (e.g. Lutz 1945; Frissel & Duncan 1965; Holmström 1970; Kellomäki 1973). Since according to Brooks (1966) the trampling tolerance of the ground vegetation is directly dependent on the fertility of the site, it should be taken into account when determining the areas which should be used for different forms of recreation.

The aim of this study is to elucidate the trampling tolerance of the forest vegetation and the plants involved when subjected to recreational use of short duration. The trampling is simulated by a mechanical tamp (cf. Wagar 1964, 1967; Kellomäki 1973). Owing to the research method, only the effects of trampling on the ground vegetation can be examined in this study. Any changes in the tree stock and soil which may possibly arise as a result of trampling remain outside the scope of the study (cf. Düggeli 1937; Burger 1940; LaPage 1962; Magill 1963; Magill & Nord 1963). In addition, an attempt has been made to determine whether the trampling tolerance of the ground vegetation and the site fertility are directly comparable to each other (cf. Brooks 1966).

MATERIAL AND METHODS

Study areas

The study was carried out during 1972—73 at the Forest Training Station (60° 47′ N; 24° 18′ E) of Helsinki University. A group of stands representing different site types was selected for the study in the vicinity of the Station. A description of the stands is presented in Table 1. In addition, both natural and cultivated areas of grass were selected for comparison. The stands used in the study are to be found in an area where the annual mean temperature is on average — 3.0— +3.5°C, the effective temperature sum 1 100—1 200 dd and the annual mean precipitation 550—600 mm (Kolkki 1966; Helimäki 1967). The study was carried out an areas 1,2 and 3 during 1972, and 4 and 6 during 1973.

Table 1. Description of the study areas.

Stand characteristic	Study area 1	2	3	4	5
Soil type	Sand, moraine	Sand	Sand, moraine	Sand, moraine	Sand, moraine
Forest site type	*Myrtillus* site type	*Vaccinium* site type	*Calluna* site type	Cultivated grass area	Natural grass area
Development class	Mature stand	Mature stand	Middle aged		
Tree species ratio	Spruce 80 % Pine 10 % Birch 10 %	Pine 100 %	Pine 100 %		
Average age of stand, yrs	95	85	45		
Stand density	0.9	0.9	0.9		
Stand basal area, $m^2 . ha^{-1}$	22	20	8		
Average height of stand	22	19	9		
Stand volume, $m^3 . ha^{-1}$	230	180	40		
Biomass of field layer, $g. m^{-2}$	99	147	137		
Biomass of bottom layer $g.m^{-2}$	55	144	289		

Experimental lay-out

The recreational activity and the trampling of ground vegetation was simulated by a mechanical tamp. The method was that developed by Wagar (1964, 1967), and subsequently applied to corresponding problems by, for instance Kellomäki (1973). The main advantages of the method are that the experimental conditions can be exactly controlled and vandalism, commonly directed at the experimental equipment in an on-site study, can be avoided.

The mass of the tamp was 7.0 kg. It was dropped onto the sample plot from a height of 50 cm. As the surface area of the tamp was 2 500 cm^2, an energy impulse with a magnitude of 0.0137 J cm^{-2} was applied to the sample plot when the tamp was dropped. It was presumed that an impulse of this size corresponds to the energy impulse which reaches the ground vegetation in normal recreational trampling (cf. Kellomäki 1973).

The experiment was carried out using a completely randomised design (cf. e.g.

Mattila 1969). At the beginning of the study, a group of sample plots which were homogeneous as regards the ground vegetation and situated on sites level enough for the tamp was picked from within the study areas. The sample plots were each 50 × 50 cm in size. The following trampling levels replicated eight times were used on the sample plots within the forest covered study areas: 0, 4, 16, 32, and 64 drops of the tamp per plot per week. The experimental lay-out used in the grass covered study areas was essentially the same except that a trampling level of one drop of the tamp per week was employed in addition to the levels described above. Metal pins fixed at the corners of the sample plots ensured that the trampling was directed at the same area of vegetation every time the treatment was carried out. Treatment was carried out at equal intervals during the period 20. 6. – 31. 7. Since most of the annual growth had taken place before the start of the trampling, it can be presumed that growth of the ground vegetation had a negligible effect on the results and the ground vegetation was not at all as sensitive to trampling as at the beginning of the growth period.

Observations and measurements

Deterioration of the ground vegetation was studied by means of coverage and biomass. Coverage analysis of the sample plots was done both before and after the trampling treatment. The coverage analysis was carried out on an area 40 × 40 cm in size in the center of the sample plot, a 5 cm wide margin being left at the edges of the sample plot. However, the deterioration of the plant cover on the grass covered study area was determined only by means of biomass.

