

Seasonal changes in home range size and habitat selection by kakapo (*Strigops habroptilus*) on Maud Island

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Abstract Seasonal changes in home range size and habitat selection of kakapo (*Strigops habroptilus*) were investigated on Maud Island. Kakapo were radio-tracked at night in each of the four seasons between December 2000 and October 2001. Home ranges were estimated for four adult males, three juvenile males and two juvenile females in each season and for nine females in summer, each based on 20 radio-fixes per season. Home range size varied from 1.8 to 145.0 ha using the minimum convex polygon method. Home ranges were smallest in winter. Habitat selection was determined by overlaying the kakapo locations and home ranges on a vegetation map of the island. For each season selection ratios were calculated for each vegetation community. Pine plantation (*Pinus radiata*) was selected for in summer, whereas the treeland community dominated by five-finger (*Pseudopanax arboreus*) was selected for in the autumn. Dense pole stands of manuka (*Leptospermum scoparium*) and pasture communities were avoided by kakapo.

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INTRODUCTION

The kakapo (*Strigops habroptilus*, Gray 1845) is a large, flightless, nocturnal parrot that is endemic to New Zealand. The kakapo was once widespread throughout the North and South Islands and was also present on Stewart Island, but is now critically endangered. With the arrival of mammalian predators in the 19th century the distribution of kakapo rapidly contracted. By the mid-20th century kakapo survived only in the remote valleys of Fiordland (South Island) and on Stewart Island, where the infiltration of predators was slower. Between 1970 and 1990, all known kakapo were moved from Fiordland and Stewart Island to predator-free islands. Initially (between 1974 and 1981) nine birds were taken to Maud Island in Pelorus Sound, Marlborough.

Kakapo are exclusively herbivorous (Best 1984) and used to inhabit a wide range of vegetation types and altitudinal and climatic zones. Fossil remains show that kakapo were most common in areas of higher rainfall (>2000mm), particularly where rimu (*Dacrydium cupressinum*) was the dominant forest species, but also in wet montane beech (*Nothofagus*) forests (Worthy & Holdaway 2002). They occurred most often in ecotones between forest, scrub, herbfields, tussock grassland or seral associations (Higgins 1999). In Fiordland they were often found in disturbed sites, such as regenerating landslides and avalanches, possibly because these areas supported a greater variety of plant species (Gray 1977; Best & Powlesland 1985).

Estimates of kakapo home range size have been made on Stewart Island and Little Barrier Island, islands containing extremely different topography and vegetation, and both very different from Maud Island. On Little Barrier Island, Moorhouse & Powlesland (1991) found that some kakapo shifted their ranges seasonally. For example, kakapo occupying lowland kanuka (*Kunzea ericoides*)-manuka (*Leptospermum scoparium*) forest in winter moved to higher altitude northern rata (*Metrosideros robusta*)-tawa (*Beilschmiedia tawa*) forest during summer.

This study sought to estimate kakapo home range sizes, and record the birds' habitat selections, on Maud Island, a highly modified island. Understanding the role that exotic, or modified native, plant associations may contribute as kakapo habitat will help to determine the suitability of other modified islands to be kakapo refugia.

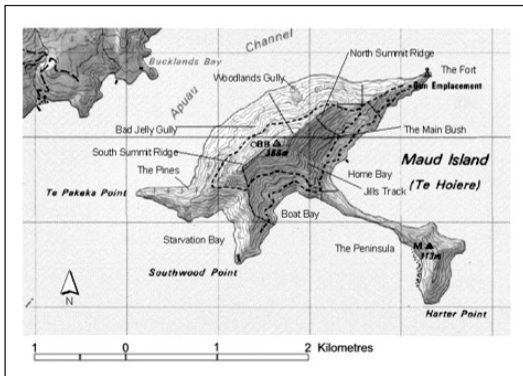
METHODS

Study area

Maud Island (Fig. 1) is a 309 ha scientific reserve located in Pelorus Sound (41° 01' S, 173° 52' E). The island was farmed until 1972 when it was purchased as a wildlife reserve (Cannington 1982). The island's rehabilitation began in 1972 when stocking rates were reduced, and regeneration was encouraged by fencing to exclude stock from most of the

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► **Figure 1** Maud Island showing the place names used in the text.

island. No mammalian predators or feral ungulates have ever established on the Island. With an annual rainfall of only 1270mm (Butler 1989), the climate of Maud contrasts with the wet, cool climates of Fiordland and Stewart Island from where the kakapo originated.

