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ESTIMATING THE HOME RANGE AND CARRYING CAPACITY FOR TAKAHE (*PORPHYRIO MANTELLI*) ON PREDATOR-FREE OFFSHORE ISLANDS: IMPLICATIONS FOR FUTURE MANAGEMENT

Summary: Predator-free offshore islands play an important role in the conservation of many of New Zealand's endemic species. Takahe (*Porphyrio mantelli*) have small populations established on four offshore islands and although hatching success is lower than that of the wild mainland population in Fiordland, juvenile and adult survival is high and populations are growing exponentially. Accurate estimates of home range size and potential carrying capacities are therefore essential for the future management of the population as a whole. The mean home range size of takahe pairs in one study population on Mana Island (217 ha) was 2.8 ± 1.9 ha. The island was assessed for current and maximum available area for takahe and the potential carrying capacity was estimated at 22 - 53 pairs. Current and maximum available areas were also used to calculate carrying capacities on each of three other islands using two different estimates of mean home range size for Maud Island (7 - 34 pairs) and Kapiti Island (5 - 33 pairs) and one estimate of home range size for Tiritiri Matangi Island (25 pairs). A model of the population growth of takahe on islands predicted that estimated carrying capacities would be reached between 1997 and 2009. The urgency of planning to make use of the considerable potential of island populations of takahe is stressed.

Keywords: endangered species; conservation; population growth, New Zealand.

Introduction

Colonisation of New Zealand since about 900 A.D. has brought about some portentous changes in the environment in which New Zealand's endemic bird species evolved. Offshore islands, especially those on which introduced predators such as cats, stoats and rats have been removed, provide a relatively disturbance-free refuge and thus play a pivotal role in the conservation of endangered species such as the kakapo (*Strigops habroptilus*), saddleback (*Philesturnus carunculatus*) and stitchbird (*Notiomystis cincta*) (Bell, 1991).

The problems facing takahe (*Porphyrio mantelli* Owen) are representative of most of New Zealand's endangered bird species. Their decline has been attributed to factors relating to the arrival of humans in this country such as habitat destruction and modification, hunting and the introduction of mammalian predators and competitors (Beauchamp and Worthy, 1988; Bunin and Jamieson, 1995). Therefore in the past, management of the last remnant population of takahe on the mainland in the Murchison Mountains, Fiordland, has focused on competitor and predator control, habitat/food enrichment and captive rearing and reintroduction (Crouchley, 1994). However, since 1983 takahe conservation has also involved the use of offshore islands, with great success in many respects. Despite the relatively low reproductive success of takahe on islands compared to those living on the mainland in terms of both chicks per egg (0.26 ± 0.29 and 0.61 ± 0.37 respectively) and juveniles per year (0.56 ± 0.68 and 0.86 ± 0.59), juvenile and adult survival is high and overall numbers are increasing steadily (Bunin, Jamieson and Eason, 1997). Reports of annual adult survival of takahe in Fiordland range from 73% to 97%, depending on year and location (Reid, 1967; Mills, 1975; Mills, 1978) while estimated annual adult survival of takahe on islands ranged from 83% in 1986 to 100% in four different years (mean = 94.1% ± 5.6%, 1986 – 1995) (Bunin *et al.*, 1997). This creates a need for the future role of islands in takahe conservation to be reviewed.

Clout and Craig (1995) endorsed the natural build-up of takahe numbers on offshore islands, rather than captive-rearing, as a more cost-effective method of increasing the overall population. Takahe are highly territorial and defend large breeding areas in Fiordland (range 2 – 80 ha, Reid and Stack, 1974;

Mills, 1975; Williams, 1960), and therefore if the behaviour of birds on islands is similar to that of mainland birds, the number of pairs of takahe any island can hold is limited. It remains to be seen how takahe will behave as their density on islands increases, although indications are that home range size on islands is considerably smaller than in Fiordland (Dawson, 1994; this study). Climatic and geographic factors on islands are different to those in Fiordland which may contribute to differences in habitat requirements. In the only study of habitat and home range sizes of takahe on islands, Dawson (1994) suggested islands such as Maud Is. (309 ha) and Tiritiri Matangi Is. (220 ha) could hold somewhere between 12 - 50+ pairs of takahe. Dawson based this recommendation on a limited sample size of one pair on Tiritiri Matangi Is. and two pairs on Maud Is. and the high variability of her data makes further home range studies on other islands desirable before drawing firm conclusions on the capacity of islands for takahe.

