VEGETATION PATTERNS IN RELATION TO BIRD NESTING PREFERENCES ON WEST ISLAND, SOUTH AUSTRALIA

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Summary

West Island near Victor Harbor, SA is an important near-shore nesting site for several bird species, but nesting behaviour in shorebirds is often affected by changes in rookery vegetation. Because the island is under increasing threat from invasion and expansion of weeds, its vegetation patterns were determined and preference analysis undertaken for nesting by Silver Gulls, (Larus novaehollandiae) and Little Penguins (Eudyptula minor), as studies in WA suggest they are affected by vegetation changes. The results indicated that there were four broad types of vegetation on the island: grass-dominated, shrub-dominated, mallow/weedy forb-dominated and native forb-dominated. These were correlated with soil and exposure features, the grasses and shrubs being most abundant on more sheltered alkaline and less saline soils, while shrubs dominated in rocky, leeward areas. The native forbs and low shrubs occurred in more exposed saline and alkaline areas, weedy forbs in more sheltered, less saline places. Nesting preference analysis showed that both the Silver Gulls and Little Penguins significantly preferred open, grass-dominated areas. Penguins were significantly less abundant in quadrats with high levels of exposed surface rock and shrubs or weedy annual forbs (although they did still nest under rocks in these areas), whereas the gulls significantly avoided native, perennial forb-dominated areas, although this may also be a reflection of the degree of exposure of the latter. As the weedy forbs are known to invade areas of increasing fertility resulting from nesting, this highlights the need for successful weed control in offshore rookeries if successful nesting is to continue in the long term.

KEY WORDS: Near offshore islands, vegetation structure, bird nesting, conservation, ordination, preference assessment, compositional analysis

Introduction

Invasion of offshore islands in southern Australia by woody or arborescent weeds such as the Mediterranean woody ephemeral Malva dendromorpha M.F.Ray (Tree Mallow: Malvaceae) has led to major alterations in vegetation structure, and this has implications for the nesting patterns of the seabirds. Ground-nesting seabirds often select nesting sites based on vegetation structure (Green & Griffiths 1994; Patterson & Best 1996; Rippey et al. 2002), and are known to be adversely affected by invasion of woody perennial shrubs on these islands (Rippey et al. 2002; Lawley et al. 2005). Seabird colonies can also affect the vegetation directly through burrowing and trampling (Hope & Thompson 1971; Sobey & Kenworthy 1979; Brown et al. 1993; Walsh et al. 1997), and guano deposition can result in increased cover by woody or annual weeds and grasses (Sobey & Kenworthy 1979; Bukaciniski et al. 1994).

One such near-offshore island is West Island, a granitic knoll about 800 m off the southern coast of South Australia, 1.5 km south west of Rosetta Head, Victor Harbor (35°37'S 138°36'E). Since the arrival of M. dendromorpha on the island, apparently some time after 1980 (SA NPWS 1983), it has covered almost the entire island, invading the ‘introduced grassland’ and ‘Disphyma crassifolium (L.) L.Bolus herbland’ vegetation associations (as defined by Robinson et al. 1996) which had previously covered the island. It also apparently displaced the white-flowered offshore island form of M. australiana M.F.Ray (= Lavatera tomentosa Sims var. tomentosa Hook.f.), also known as M. behriana Miq. (Lawley & Shepherd 2005) which had previously been common (Paton & Paton
The island is 550 m by 400 m at the widest point, with the highest point 40 m above sea level (Fig. 1) and is largely covered by vegetation, with 27 plant species reported of which six were woody shrubs or small trees; the remainder grasses or forbs. However, 16 of the species are introduced (SA NPWS 1983; Robinson et al. 1996). Twenty-three bird species have been recorded, eight of which breed or have bred there (Paton & Paton 1977), with published observations on nesting and roosting for 1968-1976 (Paton & Paton 1977; Ottaway et al. 1988), and banding and informal observations continuing to the present (D. Paton pers. comm.). The island is one of 21 identified breeding sites for Little Penguins (*Eudyptula minor* (J.R. Forster, 1781)) in South Australia (van Tets & Fullagar 1984; Edyvane 1996).