In the late 1800s most of the island's natural forest was cleared and converted to pasture but presently the island is covered in regenerating scrub. Eight vegetation types have been identified (L. Sheldon-Sayer unpubl. data). These comprise: 15 ha of pine (*Pinus radiata*) plantation established in 1973 at Te Pakeka Point; 20 ha of lowland indigenous forest above Home Bay, dominated by pepper tree (*Macropiper excelsum*), kohekohe (*Dysoxylum spectabile*) and nikau (*Rhopalostylus sapida*); unmanaged pasture comprising Yorkshire fog (*Holcus lanatus*), bracken (*Pteridium esculentum*) and exotic weeds; managed pasture dominated by yorkshire fog and cocksfoot (*Dactylus glomeratus*); treeland scrub dominated by five-finger (*Pseudopanax arboreus*), rangiora (*Brachyglottis repanda*) and bracken; coastal scrub dominated by five-finger, koromiko (*Hebe stricta*), and bracken; lowland scrub dominated by koromiko, manuka and bracken; and shrubland dominated by five-finger, bracken and pasture grasses.

In 1975, fruit trees were planted to provide additional food for kakapo. Trees included gooseberries (*Ribes grossularia*), blackcurrants (*R. nigrum*), guava (*Psidium* spp.), apple (*Malus domestica*), tree lucerne (*Cytisus proliferus*), grapes (*Vitis vinifera*) and rimu (Butler 1989).

Since 1990, kakapo on Maud Island have been provided with protein rich supplementary food, in an attempt to artificially induce breeding (Powlesland and Lloyd, 1994). Since 1999 supplementary feeding has only been undertaken prior to and during the breeding season.

Data collection

Field work was undertaken during four periods: summer (6 Dec. 2000 – 21 Jan. 2001), autumn (16 Mar. – 30 Apr. 2001), winter (15 June – 23 July 2001) and spring (10 Sept. – 18 Oct. 2001). There was a maximum of

18 kakapo on Maud Island; four adult males, nine adult females and five juveniles, two of the juveniles being the products of the single known nesting attempt on Maud Island, in 1998. During the summer period all 18 kakapo were present, however, in mid-April, eight of the adult females were removed, and the ninth in late July. The other birds were present throughout the study.

All kakapo were fitted with small backpack radio-transmitters and the positions of birds were obtained using standard radio-telemetry procedures. Positions were calculated by triangulation. To obtain each position, bearings were taken from three to five triangulation points which were precisely determined positions using global position system (GPS). Positions were obtained for each bird on the Island in four field seasons: During each of these seasons, five weeks was spent on the island and positions of the birds determined each night. Successive fixes on the same night were separated by at least five hours of darkness, in order to ensure independence.

Home range estimation

Home range estimation was carried out using the Animal Movement Analyst Extension (AMAE) (Hooze and Eichenlaub 1997) to ArcView GIS (Environmental Systems Research Institute Inc., Redlands, California). For each kakapo in each season, three estimates of home range were made: minimum convex polygon (MCP) using all fixes obtained; a fixed kernel range area using 95% of fixes; and a core range area represented by the 75% fixed kernel contour.

The MCP method of estimating home range area is the oldest and most commonly used method and is also the only method that is strictly comparable between studies (Harris *et al.* 1990). The MCP range is constructed by joining the outer locations to form a polygon, which means that single outliers can greatly increase the range area. As a result the range often includes areas that are never visited by the animal.

In order to identify areas of most intensive use, home range areas were also produced using the kernel method. The kernel home range is constructed by placing a kernel (a probability density) over each point in the sample. A rectangular grid is superimposed on the data and an estimate of density is obtained at each grid intersection using information from the entire sample (Seaman & Powell, 1996). The sophisticated representation of the internal structure of the range produced by the kernel method was thought to be appropriate for this study, because kakapo often moved over large distances to take advantage of abundant but localised food sources, and therefore, their home ranges often had multiple centres of activity. The 95% kernel contour was used to describe total range area and the 75% kernel was the contour that represented the area of most intensive use.

