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# Impact of the alien sea buckthorn (*Hippophae rhamnoides* L.) on sand dune ecosystems in Ireland

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ABSTRACT: The impact of the invasive sea buckthorn on a sand dune ecosystem was investigated. Sea buckthorn slightly altered $CaCO_3$ and pH, but had no impact on organic matter and total nitrogen. In a sea buckthorn stand, showing distinctly recognisable stages in a continuum of age, structure and succession, clear differences were observed in the vegetation, mesofauna and ground beetle communities. The few measured environmental variables did not correlate with these changes. The variation under sea buckthorn leads to a shift towards typically woodland communities. The findings are related to the impact of other invaders of sand dunes ecosystems.

## INTRODUCTION

Like most islands, the flora of the British Isles, and particularly that of Ireland, is depauperate and the vegetation has been invaded extensively by alien species. Sand dunes, often part of National Nature Reserves, are not immune to biological invasions, and a large number of reports have highlighted their invasion by exotic species. Some examples are given in Table 1. A large number of species have been recorded, although often in low numbers. Irish sites appear to be particularly prone to invasions. Although *Acer pseudoplatanus*, *Lupinus arboreus*, *Pinus* spp. and *Rhododendron ponticum* can create severe problems, the most aggressive species is sea buckthorn (*Hippophae rhamnoides* ). In most cases the advent of woody species invasion coincided with the decline in rabbit numbers following the outbreak of myxomatosis in the 1950s.

Reasons for the introduction of exotic species and their subsequent spread can be ascribed to three categories: 1) erosion control (*H. rhamnoides*, *L. arboreus*), 2) forestry plantations (conifers) 3) amenity planting (*A. pseudoplatanus*, *R. ponticum*, *Rubus spectabilis*).

*H. rhamnoides* has invaded a large number of sites and appears to be a serious threat to the native dune flora and fauna. In this study the impact of sea buckthorn on sand dune ecosystems was investigated on one Northern Irish dune system at Portstewart (Co. Londonderry), where its cover increased from 1.6% to 13% of the dune area between 1949 and 1989 (Binggeli *et al.* , in preparation). Changes in soil chemistry, flora, fauna and its impact on succession were investigated. Finally the impact of sea buckthorn on ecosystem structure and function is related to that of other woody species invasive of sand dunes ecosystems.

Table 1. Invasive species of sand dune ecosystems from selected sites in the British Isles.

| | Ireland | | | | Wales | Scotland | England | | |
|---|---|---|---|---|---|---|---|---|---|
| Species | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| *Acer pseudoplatanus* | * | * | | | | | | | |
| *Cotoneaster simonsii* | * | * | | | * | | | | |
| *Hebe speciosa* | | | * | | | | | | |
| *Hippophae rhamnoides* | * | * | | | * | | * | | |
| *Larix* spp. | | | | | | * | | | |
| *Lupinus arboreus* | | | * | * | | | | * | |
| *Malus sylvestris* | * | | | | * | | | | |
| *Oenothera erythrosepala* | | | * | | | | | | |
| *Picea stichensis* | | | | | | * | | | |
| *Pinus contorta* | | | | | * | * | | | |
| *Pinus nigra* var. *nigra* | | * | | | | * | | | * |
| *Pinus sylvestris* | | * | | | | | | | |
| *Pinus* spp. | | | | | * | | | | |
| *Rhododendron ponticum* | | * | | | | | * | | |
| *Rubus spectabilis* | | * | | | | | | | |

Sites and sources: 1) Portstewart, Co. Londonderry (Binggeli *et al.*, in preparation); 2) Murlough NNR, Co. Down (Whatmough, 1978); 3) Portavogie, Co. Down (Hackney, 1976); 4) Courtown, Co. Wexford (Quinn, 1977); 5) Newborough Warren NNR, Gwynedd (Hodgkin, 1984); 6) Tentsmuir Point NNR, Fife (Leach and Kinnear, 1985); 7) Winterton Dunes NNR, Norfolk (Doody, 1985); 8) Dawlish Warren, Devon (Doody, 1985); 9) Holkham NNR, Norfolk (Blackstock, 1985).

