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Vegetation of a freshwater dune barrier under high and low recreational uses[1]

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BONANNO, S. E., D. J. LEOPOLD, AND L. R. ST. HILAIRE. Vegetation of a freshwater dune barrier under high and low recreational uses. J. Torrey Bot. Soc. 125:40–50. 1998.—The 27.4 km freshwater dune barrier on the eastern shore of Lake Ontario protects an extensive system of high quality wetlands. The vegetation was previously undescribed, and development pressures required management decisions for which data were needed. The objective of this study was to describe and compare the vegetation under high and low recreational use. We found four community types using hierarchical classification (TWINSPAN): (1) *Ammophila breviligulata* (beachgrass) (2) *Toxicodendron radicans–Vitis riparia–Populus deltoides* (brushland) (3) *Quercus rubra–Acer rubrum* (forest), and (4) *Alnus incana* (thicket). Reciprocal averaging ordination displayed communities along a first gradient of distance from the beach. A second gradient is likely related to disturbance. Species composition was similar in beachgrass and brushland communities under high and low recreational use. Under low use, forest and shrub thicket were present on the back of the barrier, but were absent under high use. Species richness and ground cover of vegetation, and density of colonizing species were lower on equivalent physiographic zones under high compared to low recreational use.

Key words: Great Lakes Dunes; recreation impact; flora; vegetation.

Colonizing dune vegetation is well-adapted to the severe growing conditions of the beach environment (Disraeli 1984; Maun and Lapierre 1984), but very susceptible to human disturbance. Disturbance from recreational use (e.g., trampling and off-road vehicle traffic) causes changes in foredune microclimate, soils, and vegetation. Soil and microclimate changes include increased soil bulk density (Liddle and Greig-Smith 1975a; Slatter 1978), near-ground wind velocity (McAtee and Drawe 1981), and fluctuations in soil temperature and moisture (Liddle and Moore 1974). Vegetation changes include decreased percent cover and species richness (Liddle and Moore 1974; Liddle and Greig-Smith 1975b; Hosier and Eaton 1980; Charette and Shisler 1985; Carlson and Godfrey 1989), density (Bowles and Maun 1982), above ground biomass (McAtee and Drawe 1980; Nickerson and Thibodeau 1983), and mean height (Boorman and Fuller 1977) of colonizing foredune vegetation. As a result of these changes, sand is vulnerable to erosion, which destabilizes foredunes (McAtee and Drawe 1980; Nickerson and Thibodeau 1983).

When the foredune is destabilized, vegetation on the barrier interior may also be affected, since the foredune shelters and contributes to altering the growing conditions of the barrier interior (Olson 1958; McAtee and Drawe 1981). On an interior dune heath-grassland community on Lake Huron, vegetation was reduced 50% after 300 trampling passes (Bowles and Maun 1982). Similarly, on a Danish heath-grassland community, vegetation cover was reduced 50% after 200 passes, but after 2560 passes, only two of 19 species remained, with a total of 2% cover (Hylgaard and Liddle 1981). While vegetation changes within actual trampling paths on both foredunes and interior dunes have been documented, no information is available on changes leeward of such paths.

In New York State, freshwater dunes of Lake Ontario are found only on the eastern shore. Land use on these dunes ranges from full preservation to development for camping and seasonal housing. Pressure for increased use has ne-

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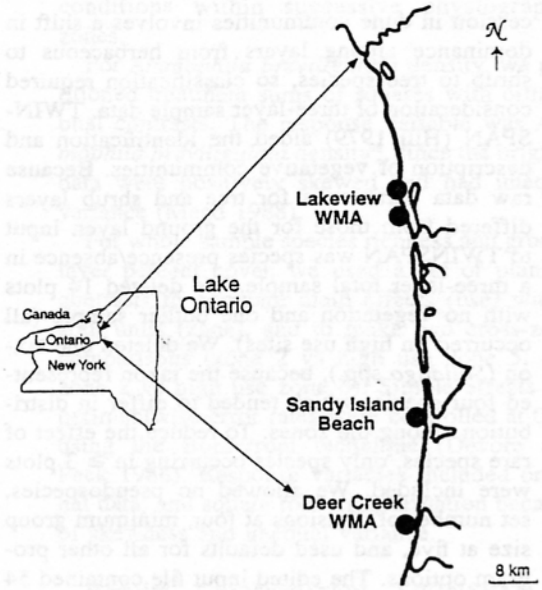

Fig. 1. Lake Ontario eastern shore study sites. Circles indicate sampling locations.

