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THE IMPACT OF TRAMPLING BY STUDENT GROUPS ON SALTMARSH VEGETATION

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ABSTRACT

The impact of 48 years of use by student groups along a well-established transect through the vegetation of the Gann saltmarsh in Milford Haven on the south-west coast of Wales was investigated. The chronic low-level trampling had reduced the abundance of the overwhelmingly dominant shrub, *Halimione portulacoides*, and resulted in an increased abundance of lower-growing species of halophyte. The diversity of the vegetation has consequently increased and the number of different plant communities has also increased. The zonation of communities on the saltmarsh is compressed into narrow bands and these zones were present at higher positions on the trampled saltmarsh. The saltmarsh at Bentlass, within the same estuary system, showed complete recovery of *Halimione portulacoides* on a former transect line used by students for at least 17 years within 12 years of abandonment. The overall species diversity and community composition on this saltmarsh were not significantly different between the untrampled and trampled areas of saltmarsh. The zonation of communities on the Gann and Bentlass saltmarshes was higher up the saltmarsh in a narrower zone in the areas that are currently being trampled or were trampled in the past. Trampling increases the diversity of saltmarsh vegetation by reducing its height and, consequently, competition. The bare ground created by trampling enables annuals and other halophytes of lower saltmarsh communities to establish higher up the saltmarsh and thus induces retrogressive succession.

The use of transects on a regular basis at particular sites can be used to illustrate the impact of the observer on the object of study. If the results of the students' work along such transects are retained, and records kept of the number of students using the transect, it is possible to examine the longer term impacts of trampling by students on the communities under examination. The longer term trends can provide yet another dimension to field teaching, the results of which are serendipitous, depending on the environmental changes which may impinge on the particular habitat and transect under study.

INTRODUCTION

Although several studies have examined the effects of outdoor recreation on different vegetation types (Bayfield, 1971, 1979; Boorman & Fuller, 1977; Burden & Randerson, 1972; Crawford & Liddle, 1977; Davies, 1938), particularly the effects of trampling by walkers (Bayfield, 1971, 1979), little has been done to examine the effects that trampling by student groups have on natural or semi-natural vegetation. There has recently been an increase in field studies by students as a direct consequence of the increase in student numbers at higher school and University level education in the U.K. Some concern has been expressed as to their effects on sensitive natural and semi-natural habitats and, as these sites are often the best examples of ecological processes and patterns, they are also often of high nature conservation value.

Transects are frequently used by student groups to describe the zonation of communities. This has the effect, intentional or otherwise, of concentrating students onto a particular area of the habitat being examined. It is the concentration of students onto particular areas that is of greatest concern.

The most obvious impact student groups have is through the physical effects of trampling the vegetation or sedentary organisms on rocky shores. The impact of removing organisms for examination in the field or subsequently in the laboratory is not quantified, but is visually less obvious.

There have been several detailed studies that have examined the impact of trampling by humans on the vegetation of major habitat formations, such as grasslands (Crawford & Liddle, 1977), sand dunes (Boorman & Fuller, 1977; Liddle & Greig-Smith, 1975; Slatter, 1978; Andersen, 1995) and montane habitats (Bayfield, 1971, 1979; Cole, 1995a). There is some dispute as to whether trampling actually increases or decreases diversity, especially with respect to the plant community which is most at risk. Liddle & Greig-Smith (1975) found species number and diversity had been reduced by trampling, contrary to Davies (1938) and Westhoff (1967). Differences in the intensity and frequency of trampling between studies as well as the vegetation type are partly responsible for the differing results (Cole, 1995a). Therefore, conclusions regarding the effects of trampling on vegetation composition are equivocal.

Experimental approaches makes it possible to examine the short-term stress effects on vegetation and its ability to recover (Bayfield, 1979; Cole, 1995a). Although it enables standardisation across several different types of shorter herbaceous vegetation (Cole, 1995a), it does not examine the long-term effects on community composition. The experimental approach used by Boorman & Fuller (1977), Bayfield (1979) and Cole (1995a) induces an acute form of stress on the vegetation, whilst trampling that occurs in the field is normally chronic, i.e. at a low level for a period of many years.

Saltmarsh vegetation is one vegetation type that is frequently used for ecological studies, but is rarely used for other recreational activities. Few studies have examined the effects of trampling by humans on saltmarsh vegetation (Beeftink *et al.*, 1978; Andersen, 1995), although Blionis (1991) considered the effects of vehicles on a saltmarsh in Scotland. The effects of trampling by sheep have been observed to increase both the number of species and community diversity in mid- and upper-marsh areas (Bakker, 1985; Bakker *et al.*, 1985; Adam, 1990), but the separation of the effects of grazing from trampling are not possible in this example.

This paper examines the chronic long-term effects that concentrating student groups on a regular basis has had on the vegetation of a saltmarsh in south-west Wales. The ability of the vegetation to recover from trampling by student groups was examined at another saltmarsh within the same estuary. The known student population that has used the study site enables the frequency and intensity of the trampling to be calculated for the trampled saltmarsh. It is possible from these observations to make an assessment of the ecological impact of this form of 'environmental education' on saltmarsh vegetation. The data collected by students on exactly the same transect makes it possible to examine inter-annual fluctuations in the vegetation composition and any long-term trends of the impact of trampling by the students.

MATERIALS AND METHODS

Site Histories

The study sites on the Gann estuary and the saltmarsh at Bentlass are located in the Milford Haven ria system in south-west Wales, and both are given statutory protection and recognition for their nature conservation value as Sites of Special Scientific Interest.

The 31.5 ha of saltmarsh in the Gann estuary (N.G.R. 1814.2073) has experienced minimal disturbance (other than by students) and the area under investigation has not been grazed within living memory. A transect 60 m long and 7 m wide, between 5.5 m and 7.7 m above chart datum, has been used every year since 1947, between March and October, by groups of students visiting Dale Fort Field Centre. The number of students visiting the site increased by 45% from an estimated 1000 in 1984 to 1454 in 1994. The trampled area is approximately 420 m^2 and students normally spend an average of 2 hours carrying out field observations. This is the site we used to examine the long-term effects of student trampling.

TABLE 1. *The mean proportion of particles in different size fractions within sediment samples taken from the Gann and Bentlass saltmarshes. Means of five replicates with standard errors.*

Particle Size Fraction	Bentlass Saltmarsh	Gann Saltmarsh
Clay (< 2 µm)	26.8 ± 5.3	23.0 ± 3.1
Silt (2 to 60 µm)	51.2 ± 5.8	31.1 ± 3.5
Fine Sand (60 to 200 µm)	14.1 ± 1.5	27.9 ± 4.0
Medium Sand (0.2 to 0.6 mm)	4.6 ± 1.6	17.7 ± 4.9
Coarse Sand (0.6 to 2 mm)	3.3 ± 1.9	1.3 ± 0.2

The 37.5 ha of saltmarsh at Bentlass (N.G.R. 1968 2017) was used by student groups at Orielton Field Centre between 1966 and 1983 for examining vegetation zonation. The student groups alternated between two parallel transect lines that were 75 m long and 10 m wide, once every two weeks. This is the site we used to examine the ability of saltmarsh vegetation to recover from a period of trampling.

The areas which were used by student groups were marked with posts on both saltmarshes and were used to define the trampled areas of the saltmarshes. The two saltmarshes are significantly different in their sediment characteristics. The Gann estuary has a much coarser texture due to the significantly greater proportion of fine and medium sand, whilst the Bentlass saltmarsh has a significantly greater proportion of silt (Table 1).