Sea buckthorn, Hippophae rhamnoides L.

Sea buckthorn, a nitrogen-fixing shrub, has a distribution extending from western Europe to China. During the late-Glacial period, sea buckthorn occurred in Great Britain (Godwin, 1956) and Ireland (Jessen *et al.*, 1959; Watts, 1959), but it is believed, at present, to be native only in the coastal region of eastern England. However, it is spreading on many dune systems in Great Britain and Ireland following its introduction chiefly for dune stabilisation (Kinahan and McHenry, 1882; Groves, 1958). Sea buckthorn is a variable species (Pearson and Rodgers, 1962) and several sub-species have been recognized (Rousi, 1971). It usually reaches a height of 3m in the British Isles but individuals as high as 11m have been found in Norway (Skogen, 1972). The habitats occupied by sea buckthorn are diverse and include, 1) sand dunes in Britain and on the European Atlantic coast where stands can be as wide as 1km (Delelis-Dusollier and Géhu, 1974), 2) tidal estuaries in Norway (Skogen, 1972), 3) gravel of river beds in the Rhone valley, and 4) gravel banks of alpine streams (Groves, 1958). Sea buckthorn is a dioecious bird-dispersed species, but often few seedlings become established. However once established, it spreads vegetatively to rapidly form large stands of impenetrable thickets.

In Ireland, introduced sea buckthorn was first recorded around 1838 in Co. Wexford and was planted on many dune systems until early this century, not just for sand stabilisation, but because it is one of the few woody plants to thrive on the coast (Groves, 1958).

## METHODS

### *Fieldwork and laboratory analysis*

A transect was established in the oldest clump of sea buckthorn on the Portstewart dunes. It was chosen to include the oldest part of the stand, locally known as the 'Black Forest', dominated by elder (*Sambucus nigra*), and an expanding front of young sea buckthorn (Fig. 1).

Six physiognomic groups were recognized along the transect:
1) 'open' fescue grassland, 2) sea buckthorn invading fescue grassland, 3) maturing sea buckthorn, 4) mature sea buckthorn mixed with some elder, 5) senescent sea buckthorn and elder and 6) elder dominated woodland (Fig. 2). In each group, a site was chosen to be typically representative of the canopy structure and ground vegetation.

At each of the six sites the following sampling procedure was adopted: the sea buckthorn stem with the largest girth diameter was cut from the stand and aged by ring count. At each site, sampling took place at five randomly selected points in November 1990. At these 30 subsites, two soil cores were taken to a depth of 0.05m using a circular corer 0.1m in diameter. One soil core per subsite was used for laboratory analyses. At each site, a soil pit was dug and four soil samples were collected at 0.05m depth intervals. pH was determined following dilution by 1:2.5 with distilled water. Organic matter was measured as loss-on-ignition of oven dried samples at 430°C overnight. Calcium carbonate percentage was determined using a calcimeter, measuring $CO_2$ evolution on addition of HCl (Bascomb, 1961). The Kjeldahl digestion method (Black, 1965) was used to determine total nitrogen. From the other cores, soil mesofauna were extracted using Tullgren Funnels. These were identified to the genus level to give a quantitative estimate of abundance for the thirty samples. Six randomly positioned pitfall traps per site were set up and left *in situ* for 3 days on 3 occasions starting on the 29 March, 18 April, and 7 May 1991 to survey ground beetles (Coleoptera: Carabidae).