The effect of trampling on the biomass of the ground vegetation was determined by the harvested quadrat method (cf. e.g. Newbould 1967). The biomass of the vegetation on the sample plots before the trampling was calculated by means of regression equations developed by Kellomäki (1974, 1975), in which the results of coverage analysis were used as independent variables. However, in the case of the grass covered sample plots, the mean values of the biomass on the untreated sample plots were used as the basic values for the biomass of the sample plots which received the trampling treatment. Both the coverage and biomass analyses of the field and bottom layers were carried out separately.

Quality of the material

In order to obtain a general description of the complete ground vegetation of the stands under study, 100 sample plots 20 × 20 cm in size were randomly selected according to the method described by Kosonen (1969) in each of the stands. The results of the coverage analyses carried out on these sample plots are presented in Table 2. The corresponding information for the sample plots which received the trampling treatment are also included in this table.

According to the table the variance of the coverage of different species and species groups is rather large in respect to the corresponding mean values. It thus can be seen that many plant species exhibit a clear grouping characteristic in which different plants grow in a mosaic pattern (cf. Greig–Smith 1964, pp. 54–93; Odum 1971, pp. 205–207). However, this generalization should be treated with reservation since the effect of the size of the sample plot on the pattern is not known. *Vaccinium myrtillus* is the most noticeable exception as regards this mosaic growth pattern.

When the plant cover of the trampled sample plots in different stands is compared with the overall vegetation of corresponding study areas, it can be seen that the vegetation on the sample plots is underrepresented, especially as far as the dwarf shrubs is concerned. Although the variance for each species is quite large, the differences cannot however be shown to be statistically significant, even though they may have some practical significance when attempts are made to generalize about the results which are presented later on in this study.

Corresponding coverage analyses were not carried out on the grass covered study

Table 2. Ground vegetation of the forested study areas.

Species or group of species	Coverage, %					
	Study area 1		Study area 2		Study area 3	
	Sample plots	Whole area	Sample plots	Whole area	Sample plots	Whole area
DWARF SHRUBS						
Vaccinium myrtillus ……….	24.6 ± 23.1	42.8 ± 25.3	0.5 ± 1.9	0.4 ± 0.6		
Vaccinium vitis-idaea ………	3.3 ± 3.4	3.8 ± 4.3	5.7 ± 3.3	15.6 ± 11.7	10.8 ± 7.0	10.5 ± 7.4
Calluna vulgaris ……………			6.9 ± 10.5	15.1 ± 17.8	13.5 ± 15.2	12.2 ± 12.5
Empetrum nigrum …………			0.6 ± 2.5	6.1 ± 7.6		1.2 ± 4.5
Linnaea borealis ……………	1.0 ± 1.7	2·1 ± 4.3				
GRASSES						
Deschampsia flexuosa ……….	1.2 ± 2.2	2.2 ± 4.3				
Luzula pilosa ………………	<0.1	0.2 ± 0.6				
HERBS						
Melampyrum sp. ……………	0.3 ± 0.9	0.6 ± 2.5				
Maianthemum bifolium ……	2.0 ± 2.5	3.1 ± 2.9				
Goodyera repens ……………	1.5 ± 0.6	0.6 ± 1.7				
Trientalis europaea …………	<0.1	0.2 ± 1.3				
Oxalis acetosella ……………		0.1 ± 0.8				
MOSSES						
Hylocomium splendens ……	15.9 ± 29.5	11.0 ± 19.4	1.5 ± 7.1	1.7 ± 6.4		
Pleurozium schreberi ……….	47.1 ± 35.5	36.9 ± 35.4	65.1 ± 7.1	55.3 ± 35.3	46.4 ± 28.9	44.5 ± 33.1
Dicranum sp. ………………	19.9 ± 27.1	24.0 ± 30.1	26.2 ± 32.0	31.4 ± 33.9		
Other mosses ………………		<0.1		0.3 ± 1.2	<0.1	<0.1
LICHENS						
Cladonia sp. ………………				<0.1	32.9 ± 21.6	39.3 ± 29.4
Cladina sp. ………………						<0.1

areas as was done on the forested study areas. The cultivated grass area which was used in the study consisted mainly of cultivated grass species e.g. *Phleum pratense* etc. Only a few randomly occuring herbaceous plants were present. The most important grass species on the natural grass area were *Phleum pratense* and different *Poa* species. In this case however, herbaceous plants were dominant. The most commonly occuring species were *Alchemilla vulgaris*, *Vicia cracca*, *Rhinanthus sp.*, *Trifolium repens*, *Taraxacum officinale*, *Prunella vulgaris*, *Ranunculus acer*, *Plantago major*, *Achillea millefolium*, *Rumex acetosella*, and *Hypericum maculatum*.