![Map of West Island](image)

**Figure 1.** Map of West Island showing aspect, orientation and elevation.

The soil is mostly 5-25 cm deep, but up to 100 cm in the gully (SA NPWS 1983), and nutrient rich from activity by Silver Gulls (*Larus novaehollandiae* Stephens, 1826), Little Penguins, and Crested (*Sterna bergii* Lichtenstein, 1823), Caspian (*Sterna caspia* Pallas, 1770), Fairy (*Sterna nereis* Gould, 1843), with occasional vagrant White-Fronted Terns (*Sterna striata* Gmelin, 1789) (Paton & Paton 1977; Robinson et al. 1996). The island was quarried for granite in the 19th and early 20th centuries and later used as an artillery target range (resulting in frequent fires), but in 1970 was made a Fauna Conservation Reserve, and subsequently in 1972, a Conservation Park (Robinson et al. 1996). Goats were introduced onto the island during the early 20th century but died out, and rabbits were introduced in the early 19th century but eradicated by 1972 (SA NPWS 1983; Robinson et al. 1996). Introductions of Pearson Island Rock Wallabies (*Petrogale lateralis pearsonii* Thomas, 1922), Tammar Wallabies (*Macropus eugenii* (Desmarest, 1817)) and Greater Stick Nest Rats (*Leporillus conditor* (Sturt, 1848)) were also unsuccessful (Robinson et al. 1996; Rippey et al. 2002). There is a small, non-breeding colony of New Zealand Fur Seals (*Arctocephalus forsteri* (Lesson, 1828)) on the island, but they are mainly found on rocky unvegetated shoreline areas at the NW corner of the island.

Following the rabbit eradication, trees and shrubs thought to have existed previously on the island were planted, including *Acacia*, *Eucalyptus*, *Myoporum* and *Casuarina* spp., but, once it was realised from historical data (such as early paintings) that the island was naturally treeless, planting was suspended. In addition, as part of the ongoing SA NPWS management plan, introduced shrubs such as boxthorn (*Lycium ferocissimum* Miers: Solanaceae) were actively poisoned (SA NPWS 1983). Such species are known to reduce seabird nesting (Lawley et al. 2005), and following their removal, native grasses were sown in an effort to create more open areas for use as rookeries (SA NPWS cited in Rippey et al. 2002). Yugovic (1998) found on the Mud Islands in Victoria that manual removal of *M. dendromorpha* also allows re-establishment by *M. australiana*, but control of *M. dendromorpha* on West Island was deemed unworkable.
due to long-term costs associated with labour and access to the island (SA NPWS cited in Rippey et al. 2002).

Because West Island is under increasing threat from weed invasion, especially by *M. dendromorpha*, and as this may be both related to past bird activity as well as potentially affecting future nesting, our study aimed to address the following questions:

1. Is there spatial heterogeneity of vegetation composition or structure on the island?
2. Is there spatial heterogeneity for soil pH, depth to rock, soil nutrient levels, conductivity/salinity, elevation and aspect/exposure?
3. Is there a relationship between the patterns of plant species and the environmental parameters?
4. Is there a relationship between bird nesting preferences and the vegetation patterns and/or environmental parameters on the island?

**Methods**

*Vegetation patterns*

The island was divided into 50 m x 50 m quadrats along compass bearings of 10° and 100°, producing 31 quadrats spanning approximately eight hectares but excluding inaccessible peripheral cliffs and rocky shore platforms (Fig. 2). Because most of the effects of exposure relate to the quadrat position relative to the eastern and southern (windward) sides of the island (Fig. 1), the mainland being to the north-west, each quadrat was given a coordinate increasing towards the east (1-5) and south (1-8). Because there is also a large gully running N to W across the island, quadrats falling in the gully were scored as 2 for a “gully-effect” shelter character, and those which included parts of the gully sides were scored as 1.

Within each quadrat three 50 m line transects were established at 12.5 m, 25 m and 37.5 m along a quadrat edge and oriented randomly (N/S or E/W) within different quadrats. Vegetation was sampled along these transects by the line intersect method, with plant species and relative cover recorded for each individual. However, as much of the grass was intermixed (predominantly *Hordeum leporinum* Link, *Lagurus ovatus* L. and *Lolium perenne* L.) and very dense, total grass cover was recorded rather than by individual species. Soil samples obtained for Total Nitrogen, Total Phosphorus, Total Potassium, pH and Electrical Conductivity (EC, as a proxy for salinity) were taken from 25 cm² areas to a depth of 5 cm at 15 m along the first transect, 25 m on the second and 35 m along the third.

In addition to edaphic properties, the number of *Malva* mericarps m⁻² (obtained from the soil samples), *M. dendromorpha* seedlings m⁻² and adult plants of the two *Malva* species m⁻² were determined. The number of active Silver Gull nests, fecundity (measured as eggs per nest), and active Little Penguin burrows within 2 m either side of the transect tapes were also recorded for the April to September survey period.

Although tern rookeries were also present on the lower central NW of the island, the study was not conducted during their breeding season, in accordance with disturbance reduction guidelines (GBRMPA 1997), and instead, the location and the number of last season’s nests m⁻² were recorded to enable comparison with our other data, the surveys of Paton & Paton (1977), and pre-*M. dendromorpha* vegetation associations on the island (Robinson et al. 1996).

