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NEST DENSITIES OF THE WANDERING ALBATROSS *DIOMEDEA EXULANS* AT THE PRINCE EDWARD ISLANDS, ESTIMATED USING GPS

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Hand-held Global Positioning System (GPS) receivers provide opportunities for detailed and rapid mapping of features, including biological ones, further enhanced by the removal during 2000 of "selective availability". GPS was used to map, describe and compare nest densities within wandering albatross *Diomedea exulans* colonies at subantarctic Marion and Prince Edward islands. On Prince Edward Island, the coordinates of 1 061 wandering albatross nests were determined and, on Marion Island, 1 779 nests. For describing nest densities of wandering albatrosses, a 50-m grid is recommended, at which scale, the densest area of Prince Edward Island was in Albatross Valley, where the area of the colony was 46 ha and nest density was 22.3 nests ha^{-1}. For Marion Island, the total area of the wandering albatross colonies was 306 ha and the nest density was 5.8 nests ha^{-1}. In the three study colonies there (Macaroni Bay, 28 nests; Sealer's Beach, 117 nests; Goney Plain, 140 nests), the density statistics did not differ greatly from the overall densities on the island, with overall mean densities of 4.9, 5.7 and 8.0 birds ha^{-1} respectively. Although comparisons with nest densities at other breeding colonies are uncertain because of differing methods of computing them, the nest densities in Albatross Valley lie within the reported ranges for other colonies of great albatrosses.

Key words: *Diomedea exulans*, GPS, nest density, Prince Edward Island, Subantarctic, wandering albatross

The availability of relatively cheap hand-held Global Positioning System (GPS) receivers from the 1990s opened new opportunities for detailed and rapid mapping of features, including biological ones. These opportunities were further enhanced by the removal, on 2 May 2000, of "selective availability" by the United States Department of Defense, whereby position fixes had been substantially degraded.

Most species of seabirds breed in colonies. For some ground-nesting species, nests may be so closely packed that breeding birds are within pecking distance of their nearest neighbours. In such cases, maximum density is achieved by hexagonal packing, as shown for royal terns *Sterna maxima* and African penguins *Spheniscus demersus* (Buckley and Buckley 1977, Siegfried 1977). In contrast, other ground-nesting seabirds breed at much greater inter-nest distances, in what might be called loose colonies. Examples of such species include the great albatrosses of the genus *Diomedea* (Warham 1990, Tickell 2000).

Scott (1993) analysed the distribution of nest sites of the wandering albatross *D. exulans* using triangulation data collected with a Vickers Instruments prismatic compass in three long-term study colonies at subantarctic Marion Island, Prince Edward Islands, in the southern Indian Ocean, whose boundaries had been previously surveyed trigonometrically. The error ellipses of nest positions were unsatisfactorily large, probably on account of the difficulties of obtaining accurate data with a hand-held compass in often windy conditions, so the approach failed to produce results considered useful.

Albatross Valley, on the east coast of Prince Edward Island, 21 km from Marion Island, supported 1 182 pairs of wandering albatrosses in December 2001 (Ryan *et al*. 2003). It is reputed to have the largest nest density of any colony of wandering albatrosses in the world, but hitherto, no density data have been available for this little-visited island. The main objective of this study is to describe and compare nest densities within wandering albatross colonies at Marion and Prince Edward islands obtained by use of a GPS receiver. The aim is also to provide guidelines for the use of GPS receivers for measuring densities of birds in loose colonies.

MATERIAL AND METHODS

Prince Edward Island (44 km^2; 46°38´S, 37°57´E) was visited under special entry permit from 17 to 22 December 2001 (Ryan *et al*. 2003). Among other objectives, all wandering albatross nests in Albatross Valley belonging to the 2001/02 breeding cohort were counted; the handful of remaining chicks from

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Table I: Densities and other statistics relating to the nest densities of wandering albatrosses at the Prince Edward Islands in the 2000/01 breeding season