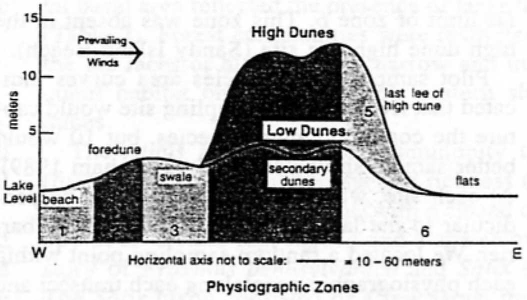

Fig. 2. Dune physiography on the eastern shore of Lake Ontario. Horizontal axis represents width of zone which varies considerably, see text description under sampling methods.

cessitated long-range land-use planning. Very few data have been available on which to base estimates of the probable effect of management decisions. Therefore, the objective of this study was to describe the vegetational patterns of the dune barrier on the eastern shore of Lake Ontario under high and low recreational use.

Methods. STUDY SITES. We selected four study sites, two under low and two under high recreational use (Fig. 1). Two years of recreational use data from The Ontario Dune Coalition provided the use criterion (S. Bonanno and B. Schrader, unpubl. data). Recreational use density was defined as mean visits/hr/km during daylight hours from the last weekend of May through the first weekend of September in 1988 and 1989. A visit represented any use constituting at least one hour of time in the dune beach area. Activities included swimming, picnicking, fishing, and hiking. Camping is prohibited in the dune areas, but does occur illegally. Low use sites (8 visits/hr/km) were located in high and low dune areas at Lakeview Wildlife Management Area (WMA). High use sites were located at Sandy Island Beach high dunes (1269 visits/hr/km), and Deer Creek WMA low dunes (251 visits/hr/km).

Dunes on low dune sites were all 1 to 10 m in height, while high dune sites included low dunes as well as secondary dunes 15 to 20 m in height. Sites altered from a natural state by sand mining, filling, excavation, building, or planting of ornamental species were excluded to control potential sources of variation other than recreational visitation. Historical accounts do not indicate past manipulations in the sampled sections of Lakeview WMA or Deer Creek WMA. Sandy Island Beach, at the time of the study, was operated as a day-use swimming beach. In addition, a former pond outlet to the lake existed there as recently as 75 years ago, so some of the dunes in that site are younger than their counterparts in the low-use/high dune site. We sampled Sandy Island Beach nonetheless because no other potential high-use site fits criteria better. All four sites have been open to casual day use for 12 or more years.

SAMPLING. Since dune vegetation varies with physiography and distance from the beach (Cowles 1899; Oosting and Billings 1942; Olson 1958), we defined six physiographic zones (Fig. 2). Beach (zone 1) extended from the water to the drift line marking the highest reach of summer storms. Foredune front (zone 2) began at that drift line and ended at the windward edge of the first dune crest. Foredune back and swale (zone 3) included the crest and lee face of the first dune and all flat terrain in the barrier interior. Swales were frequently not continuous, but intermittent with secondary dunes. Secondary dunes (zone 4) included windward and leeward faces as well as crests of all dunes lee of the first. In high dune sites, the last lee face of the most leeward secondary dune constituted zone 5, this zone was absent in low dune sites. The flats (zone 6) included the last lee face of low dunes and the low lying ecotone between the last secondary dune and open water or marsh. The leeward edge of woody vegetation defined the far limit of zone 6. This zone was absent in the high dune high use site (Sandy Island Beach).

Pilot sampling and species area curves indicated that five plots per sampling site would capture the common canopy species, but 10 would better sample shrubs and herbs (Bonham 1989). At each site, we oriented five transects perpendicular to the lake, across the width of the barrier. We located a random sampling point within each physiographic zone along each transect and sampled tree, shrub, and ground layer vegetation. Long rectangular quadrats for trees (29.4 m × 3.4 m) and shrubs (8.8 m × 1.7 m) compensated for contagious distribution of vegetation (Olson 1958). Two 15 m^2 subplots for shrubs were nested in opposite corners of each 100 m^2 tree plot. We used the point intercept method for ground vegetation (Greig-Smith 1963), with a single point of 2 mm diameter, lowered from a height of 1 m. For trees, we recorded species and dbh of woody stems ≥ 7.5 cm dbh. For shrubs, we recorded species and stem diameter at 1 m above the ground; stems > 2 cm were measured and those ≤ 2 cm were grouped into one of two size classes (< 1 cm; 1–2 cm). The ground layer sample comprised 2 sets of 20 points, located along the center line at either end of the canopy plot. We spaced points at 20 cm intervals to avoid distortion due to contagious distribution (Greig-Smith 1963) and recorded number of contacts between pin and each species, including woody individuals less than 1 m tall. To evaluate the pattern of *Ammophila breviligulata* in zones where it occurred, we used a 0.50 m^2 quadrat (33.3 cm × 150 cm) parallel to the shrub subplots, and recorded number of *Ammophila breviligulata* tillers rooted within the plot.

