Sooty shearwater (*Puffinus griseus*) harvest intensity and selectivity on Poutama Island, New Zealand

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Abstract: Rakiura Maori annually harvest sooty shearwater (*Puffinus griseus*) chicks from islands in Foveaux Strait and adjacent to Stewart Island, New Zealand. Chick availability and the number of chicks harvested were estimated during the 1994 and 1995 seasons on Poutama (Evening Island). Burrow entrance densities estimated using circular plots were significantly higher in 1994 (0.45 ± 0.03 m^{-2}) than in 1995 (0.41 ± 0.03 m^{-2}). A similar burrow entrance density (0.45 ± 0.04 m^{-2}) was obtained in 1995 using a transect sampling technique. The number of usable burrows estimated using circular plots in 1994 and 1995 was 387 508 and 337 732 respectively. Of these, chicks occupied 24% ± 6% in 1994 and 29% ± 4% in 1995. It was estimated the muttonbirders harvested 13-24% (15 722) of the chicks present on Poutama in 1994 and 17-28% (22 092) in 1995. Muttonbirders targeted areas of the island with higher chick density and less fallen stems. Excluding chicks rejected by the muttonbirder (≤ 750g), harvested chicks were significantly heavier and had less down than randomly encountered chicks. If larger heavier chicks are more likely to return and breed, then the preference for these chicks by muttonbirders would affect predictions of harvest impacts.

Keywords: burrow density; burrow occupancy; harvest intensity; Maori; selectivity; muttonbirding; Procellariiformes; *Puffinus griseus*.

Introduction

Societies around the world exploit seabirds for food, oil, feathers and guano (Cott, 1953, 1954; Fisher and Lockley, 1954; Sutton and Marshall, 1980; Feare, 1978, 1984a; Skira, 1987, 1990; Beatty, 1992). Species that nest colonially, synchronously and on the ground are highly vulnerable to human exploitation (Feare, 1984b). Societies have developed similar cultural traditions to control ownership of breeding grounds and to regulate cropping, and most have apparently had little effect on the size of the seabird populations that they crop (Diamond, 1987). In developed countries the number of people involved in collecting birds and their eggs has probably decreased, but greater mobility, more effective hunting techniques and better storage facilities has meant the harvest of some species has increased (Feare, 1984b; Bomford and Caughley, 1996). Research on sustainability has therefore become important to ensure the persistence of the seabird populations and a continuing harvests. The long-term study of short-tailed shearwaters (*Puffinus tenuirostris*[1]) in Tasmania, Australia enabled a maximum sustainable yield to be estimated and showed the overall population was in no danger of decline despite harvesting (Skira *et al.* 1985).

The sooty shearwater (*Puffinus griseus*) is the most abundant of the Procellariiformes that breed in New Zealand. The centre of its abundance is on islands in Foveaux Strait and adjacent to Stewart Island (New Zealand's third largest main island). Large populations are also found on The Snares – 48°S, 166°E (Warham and Wilson, 1982; Marchant and Higgins, 1990).

Breeding and non-breeding sooty shearwater adults return to colonies in early October for courtship and to prepare 0.3m - 4m long burrows (Warham, 1990). A single egg is laid usually between mid-November and early December (Richdale, 1944). Lost or unsuccessful eggs are not replaced. Incubation requires approximately 53 days and chicks may spend between 86 to 106 days in the burrow (Richdale, 1954), before emerging and fledging from mid-April to late May (Falla, 1934; Richdale, 1963; Warham *et al.*, 1982; Brothers and Skira, 1983). The large number of chicks and

[1]Nomenclature of birds follows Nelson (1978) and Marchant and Higgins (1990).

predictability of this breeding cycle has made this species an ideal source of food for Rakiura Maori (New Zealand's southern-most indigenous people).

"Muttonbirding" is the body of techniques whereby the chicks and fledglings of various Procellariiformes are caught, processed and preserved for food (Anderson, 1995, 1997). Archaeological data indicate that sooty shearwater chicks were widely exploited by Maori in prehistoric New Zealand, but estimates of the period of intense exploitation remain uncertain (Anderson, 1997). Hereditary rights allow Rakiura Maori to annually harvest sooty shearwater chicks on 36 islands in the Foveaux - Stewart Island (Rakiura) group during a season which extends from the 1 April to the 31 May each year (Department of Lands and Survey, 1978; Wilson, 1979; Robertson and Bell, 1984).