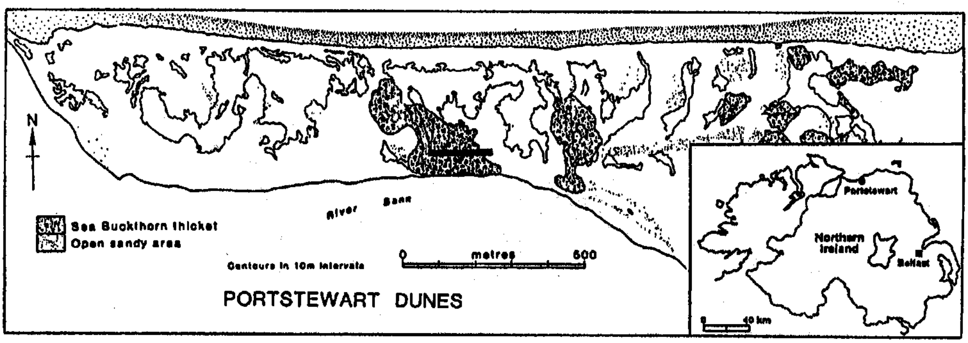


Figure 1. Location of Portstewart, and transect through sea buckthorn-elder stand.

In addition the vegetation cover was estimated in 1m$^2$ quadrats at five metre intervals along the 190m transect giving a total of 38 quadrats.

*Data analysis*

The vegetation data, following removal of shrub species, was analyzed using TWINSPAN (Hill, 1979a) which classified the 38 quadrats into vegetation types. In order to reduce the range of community variation in the soil mesofauna data, the data matrix was manipulated using DATAEDIT (Singer, 1980); rare species were deleted, sample totals relativised to 100, and these abundance values expressed logarithmically using the integer range 0 to 9. These data were analyzed using TWINSPAN and DECORANA (Hill, 1979a,b). Soil chemistry data were analyzed firstly in isolation by two way ANOVA in an attempt to determine whether significant differences existed between sites. These measures were then amalgamated with the soil mesofauna data in order to illustrate potential environmental gradients, by means of a hybrid ordination (Gauch, 1982). This involves the use of Detrended Correspondence Analysis of the mesofauna data to provide weights for a weighted average ordination of the soil chemistry. Correlation coefficients between soil chemistry and main environmental (ordination) gradients were calculated for the first and second ordination axes. A similar hybrid ordination was not carried out on the floristic data as environmental factors were not measured at each quadrat along the transect. In view of the rather poor catch per trap during the carabid survey, it was decided that in this case multivariate methods would be inappropriate. Individual trap catches were pooled over the three sampling periods, and used to provide indices of species diversity and dominance (alpha of the log series distribution and the Berger-Parker dominance index - Southwood, 1978).

Full species lists are available on request from the authors.

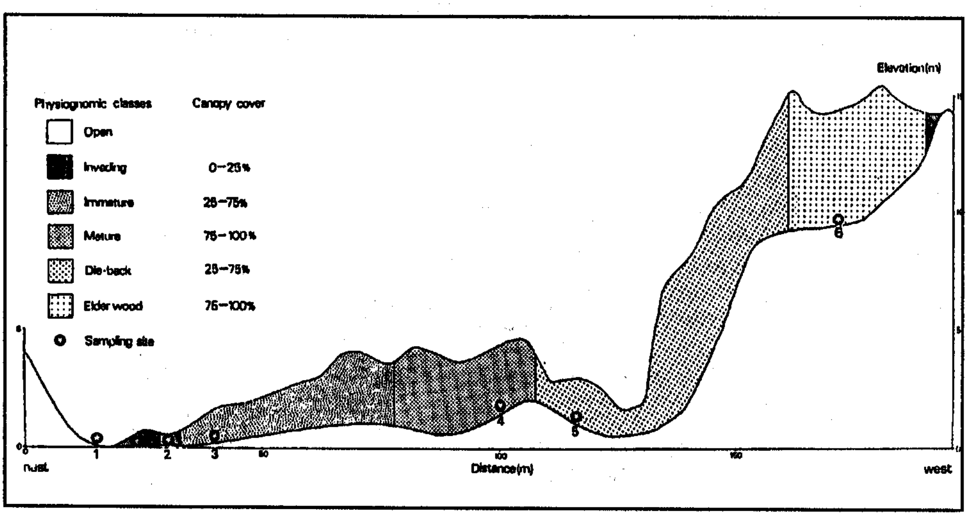


Figure 2. Diagrammatic representation of the transect.

