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# The Response of Plant Species to Low-Level Trampling Stress on Hurricane Island, Maine

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## Abstract

In 1981, a study was initiated to measure the effects of low-level trampling (100 to 200 tramples) on selected vegetation on Hurricane Island, Maine. Low levels of trampling are representative of general recreational use patterns on most Maine islands. The study was designed to compare percent survival of common island species when subjected to low-level trampling, to observe treadway formation, and to monitor recovery. The quadrupod photographic technique was used to monitor changes in area coverage of species. Climatic conditions on Hurricane Island appear to favor rapid plant recovery. Most species were able to withstand low levels of trampling stress if allowed a recovery period of 1 year. The most resistant species were *Picea rubens* and *Cladina* spp. The woody shrubs *Empetrum nigrum*, *Myrica pensylvanica*, and *Juniperus horizontalis* and the tall herbaceous species *Solidago rugosa* and *Aralia nudicaulis* were the least resistant to trampling stress. Recovery of these species was relatively slow.

particular species may differ according to whether it is growing in a pure or mixed stand (Holmes and Dobson 1976). The major objectives of this study were to measure and compare the percent survival of common island species subjected to low levels of trampling, to observe treadway formation, and to monitor plant recovery. It was hypothesized that low-level trampling would cause minimal damage and that revegetation would be rapid. A range of responses was expected because of the different morphological characteristics of the species studied and site-specific factors.

## Introduction

Virtually no quantitative research has been conducted on the effects of human recreational use on Maine island vegetation. Current policies controlling human use on islands owned by concerned individuals and conservation organizations are based primarily on visual assessment of damage. Information on the short-term and long-term effects of various levels of use should be made available to managers, so they can plan management policies actively rather than contending with problems reactively.

In 1979, a pilot investigation was initiated on Hurricane Island, Maine, to study the effects of high levels of trampling (500 to 3000 tramples) on trails located on a closed-canopy spruce-fir site. A trample is defined as a one-way pass by a single person over the trail. Dense spruce-fir stands are characteristic of many Maine islands. Area coverages of ground-

cover species are small, with light being the major limiting factor. It was found that high trampling levels produced little measurable trail formation, erosion, or soil compaction. This was attributed to the thick resilient layer of mor (an unconsolidated organic layer) and a zero percent slope. However, the groundcover vegetation that was monitored disappeared at trampling levels lower than those the pilot study was designed to analyze.

The present study, begun in 1980, was designed to quantify the effects on individual groundcover species of lower levels of human trampling (100 to 200 tramples) which are more representative of general use patterns on most Maine islands. Species response to trampling and species recovery were monitored on previously undisturbed sites over a 3-year period. Sites were selected to represent a single dominant species or several species in association. It has been observed that the survival rate of a

## Background

Hurricane Island is 12 miles off the mainland (latitude 44°02'N longitude 69°53'30"W) southwest of Vinalhaven Island at the mouth of the Penobscot Bay. The granitic, dome-shaped island is typical of many Maine coastal islands in its geology, history, climate, and vegetation.

Hurricane Island is formed of coarse-textured granite overlain by glacial till and organic deposits. Soils range from coarse gravelly sands near the shore to thick layers of mor beneath the forest canopy. Maine island soils are generally young, shallow-to-bedrock, acidic podsoils (Davis 1966).

Many islands in the Gulf of Maine were heavily used during the 18th and 19th centuries. At Hurricane Island, the most intensive human use occurred between 1870 and 1915, when the island was home and workplace to



## Methods

some 1500 people, whose lives centered around a massive granite quarrying operation. When the market for water-transported granite collapsed in the early 1900's, the entire populace abandoned the island. The effects of such extensive human use on island topography and vegetation are still apparent. A detailed history of the Penobscot Bay islands is recounted by McLane (1982).

The maritime climate of the Penobscot Bay islands has been described by Davis (1966) and Conkling (1981). It is affected by the Nova Scotia Current, which draws arctic waters into the Gulf of Maine with the effect of lowering summer temperatures 4° to 6°C below those at inland stations. Warm, moisture-laden air from the offshore Gulf Stream passing over this cooler current produces extended periods of fog early in the growing season. Thornthwaite (1948) classified the Maine coast as "perhumid", the most humid category of North American regions. In addition, heat storage in the waters of the Gulf of Maine lengthens the growing season in the autumn. This extended, relatively cool and very humid growing season yields a transitional flora with both temperate and boreal affinities (Hill 1923).