It can be seen that the deterioration of plant species of the bottom layer in particular is greatly dependent upon the prevailing moisture conditions while the trampling treatment was being carried out. Since the material was collected during two separate growth periods, an attempt was made to control these factors by taking 9 random samples of vegetation from each stand when the trampling treatment was carried out, and immediately determining their moisture content in the laboratory. According to Fig. 2 there are clear differences in the moisture content of samples taken from different sites during the same growth period. On the *Calluna*

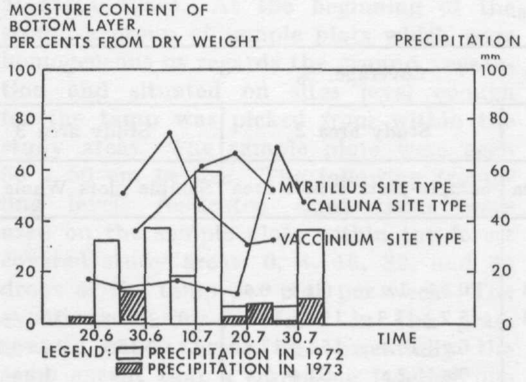

Figure 2. Moisture content of bottom layer (per cents from dry weight) of the study areas.

site type the bottom layer vegetation was also drier than the corresponding vegetation on the *Myrtillus* and *Vaccinium* site types throughout almost the whole trampling period.

Analysis of the material: the concept of trampling tolerance and the estimation of its values

The trampling tolerance of the ground vegetation can be defined as the ability of the plant cover to withstand trampling resulting from recreational use. On the basis of observations reported in the relevant literature the relationship between deterioration of plant cover and trampling is a curvilinear one (cf. e.g. Wagar 1964; LaPage 1967; Holmström 1970; Kellomäki 1973). Now it can be assumed that each time the tamp falls on the plant cover a certain amount of the plant cover under study is destroyed. The trampling tolerance is assumed to be specific for each type of plant species and plant cover. The coverage and/or biomass of the vegetation falls from the original level at a rate determined by the deterioration function shown as a curve in Fig. 3. This hypothesis can be expressed in mathematical terms as follows (Kellomäki 1973):

(1) $y_i = P^j x_i + e_i$, where

y_i = coverage (or biomass) at the end of the trampling period

x_i = coverage (or biomass) at the beginning of the trampling period

P = a parameter which expresses the coverage (or biomass) after one tramping impulse

j = amount of trampling

e_i = error term

Parameter P thus expresses the trampling tolerance specific for the plant species or the whole plant cover under study. It can be quantified by the method of the least squares (Hald 1952, pp. 207–245) according to equation (2):

$$(2) \quad \sum_{i=1}^{n} (P^j x_i - y_i)^2 = \sum_{i=1}^{n} e_i^2$$

How well the assumed relationship between deterioration of ground cover and trampling corresponds to the real situation can be tested by comparing the coverage or biomass values estimated from a model with the corresponding observed values. If the results given by the model prove to be satisfactory, then parameter P can be used for instance for ranking different forms of vegetation according to their trampling tolerance.

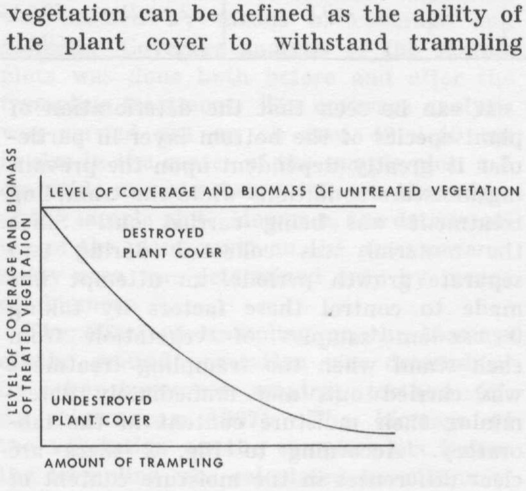

Figure 3. Theoretical relationship between deterioration of plant cover and trampling.

RESULTS

The trampling tolerance of different forest plant species

The trampling tolerance of some of the most important forest plant species, calculated from their coverage values, is presented in Table 3 by plant communities. As expected, the trampling tolerance of lichens is lower than that of other plants growing in the same plant community, and in particular lower than that of plants growing on moister sites. In general, it appeared that the trampling tolerance of the same species growing on different sites decreased when moving from moist sites to dry ones. The only notable exception to this is *Vaccinium vitis-idaea* which shows the greatest trampling tolerance on a site of the *Vaccinium* type. This is presumably due to the fact that this site represents optimal conditions as far as growth of the plant is concerned. The structure of its foliage is thus very resistant to trampling. In particular, the leaves of *Vaccinum vitis-idaea* plants which are growing on a site of the *Myrtillus* type are rather succulent and more prone to trampling damage. In general it may be true that both the external characteristics of members of a plant community and site factors, together determine their trampling

Table 3. Trampling tolerance (P-values) of some forest plant species or groups of species, and correlation between calculated and observed coverage values after trampling treatment.