Parameter	Albatross Valley 1 030 nests			Albatross Valley (offset) 1 030 nests			Colony near R.S.A. Point 28 nests		
Quadrat grid	25 m	50 m	100 m	25 m	50 m	100 m	25 m	50 m	100 m
Quadrats per ha	16	4	1	16	4	1	16	4	1
Density (nests ha^{-1})									
Lower quartile	16	8	3	16	4	3	16	6	2.2
Median	32	16	7.5	32	12	8	16	8	4
Upper quartile	48	28	19.5	48	32	20	32	12	5.8
Maximum 1	176	124	60	192	92	61	48	24	10
Maximum 2	176	96	59	176	92	50	48	24	6
Maximum 3	160	88	51	176	88	49	32	12	5
Maximum 4	160	88	50	176	80	44	32	12	4
Maximum 5	160	84	44	160	72	38	32	8	3
Maximum 6	160	84	43	160	68	36	32	8	2
Maximum 7	160	80	36	160	68	34	32	8	1
Maximum 8	144	80	34	144	68	34	32	8	
Maximum 9	144	72	34	144	68	30	16	8	
Maximum 10	144	72	29	128	68	30	16	4	
Other statistics									
Number of occupied quadrats	399	185	76	394	191	75	21	12	7
Area (ha)	24.9	46.2	76	24.6	47.8	75	1.3	3	7
Mean density	41.4	22.3	13.6	41.9	21.6	13.7	23.6	10.3	4.4
Smallest number of quadrats containing 50% of the total for colony	88	33	14	91	35	15	8	5	3
Area of these quadrats (ha)	5.5	8.2	14	5.7	8.5	15	0.5	1.2	3
Density within these quadrats	93.6	62.4	36.8	90.6	60.6	34.4	31.0	12.4	5.2

the 2000/01 cohort that had not yet fledged were ignored (Ryan *et al*. 2003). On 20 and 21 December 2001, 18 months after the removal of selective availability, a stand-alone handheld GPS receiver (Garmin II+) was used by LGU to record the position of the nests of as many of the 2001/02 cohort of wandering albatrosses in Albatross Valley as could be visited in the time available. To avoid unnecessary disturbance to the birds, observations were offset by 2 m to the east of the actual nest sites. Each nest was marked as having had its position recorded by making a small hole in the ground at this point with a pole. Two small clusters of nests, isolated from the remainder of the colony, could not be reached, and two clusters of nests in the valley west of R.S.A. Point were also recorded.

Coordinates were recorded to a thousandth of a minute; at the latitude of the Prince Edward Islands, these represent 1.8 m of latitude and 1.3 m of longitude. However, the accuracy is not as fine as this, and, even with the removal of selective availability, errors in coordinates with handheld GPS units are approximately an order of magnitude larger (Merry 2000; see Discussion).

On Marion Island (290 km^2; 46°38´S, 37°57´E), SLP similarly recorded the positions of wandering albatross nests between 27 December 2001 and 12 April 2002 using a GPS receiver (Garmin 12XL) as part of a complete round-island count of nesting birds and other fieldwork.

The geographical coordinates were transformed into rectangular coordinates in metres, using the relationship that one minute of latitude is 1 852.3 m and one minute of longitude is 1 271.8 m at the latitude (46°37´S) of Albatross Valley; these distances were computed using the algorithm of Imboden and Imboden (1972). On Marion Island, one minute of longitude averaged 1 265.3 m.

A rectangular grid, in metres, was used to map the colonies. Nest counts per quadrat were computed using quadrats with sides 25, 50 and 100 m. To make the counts independent of quadrat size, counts were expressed as nests per hectare (ha) by multiplying by 16, 4 and 1, for the quadrats with sides 25 m (area 0.0625 ha), 50 m (0.25 ha) and 100 m (1 ha) respectively. For those quadrats that contained at least one nest, summary statistics (mean, median, quartiles) were computed. For Albatross Valley alone, for the colony near R.S.A. Point, for Marion Island as a whole and, for each of the three study colonies on Marion Island, Macaroni Bay, Sealer's Beach and Goney Plain, the 10 largest densities for each quadrat were determined. In addition, colony size was estimated as the area of the quadrats containing at least one nest (the "area of occupancy"). The minimum number of quadrats that held 50% of the nests was computed, so the density within the densest part of the colony could be estimated.

Clearly, a different placement of the grid would generate slightly differing values. To obtain an idea of the extent to which this is an important consideration, the analyses for Albatross Valley were repeated with the grid offset by 50 m for the 100-m grid, 25 m for the 50-m grid, and by 12.5 m for the 25-m grid.

RESULTS

The coordinates of 1 059 wandering albatross nests on Prince Edward Island were determined, of which 1 030 were in Albatross Valley (87% of the 1 182 counted during the December 2001 survey, Ryan *et al*. 2003), 28 near R.S.A. Point and one near Cave Bay. On Marion Island, 1 779 nest positions were determined, 95% of the total population of 1 869 occupied nests (Crawford *et al*. 2003), spaced around the whole island.

At the three grid scales examined, the largest densities were obtained in Albatross Valley (Table I). When a 100-m grid, generating 1-ha quadrats, was placed over Albatross Valley (Fig. 1), 76 of the quadrats contained at least one nest, and the maximum density in any single quadrat was 60 nests ha^{-1}. With 50- and 25-m grids (0.25-ha and 0.0625-ha quadrats), the maximum nest counts per quadrat were 31 and 11 respectively, equivalent to maximum densities of 124 and 176 nests ha^{-1} respectively (Table I).