This study focuses on detailed measurement of home ranges of takahe pairs on Mana Is. (217 ha) and estimating the potential carrying capacity of Mana Is. and three other islands currently holding takahe. A model is developed to calculate how many years it will take to reach the estimated carrying capacity of takahe on these islands. We propose there is an urgent need for long term planning and management of island populations of takahe for their role in the overall management of this highly endangered species.

Methods

Study site

Mana Is. is situated approximately 4 km off the western coast of the North Island, New Zealand, 21 km north of Wellington. It is 217 ha in area, with a small lowland area on the eastern side and steep hills rising up to a rolling plateau. Mana Is. was occupied by Maori prior to 1832 and since then has been farmed by Europeans. Cattle were removed from the island in 1986 when it was taken over by the Department of Conservation to become a scientific reserve. Eradication of mice in 1991 resulted in the island being one of the few in the New Zealand region to be declared free of introduced mammals and it is therefore of immense value for conservation. The vegetation remains highly modified, being predominantly native and introduced grasses with one steep valley of secondary growth kanuka/manuka (*Kunzea ericoides*/*Leptospermum scoparium*) forest and some tauhinu (*Cassinia leptophylla*) scrub on the steep cliffs (for a full vegetation description see Timmins, Ogle and Atkinson, 1987). The current revegetation programme has established a variety of other native plants. There is little permanent water on the island (Timmins, Atkinson and Ogle, 1987), although small artificial ponds are maintained throughout the summer and the lowland area stays moist throughout the year.

Management of takahe on Mana Island

Mana Is. is one of four offshore islands to which takahe have been introduced. Three pairs were first released in 1988, the founder birds originating either from eggs collected from the wild and raised at Te Anau, or from eggs hatched and raised at Mt Bruce Wildlife Centre. At the beginning of this study in September 1994 there were 5 pairs and one trio (consisting of two females and one male). Two pairs were not used in estimating home range size because they were kept in large enclosures for management purposes.

A supplementary feeding programme for takahe was implemented on all islands for the 1994/95 breeding season. Feeding was started before the beginning of the breeding season (mid-August) and continued until the end of January. Birds were fed the equivalent of 50 - 80 g/bird/day of organic turkey breeder pellets in hoppers placed inside their home ranges.

Measuring home ranges

Pairs were located using direct observation. Observations were carried out between 1 September 1994 and 13 February 1995 as part of a behavioural study (Ryan, 1997). All takahe on Mana Is. are colour banded for easy identification. All sightings of birds were plotted on an aerial photograph of the island. Home range boundaries were drawn through the outer points using a modified minimum area method (Harvey and Barbour, 1965). This method excludes points beyond one-quarter of the range length (distance between two furthest points plotted) from any other point, thereby discounting any one-off excursions beyond the normal range of activity. A digital planimeter was used to measure the enclosed areas which were converted to hectares using the map scale (3.3 cm = 100 m). Standard deviation is used throughout this paper to describe variation around the mean.

Estimating the carrying capacity

In order to estimate the carrying capacity of Mana Is. the total area that was potentially available for use by takahe needed to be delineated and measured. This area is referred to as the maximum available area and was outlined on an aerial photograph by eliminating all areas takahe would be unlikely to include as part of their home range (e.g. beaches, steep cliffs, dense bush areas). This area was measured using the same method as above.

Although the long term plans for Mana Is. call for several more artificial ponds to be established together with suitable vegetation, much of the maximum available area is presently not suitable for nesting. Therefore an estimate of the current available area was also calculated. These two area estimates were then divided by the mean home range size to calculate the maximum and current carrying capacities of Mana Is..