Forest site type	Species or group of species	P	Correlation between calculated and observed coverage values	
			r	r^2
Myrtillus site type	*V. myrtillus*	.970	.773	.597
	V. vitis-idaea	.987	.961	.923
	L. borealis	.981	.986	.972
	Grasses	.992	.985	9.70
	Herbs	.970	.952	.906
	H. splendens	.987	.689	.475
	P. schreberi	.986	.887	.787
	Dicranum sp.	.991	.903	.815
Vaccinium site type	*V. vitis-idaea*	.989	.976	.952
	C. vulgaris	.976	.832	.692
	P. schreberi	.974	.922	.850
	Dicranum sp.	.973	.963	.927
Calluna site type	*V. vitis-idaea*	.879	.962	.925
	C. vulgaris	.865	.947	.897
	P. schreberi	.881	.847	.717
	Dicranum sp.	.894	.892	.796
	Lichens	.493	.911	.830

tolerance in such a way that both factors are strongly dependent upon each other.

The proposed curvilinear relationship between deterioration of the plant cover and trampling appears to correspond to the real situation, since the correlations between the calculated and observed coverage values of the plant species studied are relatively high. The most important exceptions are *Vaccinium myrtillus* and *Hylocomium splendens* growing on a site of the *Myrtillus* type. The rate of deterioration for these species may be faster than would be presumed from the proposed curvilinear relationship between deterioration and trampling. However, whether or not the supposed linear relationship between deterioration and trampling would have given better results has not been studied more closely. Since the material used in this study is rather small, a number of random factors such as observation errors and exceptional strong trampling caused by the unevenness of the sample plots can also distort the results.

In order to test the statistical significance of the differences observed in the trampling tolerance between plant species, the trampling tolerances for each plant species on each sample plot was estimated and used to calculate the values of the test variable. The test was carried out using a t-test, and the results are presented in Tables 4 and 5. Comparisons have been made within the same forest site type and between different forest site types.

The trampling tolerance of different plant communitis

The trampling tolerance for those forest plant communities studied, calculated on the basis of coverage, are presented in Table 6. The first thing that these results show is that the vegetation of the bottom layer has been, especially on a site of the *Myrtillus* type, more resistant than any other type of vegetation studied. The bottom layer vegetation which has been damaged to the greatest extent has been found on a site of the *Calluna* type. The reason for the fast rate of deterioration in this case lies, apart from in the moisture content of the soil prevailing during the trampling, also in the quality of the plant

Taple 4. Statistical significance[1]) of the differences between trampling tolerance of some forest plant species according to coverage. Field layer.

Forest site type	Species or group of species		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Myrtillus site type	*V. myrtillus*	(1)									
	V. vitis-idaea	(2)									
	L. borealis	(3)	**	*							
	Grasses	(4)	*	*							
	Herbs	(5)			*	*					
Vaccinium site type	*V. vitis-idaea*	(6)									
	C. vulgaris	(7)				**					
Calluna site type	*V. vitis-idaea*	(8)			***	***		**	**		
	C. vulgaris	(9)		*	***	***		***			

[1]) *: $P < 0.05$
**: $P < 0.01$
***: $P < 0.001$

Table 5. Statistical significance[1]) of the differences between trampling tolerance of some forest plant species according to coverage. Botton layer.

Forest site type	Species or groups of species		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Myrtillus site type	*H. splendens*	(1)								
	P. schreberi	(2)								
	Dicranum sp.	(3)								
Vaccinium site type	*P. schreberi*	(4)								
	Dicranum sp.	(5)								
Calluna site type	*P. schreberi*	(6)	**	***	*	***	**			
	Dicranum sp.	(7)			*		*			
	Lichens	(8)	**	***	**	***	***		*	

[1]) *: $P < 0.05$
**: $P < 0.01$
***: $P < 0.001$

cover. For this reason the abundance of lichen vegetation on this site should be kept in mind. As had been expected a lichen cover proved to be rather susceptile to trampling (cf. HOLMSTRÖM 1970; WILLARD & MARR 1970).

The vegetation typical of the *Calluna* site type, as far as the field layer is concerned, was also damaged to a greater extent than the other types of forest vegetation studied. On the other hand, the vegetation typical of the *Vaccinium* site type proved, contrary to what had been hypothesised, to be more resistant than the plant cover typical of the *Myrtillus* type. Since the tolerance values were estimated in this case on the basis of the coverage, it seems likely that the differences are due to the differences in the trampling tolerance of *Vaccinium myrtillus* and *Vaccinium vitis-*

Table 6. Trampling tolerance (P-values) of field and bottom layers of different forest site types, and correlation between calculated and observed coverage values after trampling treatment.