A dense spruce-fir forest covers most of Hurricane Island. The forest floor is primarily composed of mosses, and lichens. The understory is sparse, except where the canopy is relatively open or soils are too shallow to support an overstory. Dominant groundcover species include such rhizomatous perennials as *Maianthemum canadense* (Canada mayflower), *Linnaea borealis* (twinline), *Clintonia borealis* (bluebead-lily), *Cornus canadensis* (bunchberry), and *Aralia nudicaulis* (sarsaparilla). Characteristic shrubs include *Vaccinium augustifolium* (lowbush blueberry), *Gaylussacia baccata* (huckleberry), *Myrica pensylvanica* (bayberry), and *Juniperus horizontalis* (horizontal juniper).

During the summers of 1980 and 1981, 15 simulated trails (labeled E through S) were established at locations that showed no signs of recent human disturbance. Trail sites were chosen to represent distinct species or plant associations. Dominant species at each trail are listed in Table 1. References for nomenclature were as follows: flowering plants: Gray (Fernald 1950); mosses: Crum (1973) and lichens: Hale (1979). Two to six study plots, measuring 1 × 0.5 m were located on each trail. Plots were placed at locations with representative samples of selected vegetation and were not necessarily adjacent to each other on the trails. Each study plot was marked by a pair of stakes positioned 1 m apart on opposite sides of the trail. One stake of each pair was marked with a plot-identifying code. If soil depth was inadequate to support a stake, the corners of the plot were marked with red paint. Where no rock was exposed for paint marking, a tape was used to measure between tags affixed to roots or trees to mark the exact location of the plot.

The quadropod—a 4-legged instrument with a 1- × 0.5-m rectangular base frame which delineates the study plot—was used to record ground-cover changes over the study period. Photographs of the plot were taken by a camera mounted at the quadropod's apex and aimed directly downward so that the entire frame was in view. Variations in photographic technique are minimized, since the quadropod holds the film plane parallel with the ground surface, maintains a constant distance from the lens to the ground, and reduces vibrations. A more detailed description of the quadropod system is given by McBride and Leonard (1982).

Trails E through L were trampled a total of 100 times in three increments of 40, 40, and 20 times in July and August of 1980. Plots were photographed at 0, 80, and 100 tramples. Trails H-2 and M through S were trampled a total of 200 times in increments of 0, 80, and 100 tramples in July and

August of 1981, and 150 and 200 tramples in July and August of 1982. Plots were photographed 2 weeks after each trampling. Trampling damage was measured more accurately 2 weeks after trampling than on the same day. Two field assistants, averaging 135 pounds (61.2 kg), walked over the simulated trails a specified number of times on each trampling date. They wore soft-soled footwear instead of lug-soled boots because that is the typical footwear of recreationists coming to islands by boat. One year of recovery data were obtained for Trails M through S (1983) and 2 years of recovery data for Trails E through L (1981, 1982). Plots were photographed two or three times over the growing season of each recovery year. Photographs were analyzed in the laboratory. Projected images of the plot were mapped. Each plot was divided into three sections: a central 0.5- × 0.5-m section (Area 1) and two .25- × 0.5-m side sections (grouped together as Area 2). Trampling occurred over the center portion of Area 1. Area 2 of each plot was designated as a control. Percent coverages of species in Areas 1 and 2 were measured with a planimeter or by counting individual plants.

Relative percentages for each species were obtained in the following manner for analysis:

$$\text{Relative percent coverage} = \frac{\text{percent absolute coverage}}{\text{greatest percent coverage during the trampling phase}}$$

where:

—percent absolute coverage represents the area of the study plot which is covered by the plant species on a given measurement date

—greatest percent coverage during the trampling phase represents the greatest area coverage measurement of that plant species taken at any time during one trampling phase or season.