The same methodology was used to calculate maximum and current available area on the other three islands where takahe are present. Resident Department of Conservation staff and M. Baber of University of Auckland assisted in identifying area types on each island. Home ranges for Tiritiri Matangi Is. were derived from a concurrent study of home range behaviour. On Maud and Kapiti Is., resident staff identified home range boundaries for takahe. Maximum and current carrying capacities were then calculated using the estimated mean home range for each island. As home ranges for Maud and Kapiti Is were based on habitat boundaries and familiarity with takahe movements during the breeding season, it was felt they would tend to be over-estimates relative to those calculated for Mana and Tiritiri Matangi Is using actual plotted sightings of takahe. Thus a second estimate of maximum and current capacities was calculated for Kapiti Is. and Maud Is. using the mean home range size for Mana Is.; this assumed that habitat variables (e.g. climate, soil type, vegetation) and behaviour of takahe on Mana Is. was typical of that on the other islands.

Population growth model

A model of the population growth of takahe was constructed to estimate the time to reach the current carrying capacity of each island. Four age classes were used: juveniles (3 months to 1 yr), non-breeding yearlings (1-2 yrs), pairs breeding for their first time, and adult breeding pairs.

Estimates for the model were derived from a concurrent study of survival and productivity of island takahe by Bunin *et al.* (1997), except for juvenile survival which was calculated for this study. Numbers in each age class were calculated as follows:

$$N_{ai} = S_a(N_{ai-1} + N_{bi-1})$$
$$N_{bi} = S_a(N_{ci-1})$$
$$N_{ci} = S_j(N_{di-1})$$
$$N_{di} = ((N_{ai}P_{ai}) + (N_{bi}P_{bi}))/2$$

where

N_{ai} = adults in year *i*
N_{bi} = first time breeders in year *i*
N_{ci} = non-breeders in year *i*
N_{di} = juveniles in year *i*

and

adult survival (S_a) = 94.1 ± 5.6 %
juvenile survival (S_j) = 92.5 ± 16.0 %
productivity (juveniles per pair) of adults (P_a) = 0.91 ± 0.74
productivity (juveniles per pair) of pairs breeding for the first time (P_b) = 0.46 ± 0.52

The model was started using numbers of takahe on each island in 1996. It was run for 15 years until it was clear that the estimated carrying capacities had been exceeded.

Four assumptions were made in the model: 1) even sex ratio of juveniles; 2) breeding began at 2 years; 3) model parameters are constant over time, and 4) no transfers of takahe to or from islands.

Results

Home range sizes and carrying capacities

Home range sizes of takahe on Mana Is. appeared to fluctuate during the breeding season, but sample sizes were too small (< 10 observations) to plot home ranges at different stages of the breeding period. However, during the incubation period, pairs seemed to confine their feeding activity to a small (approximately 0.5 ha) area around the nest site. In contrast, they ranged more widely between nesting

Table 1: *Home range size (ha) and distance between nest sites (m) of individual takahe pairs breeding on Mana Island. Pairs are named with the female first.*

Pair	Home range estimate (ha)	Average distance between nests (m)	*n*
Rima and Lucky	1.2	-	
Terri and Ernie	1.2	24	1
Redleft and Tuarua	4.0	92 ± 26	3
Toni, Tilley and Alec	4.9	196 ± 41	3
Mean ± S.D.	2.8 ± 1.9		

Table 2: *Summary of current (as of end of 1995/96 breeding season) and maximum carrying capacity estimates for four offshore islands where takahe are present.*

	Mana I.	Kapiti I.	Maud I.	Tiritiri Matangi I.
Size of island (ha)	217	2023	309	220
Current number of pairs	6	2	5	5
Current available area (ha)	62	43	57	105
Maximum available area (ha)	150	92	96	105
Carrying capacity (pairs)				
Estimate using mean home range size specific to each island				
Current	22	5	7	25
Maximum	53	11	12	25
Estimate using mean home range size on Mana I.[1]				
Current	22	15	20	-
Maximum	53	33	34	-

[1]A second estimate of current and maximum carrying capacities was made for Maud I. and Kapiti I. as the method of delineating home ranges used on these islands was expected to over-estimate home ranges relative to those on Mana I. (see text).

attempts. Home range estimates were based on the maximum area used during the breeding season including renesting attempts where distances between nest sites varied considerably among the 3 pairs that renested (Table 1). Mean home range size for Mana Is. was 2.8 ± 1.9 ha.