Forest site type	Horizontal strata	P	Correlation between calculated and observed coverage values	
			r	r^2
Myrtillus site type	Field layer	.974	.865	.748
	Bottom layer	.987	.885	.783
Vaccinium site type	Field layer	.982	.983	.968
	Bottom layer	.973	.952	.907
Calluna site type	Field layer	.835	.936	.877
	Bottom layer	.818	.739	.546

idaea (cf. Tables 1 and 2). Thus the observed differences may be due to morphological and anatomical differences in the leaves of these species.

When the vegetation of the field and the bottom layer from the same sites are compared, it can be seen that the trampling tolerance of the bottom layer is greater than that of the field layer on a site of the *Myrtillus* type. However, on poorer sites this relationship has been quite the opposite. The results correspond, as far as vegetation of a site of the *Myrtillus* type is concerned, with earlier observations made by Kellomäki (1973). Differences in trampling tolerance between the individual species of the plant communities should explain the observed phenomenon. The susceptibility of *Vaccinium myrtillus* leaves to trampling should above all be stressed as has earlier been pointed out in the above-mentioned publication.

The trampling tolerance of the plant communities has also been studied on the basis of the changes taking place in the biomass of the plant communities. According to Table 7 somewhat higher P-values were obtained in this way. These results, however, do not at all change the picture given by coverage of the trampling tolerance of the plant communities under study. The differences between these two methods are caused by the fact that parts of the shoots weakly resistant to trampling and essential from the point of view of coverage, are nonessential as far as the total biomass of the plant cover is concerned (cf. e.g. Kellomäki 1974, 1975). On the other hand, the coverage and biomass of the vegetation are rather strongly intercorrelated, while the trampling tolerance of the vegetation remains similar no matter from which aspect it is looked at.

The trampling tolerances of cultivated

Table 7. Trampling tolerance (P-values) of ground vegetation of different study areas, and correlation between calculated and observed biomass values after trampling treatment.

Forest site type	Horizontal strata	P	Correlation between calculated and observed biomass values	
			r	r^2
Myrtillus site type	Field layer	.992	.893	.797
	Bottom layer	.993	.909	.826
	Total biomass	.993	.774	.599
Vaccinium site type	Field layer	.994	.930	.865
	Bottom layer	.975	.915	.837
	Total biomass	.983	.967	.935
Calluna site type	Field layer	.930	.954	.910
	Bottom layer	.865	.894	.799
	Total biomass	.896	.925	.857
Cultivated grass area	Total biomass	.980	.929	.863
Natural grass area	Total biomass	.740	.938	.879
Cultivated and natural grass areas together	Total biomass	.969	.887	.787

and natural grass areas are also presented in Table 7. The results show that the cultivated grass area was more resistant to trampling than the natural grass area. Differences between these two plant communities are probably caused by differences in the quality of the plant community. The abundance of herbaceous plants in natural grass vegetation must also be kept in mind. On the other hand, it is somewhat surprising that the grass vegetation, which usually is considered to be rather resistant, had a lower trampling tolerance than even the vegetation typical of the *Vaccinium* site type. When attempting to explain this phenomenon, short and longer term trampling should be dealt with separately. LaPage (1967) for instance has observed that damage to the plant cover of grass dominated vegetation is very thorough during the first year it is subjected to trampling. However, grass species subjected to trampling of longer duration appear to be more resistant than other plant species and are easily adaptable to a changing environment. The low trampling tolerance of grass vegetation which was found in this study may be a result of the experimental technique used, or else the fact that only short term trampling was studied.

The curvilinear form proposed for the relationship between deterioration of plant cover and trampling appears to correspond satisfactorily with the real situation, since the correlation between the calculated and observed coverage and biomass values of the plant communities are in many cases relatively high (Tables 6 and 7). When coverage is used, the degree of determination for the bottom layer of a site of the *Calluna* type is lower than for the corresponding vegetation of other sites. The rate of deterioration of this vegetation layer may be faster than the proposed curvilinear relationship between deterioration and trampling would indicate. When calculations are made on the basis of biomass, satisfactory results are also obtained in this case. The possible effect of observation

Table 8. Statistical significance1) of the differences between trampling tolerance of ground vegetation of forested study areas according to coverage.

Forest site type	Horizontal strata	(1)	(2)	(3)	(4)	(5)	(6)
Myrtillus site type	Field layer (1)						
	Bottom layer (2)						
Vaccinium site type	Field layer (3)						
	Bottom layer (4)						
Calluna site type	Field layer (5)	*	***	***	**		
	Bottom layer (6)	**	***	***	*		

1) *: $P < 0.05$
**: $P < 0.01$
***: $P < 0.001$

Table 9. Statistical significance[1] of the differences between trampling tolerance of ground vegetation of different study areas according to biomass.