The soil was passed through a 1.18 mm sieve and dried at 110° C for 24 hours. pH and conductivity results were averaged from the three transects, whereas nutrient analysis used a pooled soil sample for each quadrat. Total nitrogen (gN Kg⁻¹) was determined by the Kjeldahl method (Bremner 1996) using 250 mg of soil, and phosphorous (gP Kg⁻¹) and potassium (gK Kg⁻¹) were assessed using 1 g soil samples by the bicarbonate method (Potter & French 1971; Rayment & Higginson 1992). EC was measured with a calibrated conductivity meter after agitating 4 g of soil in 20 ml of
deionised water for 20 min. Field pH was measured using an Inoculo® Soil pH Test Kit (Inoculo Laboratories, Moorabbin, Vic.).

Data analysis

The spatial relationships of plant, bird nesting and edaphic features in the quadrats and the levels for each feature were mapped as bubble plots, with diameters reflecting the values (Figs 2 & 3). These were then compared by modified non-parametric pair-wise Spearman rank correlations ($r_s$) with JMP-IN® (SAS Institute 2003), using the Pearson product moment correlation coefficient on ranked data, as this is considered to deal better with tied scores (Zar 1996).

The quadrat x plant species matrix was also subjected to cluster analysis using Sørensen association and flexible unweighted pair group mean association (UPGMA) clustering with PC-ORD ver. 4.0 (McCune & Mefford 1999); major divisions in the resulting dendrogram used to define cluster groups. Taxa which had cover scores significantly associated with these groups ($P<0.05$) were identified using indicator species analysis (Dufrêne & Legendre 1997).

Sites and species were ordinated in PC-ORD 4.0 by non-metric multi-dimensional scaling (NMS), as this is considered to preserve original inter-sample relationships better than other ordination techniques (Minchin 1987). Dendrogram-derived groups and their indicator species were plotted into the ordination space, allowing the results of the classification and ordination to be viewed simultaneously, and as a test of the integrity of the dendrogram groups (Kent & Coker 1992). In addition, the relationship between the quadrats in the ordination space and their individual species cover and environmental scores were calculated by correlating the scores for the environmental variables against the NMS axis coordinates by biplot analysis. Significantly correlated variables ($P<0.05$) were added as vectors, with vector length proportional to the strength of the correlation (McCune & Mefford 1999).

Following the definition and mapping of vegetation groups across the island (Fig. 4B inset), their relationship to gull and penguin nesting activity was assessed by Resource Selection Analysis based on the numbers of nests or burrows in each quadrat (= “use”), with the numbers of quadrats in each vegetation cluster used to determine the expected available “resource” parameter proportions. The data were analysed for significant differences in nesting habitat preference using $\chi^2$ (Neu et al. 1974), Compositional Analysis (Aebischer et al. 1993) and Ranked Compositional Analysis with the program RSW Ver. 1 (Leban 1999).

Results

Vegetation and edaphic features

Thirty-two plant species were encountered across the 31 quadrats, of which 12 (37%) were native and 20 (63%) were introduced. The species with the highest average cover were, by far, the mixed grasses (42.1%: predominantly *Hordeum*, *Lolium* and *Lagurus*), then the succulent native perennial forbs *Tetragonia implexicoma* (Miq.) Hook.f. (5.6%) and *Disphyma crassifolium* (L.) L.Bolus subsp. *clavellatum* (Haw.) Chinnock (5.2%) and introduced shrub *Coprosma repens* Hook.f. (5.3%), with the next most common taxa being in order the introduced shrub *Lycurium ferocissimum* (2.9%), native shrub *Enchylaena tomentosa* R.Br. (2.4%) and then adult *M. dendromorpha* (1.3%).

The soils of the SE corner, the E coast and the gully were more alkaline, with pH values of up to 10 in quadrat 31. In contrast, the NW of the island was more acid; with pH 5 recorded in quadrants 2 and 3 (Fig. 2B). High EC readings were recorded at the SE (windward) end of the island, (up to 12.6 mS cm$^{-1}$), although readings of up to 11.8 mS cm$^{-1}$ also occurred in some NW quadrats (Fig. 2C).