Species Composition

The composition of the vegetation at 0.2 m vertical height intervals up the saltmarsh was recorded in the trampled area on the Gann in June 1994 and on both saltmarshes in August, 1995. Untrampled areas of saltmarsh, 5 m to one side of each of the trampled zones, were sampled in the same way at the same time. The percentage cover of all plant species was determined using pin-frame quadrats, spaced at 0.6 m horizontal intervals, at 0.2 m height intervals between 5.5 and 7.7 m above chart datum. A total of 110 and 330 points were used at each height interval in 1994 and 1995, respectively. The relative heights of each sampling station were ascertained using quick-set levelling equipment and the absolute height with respect to chart datum was established using the mean spring and neap curves for Milford Haven. This height range covers the full range of saltmarsh communities at both sites.

The differences between the untrampled and trampled sections of saltmarsh are assumed to be entirely due to the trampling. This could be safely assumed as the untrampled areas, either side of the transects, had the same species composition and the transect line was not parallel to any topographical feature, but perpendicular to the slope. Nomenclature follows that of Clapham, Tutin & Moore (1987).

Historical Vegetation Data

The changes in vegetation over the period between 1984 and 1994 on the trampled part of the Gann estuary saltmarsh were examined in order to ascertain whether the species composition of the trampled area was still changing or had reached an equilibrium with the trampling. Student data, collected on a regular basis by J. Archer-Thomson of Dale Fort Field Centre, were analysed at the 12 height class intervals described above. The 1994 and 1995 data for the Gann are also compared for inter-annual variations in species composition.

Soil Sampling and Analysis

Investigation of the effects of trampling on the physical characteristics of the substratum was restricted to an examination of the water content, bulk density, penetration resistance and particle size distribution. A penetrometer was pushed vertically into the substratum of each quadrat to ascertain the penetration resistance. Three replicate cores of the substratum were taken with a piece of copper tubing 10 cm long and 2.5 cm in diameter at each height interval both in the trampled and untrampled parts of the saltmarsh at the Gann estuary in early June, 1994. These cores were placed in sealed polythene bags and their percentage water content and bulk density calculated after weighing, drying at 105°C and re-weighing.

Statistical Analyses

Student's t-test was used to test differences in mean values for soil characteristics. The significance of differences in percentage cover of each species on the saltmarsh as a whole, or at particular height intervals, was tested using the chi-squared test. Correction was made in the calculation for low frequency observations. The diversity of the vegetation at any particular point was calculated using the Shannon-Wiener diversity index. A coefficient of similarity (Gauch, 1982) was calculated to compare the species composition of the trampled and untrampled areas of the saltmarsh.

$$\text{Similarity coefficient} = 200 \times [\Sigma\,(|Xn - Yn|) \div \Sigma\,(Xn + Yn)]$$

Where Xn is the percentage cover for the nth species in the untrampled part of the saltmarsh and Yn is the percentage cover of the nth species in the trampled part of the saltmarsh at the same altitude.

RESULTS

Soil Characteristics

The effects of trampling on the physical characteristics of the sediments was minimal. Neither the water content nor the bulk density of the substratum differed significantly between trampled and untrampled areas, overall (Table 2) or for any particular part of the saltmarsh. The penetration resistance had, however, increased significantly on the trampled area (Table 2) at all height intervals examined (Fig. 1).

Current Impacts of Trampling on Vegetation

The effects of trampling on the vegetation and proportion of bare ground varied between species and the height up the saltmarsh (Fig. 2). Not surprisingly there was a statistically significantly increase in area of bare ground on the trampled part of the saltmarsh (Fig. 2). Trampling has

TABLE 2. *The water content (percentage of dry wt.), bulk density (g cm^{-3}) and penetration resistance (kPa) of the substratum, and vegetation height (m) and overall species diversity (Shannon-Wiener index) of all parts of the trampled and untrampled Gann estuary saltmarsh. The mean and standard error of at least 36 replicates is shown.* n.s. = *not significant*, *** = P<0.001.

Variable	Untrampled saltmarsh	Trampled saltmarsh	t-test
soil bulk density (g cm^{-3})	0.654 ± 0.110	0.647 ± 0.109	0.245 n.s.
soil moisture (% dry wt)	57.1 ± 3.8	59.9 ± 5.0	0.446 n.s.
penetration resistance (kPa)	8.0 ± 0.3	10.7 ± 0.3	6.212***
% bare mud	25.7 ± 0.1	35.8 ± 0.1	3.4***
vegetation height (cm)	26.1 ± 0.7	12.0 ± 0.4	18.2***
Overall species diversity (Shannon-Wiener index)	2.92	2.50	

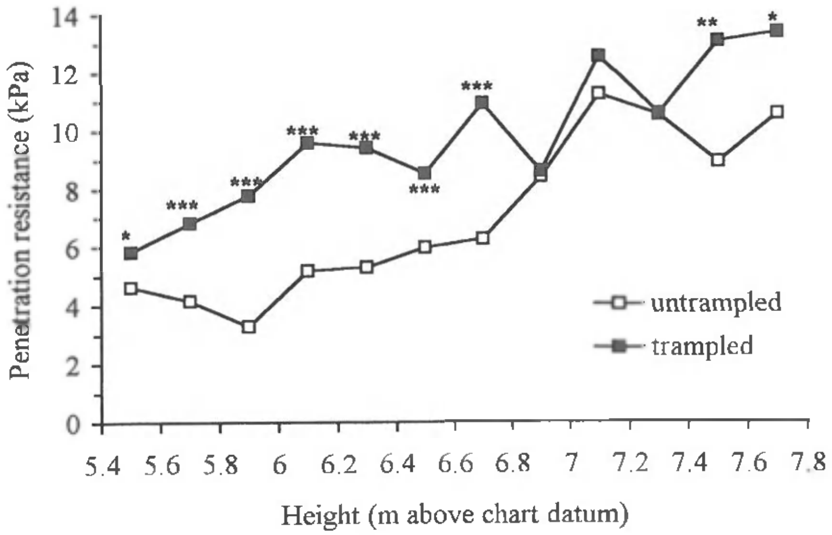


FIG. 1. The mean penetration resistance (kPa) at different elevations (m) above chart datum on the Gann estuary on the untrampled (circles) and trampled (squares) sections of the saltmarsh. Means of 11 replicates with significant differences of t-test between means at the same height interval denoted as follows: * $P < 0.05$, ** $P < 0.01$ and *** $P < 0.001$.

reduced the maximum height of the vegetation by 14 cm, on average (Table 2). This change is largely due to a significant decline in the quantity of the only shrub, *Halimione portulacoides* (Table 3). Four other species showed significantly lower cover in the trampled area: *Beta vulgaris* ssp. *maritima*, *Bostrychia scorpioides*, *Plantago maritima* and *Tripleurospermum maritimum* (Table 3). As *B. scorpioides* is a red alga epiphytic on *Halimione portulacoides*, it is not surprising that its cover had declined along with the decline of its host in the mid-marsh zone (Fig. 2).

There was a significantly greater cover of eight taxa in the trampled area in 1995: *Aster tripolium*, *Armeria maritima*, *Glaux maritima*, *Puccinellia maritima*, *Salicornia europaea*, *Suaeda maritima*, *Spergularia marginata* and the filamentous green algal mat (Fig. 2).