## RESULTS

### *Soil*

Analysis of variance (Table 2) showed no significant difference between Sites 1 to 6 for total nitrogen and pH, but there was significant inter-site variation in the case of calcium carbonate and organic matter. A least significant difference (LSD 5%) established that Sites 3 and 4 were relatively deficient in calcium carbonate when compared to Site 5, and particularly Site 6, which actually has significantly more $CaCO_3$ than Sites 1 and 2. In addition, it was found that Site 4 was richer in organic matter than Sites 1, 2, 5 and 6, forming a peak in soil organic content around the centre of the transect. Within and between-site differences in pH, $CaCO_3$ and organic matter were only observed in the top 0.05m of each soil profile.

### *Vegetation*

TWINSPAN classification of the ground vegetation along the transect illustrates the impact of *Hippophae rhamnoides* on plant communities (Fig. 3 and Table 3). It was considered appropriate to terminate the hierarchical analysis at the third division level, thus recognising four vegetation classes (the class names are defined by the ground vegetation).

*Class I*
Species-rich fescue grassland. It is divided from Class II by the presence of *Hieracium pilosella*, a species of dry, mesotrophic calcareous grasslands. Constant species include *Festuca rubra*, *Poa pratensis*, *Hypochoeris radicata*, *Hie. pilosella* and the mosses, *Hylocomium splendens* and *Rhytidiadelphus triquetrus*. Common species are *Lotus corniculatus*, *Thymus preacox*, *Senecio jacobaea*, *Rhytidiadelphus squarrosus* and *Hypnum cupressiforme*. The vegetation forms a short, herb-rich turf, 0.05m high, except in ungrazed areas around scattered clumps of *Ammophila arenaria*, and *H. rhamnoides* of the advancing clone margin.

*Class II.*
Species-poor grassland. Constant species are *Holcus lanatus*, *P. pratensis* and *F. rubra*, together with a bryophyte layer commonly composed of *R. triquetrus*, *R. squarrosus* and *Pseudoscleropodium purum*. Herbs are lacking when compared to Class I and Class III. Here the shrub/tree canopy becomes partially closed as the sea buckthorn matures, reaching a height of up to 3.5m.

*Class III.*
*Urtica dioica* communities. A nitrophilous plant, *U. dioica* is both common and abundant. Frequent species include *Heracleum sphondylium*, *Galium aparine*, *Holcus lanatus* and *P. pratensis*. These are more abundant in areas of canopy die back. Where canopy cover approaches 100%, ground vegetation is virtually absent.

*Class IV.*
Bryophyte-rich *Urtica* communities. *U. dioica* is abundant with an incomplete moss layer. Common species include *Hyp. cupressiforme*, *Bracythecium rutabulum* and *Thuidium tamariscinum*. Sea buckthorn is confined to isolated individuals amongst the elder scrub, which reaches a height of up to 6m. Again where canopy cover is nearly complete, ground cover is mainly bare soil. Woody litter is abundant in places. This class is particularly species poor, with herbs very infrequent.

Table 2. Variation in soil and selected faunal groups along a 190m transect through Sea Buckthorn/Elder Wood, Portstewart Dunes.