The highest nitrogen levels on the island occurred in the NW corner (41.1-57.2 g Kg$^{-1}$), with lower values in the SW (8.0-9.1 gN Kg$^{-1}$), but most of the island had values of 20-30 gN Kg$^{-1}$ (Fig.
Phosphorus concentrations were highly variable, sometimes over short distances (e.g. 0.54 gP Kg\(^{-1}\) in quadrat 1 and 1.59 gP Kg\(^{-1}\) in quadrat 2), but high phosphorous levels (up to 1.69 gP Kg\(^{-1}\)) occurred in the SE and NW of the island, whereas the lowest levels (around 0.30 gP Kg\(^{-1}\)) were in the NE, SW and central areas of the island (Fig. 2E). Potassium concentrations were highest in the SE and along the gully towards the W (1.20-2.16 gK Kg\(^{-1}\)), but with low values also scattered across the island (Fig. 2F).

The highest density of *Malva* mericarps (70-200 x 10\(^3\) m\(^{-2}\)) was in the centre of the island and along the gully (Fig. 3A) with the lowest numbers in the SE corner (2-23 x 10\(^3\) m\(^{-2}\)). In contrast, seedling density was almost the inverse, with the highest values (<0.1%) in the SE, NE and one W quadrat near the base of the gully (Fig. 3B). *M. australiana* was more or less confined to the S side of the island at low density (<1 m\(^{-2}\); Fig. 3C), whereas mature *M. dendromorpha* were most abundant to the N (Fig. 3D) at the time of sampling, although seedlings were present across the whole island, with high concentrations in the N, E and the SW. Nesting by Silver Gulls (Fig. 3E) and Little Penguins (Fig. 3F) was more or less confined to the NE corner, with some scattered occurrences elsewhere, and a second area of penguin burrows in the SW, but both species appeared to nest mainly in areas with lower densities of *Malva dendromorpha*.

**Figure 2.** The position of the 31 sample quadrats and the distribution patterns of the edaphic features recorded for the study, as indicated.
Correlations ($r_s$) between the soil, plant and nesting features revealed that although penguin burrow densities were not significant (P > 0.05), only ten pairs of features were still significant after Bonferroni adjustment ($\alpha = 0.05$) for multiple comparisons (Table 1). Gull nesting and clutch size correlated positively with each other, but negatively with windward (westerly) exposure; the latter correlating with quadrat elevation and elevation with seaward exposure. Elevated P was associated with EC, and EC with bare ground and exposed rock, but both EC and exposed rock levels correlated negatively with gully quadrats.

**Cluster analysis and ordination**

Cluster analysis revealed four quadrat groups of similar and distinct dissimilarity (Fig. 4A). Group 1 consisted of 18 quadrats mainly from lower to middle elevations at the NE and central parts of the island (Fig. 4B inset). There were nine associated taxa, mostly annuals or ephemerals (of which only three were native), but grasses were the only significant indicator taxon (Table 1). Group 2 represented four low-elevation quadrats (three from the gully) and these were all significantly associated with high cover by the non-endemic woody shrubs *Coprosma repens*, *Melaleuca halmaturorum* Miq. and *Myoporum insulare* R.Br.

**Figure 3.** Density maps for *Malva* mericarps m$^{-2}$, *M. dendromorpha* seedlings m$^{-2}$, adult *M. australiana* and *M. dendromorpha* m$^{-2}$, as well as the numbers of Silver Gull nests and Little Penguin burrows along transects in each quadrat, as indicated.
There were four quadrats in Group 3 representing quadrats from middle elevations to the NW, but although there were seven species associated with the cluster, none was sufficiently both abundant and restricted to these quadrats to constitute a significant indicator. Nevertheless, all except *Lycium ferocissimum* were forbs, and five were annual or short-lived introduced weeds.

The remaining five quadrats (Group 4) were all elevated sites from the S of the island. Five of their nine associated taxa were native, and there were six significant indicators: *Disphyma crassifolium* subsp. *clavellatum*, *Enchylaena tomentosa*, *Polygonum aviculare* L., *Senecio lautus* G.Forst. ex Willd, *Tetragonia implexicoma* and *M. dendromorpha* seedlings.

NMS ordination of the quadrats and species (Fig. 4B) accounted for 83.1% of the correlated variance in the first two axes, with a stress (distortion) value of 12.6%, making the ordination an acceptable representation of the inter-quadrat relationships (Faith 1991). The dendrogram-defined groups were discrete in the ordination space and separated along both axes. Correlation of the quadrat NMS positions with the environmental data showed that most of the variation was along the 2nd axis (53.4%) and related to windward exposure, gull nesting (nests per quadrat) and clutch size (mean number of eggs per nest in each quadrat), whereas the 1st axis (29.7%) was associated more with EC, Elevation, pH, seaward exposure, and amount of exposed rock or bare soil. Group 1 was associated with westerly sites, alkaline soils, lower salinity and lower levels of exposed rock or bare soil, as well as with a mixture of grasses and introduced annual or short-lived weeds. Group 2 quadrats were associated with seaward, acidic, less saline soils with more exposed surface rock, and showed increased woody shrub and nitrophilic annual weed cover. Both Groups 1 and 2 were also associated significantly with increased nesting activity and clutch size by Silver Gulls.
Table 1. Spearman Rank Correlations ($r_s$) (upper right) and probabilities (lower left) for the features recorded on West Island. Asterisks indicate $P<0.05$ (*), $<0.01$ (**) and $<0.005$ (***) with values of $P<0.004$ significant after Bonferroni adjustment ($\alpha_{0.05}$) for multiple comparisons. Eggs = average clutch size for Silver Gull nests in each quadrant.