Although six species of plant showed no statistically significant difference in overall cover between trampled and untrampled parts of the Gann (Table 3), some of them have changed their vertical position on the saltmarsh (Fig. 2). For example *Festuca rubra* had a significantly greater cover on the trampled area at the top of the upper-marsh, but a lower cover in the upper middle-marsh, whilst *Atriplex prostrata* has increased lower down in the upper marsh (Fig. 2). The percentage cover of *Limonium humile*, *Spartina anglica* and *Triglochin maritima* had not changed significantly overall (Table 3) or in any one part of the saltmarsh (Fig. 2).

The largest changes in the species composition were in the middle-marsh (6.3 to 6.9m chart datum) where the overwhelming dominant, *Halimione portulacoides*, had declined (Fig. 2). There had been an increase in the quantity of lower-growing species in this zone of the trampled saltmarsh, including *Armeria maritima*, *Aster tripolium*, *Glaux maritima*, *Puccinellia maritima*, *Salicornia europaea*, *Spergularia marginata* and *Suaeda maritima* (Fig. 2). The decline in *Halimione portulacoides* in the trampled area had increased the species diversity of the vegetation, as measured using the Shannon-Wiener diversity index, in the trampled area within the 6.3 to 6.7 m height zone of the saltmarsh (Fig. 3). Not surprisingly the similarity between the trampled and untrampled parts of the saltmarsh was at its lowest in the mid-marsh zone (Table 4).

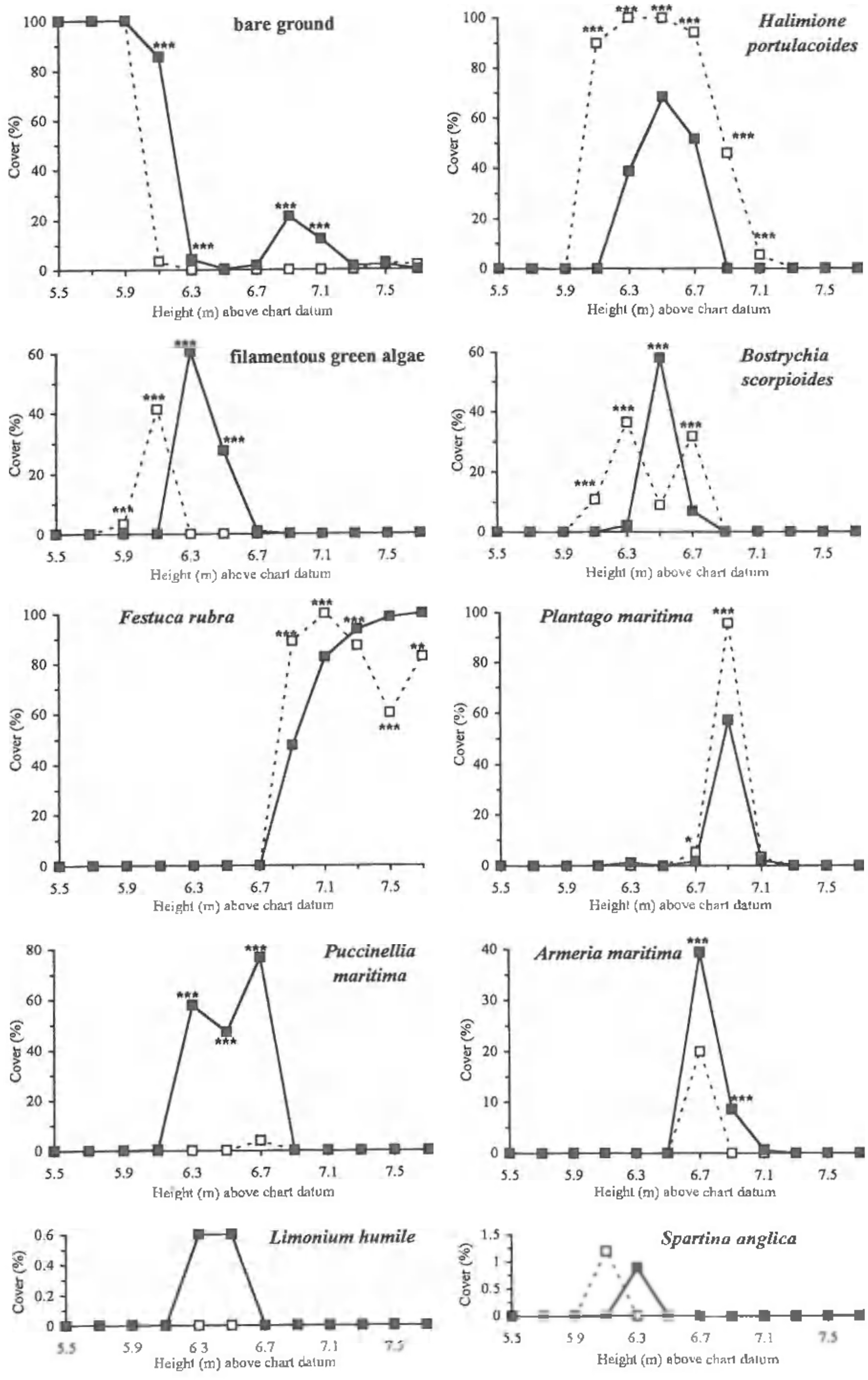
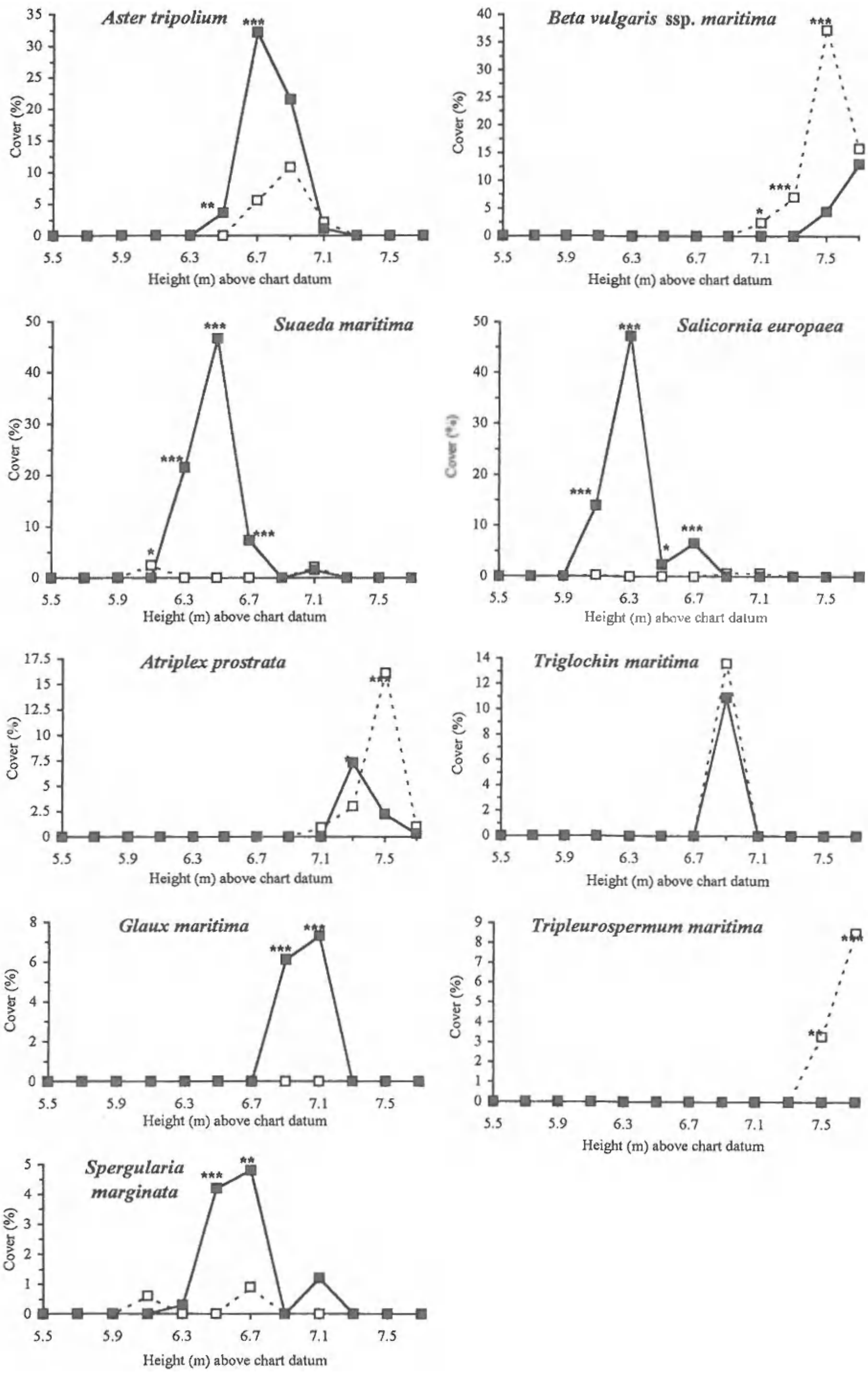


