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HABITAT PREFERENCE OF NESTING WEDGE-TAILED SHEARWATERS: THE EFFECT OF SOIL STRENGTH

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The density of nesting burrows of the Wedge-tailed Shearwater *Puffinus pacificus* was measured in 224 quadrats on Heron Island, Great Barrier Reef. Field measurements of the unconfined compressive strength of the soil material were made for each quadrat. Lowest burrow densities occurred in quadrats at both upper and lower ends of the soil strength range. Increased burrowing success at sites where soil is not so loose as to collapse, but not so compacted as to inhibit burrowing is indicated. Island development which results in soil compaction may, therefore, inhibit *P. pacificus* nesting.

INTRODUCTION

Understanding nesting preferences of seabirds is important in management of the islands on which they breed. 'Development' may impinge on these preferences in ways which are not immediately clear. Wedge-tailed Shearwaters *Puffinus pacificus* maintain a breeding population estimated at 16 000 pairs on Heron Island (Hill and Barnes 1989). The Hill and Barnes study also examined the habitat preferences for burrowing by these birds and showed that high densities were found in habitats with a substantial amount of debris on the ground, whether fallen branches in the *Pisonia grandis* forest or building materials in the developed areas.

However, their investigation did not include the relationship between vegetation, burrowing density and soil properties.

Dyer and Hill (1990) have reported that in habitats where low burrowing densities occur, the burrows tend to be aggregated. This finding is tentatively interpreted as an indication of the importance of social communication in the *P. pacificus* colony.

We report the results of a small experiment to determine if another factor, soil strength, would influence nesting-site selection. Nest construction by Wedge-tailed Shearwaters involves the excavation of burrows up to 2 m long and 1 m deep on Heron Island. Qualitative references to the effect of soil properties on Wedge-tailed Shearwater burrowing are common in the literature. Davies (1959), Serventy *et al.* (1971) and Serventy and Whittel (1976) have noted a preference for soft, loamy and friable soils, while white coral sands with little or no soil development are avoided.

Lane (1974) observed that extensive burrowing occurred where soil depth was 'adequate' on North Solitary Islands. Byrd and Boynton (1979), on Kauai Island, Hawaii, noted burrowing in both deep and shallow soils. Swanson and Merritt (1974) observed mainly horizontal burrows of 'arms length' in shallow soils on Mutton Bird Island, near Coffs Harbour, New South Wales, and soil compaction on the man-made end of Sand Island, Johnston Atoll prevented the digging of burrows by Wedge-tailed Shearwaters (Amerson and Shelton 1976).

This analysis represents a preliminary quantitative investigation of Hulsman's (1984) observation that burrowing occurs at greatest density in areas where the soil is both soft enough to dig and firm enough not to collapse.

Heron Island is a vegetated sand cay, one of the Capricorn Group of islands, lying on the Tropic of Capricorn north-east of Brisbane, Queensland (Fig. 1). The vegetated part of the cay is 13 ha in area (Flood 1981). Soils on the island are developed from unconsolidated carbonate sands derived from the calcareous skeletal remains of reef organisms. Vegetation on the island margins is largely grasses with shrubs, including *Argusia argentea* and *Scaevola sericea,* forming a dense ground storey in some areas, and some *Casuarina* and *Pandanus* spp. There is a tall *Pisonia grandis* forest in the central part of the island. Cribb and Cribb (1985) give a comprehensive description of vegetation characteristics on sand cays of the Capricorn Group. Development on the island includes a resort, a research station and a National Parks and Wildlife Service complex.

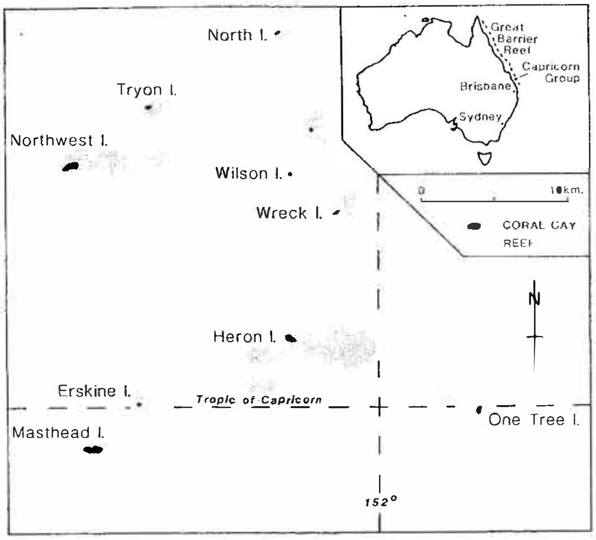

Figure 1. *Location of Heron Island in the Capricorn Group, southern Great Barrier Reef.*