Home range sizes in each season, calculated using each of the estimation techniques were compared using Friedman's test (Zar, 1996).

Table 1 Kakapo home range area for each season (Su = summer, A = autumn, W = winter, S = spring), calculated from 20 fixes per bird and using the minimum convex polygon (MCP) and kernel methods, with areas of sea excluded. (¹ – spring 19 fixes; ² – autumn 18 fixes; ³ – winter 19 fixes).

Bird	Home range area (ha)												
	MCP				Kernel 95%				Kernel 75%				
	Su	A	W	S	Su	A	W	S	Su	A	W	S	
Adult males	Piripi ¹	32.4	44.1	4.4	24.8	49.9	100.3	4.5	88.6	23.3	37.2	1.6	38.9
	Richard Henry	3.6	11.4	1.8	36.5	6.4	19.3	3.0	44.7	2.4	5.6	1.2	17.7
	Smoko	33.2	26.2	17.6	15.6	43.3	24.8	31.8	19.3	10.4	10.5	12.2	6.3
	Stumpy	98.3	20.8	9.2	34.4	161.1	36.1	13.2	53.6	99.4	19.2	6.1	27.4
Male juveniles	Gulliver ¹	46.9	83.8	14.6	47.9	55.2	128.8	27.9	97.2	25.2	45.4	14.0	61.6
	Trevor ²	23.9	145.7	42.8	54.1	25.5	219.2	42.1	49.3	7.1	72.4	10.3	11.7
	Morehu ²	20.4	75.1	13.2	29.0	24.1	64.1	37.6	22.7	8.6	24.2	18.8	8.7
Female juveniles	Kuia ³	12.1	7.7	5.9	16.7	17.6	13.0	17.5	30.4	5.5	5.8	6.8	17.7
	Boomer	20.8	39.0	16.8	14.8	44.0	28.0	33.5	17.6	20.2	7.24	14.6	6.8
	Mean	32.4	50.4	14.0	30.4	47.5	70.4	23.5	47.0	22.5	25.3	9.5	21.9
	sd	27.7	44.4	12.1	14.2	45.6	68.4	14.4	29.2	30.0	22.7	6.0	18.3

Home range asymptotes

In order to determine the number of fixes required to produce a home range, home range asymptotes were examined. Home range area asymptote is determined by examining how the range area changes as successive fixes are added. An asymptote is reached when the addition of further locations results in minimal increase in range area. Range asymptotes were investigated using the RANGES V software package (Kenward, Institute of Terrestrial Ecology, Wareham, UK).

Triangulation accuracy

Triangulation accuracy was assessed by having a transmitter placed in various unknown locations on the island, all in areas used by kakapo and, on average, 150m from the nearest triangulation points. The position of the transmitter was located using triangulation in the normal way. This was then compared to the actual transmitter location as given by GPS. The error associated with each triangulation was calculated as the distance from true position to the centre of the polygon produced by the intersecting bearings) to each of the bearing intersections. This error was not taken into consideration when calculating range sizes due to limitations in the software used.

The average difference between real and triangulated locations of test transmitters was 37.8 m ($n = 20$, $sd = 34.4$ m, range = 6.3 – 130.3 m). The average distance between the birds' estimated location (obtained by triangulation) and the intersection of the bearings that made up the triangulation was 19.9 m ($n = 752$)

Habitat selection

Seasonal habitat selection by kakapo was investigated by answering the following two questions:

1. Does the frequency of use of each habitat type, relative to their areas, vary seasonally? Triangulated kakapo

Table 2 Female kakapo home range areas (ha) in summer, calculated from 20 fixes per bird and using the minimum convex polygon (MCP) and kernel methods, with areas of sea excluded.