| | Sample Sites 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Physiognomic Classes | open | invading | immature | mature | dieback | elder |
| Age of Sea Buckthorn (years) | | 6 | 21 | 34 | 51 | 55 |
| **Soil** | | | | | | |
| pH | | | | | | |
| mean of soil cores | 8.2a | 8.0a | 7.8a | 7.6a | 8.0a | 8.0a |
| 0.00 to 0.05m | 8.0 | 7.7 | 7.8 | 8.2 | 7.7 | 7.9 |
| 0.05 to 0.10m | 8.3 | 8.2 | 8.3 | 8.5 | 8.2 | 8.5 |
| 0.10 to 0.15m | 8.4 | 8.3 | 8.5 | 8.5 | 8.4 | 8.6 |
| 0.15 to 0.20m | 8.5 | 8.4 | 8.6 | 8.7 | 8.5 | 8.7 |
| $CaCO_3$ % | | | | | | |
| mean of soil cores | 4.9a | 5.1a | 4.7ab | 3.8ab | 6.0bc | 6.7c |
| 0.00 to 0.05m | 6.6 | 4.2 | 3.5 | 5.4 | 3.3 | 5.6 |
| 0.05 to 0.10m | 8.4 | 8.6 | 7.8 | 6.2 | 7.6 | 8.1 |
| 0.10 to 0.15m | 9.5 | 8.7 | 8.4 | 6.1 | 7.6 | 8.4 |
| 0.15 to 0.20m | 9.6 | 7.2 | 8.7 | 7.2 | 7.9 | 8.2 |
| Organic matter % | | | | | | |
| mean of soil cores | 4.3a | 3.5a | 5.4ab | 7.4b | 4.3a | 3.0a |
| 0.00 to 0.05m | 2.1 | 2.7 | 5.0 | 3.0 | 7.2 | 4.2 |
| 0.05 to 0.10m | 1.2 | 0.9 | 0.9 | 0.8 | 1.5 | 0.6 |
| 0.10 to 0.15m | 0.8 | 0.7 | 0.6 | 0.5 | 0.7 | 0.6 |
| 0.15 to 0.20m | 0.7 | 0.5 | 0.4 | 0.4 | 0.6 | 0.4 |
| Total Nitrogen % | | | | | | |
| mean of soil cores | 0.12 | 0.11 | 0.18 | 0.20 | 0.17 | 0.13 |
| **Soil Mesofauna** | | | | | | |
| No. genera/$dm^3$ | 17 | 14 | 16 | 20 | 16 | 16 |
| No. indivs/$dm^3$ | 507 | 523 | 769 | 507 | 586 | 534 |
| **Carabida** | | | | | | |
| No. species/site | 6 | 9 | 6 | 5 | 8 | 5 |
| Alpha sp. diversity | 3.15 | 3.72 | 3.70 | 1.86 | 3.04 | 2.62 |
| Berger-Parker dominance index | 0.68 | 0.66 | 0.55 | 0.44 | 0.46 | 0.40 |

Note: Mean of soil parameters is expressed as a mean of 5 sub-samples for each site. Means with the same letter are not significantly different at $p<0.05$.

Table 3. Variation in vegetation along a 190m transect through Sea Buckthorn / Elder Wood, Portstewart Dunes.

| | Twinspan Vegetation Classes | | | |
|---|---|---|---|---|
| | I | II | III | IV |
| Floristics | | | | |
| No. quadrats | 6 | 10 | 12 | 10 |
| | 38 | 34 | 36 | 19 |
| Species/quadrat | | | | |
| Mean | 23.2 | 12.4 | 13.3 | 8.1 |
| Maximum | 25 | 18 | 18 | 13 |
| Minimum | 18 | 7 | 8 | 2 |
| Sample Sites | 1,2 | 3 | 4,5 | 6 |

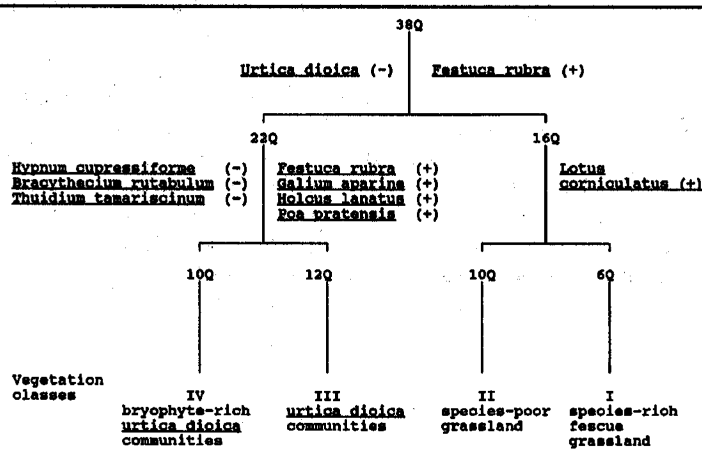


Figure 3. Two way indicator species analysis of 38 vegetation quadrats to four groups. Indicator species are given for each division.