Forest site type	Horizontal strata	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10	(11)
Myrtillus site type	Field layer (1)											
	Bottom layer (2)											
	Total biomass (3)											
Vaccinium site type	Field layer (4)		**	*								
	Bottom layer (5)	*		*	***							
	Total biomass (6)				*	*						
Calluna site type	Field layer (7)	***	**	***	***	*	***					
	Bottom layer (8)	***	***	***	***	***	***	*				
	Total biomass (9)	***	***	***	***	***	***	*				
Cultivated grass area	Total biomass (10)	**	*	**	***	*	**	*	*			
Natural grass area	Total biomass (11)	**	**	**	**	**	**				*	

[1] *: $P < 0.05$
**: $P < 0.01$
***: $P < 0.001$

errors and experimental lay-out on the results has already been discussed.

The statistical significance of the observed differences between the trampling tolerances of various plant communities was tested by means of a t-test, the results of which are presented in Tables 8 and 9. Such tests were carried out both between different plant communities and within individual plant communities. The values of the test variables have been calculated both on the basis of the coverage and of the biomass.

The relationship between trampling tolerance and site fertility

Since material representative of both the poorest and the richest sites has not been included in the study material, it is not possible to obtain a clear picture about the relationship between the fertility of the site and the trampling tolerance of the ground vegetation. The trampling tolerance of such sites, however, can be calculated with the help of existing plant cover analyses. The most reliable estimations for trampling tolerance values not measured in the field are obtained by weighting the coverage values of the species in question with the trampling tolerance of the corresponding species in other plant communities. Preferably the trampling tolerance of the species growing on sites which most resemble them from the point of view of fertility should be used.

The study material can be made more complete by calculating the theoretical trampling tolerance for the vegetation of the *Oxalis—Myrtillus* and *Cladonia* site types. The results of KUJALA's (1936) studies have been used in drawing up Fig. 4. The trampling tolerance for species typical of the *Myrtillus* site type have been used in calculating the trampling tolerance

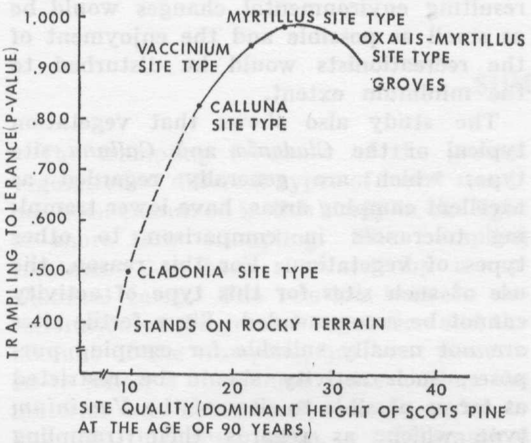

Figure 4. Relationship between trampling tolerance and site fertility.

for vegetation on a site of *Oxalis—Myrtillus* site type. In the same way the coverage of species typical of the *Cladonia* site type have been weighted with the trampling tolerance of species typical of the *Calluna* site type. The dominant height of Scots pine *(Pinus silvestris)* at the age of 90 years on each of the site types under study has been used as an indicator of site fertility (cf. e.g. Spurr 1964, pp. 125—146).

The figure clearly shows that the ground vegetation on the sites of medium fertility is more resistant than the ground vegetation on any of the other sites studied. On the other hand, sites of the *Cladonia* and *Calluna* type, which are highly valued as camping areas, have low trampling tolerances. This fact has been already indicated by the values for lichen dominated vegetation. Abundant growth of herbaceous plant species will lower the trampling tolerance of the ground vegetation on the most fertile sites in comparison to the vegetation typical of the *Vaccinium* and *Myrtillus* site types. It can be concluded from the material that the relationship between the site fertility and the trampling tolerance is a curvilinear on such that the trampling tolerance on both the poorest and richest sites is lower than that on sites of medium fertility. However, in the light of longer term trampling, this picture of the trampling tolerance of different forest site types might change. Grovelike vegetation would obviously have a much higher trampling tolerance than other types of vegetation (cf. Holmström 1970), since the regenerative power of the vegetation on this site type is much higher than on any other site type.

DISCUSSION

The greatest limitation of the simulation method is the fact that any raised points on the sample plots will receive a much stronger trampling treatment while other parts of the sample plots remain relatively untouched. However, trampling resulting from the steps of recreationists is spread more evenly over the terrain and thus trampling is more complete (Kellomäki 1973). In addition, it is difficult to control the magnitude of the trampling impulse such that it corresponds to that of real trampling. Thus the trampling tolerances calculated for different vegetation types and plant species express primarily the trampling tolerance order between different vegetation types and plant species. However, it is not possible to determined directly, on the basis of these values, how much trampling different vegetation types can withstand in absolute terms. Saastamoinen (1974) has shown that real trampling will destroy the ground vegetation on sites of the *Myrtillus* ja *Vaccinium* types faster than the simulated trampling used in this study. On the other hand, simulated and real trampling will produce results which are of rather similar magnitude in the case of the ground vegetation typical of the *Calluna* site type. As far as simulated trampling on the grass areas was concerned, the damage to the plant cover took place at a relatively faster rate than that caused by real trampling.