Bird	Home range area (ha)		
	MCP	Kernel 95%	Kernel 75%
Flossie	1.9	1.9	0.8
Fuchsia	66.9	134.9	69.9
Heather	17.2	45.4	14.8
Jean	16.5	33.8	16.5
Lisa	29.8	54.9	22.9
Nora	63.6	70.4	24.3
Ruth	25.5	28.0	12.2
Wendy	14.6	38.2	11.2
Jane	28.6	58.3	32.3
Mean	29.4	51.7	22.8
sd	22.1	36.9	19.8

locations were overlaid onto a digital map of the island's vegetation communities (L. Sheldon-Sayer unpubl. data), using ArcView GIS. The area of each community was computed, and then converted to a proportion of the entire island. Habitat selection was investigated using the procedure suggested by Manly *et al.* (1993). In each season mean selection ratios were calculated for each vegetation community from individual kakapo selection ratios. Bonferroni 95% Confidence Intervals (C.I.) were computed for the selection ratio means. An entire C.I. >1 indicated significant selection for a particular vegetation community whereas <1 indicated significant selection against the vegetation community.

2. Do kakapo selectively use the habitat types within their home ranges and does any selection change seasonally? To determine selective use of habitat types within home ranges, kernel-derived home ranges were

overlaid onto the digital vegetation map. The 95% kernel was used to represent the available area for each individual, while 75% kernel represented the used area. The proportions of each habitat type within the two kernels were computed. Selection ratios and Bonferroni 95% C.I. (Manly *et al.*, 1993) were calculated for each vegetation community in each season.

RESULTS

Home range area

The wide variation in sample size and home range area meant that not all of the home ranges were fully sampled, as determined by the asymptote method. For comparisons between birds we computed seasonal home ranges from 20 fixes randomly chosen from all the fixes available for each bird. Where home range boundaries included sea, the area of sea was excluded from the estimated home range size. Home range area estimates for adult males and juveniles for each of the four seasons are presented in Table 1, and those for adult females in summer in Table 2.

The total range area (MCP and 95% kernel) and core home range area (75% kernel) were, on average, smallest in winter. Seasonal variation in home range size was found to be significant only when calculated using the MCP method (Friedman's test, $S = 11.40$, $P = 0.01$).

Habitat selection

When habitat selection was examined for each season separately, pine plantation was preferred in the summer. Lowland scrub was avoided in all seasons, managed pasture was avoided in winter and summer, and unmanaged pasture was avoided in summer. All other communities were neither selected nor avoided (Appendix 1).

Significant selection occurred for lowland forest in summer and for treeland in autumn. Unmanaged pasture was avoided in summer. Lowland forest was avoided in autumn and spring. All other communities were neither significantly selected nor avoided (Appendix 2).

DISCUSSION

Home range size

Seasonal home range sizes on Maud Island, estimated from 20 radio-fixes and using the MCP method, varied between 1.8 and 145.0 ha. Such large variation in home range size between kakapo has not been found in previous studies. On Stewart Island home ranges were estimated to be 15 - 50 ha using the 100% MMCP method (Best & Powlesland, 1985). On Little Barrier Island, also using the MMCP method, home ranges were estimated to be 21 - 38 ha (Moorhouse & Powlesland, 1991). The smaller range sizes and greater consistency in home range size found in these studies could be related to the method of home range estimation used, the time of day fixes were taken and the number of fixes. The MMCP method minimises the adverse affects of outlying points, and produces smaller home range estimates than MCP. Best & Powlesland

(1985) and Moorhouse & Powlesland (1991) only used fixes obtained during the day, whereas we used fixes obtained at night. Trinder (1998) found that the use of day fixes resulted in under-estimation of range size.

On Maud Island, Trinder (1998) found that winter home range sizes, estimated from night triangulations and using the MCP method, were 1.18 - 43.53 ha in June 1998, and 2.04 - 32.11 ha in July 1998. This is similar to the winter home range estimates obtained by this study (1.8 - 45.3 ha) using the MCP method and a standardised number of locations.

Seasonal variation in home range size

Home range size varied greatly between seasons but the pattern of variation was not the same for all birds. Seven of the adult females had small home ranges in the winter of 2000 (J. Malham pers. comm.) During the summer these birds made excursions to the pines area returning to their winter ranges between trips. There are two possible explanations for their summer excursions: they may have been attracted by male booming which only occurred in or near the pines, or they may have been feeding on pines (see habitat selection discussion). In contrast, the male Richard Henry had a small winter home range and another small separate summer home range centred on his track-and-bowl. During autumn and spring he spent some time in both areas and consequently had much larger home ranges at these times.