Sampling occurred between early-July and mid-August, 1990 and 1991, completed one zone at a time to avoid differences attributable to season. Nomenclature follows Mitchell (1986) for vascular plants and Egan (1987) for lichens.

Analysis. For tree and shrub layers, we calculated density, relative density, basal area, and relative basal area. Shrub basal area calculations used the size class mid-point for basal area of smaller stems. Ground layer calculations included species percent cover (pins making contact/20 pins), relative cover, and percent sward (species contacts/total contacts).

Each full sample consisted of a tree plot, two shrub subplots, and two ground point sets. Succession in dune communities involves a shift in dominance among layers from herbaceous to shrub to tree species, so classification required consideration of three-layer sample data. TWINSPAN (Hill 1979) aided the identification and description of vegetative communities. Because raw data parameters for tree and shrub layers differed from those for the ground layer, input to TWINSPAN was species presence/absence in a three-layer total sample. We deleted 14 plots with no vegetation and one outlier sample (all occurred on high use sites). We deleted one taxon (*Solidago* spp.), because the taxon represented four species which tended to differ in distribution among the zones. To reduce the effect of rare species, only species occurring in ≥ 3 plots were included. We allowed no pseudospecies, set number of divisions at four, minimum group size at five, and used defaults for all other program options. The edited input file contained 54 species and 90 plots (4 sites × 6 zones × 5 transects = 120 plots, minus 5 transects absent in zone 6 at Sandy Island Beach, minus 10 transects absent from zone 5 of low dunes, minus 14 unvegetated plots, minus one outlier = 90 plots).

Communities were named and described by calculating total basal area (whole sample tree + shrub) and mean ground layer percent cover of clusters identified by TWINSPAN. We examined the pattern of community occurrence on the physiographic zones under high and low use.

We conducted Reciprocal Averaging ordination in ORDIFLEX (Gauch 1977) using the edited presence/absence TWINSPAN input file. We plotted ordination scores of high and low use plots separately, marked by physiographic zone, and identified TWINSPAN community types on the display.

ANOVA was conducted with SAS (SAS Institute, Inc. 1985) to determine differences in *Ammophila breviligulata* density, whole sample species richness, and ground layer species richness and percent cover among zones under high and low recreational use. We used a split-plot factorial experiment design (Petersen 1985; Mead 1988), with "use" as the whole plot factor (2 levels) and "zone" as the split unit factor (4 levels for *Ammophila breviligulata* density and 6 levels for species richness and percent cover). Since "use" is not applied in a controlled way to the entire site, but by many individual recreationists, it is considered as applied to a whole plot experimental unit "transect." "Zone" describes an unspecified suite of differing growing conditions within successive physiographic zones.

For *Ammophila breviligulata* density, we partitioned treatment sums of squares with orthogonal contrasts. The response variable was *Ammophila breviligulata* density$^{1/2}$, since the original data were positively skewed and had unequal variance (Mead 1988).

For whole sample species richness and ground layer percent cover, we used a set of planned contrasts to compare main effects (use) within split units (zone), and to make two cross-zone comparisons (zone 2 vs high use zone 5, and zone 2 vs high use zone 6). Simple effects experimentwise error rates were controlled at 0.05 using the Bonferroni technique (Devore and Peck 1986). Response variables included original data, and square root transformation because of skewness and unequal variance.

Results. CLASSIFICATION. TWINSPAN revealed four community types. The species composition, including basal area of woody species and percent cover of ground vegetation, of these community types is listed in Table 1. Table 2 lists mean species richness, total cover, and woody basal area of these communities. The largest community type was *Ammophila breviligulata* (beachgrass), characterized by low species richness, total cover, and woody basal area. The dominant ground layer was comprised chiefly of *Ammophila breviligulata* and *Artemisia campestris* ssp. *caudata. Populus deltoides* was the only important woody species. The beachgrass community occurred in low-use beach, foredune, and swale plots and on some plots of every zone under high use.

The *Toxicodendron radicans–Vitis riparia–Populus deltoides* (brushland) community type (16 plots) was also ground layer-dominated. Basal area was about double that of the beachgrass community type (Table 2), with *Populus deltoides* forming a patchy, open canopy, mostly on dune crests. While all dominants of the beachgrass community were also present in the brushland community, species richness and total ground layer percent cover were nearly triple that of the beachgrass community. The brushland community occurred in secondary dune and swale plots, and also in flats under high use.

The *Quercus rubra–Acer rubrum* (forest) community type (15 plots) was dominated by an open canopy. Dominants of the beachgrass community were all but gone, species richness was double that of the brushland community, and total basal area reflected the presence of large trees (Table 2). Forest communities were restricted to the lee faces of high dunes, a narrow and infrequent habitat on Lake Ontario's eastern shore dunes.