FIG. 2. The percentage cover of bare ground and the different species of plant (filamentous green algae, *Armeria maritima*, *Aster tripolium*, *Atriplex prostrata*, *Beta vulgaris* ssp. *maritima*, *Bostrychia scorpioides*, *Festuca rubra*, *Glaux maritima*, *Halimione portulacoides*, *Limonium humile*, *Plantago maritima*, *Puccinellia maritima*, *Salicornia europaea*, *Spartina anglica*, *Spergularia marginata*, *Suaeda maritima*, *Triglochin maritima* and *Tripleurospermum maritimum*) as a function of elevation (metres above chart



datum) on the untrampled (open squares) and trampled (filled squares) sections of saltmarsh of the Gann estuary. Each cover value is derived from 330 points. Significant differences of χ^2-test of frequencies (percentage cover) between trampled and untrampled sections at the same height interval are denoted as follows: * $P < 0.05$, ** $P < 0.01$ and *** $P < 0.001$.

TABLE 3. *Differences in overall percentage cover between untrampled and trampled sections of the Gann and Bentlass saltmarshes. Positive values indicate increases in cover on the trampled sections and negative values, decreases in cover. Levels of significance of x^2 tests of frequencies (percentage cover) between trampled and untrampled sections are denoted as*
* P < 0.05, ** P < 0.01 *and* *** P < 0.001. n.p. = *not present.*

Species	Gann '94	Gann '95	Bentlass '95
Armeria maritima	4.2***	2.4***	-0.1
Artemisia maritima	n.p.	n.p.	-2.2***
Aster tripolium	3.4***	2.3***	0.1
Atriplex prostrata	0.2	-0.9	-1.4***
Beta vulgaris ssp *maritima*	-0.3	-4.2***	-0.3***
Bostrychia scorpioides	0.5	-1.7**	5.2***
Cochlearia officinalis	0.3	-0.1	n.p.
Elymus pycnanthus	n.p.	n.p.	-0.5*
Festuca rubra	4.3*	0.2	-8.0***
Glaux maritima	1.3**	1.1*	n.p.
Halimione portulacoides	-20.2***	-23.1***	0.3
Limonium humile	0.3	0.1	-0.4
Plantago maritima	2.0	-3.5***	1.4***
Puccinellia maritima	5.9***	14.8***	0.2
Salicornia europaea	0.3	5.7***	0.4
Spartina anglica	2.7***	0.0	4.9***
Spergularia marginata	0.8*	0.8***	0.0
Suaeda maritima	-0.2	6.0***	0.1
Triglochin maritima	0.6*	-0.2	-0.2*
Tripleurospermum maritimum	n.p.	-1.0***	n.p.
unidentified filamentous green algae	8.8	3.7***	7.4***
Bare Ground	1.3	10.1***	-0.7

The trampling in this mid-marsh zone had altered the *Halimione portulacoides* community and encouraged the development of *Aster tripolium discoideum* community, transitional low saltmarsh vegetation and *Puccinellia maritima* community (Table 3). The annual *Salicornia europaea* community was absent from the untrampled parts of the saltmarsh and may therefore establish with trampling (Table 3). The lower part of the *Elymus pycnanthus* community and the *Armeria maritima* community had been replaced by the *Festuca rubra-Glaux maritima* and *Festuca rubra* subcommunities of the *Juncus gerardi* community as a consequence of the trampling in this transitional zone between mid- and upper marsh. Trampling had therefore increased the number of saltmarsh communities from three to six and they are in a slightly narrower intertidal zone between the upper part of the mudflats and the lowest part of the upper saltmarsh.

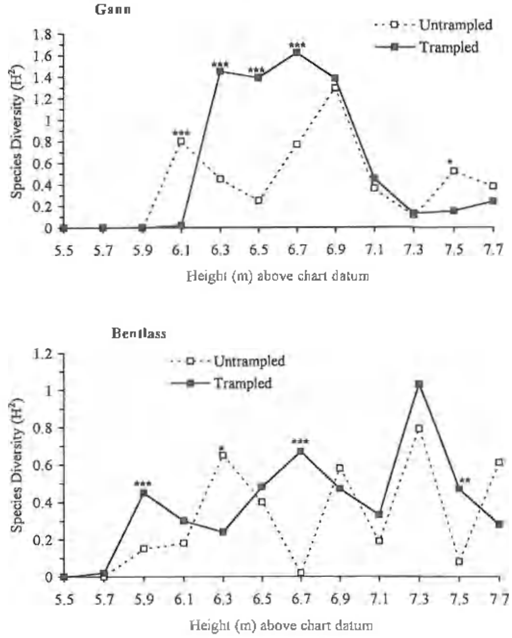


FIG. 3. Variation in species diversity (H^2) at different elevations (m above chart datum) on the untrampled (open squares) and trampled (closed squares) sections of saltmarsh of the Gann and Bentlass estuaries. See Fig. 2 for explanation of symbols indicating the significance levels of differences between means at the same elevation.

TABLE 4. *Plant communities of the trampled and untrampled sections of the Gann and Bentlass saltmarshes at different heights above chart datum: sections and the similarity coefficients of the vegetation between the trampled and untrampled areas. Nomenclature follows that of the National Vegetation Classification* (Rodwell, in press). SM6 = *Spartina anglica* saltmarsh; SM8 = Annual *Salicornia europaea* saltmarsh; SM10 = Transitional low saltmarsh vegetation; SM11 = *Aster tripolium discoideum* saltmarsh; SM13a = *Puccinellia maritima* saltmarsh typical subcommunity; SM14a = *Halimione portulacoides* saltmarsh typical subcommunity; SM16c = *Juncus gerardi* saltmarsh *Festuca rubra-Glaux maritima* subcommunity; SM16d = *Juncus gerardi* saltmarsh *Festuca rubra* subcommunity; SM17 = *Armeria maritima* saltmarsh; SM24 = *Elymus pycnanthus* saltmarsh.

