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WEDGE-TAILED SHEARWATERS AT RAINE ISLAND, GREAT BARRIER REEF: POPULATION ESTIMATE AND BREEDING STATUS

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The breeding activities of Wedge-tailed Shearwaters at Raine Island, in the far northern section of the Great Barrier Reef, have not been quantified to date. In December 1995, 58 per cent of burrows inspected with a 'burrowscope' were occupied, 52 per cent with incubation or a chick, so approximately half of the estimated 3 661 burrows were likely to be active, breeding burrows. There appeared to be a locational preference for nesting on the western end of the island. Breeding rates on Raine Island were similar to those of the principal Great Barrier Reef Wedge-tailed Shearwater colonies of the Capricorn Group of islands.

INTRODUCTION

Warham (1961) stated that 'Raine Island is probably the most important breeding station for tropical sea-birds in Australian seas'. Investigations of the avifauna in the south-west Coral Sea during two trips in September–October 1960 and November 1961, whilst finding 'extensive shearwater rookeries' on North-East Islet of Herald Cays, Chilcott Island, and Bird Island, found evidence that Wedge-tailed Shearwaters *Puffinus pacificus* 'have bred' on Raine Island (Hindwood *et al.* 1963). Lavery and Grimes (1971), however, report the island as a major Wedge-tailed Shearwater breeding colony.

The world's principal Wedge-tailed Shearwater colony is at North West Island in the Capricorn Group, Great Barrier Reef, but seabird species diversity is higher on Raine Island than on individual islands in the Capricorn Group. Nevertheless, in comparison to the Capricorn Group where the breeding ecology of the Wedge-tailed Shearwater has been studied in some depth (Hulsman 1984; Hill and Barnes 1989; Dyer 1992; Dyer and Hill 1992; Hill *et al.* 1995a, 1995b; Carter *et al.* 1996a, 1996b), there is a dearth of information on the avian ecology of Raine Island because of its relative isolation. Lavery and Grimes (1971) suggest that the extent of the Wedge-tailed Shearwater breeding season on Raine Island is poorly defined because of intermittent short-term surveys of convenience.

Raine Island Corporation records show more than 1 000 burrows in 1979 with over 50 per cent of burrows being occupied (Anita Smyth, pers. comm.). No methodology was given for this estimate or burrow occupancy rate. King (1986) reported an estimate of 5 800 active burrows in December 1982, however 'there are no reliable estimates of population size' (Taplin and Blaber 1993, p. 52). Estimates from the Raine Island Corporation Annual Reports (years not given) range from 1 000 to 116 000 birds but most estimates fall between 1 000 and 5 000 birds which indicates that a reliable estimate is essential to ascertain the significance of the colony (Taplin and Blaber 1993).

In December 1995 the Raine Island Corporation's research team visited Raine Island to perform research into the island's history, reptiles, and avian ecology. The author's primary purpose was to investigate the breeding status of the island's Wedge-tailed Shearwater colony. Whilst this December based research did not allow for the investigation of the whole breeding cycle, it provides the most comprehensive information yet collected concerning the Raine Island Wedge-tailed Shearwater colony. Considering the diversity of ground-dwelling species on Raine Island, the provision of this baseline data is beneficial for island management purposes and should be a useful basis for resource partitioning studies.

STUDY AREA

Raine Island (144°01'E, 11°37'S) is a 28 hectare coral cay situated on the leeward side of an oval patch of reef approximately 170 kilometres south-east of the tip of Cape York Peninsular, 100 kilometres ENE of Cape Grenville, on the outer fringe of the far northern section of the Great Barrier Reef. Surrounded by waters that reach depths of greater than 180 metres the island's avifauna reflects the oceanic nature of the reef (Gourlay *et al.* 1993). As a Reserve for Departmental and Official Purposes since 1985, Raine Island was declared a Fauna Refuge under the *Fauna Conservation Act 1992.*

A cliff reaching heights of approximately 2 metres at the south-eastern end of the island surrounds a vegetated phosphate rock based ridge. Sand and low level, thick, rugged vegetation consisting of grasses, succulents, creepers and small shrubs cover the ridge. This ridge itself surrounds a central depression with some rock and earth mounds remaining from guano mining. Vegetation is virtually non-existent in the central depression which, considering the preferred soil strength range of Wedge-tailed Shearwaters (Neil and Dyer 1992), is apparently too compacted for Wedge-tailed Shearwater burrowing (Fig. 1). Outside the ridge are areas of grassed beach which, during this visit, were severely depleted by turtle nesting activities.