|        | Gull  | Eggs | Peng | Tern | EC   | pH  | K   | P   | N   | Bare soil | Rock | Wind | Sea | Elev | Gully |
|--------|-------|------|------|------|------|-----|-----|-----|-----|-----------|------|------|-----|------|-------|
| Gull   | 0.907 | 0.135| 0.066| 0.420| -0.401| -0.092| 0.274| 0.268| 0.201| 0.454    | -0.662| 0.037| -0.212| -0.370|
| Eggs   | $<0.001$ *** | 0.060 | -0.140| 0.324 | -0.392| -0.134| 0.121| 0.275 | 0.171| 0.432    | -0.694| 0.026| -0.222| -0.285|
| Peng   | 0.747 | 0.470 | -0.160| 0.247 | 0.006 | 0.214| 0.110| 0.007 | 0.266| 0.001    | -0.133| -0.155| -0.270| -0.071|
| Tern   | 0.724 | 0.451| 0.391 | 0.082 | 0.155 | -0.072 | 0.163 | -0.051 | 0.041| -0.225   | 0.196 | 0.021| 0.125 | 0.193 |
| EC     | 0.019 * | 0.075 | 0.180| 0.662 | -0.405| 0.197| 0.694| 0.262 | 0.658| 0.509    | -0.110| 0.208| 0.078 | -0.624|
| pH     | 0.026 * | 0.029 | 0.973| 0.407 | 0.024 * | 0.010 | -0.210| -0.199 | -0.030| -0.387   | 0.462 | -0.385| -0.214| 0.403 |
| K      | 0.623 | 0.474| 0.249| 0.702 | 0.284 | 0.956 | 0.329 | 0.228 | 0.096| 0.164    | 0.149 | 0.010| 0.015 | -0.203|
| P      | 0.136 | 0.517| 0.557| 0.380 | $<0.001$ *** | 0.257| 0.071 | 0.339| 0.392| 0.290    | 0.083 | 0.152| 0.033 | -0.420|
| N      | 0.145 | 0.135| 0.970| 0.785 | 0.155 | 0.284| 0.217| 0.062 | -0.025| 0.122    | -0.355| -0.303| -0.322| -0.337|
| Bare soil | 0.277 | 0.359| 0.149| 0.827 | $<0.001$ *** | 0.875| 0.606| 0.029| 0.892| 0.595    | 0.079 | 0.169| 0.062 | -0.483|
| Rock   | 0.015 * | 0.010 | 1.000| 0.225 | 0.004 *** | 0.031| 0.377| 0.114| 0.513| $<0.001$ *** | -0.239| 0.346| -0.004 | -0.581|
| Wind   | $<0.001$ *** | $<0.001$ *** | 0.474 | 0.291| 0.557 | 0.009 ** | 0.424| 0.658 | 0.050 | 0.671    | 0.195 | 0.329| 0.566 | 0.242 |
| Sea    | 0.892 | 0.843| 0.404| 0.911 | 0.261 | 0.033* | 0.957 | 0.416 | 0.097 | 0.364    | 0.567 | 0.072 | 0.824 | -0.125|
| Elev   | 0.252 | 0.231| 0.142| 0.504 | 0.667 | 0.248| 0.935| 0.859 | 0.077| 0.741    | 0.983 | $<0.001$ *** | -0.001 | 0.010 |
| Gully  | 0.041 * | 0.121| 0.704| 0.299 | $<0.001$ *** | 0.025* | 0.274| 0.019* | 0.064| 0.006    | $<0.001$ *** | 0.189 | 0.504 | 0.958 |

Counts of non-active tern nests from the previous season, as they did not nest over the sampling period.