Height (m)	Gann			Bentlass		
	Untrampled Section	Similarity Coefficient	Trampled Section	Untrampled Section	Similarity Coefficient	Trampled Section
5.5	Mud	100.0	Mud	Algal Mat	97.5	Algal Mat
5.7	Mud	100.0	Mud	Algal Mat	92.0	Algal Mat
5.9	Mud	98.4	Mud	SM8	93.1	SM8
6.1	SM14a	3.0	SM8	SM8	11.0	SM8
6.3	SM14a	22.1	SM11	SM11	22.8	SM8
6.5	SM14a	42.0	SM10	SM14a	17.5	SM6
6.7	SM14a	46.6	SM13a	SM14a	78.4	SM14a
6.9	SM17	59.9	SM16c	SM14a	61.3	SM14a
7.1	SM24	77.2	SM16d	SM14a	69.6	SM14a
7.3	SM24	87.5	SM24	SM17	1.2	SM14a
7.5	SM24	60.9	SM24	SM24	82.9	SM24
7.7	SM24	86.1	SM24	SM24	84.6	SM24

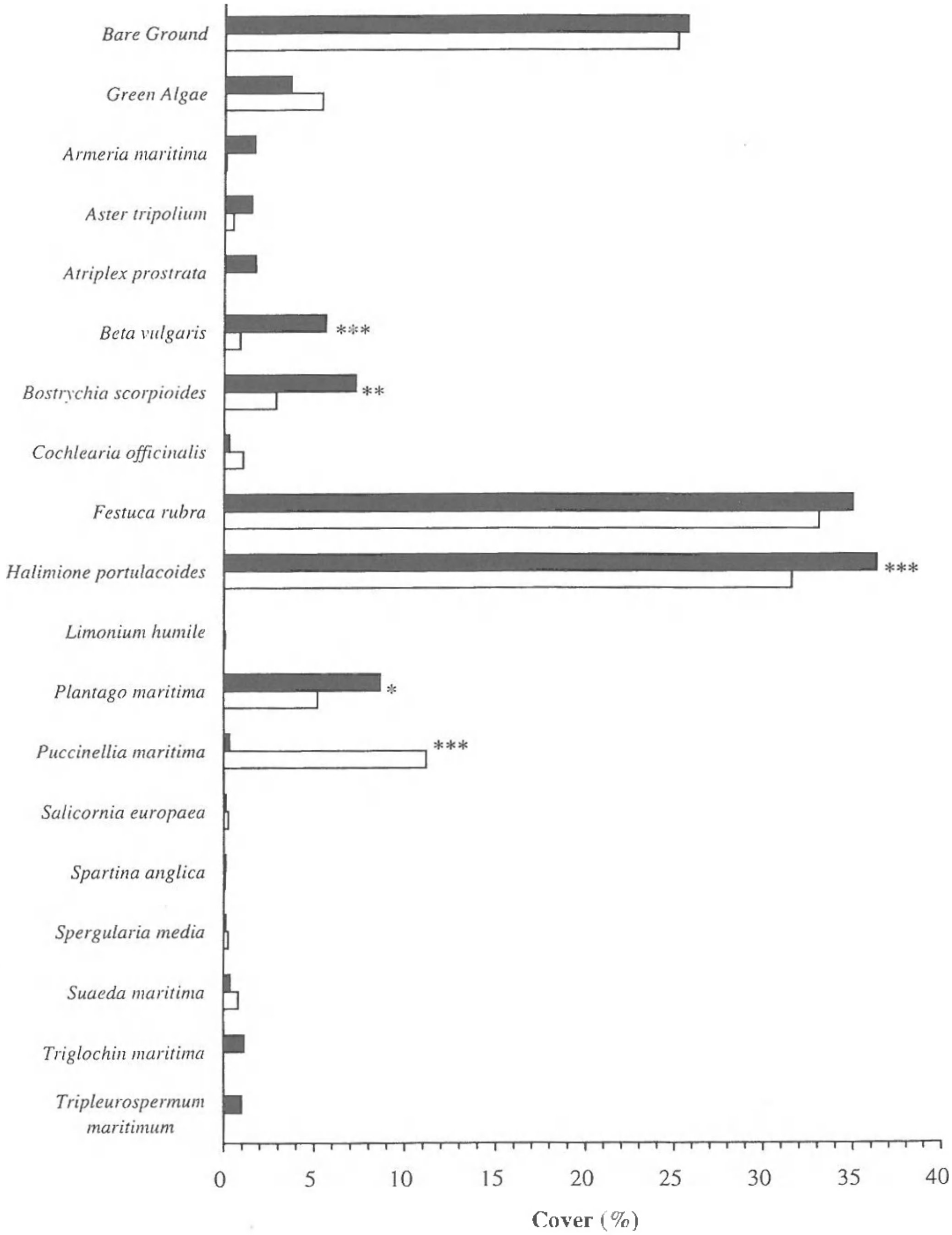


FIG. 4. The overall cover (percentage of whole zone surveyed) of each species in 1994 (open bars) and 1995 (filled bars) on the untrampled sections of the saltmarsh at the Gann estuary. See Fig. 2 for significance levels of x^2 test of frequencies (percentage cover) between treatments.