In all, 71 of the 1-ha quadrats in Albatross Valley contained at least one nest, yielding a total colony area of 76 ha. At this grid scale, there were no quadrats without nests that were entirely surrounded by quadrats with nests (Fig. 1). With 50- and 25-m grids, 185 and 399 quadrats contained nests, and the colony areas were 46.2 and 24.9 ha respectively. For those quadrats that contained at least one nest, the overall average nest densities were 13.6, 22.3 and 41.4 nests ha^{-1} for the 1-, 0.25- and 0.0625-ha quadrats respectively (Table I).

The results obtained when the grids were offset by half the length of the quadrat were similar to the original results for Albatross Valley (Table I). These offset results are not considered further.

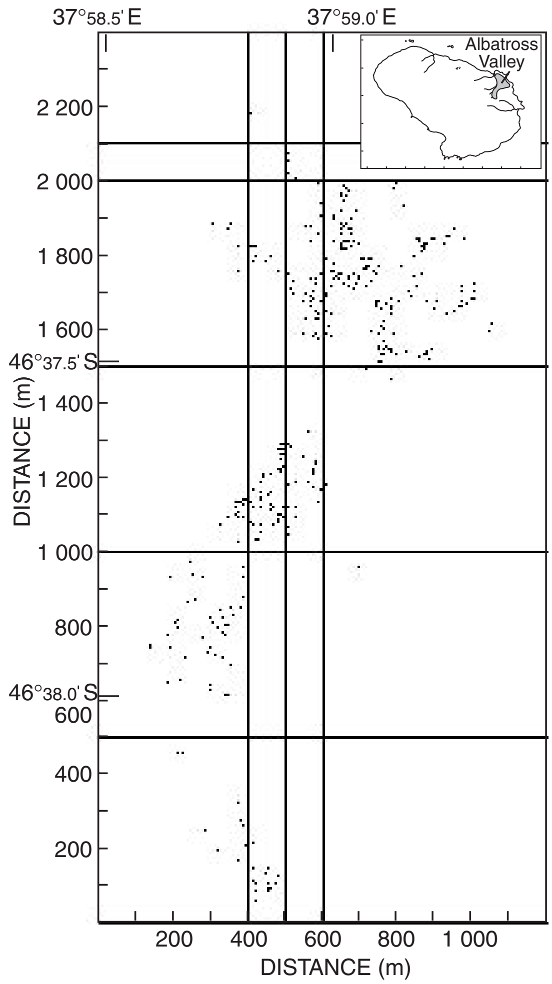

Fig. 1: Location of wandering albatross nests in Albatross Valley on Prince Edward Island, overlaid with a 100-m grid. The line y = 0 corresponds to 46°38.3100´S, the line y = 2 400 to 46°37.0151´S, the line x = 0 to 37°58.4952´E and the line x = 1 200 to 37°59.4386´E. No digital map is available to insert coastline or rivers

Using 100-, 50- and 25-m grids, the numbers of occupied grid cells (and their areas) on Marion Island were 757 (757 ha), 1 224 (306 ha) and 1 531 (95.7 ha) respectively. The respective overall densities (nests ha^{-1}) were 2.43, 5.81 and 18.6 (Table II). In the three study colonies on Marion Island, at Macaroni Bay, Sealer's Beach and Goney Plain, the density statistics did not differ greatly from the overall densities on the island (Tables II and III). Nest densities in the small colony near R.S.A. Point on Prince Edward Island were larger than in these study colonies (Table I).

DISCUSSION

Accuracy of GPS coordinates

The main sources of error (and their approximate standard deviations, *SD*) of the accuracy of horizontal GPS coordinates are satellite orbit (5 m), satellite clock (5 m), ionospheric refraction (5–15 m), tropospheric refraction (0.5–2 m), multipath reflection (0–10 m) and receiver resolution (0.1–2 m; Merry 2000). Assuming no correlation between these error sources, the anticipated minimum and maximum overall *SD*s are 8.7 and 18.9 m respectively (computed from the square root of the sum of squares of the *SD*s). Assuming a normal distribution, this is interpreted as meaning that, at best, a circle with radius 8.7 m centred on the GPS reading will be 68% certain of containing the true horizontal coordinates of the point, and that a circle of diameter 17.1 m (=1.96×8.7) will be 95% certain of containing the true coordinates. In practice, however, smaller *SD*s are frequently experienced, especially when satellite geometry is good and there are no multipath effects. For example, Merry (2000), in an experiment in which the horizontal coordinates had been predetermined to within 0.15 m, found that a Garmin 2+ GPS receiver, similar to that used on Prince Edward Island, yielded an *SD* of 2.8 m, based on 120 recordings made over a period of three days. Given the lack of reflective surfaces in the wandering albatross colonies on the Prince Edward Islands, multipath reflection effects were probably small.