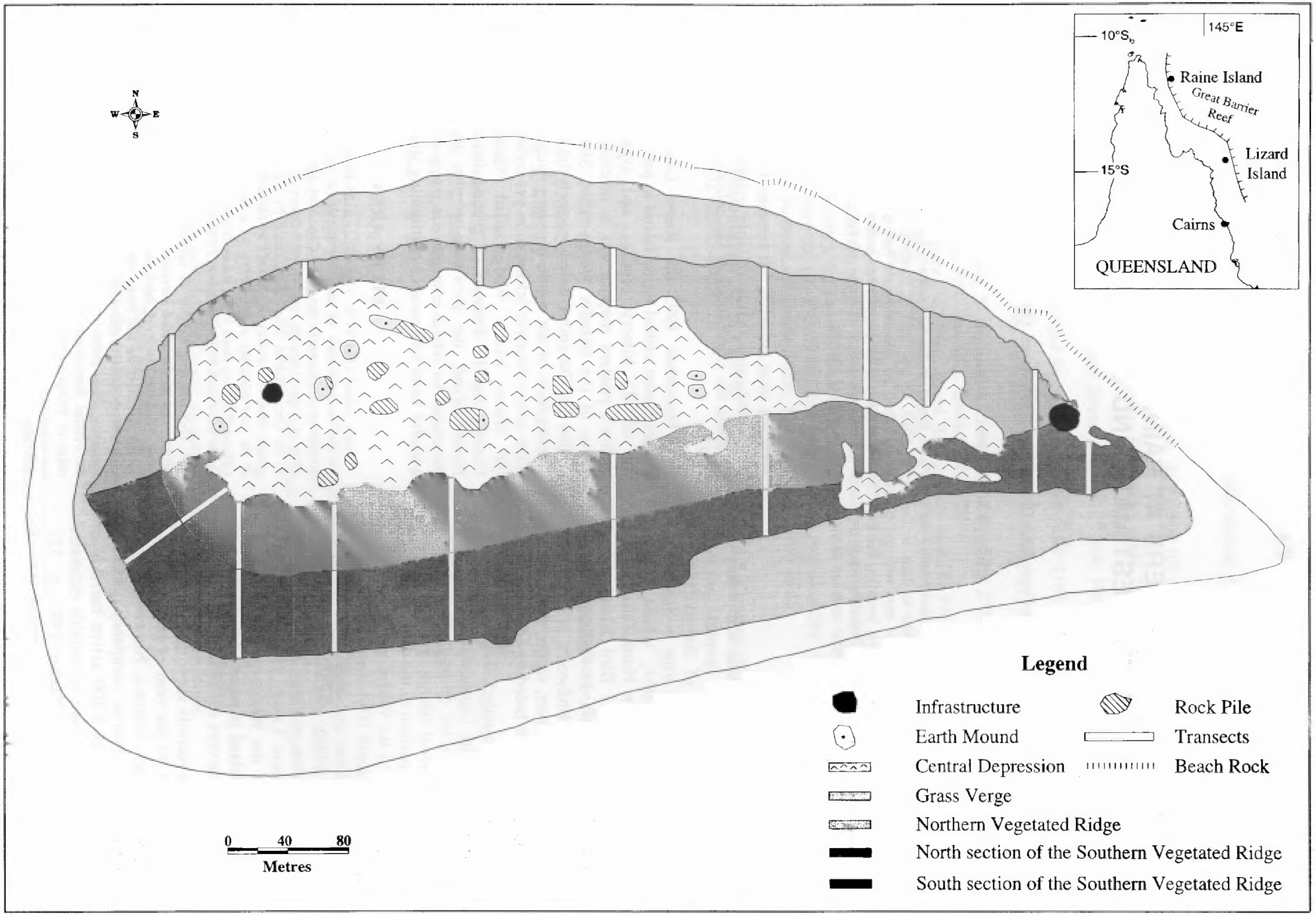

Figure 1. *Raine Island showing habitats and location of transects.*

Raine Island is an important research site because of the variety of tropical seabird species and numbers of birds and turtles that nest there. It is the largest green turtle rookery in the world and three species of Boobies *Sula sula, Sula dactylatra, Sula leucogaster* nest in close proximity to each other. There are two burrowing species: the Wedge-tailed Shearwater; and the Herald Petrel *Pterodroma arminjoniana* which has been recorded as nesting on Raine Island (Taplin and Blaber 1993).

METHODS

The aim of the research was to establish an estimate of the baseline population, in such a way that the study could be replicated by the author or others to facilitate comparison over time. There were several components of the research that were executed in the following order:

a) opportunistic inspections of cliff/ledge crevices (Fig. 1) with a burrowscope (Dyer and Hill 1991; Dyer and Aldworth 1998) at night. This was performed in conjunction with Red-tailed Tropic Bird *Phaethon rubicauda* research (John Cornelius, pers. comm.) (Table 1);

b) burrow counts according to previously identified habitats for continuing bird studies (Jeff Miller, Department of Environment). This was performed in conjunction with a bird count for the island (Table 2a); and

c) subsequent inspection of burrows to establish occupancy status for a sub-sample of burrows (Table 2b).

Data collection was limited to a couple of hours in the morning and afternoon to avoid the risk of heat stress of the birds and the researchers. The study is valuable as it can be replicated and thus permits temporal comparison. However, consideration of animal welfare limited the sampling and these limitations of the method must be considered when interpreting the results.

Opportunistic inspection of nests

Although many crevices were inspected in the cliff/ledge habitat only the occupied crevices were recorded and unoccupied crevices were not. In places active turtle diggings extended beneath the cliff creating an overhang. Regular disturbance in these areas prevents bird-nesting activities. Checks to test this assumption suggested that close investigation of these areas was not necessary.