Group 3 correlated with elevated, seaward, acidic, rocky, and bare, saline soils. This was also where the high cover scores of *Muehlenbeckia gunnii* (Hook.f.) Endl. and adult *M. dendromorpha* plotted in the ordination space. In contrast, Group 4 quadrats although still saline were less rocky, more alkaline, windward, had fewer silver gull nests and these nests had fewer eggs. These quadrats were also those associated in the MDS with *Disphyma*, *Senecio*, *Atriplex prostrata* Boucher ex DC, *Polygonum*, adult *Malva australiana* and *M. dendromorpha* seedlings, largely reflecting the Indicator Species analysis results.
Figure 4. A: Dendrogram of the quadrats using Sørensen/Flexible cluster analysis. B: NMS ordination of the quadrats, significantly correlated species and environmental parameters, with position of the dendrogram clusters indicated. Vectors indicate significant correlations between environmental feature scores and the ordination space, and biplot positions of the plant taxa represent high cover scores and directions (significant group indicator species from Table 2 are underlined). Inset shows the positions of the four dendrogram-derived vegetation associations on West Island.
Table 2. Species encountered in the survey, their codes and dendrogram group with which they are associated. Significant cluster indicator species (\(P<0.05\)) are indicated in bold. Indicator values and probabilities were derived using the indicator species analysis method of Dufrêne and Legendre (1997). * = Exotic species; § = descendants of planted native shrubs. Nomenclature follows Jessop & Toelken (1986) and Ray (1998).

| Species                                      | Spp Code   | Cluster Group | % Indicator value | \(P\)  |
|----------------------------------------------|------------|---------------|--------------------|--------|
| Dichondra repens J.R.Forst. & G.Forst.       | Dichrepe   | 1             | 27.8               | 0.238  |
| Echium plantagineum* L.                     | Echiplan   | 1             | 16.7               | 0.551  |
| Einadia nutans (R.Br.) A.J.Scott            | Einanuta   | 1             | 35.8               | 0.193  |
| Fumaria capreolata* L.                      | Fumacapr   | 1             | 16.7               | 0.636  |
| Galenia pubescens* (Eckl. & Zeyh.) Druce    | Galepube   | 1             | 30.1               | 0.221  |
| Grasses: mainly Hordeum leporinum*, Lolium perenne* & Lagurus ovatus* | Grass      | 1             | 54.5               | 0.001  |
| Medicago sativa* L.                         | Medisati    | 1             | 23.5               | 0.217  |
| Oxalis pes-caprae* L.                       | Oxalpesc   | 1             | 47.1               | 0.099  |
| Portulacca oleracea L.                      | Portoler    | 1             | 16.7               | 0.551  |
| Coprosma repens*                            | Copprepe   | 2             | 76.8               | 0.023  |
| Hypochoerus radicata* L.                    | Hyporadi   | 2             | 12.3               | 0.830  |
| Malva parviflora* L.                        | Malvpvarv  | 2             | 24.2               | 0.212  |
| Melaleuca halmatourum§                      | Melahalm   | 2             | 49.2               | 0.021  |
| Myoporum insulare§                          | Myopinsu   | 2             | 48.8               | 0.024  |
| Chenopodium album*                           | Chenalbu    | 3             | 32.1               | 0.422  |
| Lycium ferocissimum*                         | Lycifero   | 3             | 30.4               | 0.638  |
| Mesembryanthemum crystallinum* L.            | Mesecrys   | 3             | 31.3               | 0.231  |
| Muehlenbeckea gymnii                        | Muehgunn   | 3             | 15.2               | 0.807  |
| Solanum nigrum* L.                          | Solanigr   | 3             | 15.4               | 0.612  |
| Sonchus oleraceus* L.                       | Soncoler   | 3             | 12.0               | 0.842  |
| Urtica urens* L.                            | Urtiuren   | 3             | 10.9               | 0.866  |
| Atriplex prostrata*                          | Atriplpro   | 4             | 39.3               | 0.094  |
| Disphyma crassifolium subsp. clavellatum     | Dispercas  | 4             | 99.8               | 0.001  |
| Enchyelaena tomentosa                       | Enchtome   | 4             | 80.4               | 0.001  |
| Malva australiana                           | Malvaust   | 4             | 48.3               | 0.111  |
| Malva dendraoomph*                          | Malvedend  | 4             | 13.69              | 0.901  |
| M. dendraoomph* seedlings                   | Malvseed   | 4             | 70.9               | 0.003  |
| Polygonum aviculare*                        | Polyavic    | 4             | 84.1               | 0.001  |
| Senecio lautus                              | Senelaut   | 4             | 58.6               | 0.018  |
| Tetragonia implexicoma                      | Tetrimpl   | 4             | 53.7               | 0.030  |