**Table 1.—Dominant plant species on study trails and summary of changes in relative percent coverage.**

Trail	No. of plots	Dominant species	Common name	No. of tramples					Recovery	
				0	80	100	150	200	Yr. 1	Yr. 2
E	2	<i>Linnea borealis</i> L.	twinflower	80	65	50	—	—	78	80
F	4	<i>Cornus canadensis</i> L.	bunchberry	45	35	35	—	—	45	45
		<i>Dicranum</i> spp.	broom moss	100	85	65	—	—	95	100
G	4	<i>Sphagnum</i> spp.	sphagnum moss	80	35	50	—	—	75	80
H	9	<i>Clintonia borealis</i> (Ait.) Raf.	bluebead-lily	25	19	18	17	12	20	—
		<i>Aralia nudicaulis</i> L.	sarsaparilla	22	16	15	10	4	12	—
		<i>Solidago rugosa</i> Ait.	rough goldenrod	65	36	38	—	—	45	43
I	6	<i>Empetrum nigrum</i> L.	black crowberry	55	40	35	—	—	15	36
J	6	<i>Myrica pensylvanica</i> Loisel.	bayberry	27	15	16	—	—	18	31
K	4	<i>Picea rubens</i> Sarg.	red spruce	70	66	65	—	—	62	74
L,M	9	<i>Cladina</i> spp.	reindeer lichen	77	73	72	—	—	76	77
O,P	12	<i>Cladina</i> spp.	reindeer lichen	72	73	72	—	—	72	—
		<i>Dicranum</i> spp.	broom mosses	14	11	14	10	NA	14	—
Q	5	<i>Vaccinium augustifolium</i> Ait.	lowbush blueberry	71	28	20	41	42	71	—
Q,R	9	<i>Myrica pensylvanica</i> Loisel.	bayberry	52	22	21	21	21	28	—
R,S	9	<i>Juniperus horizontalis</i> Moench.	horizontal juniper	68	59	45	44	39	50	—

## Trail Descriptions

The impact of recreation pressure is influenced by both biotic and physical site-specific factors (Burden and Randerson 1971). With this in mind, brief site descriptions of each simulated trail have been included.

### Trail E: Twinflower site

Trail E is located on a level site near the top of the major central dome of granite on Hurricane Island. The overstory red spruce is 10 to 15 m high and the canopy is approximately 50 percent closed. The study plots are dominated by sprawling mats of twinflower in a sphagnum and pleurocarpous moss (predominantly *Dicranum* spp.) matrix.

### Trail F: Bunchberry, *Dicranum* site

Trail F is also near the top of the central island dome, but slopes so that some drainage flows through the trail. The overstory red spruce is 7 to 10 m high and canopy closure is approximately 30 to 40 percent. The vegetation is dominated by dense mats of pleurocarpous mosses and bunchberry.

### Trail G: Sphagnum moss site

Trail G is located on a moderate west-facing slope on the mid-slope of the central island dome and runs parallel to a wide terrace of granite. The canopy of the surrounding red spruce stand is approximately 90 percent closed.

Understory vegetation consists almost entirely of sphagnum moss with scattered lowbush blueberry plants and red spruce seedlings. The occurrence of sphagnum moss appears to be influenced by downslope drainage and runoff, part of which moves laterally along the granite terrace.

### Trails H-1, H-2, H-3: Rough goldenrod, bluebead-lily and sarsaparilla site

These trails are located on a level site 20 to 25 m from the western shoreline of Hurricane Island. The site is underlain by 0.5- to 1.0-m deep pockets of glacial till. The overstory consists of white spruce 12 to 18 m high with a canopy approximately 70 percent closed.

Trail H-1: Rough goldenrod is the dominant species found in association with Canada mayflower (*Maianthemum canadense*) and starflower (*Trientalis borealis*). Trail H-2: Bluebead-lily is the dominant species in association with Canada mayflower, sarsaparilla, and twinflower. Trail H-3: Sarsaparilla and bluebead-lily were found growing in association with Canada mayflower and starflower.

### Trail I: Black crowberry, bayberry site

Trail I is located 10 to 15 m from the edge of the western shoreline. It is adjacent to an inland white spruce forest, which shades the site in the morning. The spreading mat of black crowberry and bayberry is growing on a granite outcrop with moderate exposure to salt and wind stress. Organic material in the soil ranged between 2 and 8 cm deep.