It was impossible to differentiate between crevices likely to be utilized by Wedge-tailed Shearwaters and those that would not be used. Therefore all crevices that could be utilized by birds, either Wedge-tailed Shearwaters or Red-tailed Tropic Birds, were inspected. There was no way of determining whether or not the numerous vacant spaces provided by the 'honeycombed cave-like' effect of the phosphatic ridge were, in fact, nesting sites. Rate of occupancy in this situation is an arbitrary measure and therefore not ascertained.

Burrow counts according to previously identified habitats

A full count of Wedge-tailed Shearwater burrows was recorded for the sand and grass verges surrounding the central vegetated area. Burrow estimates, based on burrow counts in sampling transects, were established for the northern vegetated ridge, the north section of the southern vegetated ridge, the south section of the southern vegetated ridge each of which consists of grasses, succulents, creepers and small shrubs; and the earth mounds. Having no burrows, apart from in the earth mounds, the central depression was excluded from the analysis. Only one mound was investigated as the mounds were extremely susceptible to collapse and this activity posed a severe threat of exposure for very young Boobie chicks in close proximity to the mounds. Each transect was traversed by staking out 4 m wide × 5 m long quadrats, end on end, until the habitat was traversed (e.g. Hill and Barnes 1989; Dyer and Hill 1990; Dyer 1992; Dyer and Hill 1992; Hill *et al.* 1995b) according to the identified habitat sectors (Fig. 1). Burrow counts per transect ranged from zero to thirty.

TABLE 1

Burrow counts, contents and lengths for the cliff and grass verge habitats.

Habitat	Burrow count	Adult occupancy	Burrows with egg or chick	Burrows with chamber lining	Mean burrow length
Cliff Face	60	100% (occupied burrows only recorded)	79% (n = 53)	97%	1.016 m
Grass Verge	3	67%	67% (n = 3)	67%	1.500 m

TABLE 2A

Burrow census estimates for the north section of the southern vegetated ridge (NSVR), the south section of the southern vegetated ridge (SSVR) and the northern vegetated ridge (NVR).