Preference analysis

The preference analyses of nesting use (number of nests or burrows per quadrat) for the different vegetation groups by the Silver Gulls and the Little Penguins showed that both species significantly preferred the Group 1 open grassy quadrats on the NW side of the island (Figs 4E,F; Table 3), but they showed different responses to the other vegetation groups. Gulls avoided the succulent native forb-dominated, exposed and elevated sites to the W (Group 4), but neither preferred nor avoided the shrub- and the weedy forb-dominated quadrats (Groups 2 and 3). In contrast, the penguins significantly avoided the rockier shrub- and weedy forb-dominated areas, but neither preferred nor avoided the less rocky (deeper soil) native forb-dominated quadrats.
Table 3. \( \chi^2 \) analysis of utilisation-availability (Neu et al. 1974), compositional (CA: Aebischer et al. 1993) and ranked compositional analysis (RCA: Leban 1999) for active nesting by Silver Gulls and burrowing by Little Penguins between different vegetation cluster groups on West Island. Asterisks and superscripts indicate significant differences between column elements at * = \( P < 0.05 \); ** = \( P < 0.001 \). Neither means that the species neither significantly preferred nor avoided that vegetation type.

| Vegetation group       | Silver Gulls | Little Penguins |
|------------------------|--------------|-----------------|
|                        | \( \chi^2 \) | CA   | RCA | CA   | RCA |
| 1: grass-dominated     | Prefer***    | 3^a   | 3^a | Prefer* | 3^a   | 3^a |
| 2: shrub-dominated     | Neither      | 2^ab  | 2^ab | Avoid   | 0^b   | 1^b |
| 3: weedy forb-dominated| Neither      | 1^bc  | 1^ab | Avoid   | 0^b   | 1^b |
| 4: native forb-dominated| Avoid*       | 0^c   | 0^b | Neither | 2^ab  | 2^ab |

**Discussion**

The previous surveys on the island defined to main vegetation groups: introduced grassland (including many weedy forbs) at the northern and central parts of the island (Group 1) and *D. crassifolium* succulent herbfield (Group 4) in the SW corner (Paton & Paton 1977; SA NPWS 1983; Robinson et al. 1996), agreeing with studies of other southern Australian islands where grasses and other long-term grazing-related vegetation occurred mostly on more sheltered NE aspects (Robinson et al. 1996) and where similar grass- and salt-tolerant succulent-dominated associations were seen (Hope & Thompson 1971; Brown et al. 1993; Kirkpatrick & Harris 1995; Walsh et al. 1997; Lawley & Shepherd 2005). These associations appear to reflect both effects from exposure and some 150 years of grazing by goats and rabbits. In contrast, the Group 2 and 3 associations were non-indigenous assemblages from sheltered, nutrient-enriched quadrats, mostly former crested and Caspian tern nesting areas (Paton & Paton 1977).

In particular, high densities of seedling and mature *M. dendromorpha*, and soil seedbank *Malva* mericarps occurred in the SE, central N and along the gully (i.e. Groups 2 & 3) where exposure and salinity values were lower and where there was less active nesting by both gulls and penguins. *Malva australiana* grew mainly to the S where exposure rankings, salinity and nutrients were all high. This supports the competitive facilitation results of Lewis (1999) which showed that this species is most competitive under high salt and nutrient conditions. Nevertheless, the presence of *M. dendromorpha* adults and seedlings in the same environments also agrees with their finding that the latter species was more likely to dominate overall.

Many Australian soils are nutrient deficient through age, weathering and lack of volcanic or alluvial deposition (Handreck 1978), but on West Island the soils are recent and ornithogenic. Guano deposition during the various breeding seasons would be expected to cause localised nutrient heterogeneity around the rookeries (Gillham 1956b; Malloch & Okusanya 1979; Okusanya 1980), and the rookeries can themselves influence vegetation diversity through nutrient toxicity, trampling, burrowing and nesting activities (Hope & Thompson 1971; Sobey & Kenworthy 1979; Brown et al. 1993; Walsh et al. 1997), as well as promoting nitrophiles and coprophiles (Gillham 1956a, b, 1960, 1961a, b; Sobey & Kenworthy 1979; Bukacinski et al. 1994). The distribution of *M. dendromorpha* in areas that were previously tern colonies (Paton & Paton 1977) supports previous studies that found that it invades nutrient-enriched areas, displacing the birds that nested there (Yugovic 1998; Rippey et al. 2002).

The relatively high EC values on West Island, and competitive facilitation by both species under high salinity seen by Lewis (1999) both support the idea that the two *Malva* spp. are salt-tolerant or halophytic, although *M. dendromorpha* is not considered salt-requiring (A. J. C. Malloch, quoted in Rippey et al. 2002). However, Malloch and Okusanya (1979) reported salt
glands in *M. dendromorpha* which can also adapt to salinity by altering stomatal and gland density and preferential salt accumulation in older leaves (Malloch 1997), and Okusanya and Fawole (1985) further found that elevated soil phosphate improved growth at high salinities. We likewise found that *M. australiana* possesses identical and abundant salt glands, further supporting the idea that it is also salt-adapted.