Assuming that the position of each nest is determined independently, the *SD* of the inter-nest distances is given by the square root of twice the squared *SD* of the position fixes. For an optimistic *SD* of 2.8 m, the standard deviation of an inter-nest distance would be 4.0 m ($= (2 \times 2.8^2)^{0.5}$). For the theoretical anticipated minimum and maximum *SD* of 8.7 and 18.9 m, the inter-nest distance *SD*s would be 12.3 and 26.7 m respectively. These are greater than the observed distances between most neighbouring nests in Albatross Valley. Therefore, it was deemed unwise to calculate statistics based on inter-nest distances from the coordinates obtained during this study. Consequently, the analysis was focused on statistics based on nest densities within quadrats; the quadrats based on a 25-m grid probably represent the finest grid at which meaningful results can be obtained.

However, there is autocorrelation in time between errors (C. L. Merry, University of Cape Town, pers. comm.). In the context of this analysis, this means that the positions of nests determined over a short period of time are all likely to have a similar shift relative to their true coordinates. Inter-nest distances calculated from these positions are likely to be more accurate than the above analysis suggests. Observational experiments, using a configuration of points at known distances apart, with a careful record of the time at which each position fix was made, would be valuable in assessing this. The objective of the experiment would be to produce guideline times during which position fixes for all the nests in quadrats of various sizes need to be determined.

Differential GPS could potentially reduce errors to <1 m. Besides the equipment being cumbersome rela-

Table II: Densities and other statistics relating to the nest densities of wandering albatrosses at Marion Island in the 2000/01 breeding season

Parameter	Marion Island 1 779 nests		
Quadrat grid	25 m	50 m	100 m
Quadrats per ha	16	4	1
Density (nests ha^{-1})			
Lower quartile	16	4	1
Median	16	4	2
Upper quartile	16	8	3
Maximum 1	128	36	18
Maximum 2	96	36	15
Maximum 3	80	32	14
Maximum 4	80	32	13
Maximum 5	80	32	13
Maximum 6	64	28	11
Maximum 7	64	28	10
Maximum 8	64	24	10
Maximum 9	64	24	9
Maximum 10	64	24	9
Other statistics			
Number of occupied quadrats	1 531	1 224	757
Area (ha)	95.7	306	757
Mean density	18.6	5.8	2.4
Smallest number of quadrats containing 50% of the total for colony	643	348	151
Area of these quadrats (ha)	40.2	87.0	151
Density within these quadrats	22.1	10.2	5.9

Table III: Densities and other statistics relating to nest densities of wandering albatrosses at the three study colonies on Marion Island in the 2000/01 breeding season

Parameter	Macaroni Bay 28 nests			Sealers Beach 117 nests			Goney Plain 140 nests		
Quadrat grid	25 m	50 m	100 m	25 m	50 m	100 m	25 m	50 m	100 m
Quadrats per ha	16	4	1	16	4	1	16	4	1
Density (nests ha^{-1})									
Lower quartile	16	4	1	16	4	1	16	4	2
Median	16	4	1	16	4	2	16	8	4
Upper quartile	16	4	2	16	8	3	16	8	6
Maximum 1	32	8	4	32	12	9	80	24	13
Maximum 2	32	8	2	32	12	7	64	20	9
Maximum 3	16	8	2	32	12	6	64	20	9
Maximum 4	16	8	2	32	12	6	48	20	8
Maximum 5	16	8	2	32	12	5	48	20	8
Maximum 6	16	4	2	32	12	5	48	16	7
Maximum 7	16	4	2	32	12	5	32	16	7
Maximum 8	16	4	1	32	12	5	32	16	6
Maximum 9	16	4	1	16	12	4	32	16	6
Maximum 10	16	4	1	16	8	4	32	12	6
Other statistics									
Number of occupied quadrats	26	23	19	109	82	46	105	70	32
Area (ha)	1.6	5.8	19	6.8	20.5	46	6.6	17.5	32
Mean density	17.2	4.9	1.5	17.2	5.7	2.5	21.2	8.0	4.4
Smallest number of quadrats containing 50% of the total for colony	13	10	7	52	26	13	36	20	10
Area of these quadrats (ha)	0.8	2.5	7	3.3	6.5	13	2.3	5.0	10
Density within these quadrats	17.2	5.6	2.0	18.0	9.1	4.5	31.1	14.0	7.0

tive to a 150 g hand-held GPS receiver, these depend on regional monitoring stations on the ground to provide correction signals, and the nearest such stations to the Prince Edward Islands are in South Africa, and would be unlikely to improve accuracy over that achieved by the stand-alone GPS receiver as used in this study (C. L. Merry, pers. comm.).