The results obtained in this study concerning the trampling tolerances of different plant species are rather similar to those reported in earlier studies. For instance, Holmström (1970) has shown that the dominant plant species of the field layer of poor forest sites, *Calluna vulgaris* in particular, are sensitive to trampling (cf. Hoogesteger 1974; Kardell 1974). Earlier studies have also shown that many species of herbs have a low trampling tolerance (e.g. LaPage 1967; Willar & Marr 1970; Kellomäki 1973). It has been found in this study that the trampling tolerance of lichens is particularly low (cf. Holmström 1970; Willard & Marr 1970; Hoogesteger 1974). According to the observations made by Hoogesteger (1974), of the bottom layer species, *Dicranum* species are in general more resistant than other species of mosses.

The material included in this study also gives some indications of the differences between the types of ground vegetation growing on different sites. Although the poorest and the richest sites are not included in the material, it can however be seen that there is a clear relationship between the site fertility and the trampling tolerance of the ground vegetation. However, the linear relationship postulated by Brooks (1966) could not be demonstrated; on the contrary, this material indicated that the relationship is of curvilinear form. Before the validity of this hypothesis can be established a new and more representative material would have to be collected. This would enable more attention to be paid to the prevailing differences in the ecological conditions occurring in various parts of the country, which may subsequently alter this picture of the trampling tolerance of forest vegetation. In particular, it may be possible to show that the forest vegetation of Northern Finland has a noticeably lower trampling tolerance than could be presumed from this material.

Although the presented trampling tolerance values as such do not express the trampling tolerance of different vegetation types in absolute terms, they can be used when attempting to minimise the changes in the ground vegetation resulting from recreational activities. If the locality of different site types in a forest area intended for recreational use is known, the relative trampling tolerance of different parts of the area can then be shown. Thus the localisation of different recreational activities can be arranged in such a way that the resulting environmental changes would be as small as possible and the enjoyment of the recreationists would be disturbed to the minimum extent.

The study also shows that vegetation typical of the *Cladonia* and *Calluna* site type, which are generally regarded as excellent camping areas, have lower trampling tolerances in comparison to other types of vegetation. For this reason, the use of such sites for this type of activity cannot be recommended. Since fertile sites are not usually suitable for camping purposes, such activity should be restricted as far as possible to sites of the *Vaccinium* type which, as regards their trampling tolerance and suitability as camping sites, can be regarded as satisfactory. It should however be stressed that forest vegetation in general is easily damaged despite the difference which have been observed (cf. Kellomäki 1973; Saastamoinen 1974). The best long term solution in this respect is grass dominated meadow vegetation, although in this study meadow vegetation was found to be less resistant than other forms of vegetation. In particular, it should be kept in mind that resistant secondary species will gradually appear in such vegetation as the trampling continues. This process will not become apparent in such a short trampling period as was used in this study (cf. LaPage 1967). On the other hand, the secondary species appearing in a forested area may be smaller, and stabilisation of the vegetation on such areas will take place at a slower rate than in meadow vegetation dominated by grasses and herbs (cf. Hoogesteger 1974; Kardell 1974). Account should also be taken of the fact that the trampling tolerance of meadow vegetation or cultivated grass areas can be much more efficiently improved, for instance by fertilisation, than the trampling tolerance of natural forest vegetation (cf. e.g. Appel 1950; Cordell & Talhelm 1969; Herrington & Bearsley 1970; Beardsley & Wagar 1971; Cordell & James 1971; Lime & Stankey 1971; Merriam & al. 1971).

SUMMARY

The trampling tolerance of the ground vegetation of different types of forest stands has been examined in this study in the light of short term trampling. The trampling treatment has been simulated by a mechamical tamp. The relation between deterioration of the ground vegetation and the amount of the trampling has been presumed to follow a curvilinear pattern when the material was being analysed. In order to quantify this relationship, a mathematical equation has been developed for every plant community and their members of which the trampling tolerance has been analysed. The trampling tolerance of different plant communities and their members has been compared using a parameter of the developed equations. Vegetation growing on sites of the *Myrtillus*, *Vaccinium* and *Calluna* types have been included in the study.

A clear difference in the trampling tolerance between the ground vegetation of sites which vary as regards their fertility was shown in the study. According to the hypothesis, the ground vegetation typical of the *Calluna* site type was found to have a trampling tolerance lower than the vegetation of the most fertile sites which were studied. It can be concluded from the material that the relationship between the site fertility and the trampling tolerance of the ground vegetation is a curvilinear one such that the trampling tolerance of the vegetation on the poorest and the richest sites is lower than that of the vegetation growing on sites of medium fertility. However, it does appear that the most fertile sites have a higher trampling tolerance than the poorest sites. In addition, information about the trampling tolerance of a number of commonly occurring forest plants is also presented.