The aim of the research was to estimate burrow entrance density (burrow entrances not blocked by soil), burrow density (potential nest sites), chick occupancy and consequently the number of chicks available on Poutama for harvest. Two survey techniques and burrow sampling methods were compared and used to estimate the number of chicks. The percentage of chicks harvested by muttonbirders was determined as the essential first step in estimating whether or not current harvests are sustainable.

Muttonbirders prize larger and fatter chicks, and there is preliminary evidence that such birds have better survival from fledging to breeding age (Sagar and Horning, 1998). Harvested chicks were compared with randomly encountered chicks to assess the potential importance of quality (body condition) in predicting harvest impacts. This study also assessed whether muttonbirders target areas of the island with higher burrow entrance and chick density, or sites where vegetation composition, slope, or soil moisture facilitate the harvest. If such selectivity exists and chick quality varies spatially with these factors, the impact of the harvest may be greater or lesser than predicted by a purely demographic approach.

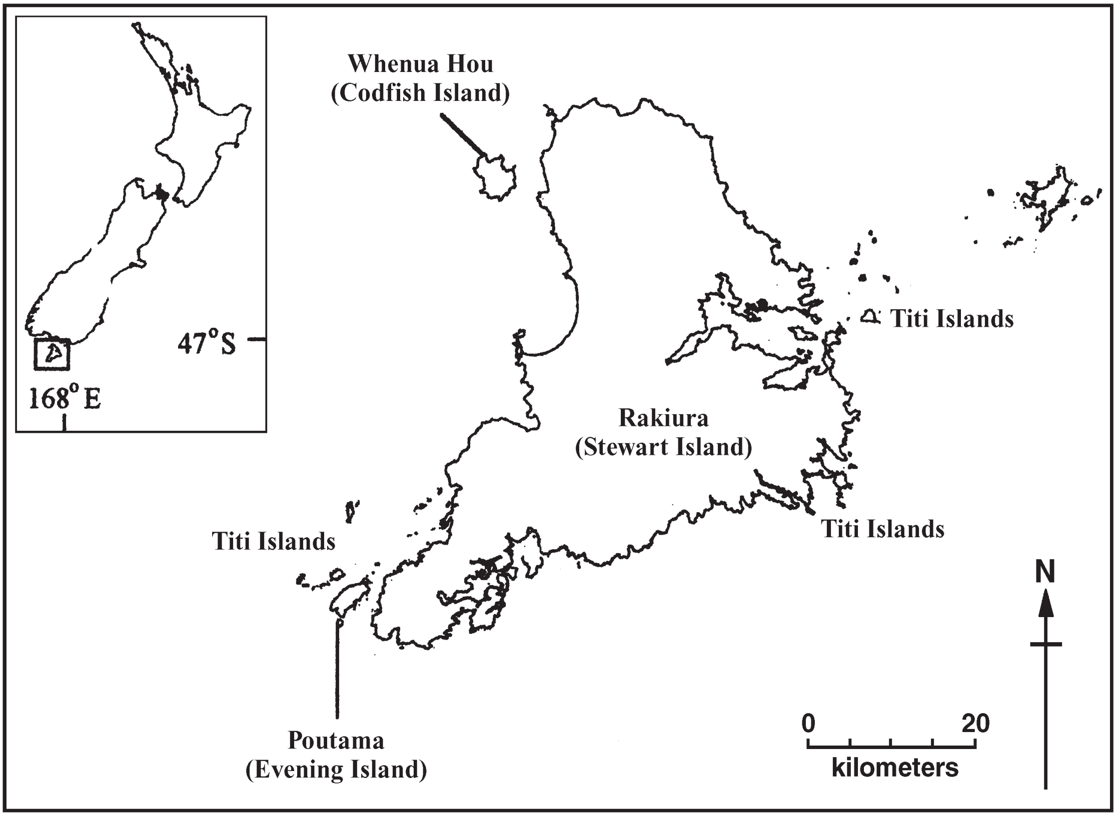

Figure 1: Rakiura (Stewart Island) and adjacent Titi (Muttonbird) Islands showing the study location, Poutama (Evening Island). Inset: Map of New Zealand.