The *Alnus incana* (thicket) community type (five plots) had the highest species richness (Table 2). Shrubs were dominant, with a closed canopy of *A. incana* ssp. *rugosa* and a sparse overstory of *Fraxinus pennsylvanica* and *Salix* spp. The *Salix* taxon consisted of a few large, multistemmed individuals of *Salix fragilis* and *S.* x *rubens.* The two species were combined for the analysis because they were an important element of this community that would have been eliminated individually under the rarity criterion (presence in ≥ 3 plots). The ground layer was dominated by *Phalaris arundinacea, Rubus idaeus,* and *Glyceria striata* and was characterized by a wide variety of herbaceous species present in low abundance. The thicket community occurred in plots on flats, secondary dunes, and lee of high dunes.

ORDINATION. Reciprocal Averaging separated TWINSPAN community types well under both low use (Fig. 3a) and high use (Fig. 3b). Under low recreational use, the first axis separated samples generally by distance from the beach. The second axis further separated the *Toxicodendron radicans–Vitis riparia–Populus deltoides* (brushland) community (CT2) from the *Ammophila breviligulata* (beachgrass) community (CT1), and also separated the *Quercus rubra–Acer rubrum* (forest community) (CT4) from the *Alnus incana* (thicket) community (CT3) (Fig. 3a). Under high recreational use, samples were well separated along the first axis, distance from the beach (Fig. 3b.). The Reciprocal Averaging species ordination illustrates the disjunction of species distribution between beachgrass and forest community types (Fig. 3c). While there is an overlapping species distribution between adjacent community types (e.g., beachgrass and brushland), there is none beyond that.

ANOVA. Square root transformation of stem/tiller density data satisfied ANOVA assumptions better than original data, and differed somewhat in interpretation, so results are reported for transformed data. Interaction was important for *Ammophila breviligulata* density$^{1/2}$ between use and zones 2 versus 3–4 ($F = 4.14$, $P = 0.05$). The interaction plot (Fig. 4) reveals a difference in magnitude of response rather than direction, indicating that density$^{1/2}$ P values are meaningful,

Table 1. Species composition of all community types identified by TWINSPAN. Major species itemized: canopy and shrub species with ≥0.01 m^2 ha^{-1} basal area, and ground species with ≥2% cover in the community type. Community types are: CT1, *Ammophila breviligulata* (beachgrass); CT2, *Toxicodendron radicans–Vitis riparia–Populus deltoides* (brushland); CT3, *Querus rubra–Acer rubrum* (forest); CT4, *Alnus incana* (thicket).

Species	CT1 (beachgrass)	CT2 (brushland)	CT3 (forest)	CT4 (thicket)
Woody (BA, m^2 ha^{-1})				
Acer pensylvanicum				0.22
A. rubrum (ACRU)				7.42
A. saccharum (ACSA)				3.99
Alnus incana ssp. *rugosa* (ALIN)			11.96	0.61
Amelanchier spp.				0.19
Cornus amomum			0.28	
Fagus grandifolia				4.51
Fraxinus pennsylvanica			4.24	
Ilex verticillata (ILVE)				0.50
Populus deltoides (PODE)	2.70	4.11		
Prunus serotina			0.02	1.96
P. virginiana (PRVI)	0.02	0.04	0.02	0.21
Quercus rubra var. *borealis* (QURU)				13.33
Rhamnus cathartica		0.03		
Rubus allegheniensis				0.04
R. idaeus (RUID)			0.29	0.08
Salix cordata (SACO)		0.02		
Salix spp.		0.02	3.09	
Solanum dulcamara			0.02	
Viburnum lentago			0.02	0.79
V. recognitum (VIRE)			0.02	0.07
Vitis riparia (VIRI)		0.07	0.20	0.01
All others	0.01	0.36	0.03	0.52
Ground (% cover)				
Alnus incana spp. *rugosa*				3.0
Ammophila breviligulata (AMBR)	14.7	4.5	3.3	
Aralia nudicaulis (ARNU)			7.5	
Artemisia campestris ssp. *caudata* (ARCA)	3.6	4.7		
Boehmeria cylindrica				2.5
Calamagrostis canadensis			2.5	
Centaurea maculosa (CEMA)		5.6		
Deschampsia flexuosa			2.8	
Equisetum × *litorale*				2.0
Festuca ovina			2.5	
Galium triflorum				3.5
Glyceria striata				12.0
Impatiens capensis				2.5
Juncus balticus var. *littoralis*		3.1		
Lycopus virginicus				3.0
Lysimachia terrestris				2.0
Moehringia lateriflora (MOLA)		3.0	2.7	
Onoclea sensibilis (ONSE)				7.0
Phalaris arundinacea (PHAR)				14.5
Placynthiella oligotropha (PLOL)		2.5		
Poa compressa (POCO)		2.7	3.5	5.0
Polygonum cilinode			4.0	
Prunus virginiana				5.0
Rubus allegheniensis			2.5	
R. idaeus			7.3	14.0
Saponaria officinalis (SAOF)		3.8	2.8	
Smilacina stellata			2.2	
Smilax hispida			2.2	
Solidago caesia			4.2	
Solidago spp.		10.3	8.0	2.5
Toxicodendron radicans (TORA)		22.5	10.5	2.0
Vitis riparia	1.8	22.8	7.3	
All others	4.0	9.8	28.8	14.5

Table 2. Mean species richness, total cover, and total woody basal area of TWINSPAN-identified community types (CTs).