Habitat *Sample/Area (m²)	No. of burrows in sample	Burrow estimate	Standard error
NSVR 1245/22,961	91	1 678	469
SSVR 1528/30,369	46	898	402
NVR 1567/22,961	54	915	416
Central Mound 20/668	10	167	one quadrat sample
Whole Island	201	3 658	involves habitat errors (≈±30%)

*Sample areas are presented as ratios (i.e. sample area/habitat area — each measure is in square metres).

TABLE 2B

Burrow contents and lengths for the north section of the southern vegetated ridge (NSVR), the south section of the southern vegetated ridge (SSVR), and the northern vegetated ridge (NVR).

Habitat *Sample/Area (m²)	No. of burrows inspected	Adult occupancy	Burrows with egg or chick	Burrows with lined chamber	Mean burrow length
NSVR 1245/22,961	57	63%	55% (n = 51)	63%	1.020 m
SSVR 1528/30,369	32	56%	53% (n = 30)	59%	1.086 m
NVR 1567/22,961	42	55%	48% (n = 40)	59%	1.024 m
Central Mound 20/668	10	40%	40%	40%	0.885 m

*Sample areas are presented as ratios (i.e. sample area/habitat area — each measure is in square metres).

Areas of sample transects were later corrected according to the map so that there was consistency of scale between the island area as represented on the map (28 hectares) and sample areas which were digitally ascertained from the map (Table 2a). Because of the three-dimensional nature of the environment, transect areas were adjusted according to the two-dimensional map. This standardized the scale of areas involved in calculation and further refined the methodology, reducing error (e.g. Hill and Barnes 1989; Dyer 1992; Dyer and Hill 1992; Hill *et al.* 1995b).

'Ratio population estimates', the method of analysis advocated by Snedecor and Cochran (1967) which is designed to eliminate the influence of different sized sampling units (Norton-Griffiths 1978), and standard errors were derived from the transect data in the northern vegetated ridge, the north section of the southern vegetated ridge, the southern section of the southern vegetated ridge, and central mound (Table 2a). This methodology allows for comparison with similar work in the Capricorn Group (e.g. Hill and Barnes 1989; Dyer 1992; Dyer and Hill 1992).

Inspection of burrows to establish occupancy status

Subsequently at least 60 per cent of burrows in each transect was inspected to determine occupancy rates, the stage of the breeding cycle, burrow length, and usage of nest lining (burrows counted: 201; burrows inspected 141 — i.e. 70 per cent of burrows were inspected). Burrows inspected per transect ranged from zero to eighteen. Burrows deemed to be too close to surface nests of other species were not investigated; thus ethical considerations rather than statistical rigour determined process.

RESULTS

Opportunistic inspection of nests

It is purported that the number of Wedge-tailed Shearwaters (60 individuals) recorded in the cliff face is a full representation of the population in that particular habitat unless some, that nest deeper in the crevices than the burrowscope can reach, were missed. Burrow estimates, rate of burrow occupancy, description of burrow contents and a summary of burrow lengths, for the cliff habitat, are presented in Tables 1 and 2b.

Burrow counts according to previously identified habitats

The burrow census estimate for the island was 3 658 burrows (SE ≈± 30%) or 3 721 burrows if the occupied cliff face and grass verge nests and burrows are included (Table 2a).

The highest proportion of burrows was found in the north section of the southern vegetated ridge with a burrow density of 0.073/m^2 as compared to burrow densities of 0.035/m^2 and 0.030/m^2 in the northern vegetated ridge and south section of the southern vegetated ridge habitats respectively. Of ten transects in the eastern half of the island only one of the four in the northern vegetated ridge, and the only two in the north section of the southern vegetated ridge, had burrows. No burrows were found in the other seven transects situated on the eastern half of the island, thus, only 20.14 per cent of burrows (22.89% of occupied burrows) were located on the eastern side of the island. The majority of burrows, then, were found north, south and west of the compacted central depression on the widest side of this teardrop shaped island.