The two smallest home ranges were found in the lowland area, around the staff houses. The mid-size home range was on the high plateau of the island where it was drier, although it included a large pond which was kept filled with water throughout the summer. The largest home range was that of the trio and was in the lowland area, but further away from the houses.

The maximum available area for takahe on Mana Is. was estimated at 150 ha. Dividing this area by the mean home range size gave an estimate of 53 pairs of takahe that could theoretically be supported on the island (Table 2). However, much of the habitat is considered to be limited by water and a lack of vegetation suitable for nesting and/or cover from aerial predators. Therefore, without any modification to the current area (62 ha), the number of pairs that could be supported decreases to 22 in total, 16 more than already present as of the 1995/96 breeding season. A similar range of carrying capacities were calculated for Maud and Kapiti Is. using the mean home range size calculated for Mana Is. (see Table 2).

Mean home ranges specific to each island were determined for Kapiti Is. (8.0 ± 0.3 ha, n = 2) and Maud Is. (8.0 ± 1.5 ha, n = 5) from home-ranges drawn on aerial photographs by resident DoC staff based on familiarity with the birds movements and sightings while working around the islands throughout the breeding season. Estimates of current and maximum carrying capacity using these island-specific home ranges were much lower than using mean home range size on Mana Is. (Table 2). Mean home range size on Tiritiri Matangi Is. (4.1 ± 1.5 ha, n = 3; Baber, 1996) was calculated using direct observations through the breeding season entered in to a computer programme (RANGES IV 1990). This was similar to the mean home range found on Mana Is. Tiritiri Matangi Is. has no areas that can be developed for use by takahe (M. Baber, pers. comm.) thus current and maximum available areas are the same (Table 2).

Model results

The model predicts that, given constant productivity and survival, the total population of takahe on each island will increase rapidly (Figure 1). Based on total breeding pairs, the carrying capacity of Mana

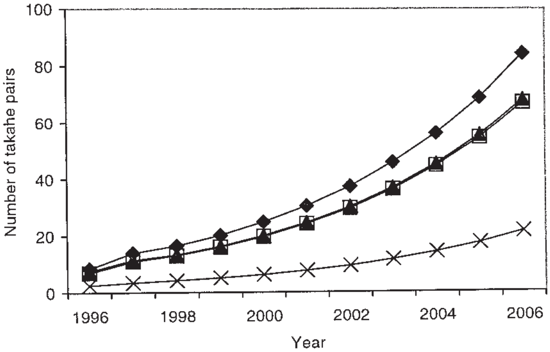

Figure 1: *Predicted growth of takahe populations based on number of pairs on Mana Island (solid diamonds), Maud Island (open squares), Tiritiri Matangi Island (solid triangles) and Kapiti Island (crosses).*

Table 3: *Estimates of the year when current and maximum carrying capacity will be reached on three offshore islands using Mana Island home range size and island-specific home range sizes. A second estimate of current and maximum carrying capacities was made for Maud and Kapiti as the method of delineating home ranges used on these islands was expected to over-estimate home ranges relative to those on Mana.*

	Year when carrying capacity will be reached			
	Estimate using island-specific home range size		Estimate using Mana Island home range size	
Island	Current	Max.	Current	Max.
Mana	2000	2004	2000	2004
Maud	1996	1997	2000	2003
Tiritiri Matangi	2001	2001	-	-
Kapiti	1998	2003	2005	2009

Is. (22 pairs) with vegetation and water as is will be reached in the year 2000 (Table 3). If habitat modification is carried out providing additional nesting areas, the maximum carrying capacity will be reached in 2004.