Community type	# Plots	Mean species richness (#/plot)	Mean total cover (1-bare)	Mean total BA (m^2 ha^{-1})
Ammophila breviligulata (beachgrass)	54	3.0	23	2.73
Toxicodendron radicans–Vitis riparia–Populus deltoides (brushland)	16	8.1	66	4.65
Quercus rubra–Acer rubrum (forest)	15	15.9	68	34.45
Alnus incana (thicket)	5	17.0	64	20.19

though interpretation is modified by use (Mead 1988). The data provide strong evidence that *Ammophila breviligulata* density$^{1/2}$ is significantly greater under low versus high use (F = 5.9, $P = 0.02$) and significantly greater on the foredune versus the interior zones (zone 2 vs 3–4, F = 25.5, $P = 0.0001$). *Ammophila breviligulata* density$^{1/2}$ is higher on the beach and foredunes (zones 1 and 2) under low use than high (simple effect $P = 0.05$ and < 0.01, respectively). On swales and secondary dunes (zones 3 and 4), *Ammophila breviligulata* density drops more rapidly under low use than high (Fig. 4), so that density$^{1/2}$ is not significantly different under high use than low, and interaction is not significant.

Since interpretation of ground layer percent cover, ground layer species richness, and three layer species richness did not differ between transformed and original data, results from original data are reported (Mead 1988). Interaction between the effect of zone and use level was highly significant for ground layer percent cover, ground layer species richness, and three layer species richness ($P \leq 0.0006$, Table 3) and indicated a difference in magnitude rather than direction. Differences in the mean under high versus low recreational use within each zone (simple effects comparisons) for all three variables were significant on swales, secondary dunes, back lee faces of high secondary dunes, and flats (zones 3–6) ($P < 0.01$ in all cases, Fig. 5a,b,c). In cross-zone comparisons, the data provide no evidence that the back lee faces of high dunes and the flats under high use support significantly greater ground layer percent cover or species richness than foredunes under low recreation.

Discussion. The classification and ordination results reveal a pattern where the character of dune vegetation communities and the progress of dune vegetation succession are similar under both low and high use, but delayed and abridged under high. Where sand and colonizing vegetation were disturbed on the lakeward side of the barrier, stabilization was delayed, both there and in the barrier interior because sand movement and deposition remained at high levels.

The gradient suggested by the Reciprocal Averaging first axis is distance from the beach, along with the associated complex set of changing conditions. Changes with distance include decreased wind velocity, particularly at the soil surface (Baldwin and Maun 1983; Willetts 1989), increased air temperature and soil moisture (Baldwin and Maun 1983), and reduced sand accretion (Goldsmith et al. 1990). Factors associated with soil development, which increases with distance from the beach, include increasing organic matter and moisture retention, decreasing pH, and increased leaching of cations and mobile nutrients (Olson 1958; Baldwin and Maun 1983; Costa et al. 1991). Aggregation of sand by microorganisms increases (Forster and Nicolson 1981) with increasing populations of bacteria and fungi (Halvorson and Koske 1988) associated with distance from the beach.

The second axis may be related to frequency of physical disturbance relative to beachgrass and brushland community types. The *Toxicodendron radicans–Vitis riparia–Populus deltoides* (brushland) community low-use plots (Fig. 3a) are lower along axis two than the high-use plots (Fig. 3b). *Placynthiella oligotropha,* a crustose sand-binding lichen of undisturbed, bare sand (Brodo 1961) occurred only on these low-use plots and lies in the lowest second axis position for that community. Physical disturbance associated with high use is likely responsible for the absence of this lichen in high use sites. In trampling experiments on Lake Huron dunes, lichens were the most heavily impacted taxon (Bowles and Maun 1982). A year after cessation of trampling, lichen cover had declined further, while other species showed varied levels of recovery.

Axis two separation for forest and thicket community types may be related to fluctuating water levels as opposed to amount of moisture.