### Trail J: Bayberry site

Trail J is located just above the high tide line in a 1- to 2-m-wide gravelly depression between two granite outcrops on the western shore



of the island. It is very exposed to storm seas, wind, and salt stress. The soil averaged 2 to 4 cm deep and is composed of granite chips and mixed organic matter. Bayberry is the dominant species. Less prevalent plants are various graminoids, plantain (*Plantago* spp.), yellow clover (*Trifolium* spp.) and New York aster (*Aster novae-belgii*).

**Trail K: Red spruce seedling site**

Trail K is located on an east-facing site where glacial till and mineral soil are mixed between large granite boulders. The overstory is dominated by red spruce 18 to 20 m high with a canopy approximately 50 percent closed. The understory is dominated by red spruce seedlings 2 to 6 cm in height.

**Trails L-1, L-2: Cladina site**

Trails L-1 and L-2 are located near the top of an isolated granitic dome in a small level clearing that borders a stand of red spruce. Both sites have a 2- to 3-cm soil layer consisting of organic material over bedrock. *Cladina* spp. predominate with scattered stems of huckleberry, horizontal juniper, starflower, and Canada mayflower.

**Trail M: Cladina site**

Trail M is located on a flat granite ledge near the top of the central island dome. Several red spruce trees 3 to 8 m high provide a small amount of shade. Shallow organic soil mixed with granite chips has accumulated to a depth of 2 to 4 cm. *Cladina* spp. are dominant, in association with pleurocarpous mosses, crustose, and squamulose lichens.

**Trail O: Dicranum site**

Trail O is located near the top of the central island dome on a level site. The overstory of red spruce is 7 to 10 m high with a canopy approximately 75 percent closed. The organic soil layer is relatively deep, an average of 5 to 10 cm. Groundcover vegetation consists of a variety of fruticose lichens in a pleurocarpous moss matrix.

**Trail P: Dicranum, Cladina site**

Site characteristics are similar to those of Trail O.

**Trail Q: Lowbush blueberry, bayberry site**

Trail Q is located on the top of a level granite outcrop that is part of a peninsula that extends southwestward from the central island dome. The site is characterized by thin, very well-drained soils and bare ledge. There is no overstory. The plots are vegetated by spreading mats of lowbush blueberry in association with bayberry.

**Trail R: Horizontal juniper, bayberry site**

Trail R is located on the midslope of the granite outcrop described in the Trail Q site description. Several white spruce trees 3 to 5 m high provide limited shade over the site. The plots are vegetated by spreading mats of horizontal juniper in equal association with bayberry.

**Trail S: Horizontal juniper, bayberry site**

Site characteristics are similar to Trail R. Horizontal juniper is the dominant species.

**Results and Discussion**

A summary of changes in relative percent coverage of dominant species at low levels of trampling is presented in Table 1. Measurements represent the combined plot data for each trail. Data from trails with similar site characteristics and the same dominant species were also grouped.

In Table 2, species are grouped according to their response to trampling stress and their ability to recover. The ability of a species to tolerate stress associated with trampling is a function of the species' reproductive strategy, morphological factors, and physical site-specific factors. Morphological factors characteristic of vegetation that is resistant to damage have been described by Frenkel (1970). Examples of such characteristics include:

- diminutiveness
- spreading habit or rosette formation
- small leaves
- hemicryptophytic (underground buds) or therophytic (annual) life form
- attenuated life span under unfavorable conditions
- good nutrient uptake and regeneration
- strong and thick cell walls
- flexible vegetative parts

**Table 2.—Classification of species according to response to trampling.**

Response	100 Tramples	200 Tramples
Group I—largely unaffected	<i>Picea rubens</i> <i>Cladina</i> spp.	<i>Cladina</i> spp.
Group II—rapid recovery of treadway (90–100 percent recovery by Year 1)	<i>Linnaea borealis</i> <i>Cornus canadensis</i> <i>Dicranum</i> spp. <i>Sphagnum</i> spp. <i>Aralia nudicaulis</i>	<i>Vaccinium augustifolium</i> <i>Dicranum</i> spp. <i>Clintonia borealis</i>
Group III—slow recovery of treadway (20–60 percent recovery by Year 1)	<i>Solidago rugosa</i> <i>Empetrum nigrum</i> <i>Myrica pensylvanica</i>	<i>Myrica pensylvanica</i> <i>Juniperus horizontalis</i> <i>Aralia nudicaulis</i>



In the discussion that follows, morphological and site-specific factors are related to plant response to low-level trampling for each species or genus.