For the other islands, time to reach carrying capacity predicted by the same model varies greatly depending on which estimate of carrying capacity is used. If the mean home range specific to each island is used then current and maximum carrying capacities of Maud Is. will be reached by 1997 and Tiritiri Matangi Is. will reach its carrying capacity in 2001. Kapiti Is., due to its low starting population (two pairs), will not reach its estimated maximum carrying capacity until 2003. If the mean home range size on Mana Is. is used to estimate carrying capacities then current and maximum carrying capacities will be reached between 2000 and 2003 for Maud Is. and 2005 and 2009 for Kapiti Is. (Table 3).

Discussion

The conservation of several of New Zealand's threatened bird species, including takahe, has involved translocation to predator-free offshore islands. Although little research on home range size has been carried out on islands, there are varying opinions on how many takahe pairs these offshore islands can support. The Department of Conservation planned for a total of 25 - 35 pairs on all four islands (Crouchley, 1994), while Dawson (1994) estimates that each island, such as Tiritiri Matangi and Maud Is, could hold as many as 50+ pairs of takahe. Planning for the use of these islands in the future could vary greatly depending on what the carrying capacity is estimated to be. Future restoration plans will also affect the amount of habitat suitable for takahe and will determine whether there is a place for large, self-maintaining populations of takahe on these islands in the long term. Therefore accurate estimation of home range size and carrying capacity are essential for future management of takahe on islands. However, there are several factors which make this difficult. For example, seasonal variation, differing habitat quality between islands, unknown effects of high population densities on spatial behaviour and the method used for measurement can all affect estimates of home range size. Estimation of carrying capacity is complicated by the additional factor of changing habitat availability as regeneration occurs on the islands.

Takahe on Mana Is. had an average home range size of 2.8 ha over the breeding season depending on the stage of breeding. Home range size appeared to be at its greatest when pairs were between nesting attempts and possibly locating new nesting sites, while home ranges were smaller during incubation. Dawson (1994) measured home range size over three seasons (autumn, winter and summer) and found the largest home range size was used in summer in two of three pairs. This suggests that to obtain a maximum estimate of home range size measurements should be taken during the breeding season (summer) and between nesting attempts when demand for resources should be at their highest.

The mean home range size calculated from maps of 1994/95 territories on Maud and Kapiti Is was 8.0 ha. This is somewhat larger than the mean calculated for Mana Is. However, some of this difference may be accounted for by the methods used to estimate home range size. The modified minimum area method based on actual sightings of takahe used for home ranges on Mana Is. is known to give smaller estimates than other methods based on sightings (Mohr, 1947; Harvey and Barbour, 1965). Home ranges for birds on Maud and Kapiti Is. were based on habitat boundaries and familiarity with takahe movements and would therefore tend to give a larger estimate relative to methods using plotted sightings of birds.

The average home range size on Mana Is. (2.8 ha) and those estimated from home range data supplied by DoC for Maud and Kapiti Is. (8.0 ha) were similar to the average home range size for Maud and Tiritiri Matangi Is. (5.5 ± 7.4 ha, n = 3) found by Dawson (1994) (see Table 4). In a more

Table 4: *Home range estimates (ha) for offshore islands and mainland (Fiordland) from various studies.*

Population		Mean	Range	*n*
Mana I.	This study 1994/95	2.8	1.2 - 4.9	4
Tiritiri Matangi, Maud Is.	Dawson, 1994	5.5	1.0 - 18.0	3
Tiritiri Matangi I.	Baber, 1996	4.1	2.8 - 5.7	3
Fiordland	Williams, 1960	-	5 - 20	-
Fiordland	Reid and Stack, 1974	30 - 35	2.5 - 80	29
Fiordland	Mills, 1975	-	2 - 56	-

recent study of takahe on Tiritiri Matangi Is., Baber (1996) calculated a similar mean home range size to this study (4.1 ha). However, calculation of mean home range sizes on Tiritiri Matangi Is. became an order of magnitude larger than all other estimates when the supplementary feeding programme was terminated at the end of the breeding season (25.0 ± 12.9 ha, n = 3). Termination of the supplementary feeding programme on Mana Is. since this study was completed did not appear to affect home range sizes (J. Christensen, pers. comm.). This may indicate that food resources on Tiritiri Matangi Is. are limited due to poorer habitat quality. On Mana Is., the habitat is heterogeneous, with three of the four home ranges measured in this study occurring in the moist lowland area. Habitat on Tiritiri Matangi Is. is more homogeneous and similar to that of the high plateau area on Mana Is. where conditions are drier. This may affect food quality and thus home range size.