Methods

Study location

The study was conducted over the 1994 and 1995 birding seasons on Poutama (Evening Island – 47°16'S, 167°23'E), a predator-free "beneficial" island (an island to which only certain Rakiura families have right of access) in the south-western Rakiura Titi (Muttonbird) Island group (Figure 1). The island operates under an "open *manu*" system (a system where muttonbirders can harvest chicks from anywhere on the island at any stage of the season). The island is approximately 60 ha, and predominantly covered in "muttonbird scrub" species such as Tete-a-weka (*Olearia angustifolia*[2]) and Tupare (*Olearia colensoi grandis*). Understorey species consist mainly of Punawi (*Stilbocarpa lyalli*) and ferns (*Polystichum vestitum*, *Blechnum durum*, *Asplenium obtusatum* subsp. *obtusatum*, *A. scleroprium*, *A. flaccidum x terrestre*, and *Histiopteris incisa*) with areas of grass (*Poa tennantiana* and *Isolepis praetexta*).

Estimating burrow occupancy

Poutama was sub-divided into 16 similar sized areas using muttonbirder access tracks as boundaries. Five survey points were randomly selected in each of these areas. It was initially proposed burrow occupancy would be surveyed along a transect at each of these 60 survey points. However, equipment failure and time restrictions meant this was not possible.

In 1994 184 burrows (13 transects - 130 burrow entrances) were surveyed for chicks, while in 1995, 526 burrows (38 transects - 380 burrow entrances) were sampled. At least two transects in each area were surveyed in 1995. For consistency the 130 burrow entrances from 1994 were resurveyed in 1995. The ratio of burrow entrances to burrows and the proportion of burrows with more than one entrance were estimated each year.

At each transect the presence of chicks in the first ten burrow entrances encountered 1m either side of a transect centre-line was determined using an infra-red burrowscope [see Lyver *et al*. (1998) for the design of the burrowscope]. Burrow entrances that bisected the outer boundaries of the transect were included only if their centres were within one metre of the centre-line. Burrow entrances defined the entry/exit holes on the ground's surface which potentially could lead into one or more usable burrows. Burrows were considered potentially usable if they were ≥ 0.2m, the shortest occupied burrow found, even if an obvious nest chamber was not found. When burrows diverged from a single entrance each branch was recorded as an independent burrow. Single tunnels with two or more entrances (and only one chamber) were recorded as one burrow.

Burrows were described as occupied (presence of a chick) or unoccupied (entire burrow searched, but no chick found). When extreme length, narrow width, corners or obstructions (usually rocks or roots) prevented penetration of the burrowscope to the end of burrows, it was designated as "unknown" occupancy. The first survey was conducted in the two weeks prior to the commencement of harvesting (1 April) each year. A second survey conducted at the end (19-22 April) of the *nanao* was used to assess the proportion of chicks removed. The nanao is the first part of the harvest season (1 April to ~20 April) when chicks are caught in daylight by extracting them from breeding burrows (Richdale, 1946; Wilson, 1979).

An alternate technique for estimating burrow occupancy was to monitor muttonbirders catching chicks in the nanao. Here, the total number of burrows that muttonbirders prospected and the proportion of successful strikes (burrows from which chicks were caught) were recorded.

The second part of the season (~ 21 April to 31 May) is called the *rama*. During this phase chicks are caught at night on the ground's surface as they emerge from burrows to fledge (Richdale, 1946; Wilson, 1979). The change over times between harvest methods were specific to Poutama, although the overall start and finish dates for the season are binding for all islands.

Method 1: Burrow number and density in circular plots

An annual count was made of the number of burrow entrances within a 2m radius circular (12.56m^2) plot at the five survey points in each of the 16 areas. Each of the survey points was used as the centre of a circular plot. The number of burrow entrances in each of the 80 plots was multiplied by the total area of Poutama (600 000m^2) divided by plot size. Using the 80 estimates, the average number (± 95% C.I) of burrow entrances for Poutama each year were calculated and then adjusted for the proportion of burrows with two entrances. The average estimate was then adjusted by the ratio of burrows to burrow entrances (some burrow entrances were openings for more than one burrow) to determine the total number of burrows on the island. Average burrow and burrow entrance densities were obtained by dividing each estimate by 600 000m^2. Chick density was calculated by multiplying burrow density with burrow occupancy.