A comparison of nest density and nearest-neighbour distance in great albatrosses

Great albatrosses breed at Subantarctic and southern cool-temperate islands in loose colonies on coastal and inland plains and gentle slopes with short vegetation, often in mires (Marchant and Higgins 1990, Tickell 2000), but information on nest densities for the genus is limited. At Bird Island, South Georgia, Tickell (1968) reported wandering albatross nest densities of 40–106 nests ha^{-1} in "most favoured" areas. At Possession Island, Crozet Islands, nest densities in three areas were 0.35, 0.82 and 1.01 nests ha^{-1} (Weimerskirch and Jouventin 1987), more than two orders of magnitude less dense than at Bird Island. This difference is probably partly because densities were measured in small (0.85–2.5-ha) study plots on Bird Island, but over areas ranging from 1.6 to 5.1 km^2 in size on Possession Island, and probably containing some areas unsuitable for breeding.

Nest densities for the Antipodean albatross *D. antipodensis* and Gibson's albatross *D. gibsoni* have been reported as 20 and 26 nests ha^{-1} respectively (Warham and Bell 1979, Warham 1990). Ryan *et al.* (2001) gave nearest-neighbour distance for the Tristan albatross *D. dabbenena* as "as little as 3 m", but noted that nests were as far as 500 m apart. No nest density data are available for this species of great albatross.

Westerskov (1963) and Warham (1990) reported 153 and 20 nests ha^{-1} respectively for the southern royal albatross *D. epomophora* at Campbell Island, where the species breeds in broadly similar habitat to that of wandering albatrosses (JC pers. obs.). In contrast, the northern royal albatross *D. sanfordi* breeds at a density as large as 520 nests ha^{-1} and approaching 800 nests ha^{-1} on the The Forty-Fours and The Big Sister, Chatham Islands, respectively (Robertson 1974).

Because of the wide variety of approaches to computing nest densities, it is difficult to make strong comparisons between these studies. However, knowing the coordinates of each nest as accurately as can be achieved, even with stand-alone hand-held GPS receivers, enables alternative approaches to be explored and compared. The concept of applying a grid of an appropriate dimension, as done here, enables an "area of occupancy" to be calculated in an objective way. The scale of this grid makes a considerable difference to the results, as demonstrated in Tables I–III. Of the three grid scales considered in this study, the 100-m grid reveals large areas that do not contain nests (Fig. 1), and which may therefore be unsuitable habitat. This biases nest densities downwards. The 25-m grid, especially on Marion Island where nest densities are relatively low, resulted in a large proportion of quadrats with only a single nest (1 779 nests in 1 531 quadrats, Table II); intuitively, choosing too fine a grid can generate unrealistically high densities. It is believed that the 50-m grid, because of the small area with no nests and relatively small proportion of quadrats with only one nest, is sensible and appropriate for wandering albatrosses. Its adoption is therefore proposed when comparing nest densities between breeding colonies for this species. It might also be appropriate for other loosely colonial species.

It is clearly desirable that areas selected as study colonies for birds should be representative of the population being sampled. Using the 50-m-grid as the basis of comparison, the colony at Sealers Beach has a mean density similar to the mean for Marion Island (5.7 v 5.8 nests ha^{-1}); the colonies at Macaroni Bay and Goney Plain have densities 16% below and 38% above the average respectively, and close to the lower and upper quartiles of nest density on the islands respectively (Tables II and III). From the viewpoint of nest densities in the three study colonies being representative of the range of densities on Marion Island, they were well chosen.

It would seem that the wandering albatross does not breed at exceptional densities for a great albatross in Albatross Valley on Prince Edward Island, with this study reporting overall mean and median densities, using a 50-m grid, of 22 and 16 nests ha^{-1} respectively (Table I). Although the comparisons are uncertain because of the differing methods of computing densities, these densities within Albatross Valley lie within the reported ranges for other colonies of great albatrosses. What does seem to be exceptional is that more than a thousand pairs breed annually in this valley in what may be considered a single colony (Fig. 1). This affords the privileged visitor to this specially protected island one of the most spectacular ornithological sights in the world.

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Albatross Valley, Prince Edward Island (photo R. J. M. Crawford)