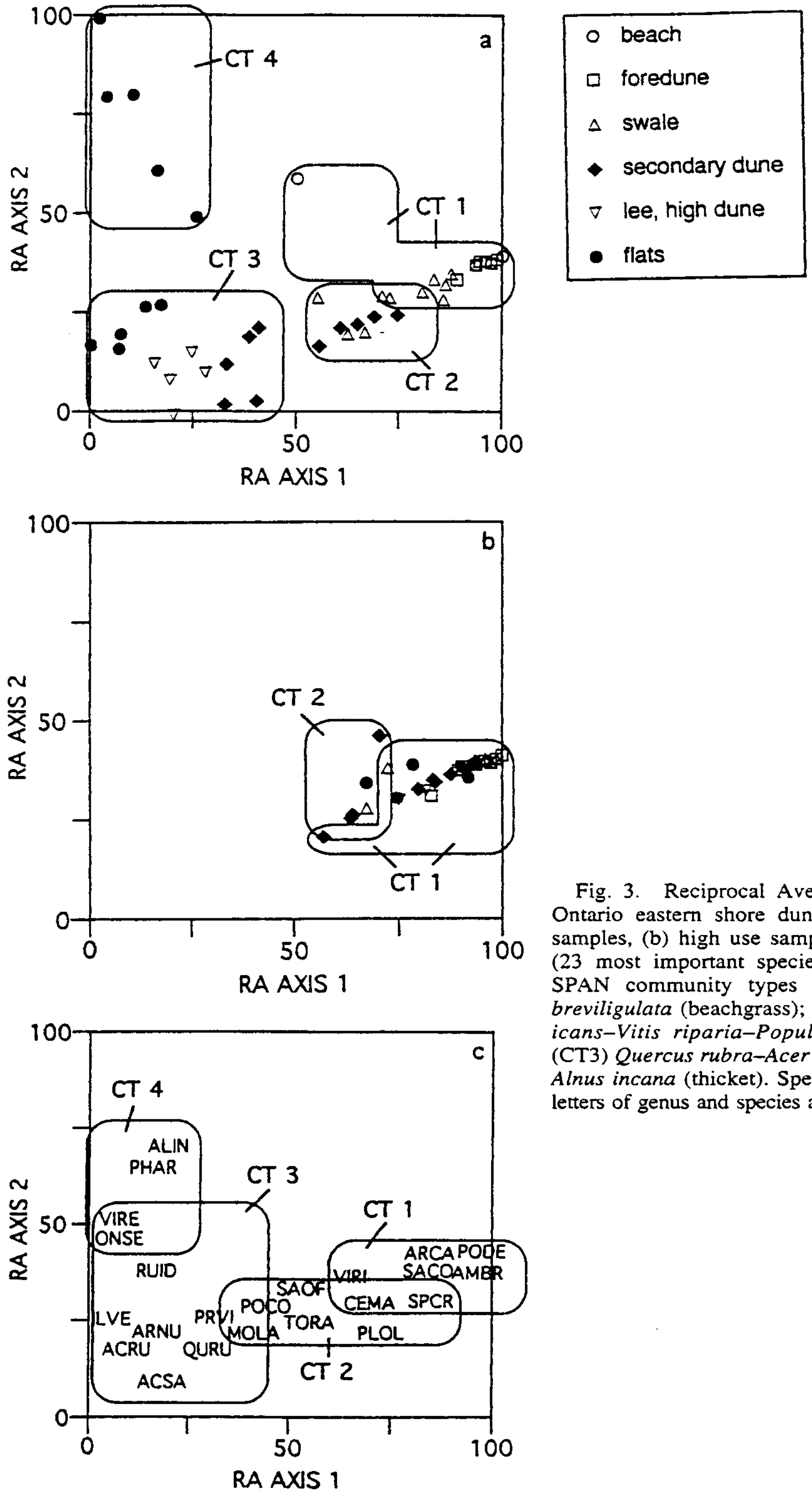

Fig. 3. Reciprocal Averaging ordination of Lake Ontario eastern shore dune vegetation. (a) low use samples, (b) high use samples, (c) species ordination (23 most important species). Boxes delimit TWINSPAN community types (CTs): (CT1) *Ammophila breviligulata* (beachgrass); (CT2) *Toxicodendron radicans–Vitis riparia–Populus deltoides* (brushland); (CT3) *Quercus rubra–Acer rubrum* (forest); and (CT4) *Alnus incana* (thicket). Species codes are the first two letters of genus and species and are identified in Table 1.