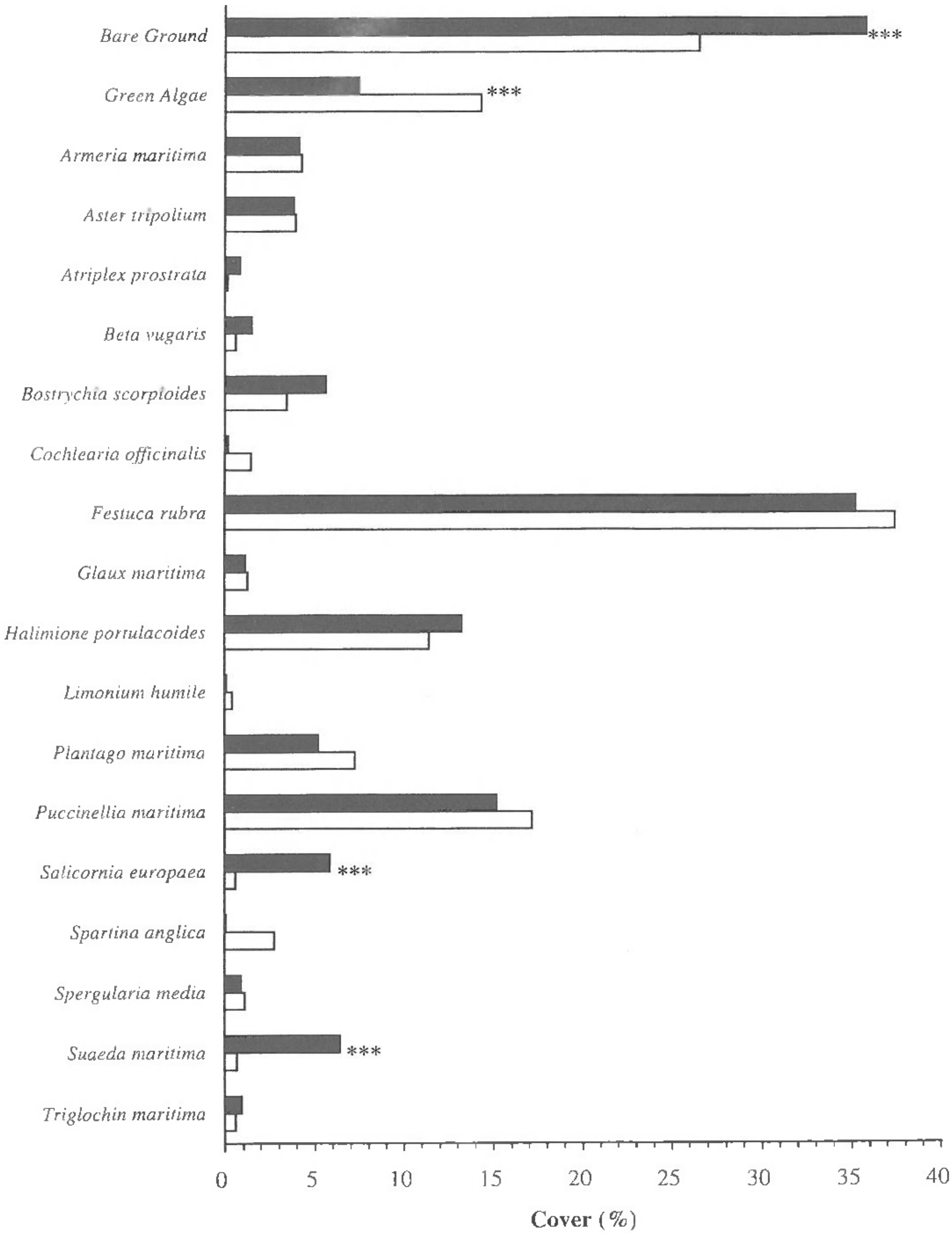


FIG. 4 concluded. The overall cover (percentage of whole zone surveyed) of each species in 1994 (open bars) and 1995 (filled bars) on the trampled sections of the saltmarsh at the Gann estuary. See Fig. 2 for significance levels of x^2 test of frequencies (percentage cover) between treatments.

TABLE 5. *F variance ratios (Fvar) and correlation coefficients (r) between percentage cover of individual species and time over a 10 year period of monitoring (1984 to 1993) of the trampled section of the Gann saltmarsh. Where there is a significant correlation between percentage cover and time (years) the mean rate of change in percentage cover per annum is shown with ± 1 S. E. bar.* *** P<0.001, ** P<0.01, * P<0.05.

Species	Fvar	r	mean rate of change in abundance (% $annum^{-1}$ ± S. E.)
Armeria maritima	1.36	0.006	
Aster tripolium	2.44*	0.125	
Halimione portulacoides	1.54	-0.133	
Beta vulgaris ssp. *maritima*	1.01	-0.007	
Bostrychia scorpioides	1.88	0.100	
Cochlearia officinalis	1.78	-0.045	
Festuca rubra	1.51	0.035	
Glaux maritima	1.35	0.191	
Limonium humile	1.93	-0.139	
Plantago maritima	1.18	0.146	
Puccinellia maritima	2.73**	0.101	
Salicornia europaea	3.35**	-0.262**	-0.54 ± 0.19
Spartina anglica	2.56*	0.204*	0.26 ± 0.11
Spergularia marginata	2.65**	-0.316***	-0.07 ± 0.02
Suaeda maritima	2.94**	-0.023	
Triglochin maritima	1.64	-0.242*	-0.13 ± 0.05
Unidentified green algae	4.97***	0.016	
Bare Ground	0.97	-0.040	
Shannon-Wiener Index	2.21*	-0.030	
Vegetation Height	0.57	-0.003	

Inter-annual variations in Species Abundance

The effects of trampling on the vegetation and the proportion of bare ground varied between years, depending on the species (Table 3). There was no significant difference in the area of bare ground between trampled and untrampled parts of the Gann saltmarsh in 1994, but, in 1995, the area of bare ground on the trampled part of the saltmarsh was greater (Table 3 and Fig. 4). This significant increase in the area of bare ground was due to the decline in the cover of the ephemeral filamentous green algal mat between the two years (Fig. 4) in the lowest parts of the saltmarsh as well as the upper mid-marsh zone (Fig. 2). The consistency in the percentage cover obtained for most species, particularly the perennials, and consequently the differences between the trampled and untrampled sections of the Gann saltmarsh (Table 3) give increased confidence in the reliability of the data.

There are significant increases in the cover of two of the annual species, *Suaeda maritima* and *Salicornia europaea* on the trampled part of the saltmarsh (Fig. 4). On the untrampled part of the Gann saltmarsh, there are significant increases in the cover of *Beta vulgaris* ssp *maritima*, *Halimione portulacoides*, *Bostrychia scorpioides* and *Plantago maritima* with an accompanying decline in *Puccinellia maritima* (Fig. 4).

There are a number of species which showed significant differences in cover between years, yet few of these actually show a significant trend with time (Table 5). The area of bare ground has not increased significantly over the 10 year period. This means that a 45% increase in use over that period has not added to the impact of the previous 37 years of trampling. The cover of *Spartina anglica* has increased significantly over the study period, whilst the cover of *Salicornia europaea*, *Spergularia marginata* and *Triglochin maritima* have declined significantly over the same period (Table 5).

The small change in the abundance of the different species between 1984 and 1994 is partly a consequence of the fact that the major changes in the trampled area of the saltmarsh occurred prior to the present study. Although there is no significant trend with time in the cover of some species, they do show statistically significant inter-annual variations (Table 5). These are not due to student error as careful sampling and identification by the authors showed significant changes in the cover of a number of species between 1994 and 1995 on both the untrampled and trampled parts of the saltmarsh (Fig. 4). The annual taxa; *Salicornia europaea*, *Suaeda maritima* and green algae show significant differences in overall cover between the two years on the trampled area. This is due to the inherent variability of populations, and therefore cover, of annuals as compared to those of perennials.

Recovery of saltmarsh vegetation after trampling at Bentlass

A comparison of the untrampled sections of the Gann and Bentlass saltmarshes showed significant differences in the overall cover of seven out of the 21 species found at the two sites. This is, probably, in part due to the differences in the textural characteristics of the substratum (Table 1) and therefore calculations of resilience of individual species to trampling cannot be made in the same way as Cole (1995b). It is possible to examine the similarity in overall species composition as well as cover of individual species between the former trampled area and untrampled parts of the saltmarsh (Table 3).

There were two species absent from the former transect line at Bentlass which were present on the adjacent untrampled portion of saltmarsh, *Beta vulgaris ssp maritima* and *Artemisia maritima* (Fig. 5). There were, however, a number of significant differences in the cover of certain species, with the filamentous green algae, *Bostrychia scorpioides*, *Plantago maritima* and *Spartina anglica* being more abundant overall on the former transect line and *Atriplex prostrata*, *Festuca rubra*, *Elymus pycnanthus* and *Triglochin maritima* having significantly greater cover away from the former trampled area (Fig. 5). It is interesting to note, that the cover of *Halimione portulacoides* on and off the transect line was virtually identical (Fig. 5). Although this suggests that a full recovery of this shrub is possible within 12 years after trampling ends, the zone dominated by *Halimione portulacoides* is higher up the saltmarsh (Fig. 5 and Table 4). *Puccinellia maritima*, *Aster tripolium*, *Spartina anglica*, *Festuca rubra* and *Atriplex prostrata* were all found further up the saltmarsh on the former trampled zone compared to the untrampled areas of the saltmarsh (Fig. 5).

Although there had been a 15cm rise in the level of the sediment at the lowest part of the saltmarsh, where marker posts for the transect have remained in place, since the transect was first used in 1966, many of the communities were further up the saltmarsh both in terms of distance and absolute height on both trampled and untrampled (Table 4). This means that there was a great deal of similarity between untrampled and former trampled parts of the saltmarsh at most height intervals except where there was a transition from one community type to another on the untrampled parts of the saltmarsh (Table 2).

The overall species diversity of the saltmarsh vegetation on the former trampled area was marginally higher (2.80) than on the untrampled area of the saltmarsh (2.77) as measured using the Shannon-Wiener diversity index. There were, however, significant differences in the diversity at specific height intervals on this saltmarsh (Fig. 3).