### **Group I Species—largely unaffected**

*Cladina* spp. were the least affected by trampling stress and showed zero percent loss in cover after both 100 and 200 passes. On the 4 *Cladina* spp. trails, no distinct treadway developed. Some crushing and fragmenting did occur. Regrowth from fragments was observed. The per-humid climate and zero percent slope combined with low trampling levels undoubtedly contributed to the resiliency of the lichens in this study.

Red spruce seedlings were also resistant to damage. Recovery was greater than 100 percent in 1982. In general, the woody pliant stems of spruce seedlings bent without breaking during trampling. The small acicular leaves were relatively unsusceptible to mechanical damage. The damage that occurred was restricted to slight defoliation and breakage of side twigs. The growth observed in the treadway area in 1982 was paralleled in the control plots. Site conditions chosen for the tests appeared particularly favorable to spruce seedling establishment and growth. It is expected that competition among seedlings will eventually restrict growth and cause mortality.

### **Group II Species—rapid recovery by year 2**

Twinflower declined from 80 percent to 50 percent area coverage by 100 tramples. Recovery was rapid and by 1982 there was no sign of trampling in the study plot. Twinflower buds are more exposed than those of rhizomatous perennials such as Canada mayflower and bunchberry. This appears to have been compensated for by prolific runner growth and the diminutiveness of the species.

Bunchberry declined slightly, from 45 percent to 35 percent coverage, after 100 tramples. Bunchberry is a rhizomatous perennial. Each "plant" is a ramet, one of several shoots that grow from an extended underground net of stems or rhizomes. The rapid recovery observed can be attributed to the appearance of new ramets from cryptophytic buds protected from trampling damage and nourished by undamaged rhizomes. It appears that low levels of trampling do not significantly harm underground rhizomes of bunchberry.

Bluebead-lily showed a pattern of decline and recovery similar to that of bunchberry. Bluebead-lily supports a tall (30-cm) flower stalk that grows from a basal rosette of large sturdy leaves. Although the flower stalk is vulnerable to breakage and injury, the sturdy leaves, rosette growth, and rhizomatous underground parts enable the plant to withstand low levels of trampling.

Lowbush blueberry declined to approximately half its original area coverage after 200 tramples. Recovery was surprisingly rapid, possibly because of reduced competition from bayberry, which appeared to be more susceptible to trampling stress. Most of the damage in the treadway was in the form of breakage of woody stems and defoliation. Although this species is relatively susceptible to damage by trampling, it is able to revegetate rapidly after trampling has stopped.

Dicranum and sphagnum moss declined by 30 and 35 percent, respectively, of their original coverage after 100 passes. Recovery for both genera was approximately 95 percent by the first year, and was complete in 1982. Control data indicate that a drought period during the trampling phase contributed to the decline in sphagnum moss coverage at 80 and 100 tramples.

The percent coverage of *Dicranum* in control plots did not decline during the drought period, which indicates that the decrease in *Dicranum* was a consequence of trampling more than that of sphagnum moss. Thin cell wall structure and lack of anchoring roots increase the susceptibility of mosses to mechanical damage. However, the decrease in coverage of mosses during trampling is followed by rapid regeneration from fragments and vegetative reproduction. Similar results were obtained in a study by Studlar (1980) conducted in a humid mountain-lake site.

### **Group III Series—slow recovery**

Sarsaparilla is a rhizomatous perennial which was not resistant to low level trampling stress and showed poor recovery compared to the other rhizomatous perennials studied. Sarsaparilla is a tall plant (30 to 40 cm) whose stem supports a large mass of foliage. The tall stem is susceptible to breakage, and greater reserves are required by underground rhizomes for sprouting and regrowth.