Inspection of burrows to establish occupancy status

It was not possible to ascertain whether there were eggs or chicks in 12 per cent of the occupied cliff face burrows because of obstructions or loss of control of the head of the burrowscope. Similarly the breeding status of 6 per cent of occupied burrows in the south section of the southern vegetated ridge, 10 per cent in the north section of the southern vegetated ridge, and 5 per cent in the northern vegetated ridge could not be determined. The sample sizes for calculating breeding rates were adjusted accordingly (Table 2a).

Approximately 52 per cent of burrows were occupied by breeding birds with no evidence of breeding in 6 per cent of occupied burrows (i.e. approx. 58% of all burrows were occupied). Approximately 21 per cent of occupied nests in the cliff face had no evidence of breeding (Table 1). One burrow in the cliff face and two burrows in the north section of the southern vegetated ridge each contained a chick (three in total) (Dyer and Carter 1997). One burrow in the cliff face habitat, one in the south section of the southern vegetated ridge, and two in the north section of the southern vegetated ridge contained a pair of birds (four burrows, eight birds).

Based on breeding success to the incubation stage in December 1995, 52 per cent of 3 661 plus 53 from the cliff face crevices results in an estimate of 1 957 breeding pairs of Wedge-tailed Shearwaters on Raine Island. The additional birds present on the island may have been roosting, pre-breeders or failed breeders.

DISCUSSION

Some problems are recognized with the methodology. For instance, to avoid undue disturbance of surface nesting species, collection of all required data should have been recorded at the same time. Any future burrow counts and monitoring of Wedge-tailed Shearwater burrow contents should be performed simultaneously. In fact several ground nesting species could be investigated in conjunction with Wedge-tailed Shearwater monitoring.

A technical problem with the methodology involved sampling of contents of burrows that was, for ethical reasons, biased towards those burrows that were not in close proximity to other occupied surface nests. This may not influence results but the closeness of surface nesters could be seen as an attraction for Shearwaters through protection from predators at the burrow entrance; for example, nesting Boobies could deter Buff-banded Rails *Gallirallus philippensis* from venturing into nearby burrows (Dyer 1997). Alternatively, the presence of Boobies in close proximity to previous season's burrows may deter Wedge-tailed Shearwaters themselves from returning to their burrows. The direction of any bias, if it exists, is not possible to determine without further research.

The birds nesting in the grass verge could be inexperienced breeders. Given the degree of disturbance by turtles in the vegetation zone these nests were unlikely to survive the season. Very little vegetation remained in this zone except in a small area on the northern beach. This problem was not confined to the grass verge. Wayward green turtles that managed to surmount the ridge had destroyed Wedge-tailed Shearwater burrows and nests of other species.

Birds actively dig burrows and burrow numbers, in the past, have been used to establish population estimates (e.g. Shipway 1969; Jahnke 1975; Kikkawa and Bowles 1976; Ogden 1979; Hulsman 1984; Hill and Barnes 1989; Hill and Rosier 1989; Walker and Hulsman 1989; Dyer and Hill 1992; Neil and Dyer 1992). It is important, then, to understand to what extent burrows are being utilized.

A population of approximately 1 960 breeding pairs of Wedge-tailed Shearwaters, or approximately 4 370 birds (twice 58% occupancy + twice 60 from cliff face crevices) excluding surface birds, on Raine Island falls within the range of the majority of estimates which fall between 1 000 and 5 000 birds (Taplin and Blaber 1993). To place this in perspective though, it must be remembered that the previous estimates may have been determined by doubling the active burrow counts/estimates to establish the number of birds. If this was the case, a comparative estimate for the December 1995 research would be approximately 7 320 birds based on twice the burrow estimate and assuming that previous estimates did not include birds occupying the cliff face crevices. This falls outside the range of the majority of estimates identified by Taplin and Blaber (1993).

Because of the lack of information concerning methodology for earlier estimates, it is impossible to establish trends over time and it is futile to attempt to do so. Certainly the estimate of birds (approximately 4 370) based on observations of burrow occupancy is a much more realistic and reliable estimate than that established by the burrow count (approximately 7 320). However, it is suggested that for comparison with earlier estimates the latter figure could be more appropriate. Perhaps all previous estimates, assumed to be based on burrow counts, should be adjusted by the occupancy rate found in this study. It should be noted that occupancy rates may not be consistent over time so there will always be some doubt as to the reliability of the comparison. Complications of comparing temporal data for Wedge-tailed Shearwaters where the methodology is not consistent over time is discussed by Dyer *et al.* (1995).