Discussion

In many studies of the ecological effects of recreation, it has been demonstrated or assumed, that trampling has a deleterious effect (Boorman & Fuller, 1977). In contrast, this study demonstrates that trampling by students had largely increased community and species diversity on a saltmarsh (see Fig. 3 and Table 4). These observations are in accordance with similar studies on the effects of trampling in other habitats (Davies, 1938; Goldsmith, Munton & Warren, 1970; Speight, 1973; Liddle & Greig-Smith, 1975; Tivy & O'Hare, 1981).

On the saltmarshes studied, the changes in diversity were largely a result of a decline in the overwhelmingly dominant shrub, *Halimione portulacoides*, which had allowed the lower growing species to increase in abundance and to spread up and down the saltmarsh. Cole (1995b) also found that woody chamaephytes have a lower resilience to trampling. This is because woody shoots are more likely to be broken than non-woody stems of herbaceous perennials. Non-woody herbaceous plants are able to replace damaged shoots more rapidly after damage due to their inherently faster growth rates (Grime, Hodgson & Hunt, 1990).

Generally, the species which increase in abundance when trampled are hemi-cryptophytes and therophytes (Cole, 1995b). On the Gann estuary, three hemi-cryptophytes (*Puccinellia maritima*, *Armeria maritima* and *Glaux maritima*), one halophyte (*Aster tripolium*), and two therophytes (*Salicornia europaea* and *Suaeda maritima*), have increased in abundance as a consequence of trampling (Fig. 4). Hemi-cryptophytes are able to recover rapidly after leaf material is damaged whilst annuals are able to establish in the areas of bare ground created by the death of less resistant species. *Aster tripolium* is similar to the hemi-cryptophytes, *Puccinellia maritima* and *Armeria maritima*, in terms of the position of its meristem and this will therefore confer similar advantages for this species.

Many trampling studies have concentrated on the effects it has on the soil, but as saltmarshes largely develop on undifferentiated sediments with virtually no structure, trampling is unlikely to affect it significantly. The observations on the Gann estuary confirm that the bulk density of the sediment is unchanged. Blionis (1991) found that vehicles compacted the more sandy substrate at Culbin Sands and resulted in the loss of the thin litter layer. There is no significant change in the water content of the Gann sediment. If anything, trampling will tend to reduce the absolute height of the substratum and thus result in increased frequency of inundation due to the lower elevation (Blionis, 1991). The changes in penetration resistance of the substratum are unlikely to influence significantly the growth of saltmarsh plant roots, as it is still relatively low compared to most soils and is well below the threshold of 1MPa that is considered to be the maximum penetration resistance that roots can grow in.

The trampling intensity on the Gann saltmarsh is approximately 7.3 student hours m^{-2} a^{-1} at present, but was formerly at about 4.8 student hours m^{-2} a^{-1}. It is not clear whether this level of trampling intensity is large or small, but this increase in use appears to have had little effect on the species composition (Table 5). For example, it has only resulted in the loss of one species, *Tripleurospermum maritimum*, and the appearance of three others, *Spartina anglica*, *Glaux maritima* and *Limonium humile*, in a 420 m^2 area of saltmarsh. Both these latter two species were already present elsewhere on the saltmarsh. It is only the change in relative abundance of the species over a 48 year period that has resulted in significant changes in the vegetation. It appears therefore that this saltmarsh has a high level of inertia (Westman, 1985). Although other disturbance events, such as oil spills, do have rapid short term effects on *Spartina anglica* and some other saltmarsh plants, they can recover equally quickly. This is due in part to fresh deposits of sediment covering any oil-contaminated layers (Baker, 1971), but also the fact that saltmarshes are naturally dynamic ecosystems where the level of the substratum can rapidly accumulate or erode due to changes in particular river courses and channels.

This suggests that the vegetation has reached an equilibrium with the trampling pressure. Where there are changes in the area of bare mud, they are likely to be due to changes in the quantity of the algal mat as seen between 1994 and 1995 (Fig. 4). *Armeria maritima*, *Aster tripolium*, *Puccinellia maritima*, *Salicornia europaea*, *Spergularia marginata* and *Suaeda maritima* on the Gann estuary have trampling resistance levels of 100% or more and some species, such as *Glaux maritima*, could have theoretically infinite resistance values (using the method of Cole, 1995a), if those species were not originally present on the saltmarsh prior to trampling (Table 5). The quantification of trampling resistance and resilience does not, therefore, overcome completely the problems it attempts to rectify in comparing different species or communities. It is clear, however, that the findings in this study confirm those of Andersen (1995) that saltmarshes are relatively resistant to trampling compared to other coastal ecosystems.

From the analysis of the saltmarsh at Bentlass it is clear that the abundance of 10 species still differ significantly between the former trampled area and the untrampled parts of the saltmarsh (Fig. 5). Although nothing is known of the detailed cover values for the different species on the trampled section of saltmarsh at Bentlass prior to trampling, the data presented by Cowell & Baker (1969) indicates that *Spartina anglica* was far more abundant in 1966 and 1968 than it is today even on the untrampled parts (Fig. 5). There is far more *Halimione portulacoides* today and this is almost certainly due to the dieback of *Spartina anglica* during the 1970's (Baker, Wilson & Levell, 1984).