Under sea buckthorn there was a decrease in the total number of species (from 43 to 19) and the mean number of species per quadrat (from 23.4 to 7.9) (Table 3).

*Mesofauna*

Certain mesofaunal genera were present at all sites (e.g. Oribatei: *Oppia* sp.), whereas the appearance of others occurred at distinct sites; for example, *Nanhermannia* sp. (Oribatei) was either the dominant or first sub-dominant genus at Sites 3 to 6, but was absent from Sites 1 and 2. Sea buckthorn appeared to have no influence on calculated values of generic richness (Table 2). However this may conceal effects on species diversity, which could not be estimated as identification beyond generic level has not been completed for all the invertebrates in the samples. A TWINSPAN analysis of these data regrouped the individual samples into their parent sample sites (Fig. 4). The open canopy Sites 1 and 2, split from the remainder at the first division, followed by the elder wood site (Site 6) at the next level. The

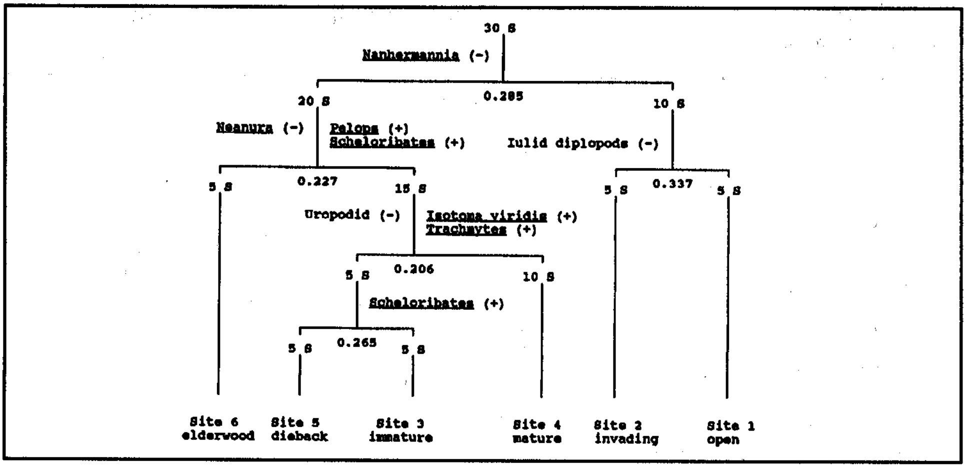


Figure 4. Two way indicator species analysis of 30 mesofauna samples to six groups. Indicator genus/species are given for each division. Eigenvalues are given in brackets.

site-specific nature of the soil invertebrate communities can be seen in the DECORANA analysis (Fig. 5). The sites occupy distinctly different places on the ordination. Sites 1 and 2 ordinate together to the right of Axis 1 forming an open canopy group, distinct from the woodland group (Sites 4, 5 and 6). Site 3 is intermediate between these groups in the centre of the ordination, close to the weighted averages of the environmental data. The lack of variability in the environmental parameters along the transect allows no obvious gradient to be inferred from the ordination of soil mesofauna data. Further, all correlation coefficients between ordination scores and environmental variables proved non-significant at $p<0.05$ level.

### *Carabid beetles*

The carabid survey established that the species-rich fescue grassland of Site 1 is dominated by *Amara aenea*, a xerophilous species of open sandy ground (Lindroth, 1974), whilst the most common ground beetles of the remaining five sites, with a sea buckthorn/elder canopy, were woodland species. *Pterostichus strenuus*, the most frequently caught carabid, appeared closely associated with damper, bryophyte rich sites (Sites 2, 3 and 5), whereas *Notiophilus biguttatus* and *Calathus piceus* were more abundant in drier areas with sparse ground vegetation (Sites 4 and 6). Table 2 shows that sea buckthorn has little effect on carabid diversity, other than to marginally increase species richness when immature, as it invades grassland sites. However the dominance index clearly declines as the scrub matures.