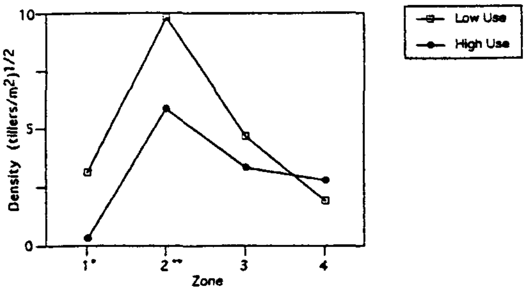

Fig. 4. Density (in transformed units) of *Ammophila breviligulata* on Lake Ontario eastern shore dunes in 4 different zones: (1) beach; (2) windward side of foredunes; (3) crest and lee of foredunes and swales; and (4) secondary dunes. Zone numbers followed by an asterisk (*) represent a significant difference of $P = 0.05$ at that zone between high and low use, two asterisks (**) represent a significant difference of $P \leq 0.01$.

The *Quercus rubra–Acer rubrum* (forest) community included samples on well-drained lee slopes and samples saturated to the surface, and the *Alnus incana* (thicket) samples were all moist to saturated. Wetter forest plots supported *Viburnum lentago, Ilex verticillata,* and *Alnus incana* populations of low basal area, rather than the dense closed canopy of *A. incana* that dominated the thicket community type. *Alnus* species are early-successional colonizers that invade disturbed or new soil, and form dense thickets whose stability is measured in decades (Huenneke 1987), while succession to a mesic forest is measured in centuries (Olson 1958). Succession is likely held in this early state by fluctuating water levels and the attendant seasonal flooding and subsequent drainage associated with this type of wetland.

Ammophila breviligulata density is sensitive to high recreational use and its associated increase in trampling and sand movement. The pattern of higher *Ammophila breviligulata* density on low use beaches and foredunes is similar to differences in *Ammophila breviligulata* percent cover on New Jersey dunes (Charette and Shisler 1985) and on a northern Massachusetts barrier (Carlson and Godfrey 1989) under high versus low recreational use. The greater numbers of *Ammophila breviligulata* tillers on the lakeward zones under low use trap sand more effectively than the sparser supply under conditions of high use, resulting in less sand movement and therefore more stable conditions on the interior zones under low use.

High recreation use on the beach is also destructive to ephemeral seedlings and characteristic beach annuals such as *Cakile edentula* (Payne and Maun 1984). These plants are washed away seasonally, but they trap sand and contribute to foredune initiation (Adair 1990) and may provide an ephemeral habitat for in-

Table 3. Analysis of Variance table for ground layer percent cover and species richness, and three layer species richness in low and high use zones of Lake Ontario eastern shore dunes.

Source	df	MS	F	p
Ground Layer Percent Cover				
Use	1	19486.67	83.04	0.0001
Transect (Use)	18	234.66		
Zone	5	6611.55	24.94	0.0001
Zone * Use	5	1293.82	4.88	0.0006
Error	75	265.09		
Total	104			
Ground Layer Species Richness (#/point set)				
Use	1	187.43	132.31	0.0001
Transect (Use)	18	1.41		
Zone	5	53.97	23.78	0.0001
Zone * Use	5	16.14	7.11	0.0001
Error	75	2.27		
Total	104			
Three Layer Species Richness (#/full sample)				
Use	1	762.23	119.35	0.0001
Transect (Use)	18	5.56		
Zone	5	283.72	44.43	0.0001
Zone * Use	5	76.75	12.02	0.0001
Error	75	6.39		
Total	104			