The pH patterns on West Island reflect the combined influences of nesting and salinity, with more acidic soils in the sheltered NW corner correlated with silver gull nesting, and alkaline soils with the more salt-spray exposed SW corner. The pH of guano-derived soils depends on proximity to the source, their age and the degree of salt spray, with fresh guano the most acidic, and aged, distant and/or saline soils generally more alkaline (Gillham 1956b). The more acidic areas were nutrient rich, with P levels highest in quadrats with pH < 7. Nevertheless, Malloch and Okusanya (1979) found that *M. dendromorpha* grew mainly on slightly alkaline, but nutrient-rich, saline soils, and we similarly found that *Malva* seedling density was associated with more alkaline areas.

The high soil mericarp levels reflect long-term seed bank accumulation. Bhowmik (1997) noted that up to $1 \times 10^6$ weed seeds m$^{-2}$ is not unusual, especially on fertile soils, although coastal seed banks often contain fewer seeds due to higher disturbance (Looney & Gibson 1995). Germination depends on both dormancy controls and weather conditions (Templeton & Levin 1979), and *M. dendromorpha* and *M. australiana* have similar life cycles; germinating over winter, flowering in spring and seeding across early to mid-summer. They behave as annuals or occasionally biennials under seasonally dry southern Australian summers (Rippey et al. 1998), and like most Malvaceae, establish persistent seed banks (Roberts & Boddrell 1984). Most *Malva* species display low, erratic, light-requiring germination due to physiological and environmental controls (Okusanya 1979a; Pérez-García et al. 1995), allowing germination to occur over more than a century (Spira & Wagner 1983), and this is reflected in the very low germination seen on the island (<0.25% p.a.). Nevertheless, the enormous, long-lived seed bank still produced dense seedling cover across much of the island makes removal or control a difficult and long-term problem.

The distribution of *M. australiana* across much of the island was also related to the nesting density of the birds, with active silver gull nests and little penguin burrows to the NW (sheltered) of the island where there is proportionately less *Malva*, although there were numerous long-abandoned penguin burrows over much of the central (*Malva*-dominated) parts of the island. Our preference analysis and correlation results agree with previous observations that Silver Gulls and other open

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**Notes**

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**Further Reading**

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ground-nesting species avoid tall, dense vegetation (e.g. Gillham 1956a; Gillham 1960, 1961a, c; Robinson et al. 1996; Rippey et al. 1998), and that the altered habitat once the birds are forced to move may actually favour the invading weeds even more. Rippey et al. (2002) found that M. dendromorpha reduced nesting by crested and Caspian terns on the Shoalwater Islands in Western Australia through increased canopy development, as well as deterring burrowing by Little Penguins and nesting in bridled terns by excluding undergrowth, and this latter effect was also seen in the preference analyses. The change in tern nesting patterns on West Island suggests that these open-area nesters have been affected, with the main colonies now to the lower W in areas with lower Malva cover, rather than the central and NW (Group 2&3 vegetation association-dominated) areas where nesting was reported by Paton & Paton (1977).

In conclusion, the present vegetation patterns seen on West Island appear to have been the result of combined effect of several long-term impacts. Initially, herbivore grazing created the extensive introduced grassland in sheltered less saline areas (actually favouring open-nesting birds), but then subsequently the spread of M. dendromorpha across those areas with higher salinity and/or nutrients in the absence of herbivores caused a second impact. The effect of these impacts is similar to other studies of offshore islands; the distribution of bird nesting on the island has been affected, with both gulls and penguins significantly preferring the open areas. The gulls mainly used the grasslands, whereas the penguins also used the native forb-dominated succulent herbfields, presumably because of cover afforded by the low, spreading shrubs there. If M. dendromorpha is allowed to continue to spread on West Island, then both open ground and sheltered low-shrub associated birds risk losing further reproductive habitat, making the ongoing control of this weed an important consideration in the management of the island despite the costs associated with effective control measures.

Acknowledgements

The study was part of work undertaken towards B.Sc. Hons degrees by TZ and AL within the Department of Botany (now Discipline of Environmental Biology). The School of Earth and Environmental Sciences, The University of Adelaide, is thanked for the provision of resources towards the study. The SA NPWS are thanked for permission to undertake research on West Island, as are Prof. Anthony Cheshire, Dr Sean Connell and their students for assistance with access to the island. Dr Sue Carthew and Assoc. Profs José Facelli and David Paton are thanked for comments on the manuscript.

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