METHODS

Twelve systematically spaced, continuous transects perpendicular to the long (east/west) axis of the island were surveyed. Contiguous quadrats, 3 m × 10 m, were examined. In each of the 224 quadrats the number of *P. pacificus* burrows was recorded. This sampling technique is that used for the *P. pacificus* census on Heron Island by Hill and Barnes (1989). In each quadrat ten measurements were made of soil strength using a 'Geotester' penetrometer. Penetrometer tests are largely a measure of the resistance of the soil material to deformation by shearing. In granular soils such as those of a coral cay, the shearing strength is highly dependent on the packing (or density) of the soil (Young and Warkenstein 1975). Soil packing is increased by the incorporation of organic detritus and by the weathering of the soil particles during soil development and by static and dynamic loading (compaction). Thus, the penetrometer test is a rapid field method of estimating the propensity for collapse and the resistance to excavation of the soil material.

The median of the replicate soil measurements and the burrowing density were calculated for each quadrat. The median was used because, in these heterogeneous granular soils, a single atypical observation could strongly bias the quadrat average. In a very small number of instances, the degree of soil strength was such that the measurement went off the scale of the instrument, and for these the maximum value was allocated to the observation. The data were subdivided according to habitat types: *Pisonia* debris, *Pisonia* bare, *Pisonia* grass, Fringe, Clear, and Turf and buildings habitats combined as described in Table 1. Before development the area in the latter category included each of the other habitat types.

RESULTS AND DISCUSSION

The variation in burrowing density with habitat was comparable with reported habitat preferences (Hill and Barnes 1989), with highest densities occurring in the *Pisonia* debris ($\bar{x}$ = 6.9 burrows per quadrat) and *Pisonia* bare ($\bar{x}$ = 3.9) habitats. In each of the other habitat classes the burrowing density was < 2.4 per quadrat.

Soil strength was at a minimum in the *Pisonia* grass habitat ($\bar{x}$ = 0.3 kg cm^{-2}) and at a maximum in the Turf and buildings ($\bar{x}$ = 2.4 kg cm^{-2}) habitat. The mean soil strength in the Turf and buildings habitat was significantly greater than that for the Clear ($\bar{x}$ = 1.0 kg cm^{-2}), *Pisonia* bare ($\bar{x}$ = 0.7 kg cm^{-2}), *Pisonia* debris ($\bar{x}$ = 0.6 kg cm^{-2}), Fringe, ($\bar{x}$ = 0.6 kg cm^{-2}) and *Pisonia* grass ($\bar{x}$ = 0.3 kg cm^{-2}) habitats (t-test; $p < 0.05$). The mean soil strengths in the Clear, *Pisonia* bare and *Pisonia* debris habitats were significantly greater than that for *Pisonia* grass. There was no significant difference between the Fringe and *Pisonia* grass habitats with respect to soil strength.

TABLE 1

Habitat classification and characteristics.

Habitat	Characteristics
Pisonia bare	*Pisonia* forest with ground layer of bare sand or leaf litter.
Pisonia grass	*Pisonia* forest with ground cover of grass.
Pisonia debris	*Pisonia* forest with ground layer of fallen debris.
Fringe	Vegetation communities of the island fringe.
Clear	Areas largely free of canopy cover.
Turf and buildings	Maintained lawns and building structures incorporating paved areas and pathways etc.