## DISCUSSION

### *Changes in soil chemistry, flora and fauna along the transect*

Sea buckthorn had a small (but significant) impact on measured environmental variables, such as $CaCO_3$ and organic matter, at Portstewart. This may be because of the high $CaCO_3$

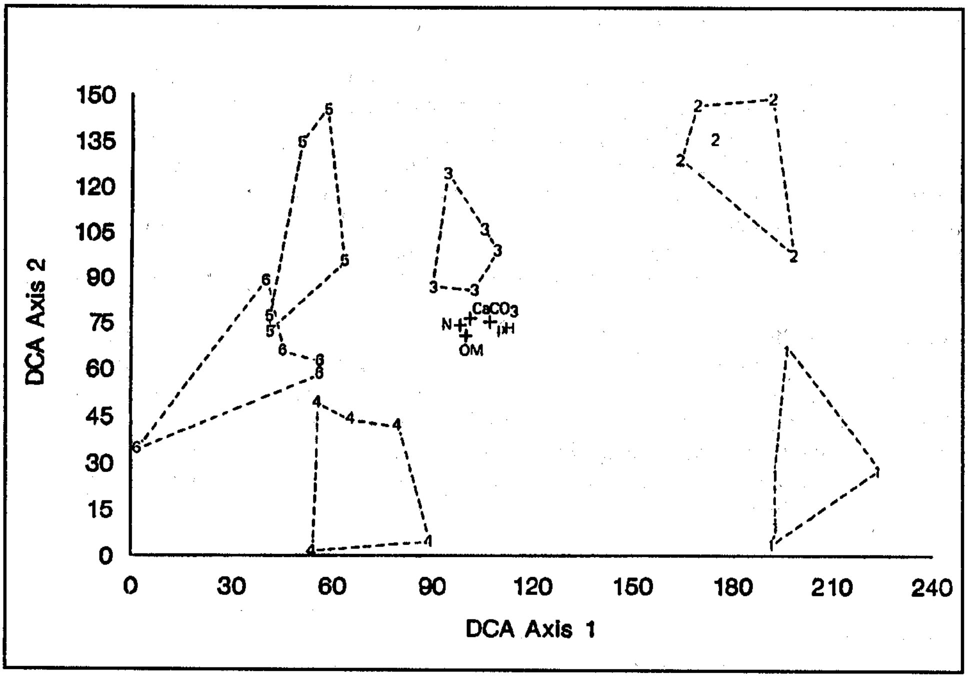


Fig. 5. Hybrid ordination of soil mesofaunal samples and soil factors. The numbers indicate sampling sites ($CaCO_3$ = calcium carbonate, OM = organic matter, N = total nitrogen).

(*ca.* 8 to 9%) of the sand. At Murlough Bay (Co. Down), where the pH of the sand is around 6, the pH under stands of sea buckthorn rapidly decreased to 4 or lower (Binggeli *et al.* unpublished). Such a low pH is believed to be the reason for the dieback of sea buckthorn on acid sand at Murlough Bay dunes (Co. Down), as the nitrogen fixing bacterium does not survive at a pH of less than 4 (Westhoff, 1989). The observed senescence of part of the transect at Portstewart (atypical of the site) is difficult to explain but could be caused by parasitic nematodes on N-fixing nodules as demonstrated in the Netherlands (Zoon, 1986).

The expected increase in total nitrogen as sea buckthorn invades dune grassland was not observed, however as Waughman (1972) stated, *Lotus corniculatus* fixes relatively more nitrogen than sea buckthorn and this species is commonly found at Sites 1 and 2.

The decrease in dominance found in the carabid survey as the scrub matures is similar to the results of Day's (1984) survey of 31 Northern Irish habitats. However, his observed higher species diversity was not found. The species diversity and dominance index of the dune grassland (Site 1) is similar to that of dune sites surveyed by Day.

At the six sampled sites, representing distinctively recognisable stages in a continuum of age, structure and succession of the sea buckthorn stand, clear differences were observed in their corresponding vegetation, mesofauna and ground beetle communities. The few measured environmental variables did not correlate with these changes. This clearly indicates that other variables, such as light, humidity, nutrient cycling, should be investigated, and that a refinement of the soil sampling procedure must be considered. For the soil analysis the use of 0.05m deep bulk samples may not be adequate.