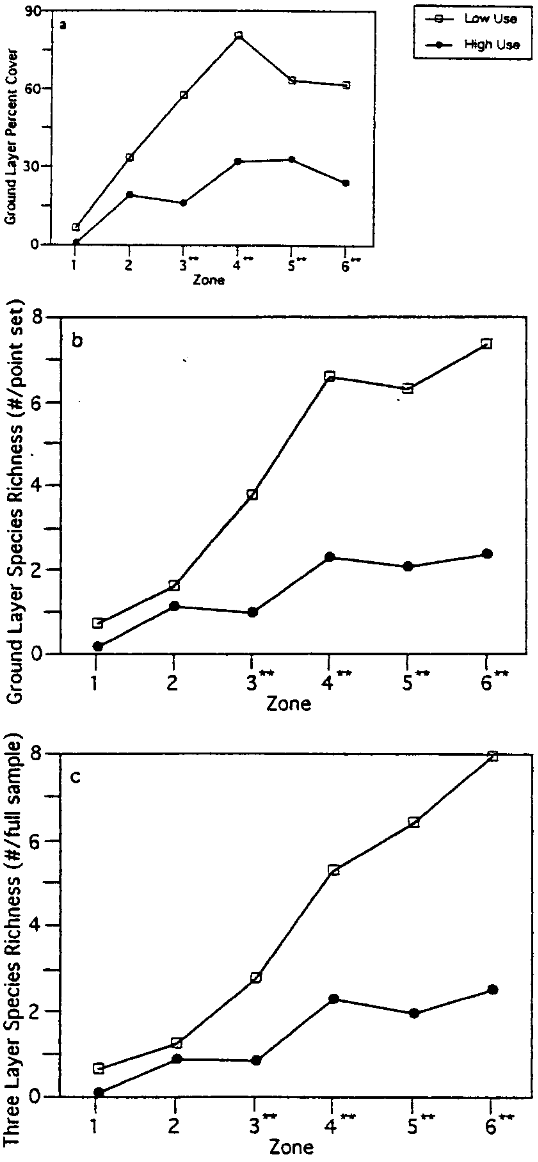

Fig. 5. Ground layer percent cover (a), ground layer species richness (b), and three layer species richness (c) on Lake Ontario eastern shore dunes. Zones 1, 2, 3, 4, 5, 6 are beach, foredune, swale, lee of secondary dunes, and flats, respectively. Zone numbers followed by two asterisks (**) represent a significant difference of $P \leq 0.01$ at that zone between high and low use. SE for Fig. 5a. is 5.15, SE for 5b. and 5c. is 0.48.

vertebrates and the shorebirds that feed on them. In high use sites these ephemeral habitats are often lacking (nine of the ten beach plots were unvegetated).

Lower ground layer percent cover in zones five and six (lee of secondary dunes and flats) under high use is consistent with increased density of colonizing species (*Ammophila breviligulata* and *Artemisia campestris*) on the interior zones (swales and secondary dunes). These findings suggest destabilized conditions, with sand moving more freely on the barrier interior and lee side under high use than low. Under severe foredune microclimate conditions few species can survive (Liddle and Moore 1974; McAtee and Drawe 1981; Baldwin and Maun 1983), and those that do provide lower cover than vegetation supported by more stabilized conditions (Oosting and Billings 1942; VanDenack 1961).

The radical difference in vegetation between high and low use on zone 5 (lee of last secondary dune) is likely confounded by dune age since stabilization is a critical factor associated with both soil formation (Olson 1958) and vegetation development (Olson 1958; Morrison and Yarranton 1973, 1974). The eastern Lake Ontario dune barrier is believed to have originated at about 5000 years ago, during significantly lower lake water levels (Sutton et al. 1972). A comparison of USGS topo maps of the area from 1893 and 1958 show that the barrier width has changed over time, from narrower to wider in some areas, and the reverse in other areas. The high secondary dunes at Sandy Island Beach flanked a pond outlet channel to the lake 100 years ago, suggesting that the available time for stabilization of that site is shortened. The dune high use area was developed after the channel closed, around 1910. The dune low use area has likely not been disturbed by channel processes in recent history. The differences on the lakeward and more recently stabilized interior zones (beach, foredunes, swales, secondary dunes, and flats) were very likely developed during a similar time span under similar influences from lake and wind.

The recreation impacts associated with the eastern shore dunes of Lake Ontario involve ongoing disturbance with no likelihood of cessation. Studies have shown an increase in ruderal species on mined and other disturbed dunes that persisted or even increased over time (Carls et al. 1987, Buckney and Morrison 1992, Partridge 1992). While recreation disturbance is relatively minor when compared to development, sand mining, or even the natural cycle of erosion and accretion, it is continual. Some areas (not sampled) of Lakeview WMA barrier received anthropogenic disturbance 25–100 years ago, but have been undisturbed since. These areas support a flora noticeably richer than adjacent, unaltered areas, though this increased richness is due to ruderal species. On U.S. Atlantic coast barrier islands, ruderals occurring in developed areas, e.g., on roadsides and near parking lots, greatly expanded the species richness of Assateague Island (Stalter and Lamont 1990) and Fire Island (Stalter et al. 1986). Where all other factors are equal, dune communities on the eastern shore of Lake Ontario are held in a very early, species-poor successional state under high recreational use.

It might be argued that indicators of healthy vegetation such as high percent cover, richness, and diversity are not necessarily the only value to be preserved, particularly on resource areas dedicated to recreation, e.g., Sandy Island Beach. However, on a dune barrier the integrity of the vegetation is essential to maintain the sand dune resource that is so attractive for recreation. Carlson and Godfrey (1989) compared vegetation percent cover and species richness on a Massachusetts dune barrier impacted by heavy recreational use before and two years after implementation of a management plan. With fencing, walkovers, education, trail restrictions, and vehicle control, vegetation showed statistically significant increases in percent cover and species richness two years after implementation of the management plan, even with continued heavy recreational use of the resource. While recreation can and does clearly compromise the integrity of a dune barrier, well-planned and executed management can mitigate those effects while allowing high recreational use.

On the eastern shore of Lake Ontario, the dune barrier is valued for differing reasons by competing interests. However, the interests of all groups depend on the continued existence of the dune barrier, which depends on healthy dune vegetation. Therefore, it is in the best long-term interest of every dune property owner and land manager to protect dune vegetation from the effects of recreational use and other disturbances.

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