Effect of feed-stations on home-range size

Kakapo were being fed supplementary food before and during the breeding season but this study provided no opportunity to investigate the effect of supplementary feeding on home range size. Trinder (1998) observed an increase in home range size when supplementary feeding stopped in winter but the difference was not significant. In contrast J. Malham (pers. comm.) noted that supplementary feeding in summer did not appear to constrain birds' home ranges since they wandered widely and fed from more than one feed station. Furthermore, birds were unable to rely entirely on feed stations because they were often empty for several days before being re-filled.

Habitat selection

As has been found on Little Barrier Island (Moorhouse & Powlesland 1991), there was considerable individual variation in the use of habitats and plant species. For example, Piripi's winter home range was on the exposed summit of the island where shrubland was the dominant community, whereas Stumpy's home range was located in lowland forest. Furthermore, no individual kakapo spent the entirety of one season within a single vegetation type and birds often moved between types within a single night (Walsh, 2002).

The relatively small home ranges occupied in the winter contrasted with the more extensive movements

made by kakapo to exploit locally abundant foods at other times of year. For example, in autumn Trevor moved to the end of the peninsula where he remained for several days feeding on poroporo (*Solanum aviculare*) fruit.

In autumn treeland scrub made up larger proportions of the home ranges than would be expected by chance alone. This may be because kakapo were feeding on five-finger berries, as they did extensively in the previous year (J. Malham pers. comm.).

Nearly all of the kakapo visited the pines plantation during summer. Past feeding sign and faecal analyses (J. Malham, N. Parker pers. comm.) have indicated kakapo feed on pine needles and bark throughout the year, and on young cones in the spring and summer. Pine may be a favoured food because it is rich in turpines; all but one of the kakapo on the island had been raised on a diet of rimu fruit which is also rich in turpines, and kakapo on Little Barrier Island were observed to feed on turpene-rich kauri (*Agathis australis*) leaves. Although the pines were favoured for feeding, the relatively open forest floor of the plantation, and the straight, often branchless, tree trunks seemed to provide poor roosting habitat. When kakapo foraged in the pines during the night, they moved into a narrow band of dense lowland scrub within the pine plantation at dawn to roost.

Although Best (1984) observed concentrated feeding activity on manuka by kakapo on Stewart Island, the dense pole-stand of manuka on Maud Island was avoided by kakapo. These pole-stands had no understorey and perhaps had too few palatable species for kakapo to bother visiting them.

Kakapo consistently avoided pasture. However, they did make some use of these areas, mostly at the boundary between pasture and other habitats. A number of pasture species are eaten by kakapo; Gray (1977) recorded pasture plants in kakapo diets on Maud Island, and J. Malham (pers. comm.) found grass chews on Maud Island throughout the year. Kakapo also used the limited areas of pasture on Little Barrier Island (Moorhouse & Powlesland, 1991). It is likely that at least some of the kakapo recorded foraging in unmanaged pasture were not feeding on pasture plants but on species that have been planted or have naturally regenerated within the pasture.

Overall, lowland forest was neither selected nor avoided by kakapo, but kakapo including it in their home ranges favoured it in summer and avoided it in autumn and spring. For example, the adult male Richard Henry spent the entire summer near his track and bowl system on the ridge within the forest but spent his winter in a small area of treeland scrub, and during the autumn and spring moved between the two areas. Eight of the nine adult females were transferred from Maud Island to Codfish Island in the autumn. One female, Fuschia, occupied Main Bush for several years, suggesting that lowland forest is suitable for kakapo year-round.

Kakapo are able to survive on highly modified Maud Island but despite supplementary feeding they have only bred there once. This suggests that Maud Island's vegetation does not provide sufficient high quality food to trigger or support breeding, though it is more than adequate to support non-breeding birds.

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APPENDICES

Appendix 1 Habitat selection by kakapo on Maud Island. Habitat selection was determined by the frequency of use of each habitat type relative to its area on the island. Selection ratios and 95% Bonferroni C.I. (Manly *et al.* 1993) for each vegetation community type (“+” indicates significant selection for a community, “-” against a community).