*Impact of sea buckthorn on dune ecosystem*

Table 4, based on our work at Portstewart and Murlough, and published literature, summarises the impact of sea buckthorn on sand dune ecosystems. From a nature conservation perspective, when compared to typical dune vegetation, sea buckthorn invasion has several positive and negative impacts on the ecosystem. On one hand it clearly decreases plant species richness and displaces rare species. However it appears to have an overall positive impact on faunal diversity. The changes lead to a shift towards typically woodland communities. This trend is also noticeable in bird diversity which increases; woodland species such as wren, willow warbler and dunnock breed in sea buckthorn scrub.

Sea buckthorn alters the nutrient status of the soil (e.g. increases nitrogen at sites without other nitrogen-fixing species. It also modifies soil structure in increasing litter content and soil humidity. Under dense canopy it reduces plant (particularly grass) competition and affects seed dispersal of some species by providing roosting sites for birds which disseminate seeds. Such changes provide the conditions required for the regeneration of some woody plants. For instance sycamore and elder are intolerant of grass competition and the latter species requires high nitrogen status for growth.

Table 4. Impacts of Sea Buckthorn on Sand Dune Ecoystem.

positive
1. stabilizes shifting sands,
2. controls movement of people,
3. facilitates woody plant regeneration,
4. provides breeding sites, shelter and winter food for birds,
5. provides habitats for badgers,
6. increases earthworm and millipede abundances,
7. increases microflora abundance.

positive / negative
1. lowers soil pH.

negative
1. increases nutrient status,
2. replaces botanically interesting plant communities, resulting in the displacement of uncommon or rare plant species, which require nutrient deficient conditions,
3. decreases plant species-richness,
4. facilitates the establishment of exotic woody plants such as *Acer pseudoplatanus*, *Clematis vitalba*, *Rubus spectabilis*,
5. invades all dune habitats,
6. is hard to control as its vegetative spread requires long-term management. Established stands are difficult to eradicate.

Conclusion: The positive impacts increase species and habitat diversity, but the negative effects lead to the development of vegetation and invertebrate communities fundamentally different from the invaded habitats. If its spread can be controlled, some sea buckthorn should be preserved.

The way sea buckthorn facilitates the establishment of both native and exotic woody species supports the view that invasive plant species not only alter the ecosystem's resource acquisition and utilization (e.g. nitrogen fixing increases nutrient availability), as well as disturbance frequency and intensity, (e.g. changes in sand stability) as suggested by Vitousek (1990), but can also have a significant impact on plant regeneration of late successional species (Binggeli, 1990). Such impacts lead to a shift in species composition and structure of plant communities.

In South Africa, acacias (*Acacia cyclops*, *A. longifolia* and *A. saligna*) were used widely for dune stabilization and were established by sowing seeds among grasses. Like sea buckthorn they have the ability to form impenetrable thickets which suppress and replaces native vegetation (Avis, 1989). These acacia species also have an important impact on the ecosystem function as they alter nutrient cycling. They produce more litter with three times the nitrogen content. Soil nitrogen concentrations increase under acacia canopies (Witkowski, 1991). Another species, *Casuarina equisetifolia*, has a low invasive potential in South Africa, but produces a copious leaf litter and its roots are very fibrous, covering a large area of ground around each tree. This is the result of a symbiotic association with a bacterium of genus *Frankia*; as a consequence no other species grow under the trees (Avis, 1989).

## CONCLUSION

Sea buckthorn significantly affects the fauna, flora and some soil characteristics of Irish dunes. Since some of its impacts are not deleterious sea buckthorn should not be eradicated, but its spread must be controlled. Large stands containing elder should be conserved with their spread checked, but small clones, and in particular younger ones should be eliminated. Sea buckthorn is only one of the numerous species invading sand dunes worldwide. Since sand dune ecosystems are very susceptible to species invasions, the management of dune habitats should include early eradication of all species showing any invasive potential before the extent of the problem becomes practically and financially impossible to control.

## ACKNOWLEDGMENTS

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