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Seloste:

METSÄKASVILLISUUDEN KULUTUSKESTÄVYYS

Tutkimuksessa on tarkasteltu metsäkasvillisuuden kulutuskestävyyssuhteita lyhytaikaisen kulutuksen valossa. Tällöin kulutusta on simuloitu tarkoitukseen rakennetulla junttalaitteella. Kasvillisuuden kulumisen suhde kulutuksen määrään on oletettu aineiston analyysissä käyräviivaiseksi. Tämän riippuvuuden kuvaamiseksi on kehitetty matemaattinen lauseke, jonka parametriä hyväksikäyttäen on suoritettu eri kasvillisuusmuotojen keskinäistä vertailua. Tutkimuksen piiriin on tällöin kuulunut mustikka-, puolukka ja kanervatyypin metsäkasvillisuutta.

Tutkimuksessa voitiin osoittaa selviä kulutuskestävyyseroja viljavuuden erilaisten kasvupaikkojen pintakasvillisuuden välillä. Oletusten mukaan osoittautui kanervatyypin pintakasvillisuus kulutuskestävyydeltään muuta tutkittua, viljavuudeltaan parempien kasvupaikkojen kasvillisuutta heikommaksi. Aineistosta on pääteltävissä, että pintakasvillisuuden kulutuskestavyyden ja kasvupaikan viljavuuden välinen suhde muodostuu käyräviivaiseksi siten, että kaikkein karuimmalla ja viljavimmalla kasvupaikoilla kasvillisuuden kulutuskestävyys jää alhaisemmaksi kuin keskiviljavilla kasvupaikoilla. On kuitenkin luultavaa, että kaikkein viljavimpien kasvupaikkojen pintakasvillisuuden kulutuskestävyys on huomattavasti korkeampi kuin kaikkein karuimpien kasvupaikkojen pintakasvillisuuden. Karujen kasvupaikkojen pintakasvillisuuden heikko kulutuskestävyys johtui ennen muuta jäkäläkasvillisuuden nopeasta ja perusteellisesta tuhoutumisesta kulutuksessa. Viljavien kasvupaikkojen pintakasvillisuuden heikko kulutuskestävyys puolestaan johtui näille kasvupaikoille ominaisten ruohojen alhaisesta kulutuskestävyydestä. Työssä on esitetty myös tietoja eräiden muiden tavallisten metsäkasvien kulutuskestävyyssuhteista.

O.D.C. 907.1 182.4718

KELLOMÄKI, SEPPO and SAASTAMOINEN, VARPU-LEENA

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A clear difference in the trampling tolerance between the ground vegetation of sites which vary as regards their fertility was shown. The relationship between the site fertility and the trampling tolerance of the ground vegetation was a curvilinear one such that the trampling tolerance of the vegetation on the poorest and richest sites was lower than that of the vegetation growing on sites of medium fertility. In addition, information about the trampling tolerance of a number of commonly occurring forest plants is also presented.

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Seloste

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Tutkimuksessa selvitettiin lisäksi eri kulutuskestävyyksiä erilaisten kasvupaikkojen pintakasvillisuuksien välillä. Oletetaan [illegible] osoittavat [illegible] pintakasvillisuus kulutuskestävyydeltään muuta tekijöitä, että [illegible] parempien kasvupaikkojen harvoimmilla heikommaksi. Aineiston on päätellään, että pintakasvillisuuden kulutuskestävyyden ja kasvupaikan viljavuuden välinen suhde osoittautuu käyräviivaiseksi siten, että heikoilla karuimmilla ja viljavimmilla kasvupaikoilla kasvillisuuden kulutuskestävyys jää alhaisemmaksi kuin keskiviljavilla kasvupaikoilla. On kuitenkin huomattava, että kaikkein viljavimpien kasvupaikkojen pintakasvillisuuden kulutuskestävyys on huomattavasti suurempi kuin kaikkein karuimpien kasvupaikkojen pintakasvillisuuden. Karujen kasvupaikkojen pintakasvillisuuden heikko kulutuskestävyys johtuu ennen muuta jäkälävaltaisuuden [illegible] ja [illegible] [illegible] kulutuksesta. Viljavien kasvupaikkojen pintakasvillisuuden heikko kulutuskestävyys puolestaan johtuu näille kasvupaikoille ominaisten ruohojen alhaisesta kulutuskestävyydestä. Työssä on esitetty myös tietoja eräiden muiden tavallisten metsäkasvien kulutuskestävyysarvioista.

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A clear difference in the trampling tolerance between the ground vegetation of sites which vary as regards their fertility was shown. The relationship between the site fertility and the trampling tolerance of the ground vegetation was a curvilinear one such that the trampling tolerance of the vegetation on the poorest and richest sites was lower than that of the vegetation growing on sites of medium fertility. In addition, information about the trampling tolerance of a number of commonly occurring forest plants is also presented.

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