Rough goldenrod reacted similarly to sarsaparilla. Rough goldenrod is a tall, leafy biennial that is not resistant to trampling damage. The zero percent recovery observed in 1982 could be attributed to replacement of trampled goldenrod plants by rhizomatous perennials such as mayflower, starflower, and bluebead-lily.

Black crowberry, horizontal juniper, and bayberry are woody shrubs which, on Maine islands, have a low spreading growth form. These species are typically found on shallow soils in ledgy exposed areas. The treadways created after 100 and 200 tramples on Trails I, Q, R, and S remained visible during the entire recovery period. It is likely that a corresponding increase in soil temperature, reduced moisture retention, and shallow, infertile soils inhibited regeneration of trampled



areas. In the case of black crowberry, tolerance of trampling stress may have been further reduced by salt and wind stress and possibly wave action. Black crowberry is a tundra plant which, in Maine, is at the southern end of its range. It is typically found on exposed seaward-facing shores of the Maine coast (Conkling 1981). On Trails I and J, bayberry was able to recover, possibly because it had no competitors.

In conclusion, most of the island plant species studied were able to recover from low levels of trampling if allowed a recovery period of at least 1 year. In general, island climatic conditions appear favorable for rapid recovery. The species that were found to be most resistant to low-level trampling stress were red spruce and *Cladina* spp. (on zero percent slope).

Those particularly susceptible to trampling damage were the woody shrubs; black crowberry, bayberry, and horizontal juniper, which were growing on exposed sites with thin soils. Recovery for these species is relatively slow. The treadways formed after 100 to 200 passes remained visible even after 2 years of recovery. The tall herbaceous species rough goldenrod and sarsaparilla are also intolerant to trampling stress.

It is apparent that trampling damage can occur at very low levels of use and that recovery periods vary according to morphological characteristics of species and site-specific factors. In general, treadways became visible between 40 and 80 tramples and remained the same width (approximately 30 cm) with additional trampling. Further research is needed on the long-term effects of low-level trampling. The results of this study indicate that managers should locate trails away from island species such as black crowberry, horizontal juniper, and bayberry growing on exposed sites. Such exposed sites appear to be highly stressed in an island environment. In particular, an unusual species such as black crowberry should be protected.

## Literature Cited

- Burden, R. F.; Randerson, P. F. **Quantitative studies of the effects of human trampling on vegetation as an aid to the management of semi-natural areas.** *Journal of Applied Ecology* 9:439-457; 1972.
- Conkling, P.W. **Islands in Time.** Camden, ME: DownEast Books; 1981.
- Crum, H. **Mosses of the Great Lakes Forest.** Ann Arbor, MI: University Herbarium, University of Michigan; 1973.
- David, R. B. **Spruce-fir forests of the coast of Maine.** *Ecological Monographs* 36:79-94; 1966.
- Fernald, Merritt Lyndon. **Gray's Manual of Botany, 8th Ed.** New York: American Book Company; 1950.
- Frenkel, R. E. **Ruderal vegetation along some California roadsides.** *University of California Public Geography* 20:1-163; 1970.
- Hale, M. E. **How to know the Lichens.** 2nd Ed. Dubuque, IA: Wm. C. Brown Company; 1979.
- Hill, A. F. **The vegetation of the Penobscot Bay region, Maine.** In: *Proceedings, Portland Society of Natural History*; 1923(III):306-438.
- Holmes, Daniel O.; Dobson, Heidi E. M. **Ecological carrying capacity research, Yosemite National Park.** Part 1. Springfield, VA: U.S. Department of Commerce, National Technical Information Service No. PB-270 955; 1976. 247 p.
- McBride, J. C.; Leonard, R. E. **A system for measuring groundcover changes.** *Parks* 7(1):20; 1982.
- McLane, C. B. **Islands of the Mid-Maine Coast: Blue Hill and Penobscot Bays.** Woolwich, ME: Kennebec River Press; 1982.
- Studlar, S. M. **Trampling effects on bryophytes: Trail surveys and experiments.** *The Bryologist* 83(3): 301-313; 1980.
- Thornthwaite, C. W. **An approach toward a rational classification of climate.** *Geographical Review* 38: 55-94; 1948.

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