The result that the burrow density in the north section of the southern vegetated ridge was about twice that found in the northern vegetated ridge and the south section of the southern vegetated ridge can be explained. All transects in the north section of the southern vegetated ridge contained burrows, there being no transects in the north section of the southern vegetated ridge on the extreme eastern end of the island whereas three and four transects had no burrows on the eastern end of the island in the northern vegetated ridge and the south section of the southern vegetated ridge habitats respectively. This could be interpreted as a preference by birds for a particular habitat, the north section of the southern vegetated ridge, but it is probably a reflection of an overall locational preference for the western end of the island. This preference may be due to sub-strata for digging, resource partitioning through competition, prevailing weather conditions, or a combination of a variety of reasons that only further investigations will reveal.

The breeding rate recorded for Raine Island (52%) is relatively similar to breeding rates in the Capricorn Group: 49 per cent on Heron Island and 48 per cent North West Island in the incubation stage of the 1990–91 breeding season (Dyer 1992). The rate of breeding success is likely to be affected between hatching and fledging. On Heron Island only 48 per cent of incubation burrows recorded in December 1993 had fledgling chicks in May 1994 (Carter *et al.* 1996b) thus only about one quarter of breeding burrows may produce chicks to fledging stage. Many chicks do not survive fledging so the Raine Island Shearwater population may not be as secure as previously thought.

Serventy *et al.* (1971) and Warham (1990) claim protracted breeding in Wedge-tailed Shearwaters within colonies. The hatching of chicks in December on Raine Island, which is very early in the season relative to other colonies, may support this. Certainly the timing of hatching appears to vary between colonies (Dyer and Carter 1997).

Compared to the Capricorn Group colonies, relatively few surface birds were seen at night on Raine Island. Those in burrows were mostly associated with breeding; therefore, it is assumed that if changeovers were occurring, birds were not delaying take-off prior to commencing feeding forays. With few birds resting or roosting at night, relatively few seen at sea, and no rafting (i.e. bird congregating at sea just prior to dusk) witnessed, feeding may not have been occurring in the local area. Some birds were seen on the wing at dusk but not in great numbers. The few non-breeding birds that were present on the island may have been roosting, pre-breeders or failed breeders. With few surface birds and a higher rate of non-incubating birds in cliff face crevices it could be assumed that roosting birds may prefer to utilise the cave like structure of the cliff face habitat. This may result from competition for surface space that does not occur to such a high degree on other islands. However, it is acknowledged that the degree of evidence presented in this paper is speculative. It raises questions that can only be answered by more detailed research.

CONCLUSION

The initial difficulties encountered in the field exposed the necessity for a professional survey of the island accompanied by the placement of permanent location markers that are recorded on a digitised map. This has since occurred. Whenever possible, because of the short time frame of research trips to the island, experienced researchers who are familiar with the island should assist new researchers in the development of research design, particularly in planning for data collection.

Three population estimates were provided: 1 960 breeding pairs; 4 370 birds; and 7 320 birds (extrapolated from burrow counts). The first two estimates are considered to be equally reliable and the latter is for the purposes of comparison with earlier studies only. The breeding rate at the incubation stage of the cycle, with 52 per cent of burrows occupied by incubating birds or birds brooding chicks, is similar to that found for other colonies of Wedge-tailed Shearwaters.

It is not yet advisable to make any inferences on trends in the Raine Island Shearwater population. One of the most important points raised by this paper is that temporal comparability is impossible based on existing data. If trends are to be established the data recorded for this study should be used as a baseline for further investigations so that the status of the Shearwater population can be monitored over time. It is imperative to understand population trends if management is to be effective. Also, the fact that Shearwaters are exposed to a greater degree of competition for resources on Raine Island than at other breeding locations suggests that investigations of communities and resource partitioning should be incorporated in further studies into the avian ecology of the island.

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