Current population densities on islands and in Fiordland are relatively low which makes determining minimum space requirements difficult. To a certain extent territory size will expand to fill unoccupied areas but is likely to contract with the pressure of high population density (Krebs, 1971; Ricklefs, 1973) allowing more birds to settle and breed. In Fiordland, estimated home ranges are larger than those on most islands (Table 4) but they are not thought to be determined by food resources (Williams, 1960). It is possible that the aggressive nature of takahe and current low densities in Fiordland result in home ranges that are in excess of what is required to satisfy food requirements. Home ranges on islands are smaller than those in Fiordland, but there is a high degree of variation both between and within islands (Table 4), suggesting that in addition to differences in habitat quality, home ranges may be larger than required to satisfy food requirements. The areas measured in this study are home ranges rather than defended territories and thus may be more inclined to contract at higher population densities.

In estimating the carrying capacity for Mana Is., the mean home range size was chosen as an intermediate figure to balance the effects of increasing density with varying habitat quality as discussed above. For simplicity, change in habitat availability due to replanting of native trees and natural succession has not been taken into account. However, on Mana Is. at least, the estimated grass cover in the year 2030 (well beyond the extent of the model) will be approximately 100 ha (Miskelly, *unpubl.*; Department of Conservation, Wellington), which lies between the current and maximum estimates of area availability (Table 2). Thus an intermediate figure between the current and maximum carrying capacities might be appropriate for longer term planning. Habitat development may be required to improve some areas for takahe, including additional planting for nesting and cover from aerial predators (hawks and gulls) and increased water availability in the form of ponds.

For Kapiti and Maud Is, estimates based on mean home range size on Mana Is. give an optimistic scenario and assume that differences in habitat quality and behaviour between islands are negligible. Estimates based on mean home ranges specific to Kapiti and Maud Is. make fewer assumptions as far as habitat quality and behaviour are concerned but may be over-estimates in comparison to Mana Is. due to the different methods used in delineating home ranges. We believe the most appropriate carrying capacity for long term planning would be intermediate to the smallest and largest of the four estimates for the following two reasons: 1) differences in habitat quality between islands and gradual regeneration both reduce the likelihood of the largest estimates being attained, but 2) contraction of home ranges at higher densities and habitat improvements both reduce the likelihood that minimum estimates will be most applicable.

Estimates of carrying capacity calculated here are considerably higher than those in the Takahe Recovery Plan (Crouchley, 1994), and similar to those suggested by Dawson (1994). Despite current low hatching success on islands (Bunin *et al.* 1997), high adult and juvenile survival means that populations on islands are growing rapidly.

Although the model used in this study had simplified assumptions and parameters, it demonstrates that the time span until carrying capacity of the islands is reached may be 12 years at most and less if conservative estimates are used. Given that takahe are not necessarily part of the long-term restoration plans for the islands they currently inhabit (Miskelly, unpublished DoC report), it is imperative that the potential of island populations as a reservoir for the establishment of an additional large population on the mainland is seriously considered. The use of islands has greatly reduced the possibility of extinction for takahe and gives more flexibility for research into the release of takahe somewhere on the mainland other than Fiordland. Likely places may be Nelson, the Tararua Ranges and Ruahine Ranges, where takahe may have survived until late last century (Reid, 1974). Alternatively, island birds could be used to boost the Fiordland population, although any genetic adaptation to lowland climates occurring in island populations may complicate this. Whatever role island populations may play in the overall management of takahe, it is clear from this study that urgent planning is required to make full use of their considerable potential.

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