Summer

Vegetation type	Selection ratio	Lower C.I.	Upper C.I.
Pine plantation	4.464 (+)	2.504	6.425
Lowland forest	1.313	-0.304	2.930
Treeland scrub	1.058	0.337	1.778
Coastal scrub	1.290	0.784	1.793
Lowland scrub	0.445 (-)	0.264	0.625
Shrubland	0.756	0.303	1.210
Unmanaged pasture	0.371 (-)	0.119	0.623
Managed pasture	0.332 (-)	0.057	0.607

Autumn

Vegetation type	Selection ratio	Lower C.I.	Upper C.I.
Pine plantation	3.717	0.585	6.849
Lowland forest	0.954	0.076	1.831
Treeland scrub	1.501	0.395	2.607
Coastal scrub	0.842	0.233	1.450
Lowland scrub	0.428 (-)	0.219	0.638
Shrubland	0.814	0.119	1.509
Unmanaged pasture	1.519	0.191	2.847
Managed pasture	0.494	-0.063	1.051

Winter

Vegetation type	Selection ratio	Lower C.I.	Upper C.I.
Pine plantation	2.145	0.104	4.186
Lowland forest	1.225	-0.734	3.186
Treeland scrub	1.667	0.460	2.874
Coastal scrub	1.272	0.432	2.112
Lowland scrub	0.501 (-)	0.318	0.684
Shrubland	0.752	-0.014	1.517
Unmanaged pasture	0.721	-0.046	1.488
Managed pasture	0.129 (-)	-0.124	0.382

Spring

Vegetation type	Selection ratio	Lower C.I.	Upper C.I.
Pine plantation	3.079	0.470	5.687
Lowland forest	0.462	-3.390	0.958
Treeland scrub	0.938	-6.212	1.939
Coastal scrub	1.557	0.907	2.207
Lowland scrub	0.485 (-)	0.131	0.839
Shrubland	1.149	0.320	1.978
Unmanaged pasture	0.362	0.059	0.665
Managed pasture	0.648	-0.351	1.648

Appendix 2 Habitat selection by kakapo within their home ranges on Maud Island. Habitat selection determined by the ratio of the proportion of each habitat type found in core home ranges (75% kernel) to that found in total home ranges (95% kernel). Selection ratios and 95% Bonferroni C.I. (Manly *et al.* 1993) for each vegetation community type (“+” indicates significant selection for a community, “-” against a community).

Summer

Vegetation type	Selection ratio	Lower C.I.	Upper C.I.
Pine plantation	1.945	0.909	1.480
Lowland forest	1.170 (+)	1.088	1.253
Treelandscrub	1.106	0.773	1.438
Coastal scrub	0.876	0.738	1.014
Lowland scrub	0.983	0.763	1.203
Shrubland	1.008	0.747	1.269
Unmanaged pasture	0.634 (-)	0.282	0.986
Managed pasture	0.883	0.541	1.225

Autumn

Vegetation type	Selection ratio	Lower C.I.	Upper C.I.
Pine plantation	0.952	0.737	1.167
Lowland forest	0.483 (-)	0.024	0.942
Treeland scrub	1.509 (+)	1.229	1.789
Coastal scrub	0.888	0.502	1.273
Lowland scrub	0.910	0.613	1.207
Shrubland	1.084	0.556	1.613
Unmanaged pasture	1.016	0.429	1.602

Winter

Vegetation type	Selection ratio	Lower C.I.	Upper C.I.
Pine plantation	1.057	0.888	1.227
Lowland forest	1.009	0.516	1.501
Treeland scrub	0.815	0.617	1.013
Coastal scrub	0.989	0.571	1.407
Lowland scrub	1.040	0.749	1.330
Shrubland	1.262	0.675	1.850
Unmanaged pasture	1.005	0.252	1.758
Managed pasture	1.086	0.883	1.289

Spring

Vegetation type	Selection ratio	Lower C.I.	Upper C.I.
Pine plantation	1.076	0.887	1.265
Lowland forest	0.717 (-)	0.443	0.991
Treeland scrub	1.242	0.851	1.633
Coastal scrub	0.916	0.521	1.311
Lowland scrub	0.864	0.365	1.364
Shrubland	1.247	0.846	1.628
Unmanaged pasture	0.780	0.106	1.454
Managed pasture	1.157	0.391	1.923