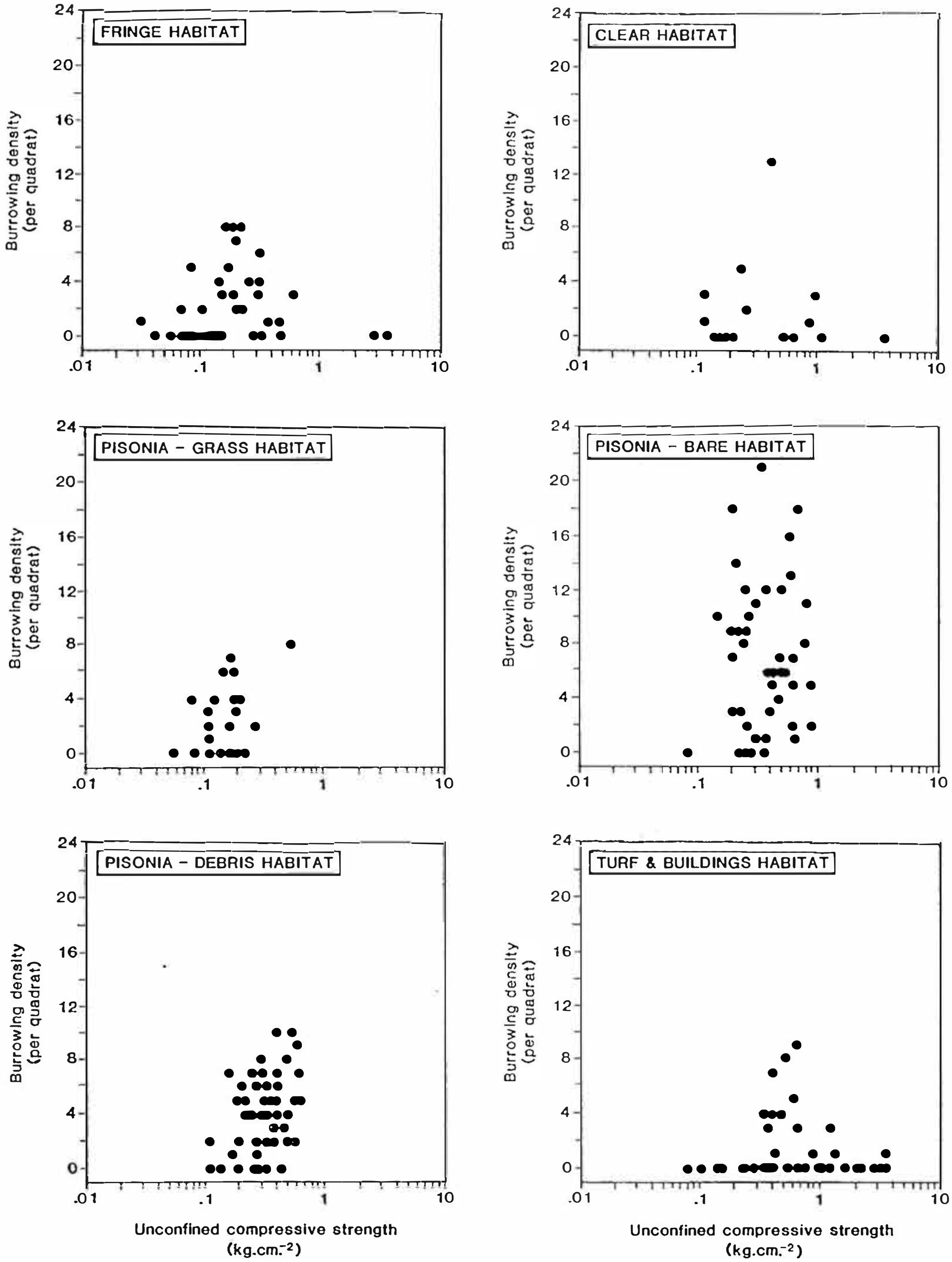

Figure 2. *Relationship between soil strength and* P. pacificus *burrowing density for each of six habitat classes on Heron Island.*

The relationship between soil strength and burrowing density for each habitat is shown in Figure 2. The burrowing density tends to increase into the midpart of the soil strength range, suggesting that the relationship of soil strength and burrowing density is generally similar in all habitats. Highest burrowing densities ($\geq$ 4 per quadrat) generally occur where soil strength is in the range 0.2 to 0.6 kg cm^{-2} (i.e. < 17% of the observed soil strength range). In quadrats where burrow densities exceed this threshold, 76 per cent have soil strengths within this range and 24 per cent lie outside it. If the density threshold is increased to $\geq$ 8 burrows per quadrat, those lying within the specified range represent 77 per cent of the total. The observed relationship between burrowing density and soil strength, as shown in Figure 2 and evident in each of the habitats, tends to confirm a pattern of greater burrowing success at sites where the soil is loose enough to burrow easily, but not so loose as to collapse. These results represent a quantitative confirmation of Hulsman's (1984) observation.

Comparison of the results for the Turf and buildings habitat with those for the natural habitats gives some indication of the effect of soil modification by island development on burrowing success. Only 11 per cent of quadrats with natural vegetation have soil strengths greater than 1.0 kg cm^{-2}, but 40 per cent of those in the Turf and buildings habitat lie above this value. Burrows are very rare at soil strengths greater than 1.0 kg cm^{-2}. It seems likely, therefore, that the higher soil strengths arising from compaction associated with island development will inhibit *P. pacificus* burrowing.

CONCLUSION

The pattern of *P. pacificus* burrowing which emerges is one in which the vegetation type (Hulsman 1984; Hill and Barnes 1989), the quantity of debris on the ground surface (Hill and Barnes 1989), the social interactions of the birds (Dyer and Hill 1990) and the properties of the substrate relevant to nesting burrow construction and stability, all play a part. Although soil strength greater than 1.0 kg. cm^{-2} does occur infrequently in the natural soils of the sand cay, it seems likely that the higher levels of soil strength associated with island development will reduce the success of *P. pacificus* burrowing.

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