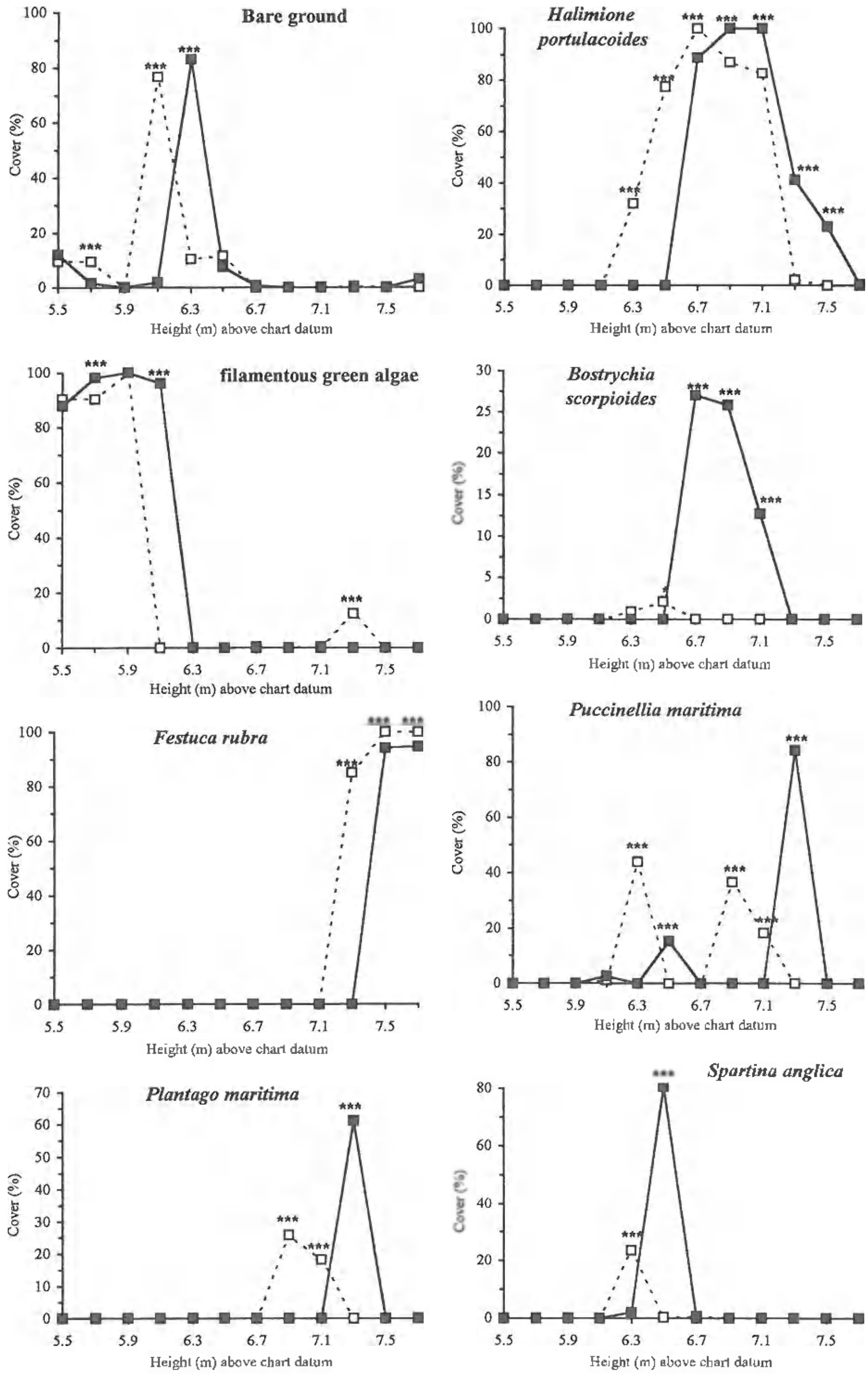


FIG. 5. The changes in percentage cover of bare ground, filamentous green algae, *Armeria maritima, Aster tripolium, Atriplex prostrata, Beta vulgaris* ssp. *maritima, Bostrychia scorpioides, Elymus pycnanthus, Festuca rubra, Halimione portulacoides, Limonium humile, Plantago maritima, Puccinellia maritima, Salicornia europaea, Spartina anglica, Spergularia marginata, Suaeda maritima* and *Triglochin maritima* with height (m)

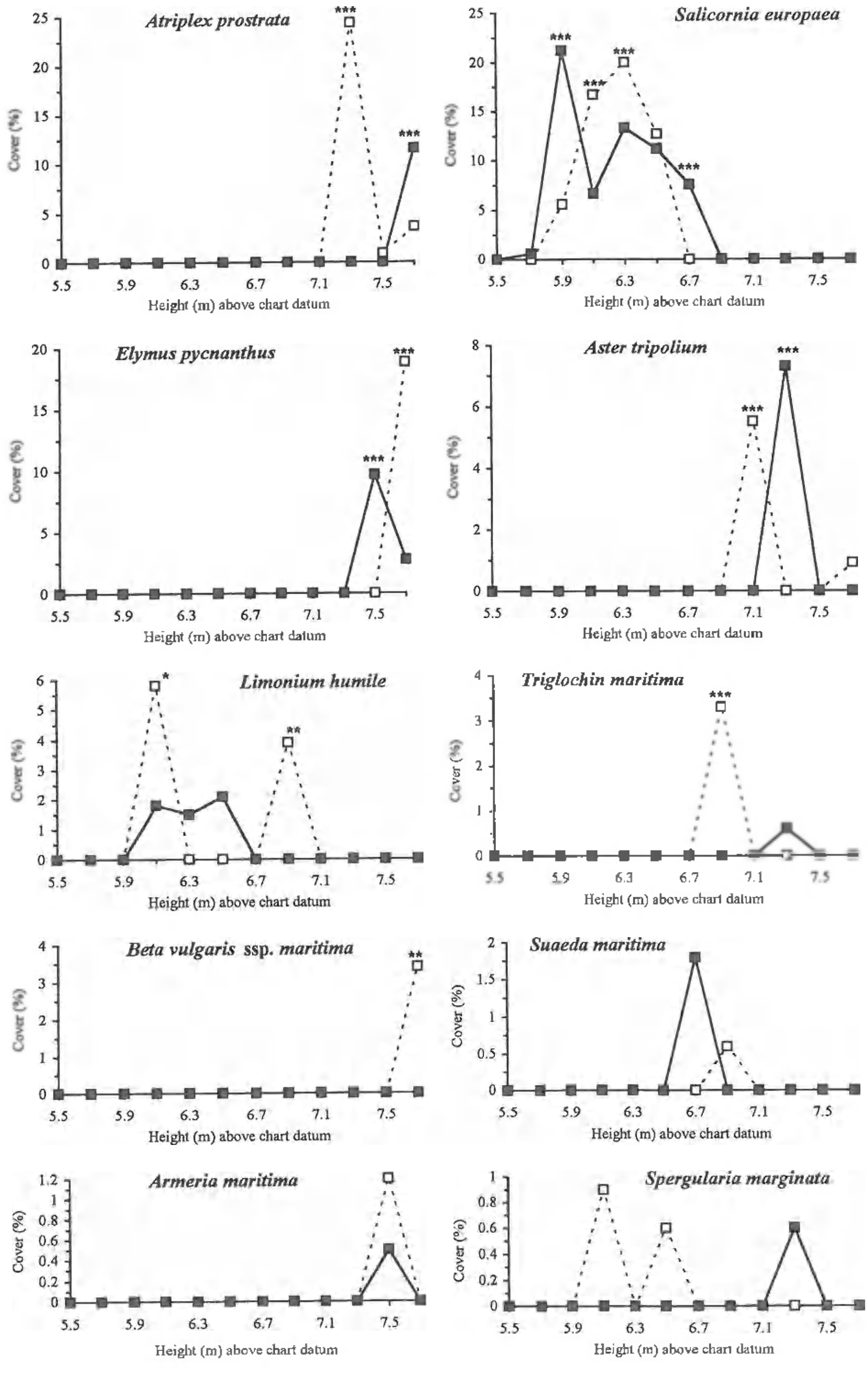


FIG. 5. concluded. chart datum on the Bentlass estuary on the untrampled (open squares) and trampled (filled squares) sections of saltmarsh. Each cover value derived from 330 points. See Fig. 2 for significance levels of c^2 test of frequencies (percentage cover) between treatments at the same height interval.

Although the Bentlass saltmarsh vegetation differs in its community composition from the Gann it is worth noting that the species most sensitive to prolonged trampling, *Halimione portulacoides* has recovered fully on the former trampled area of saltmarsh within 12 years. This shows that saltmarshes are hardly malleable (Westman, 1985) and can re-establish the same communities as the untrampled sections of the adjacent saltmarsh with little change. The length of time required for this full recovery is not more than 12 years and therefore gives us an estimate of its elasticity (Westman, 1985). Saltmarshes may be exceptional in their elasticity and malleability to disturbances, but this is almost certainly due to the naturally large and rapid changes that can occur in rates of sedimentation and erosion. As a consequence, effective means of dispersal and regeneration have been selected for in saltmarsh plants (Huiskes *et al.*, 1995) and thus damage through trampling appears not to have a large and long lasting effect in such a dynamic ecosystem.

The implications for field teaching on saltmarshes are that, although there may be short-term visually obtrusive damage to vegetation, it has a high capacity to recover or regenerate from propagules brought in by the tides. These observations can be used to illustrate to students the impact of the observer on the object of study. The maintenance of historical data gathered by staff at field centres at sites being used of long periods, such as the Gann, can therefore also be used to monitor ecosystem responses to long-term and often subtle environmental changes or to highly infrequent stochastic and often catastrophic environmental events which may shed light on factors influencing community and ecosystem structure.

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