[2]Nomenclature of plants follows Salmon (1980) and Wilson (1982).

Method 2: Burrow number and density along transects

The second method of burrow number and density estimation used the 38 transects from the burrow occupancy survey. Transects were initiated from survey points which meant there was some sampling over-lap with circular plots at 38 (the maximum number of transects surveyed) of the survey points. Each transect area was determined from the maximum distance (m) required for 10 burrow entrances to occur within one metre either side of a transect centre-line. The maximum transect length was taken at the distance where a line perpendicular from the centre of the tenth burrow entrance bisected the transect centre-line.

The number of times a particular transect's area would fit into the land area of Poutama was calculated by dividing the area of Poutama by the area of a transect (eg. $600\,000 m^2/17.5 m^2 = 34\,285.7$ transects of this size would be required to make up the land area of Poutama). This estimate was calculated for each of the 38 transect areas. Each of these 38 estimates were then multiplied by 10 (the constant number of burrow entrances per transect) and the average (± 95% C.I.) taken. Estimates of the total burrow and burrow entrance number, burrow entrance density and burrow density were adjusted and calculated as for Method 1.

Estimating proportion of chicks harvested

The total number of chicks on Poutama each season was estimated from total number of burrows multiplied by the proportion of burrows occupied by chicks before the harvest began. The number of chicks harvested each day during the nanao and rama were obtained from the muttonbirders on Poutama each year. Reliable daily harvest totals were reported by the birders in 1994, however in 1995 catch totals from only three of the seven birding families were consistently reported. A daily estimate was made for the other families taking into account the number and age of muttonbirders in the family, the length of time they harvested and weather conditions at the time. The estimates were also based on the number of chicks caught by the other muttonbirders for which we had definite daily totals. This enabled the proportion of chicks removed to be estimated each season.

A second method was used to assess the proportion of chicks caught by muttonbirders over the nanao. This technique used the estimates of chick occupancy from the burrowscope surveys prior to the nanao in 1994 and 1995. Chick occupancy estimates from the second survey immediately after the nanao were used to check the proportion of chicks remaining. This method was compared with the first to provide an indication of accuracy and consistency.

Selectivity of areas for harvest during nanao

The three muttonbirders present during the nanao on Poutama were asked to mark the areas where they harvested each day on a map. Muttonbirders could have potentially harvested for 21 days over the nanao. Each time a muttonbirder harvested within an area during the nanao an index score of "1" was given. If a muttonbirder visited an area more than once in a day, it was still only given an score of "1". Scores were then totalled for the three muttonbirders to obtain the overall "harvest frequency" for each of the 16 areas.

Potential correlations between "harvest frequency" and "area characteristics" gathered from the transects used in the 1995 burrow occupancy survey were assessed. The area characteristics investigated were burrow entrance density, chick density, burrow occupancy, mean burrow length, slope, soil moisture content, % ground cover and % stem number. Thirteen of the areas had two burrow transects surveyed, while the remaining three areas had four. The index for soil moisture was based on a scale of zero to three: 0 - dry; 1 - slightly damp; 2 - moist; and 3 - wet. Ground cover below 1.5m was divided into five categories and the percentage of the transect area that each covered

Table 1. Average estimates of usable burrows and burrow occupancy on Poutama during the 1994 and 1995 muttonbirding seasons (lower and upper 95% Confidence Intervals given in brackets).

	Usable Burrow Estimates (95% Confidence Intervals)		Burrow Occupancy Estimates (95% Confidence Intervals)		
Year	Circular Plots	Transect Plots	Burrowscope (pre-nanao)	Burrowscope (post-nanao)	Birder Strike Rate
1994	387 508 (358 580 - 416 433) n = 80	-	24.5 (18.3 - 30.7) n = 184	14.1 (9.1 - 19.1) n = 184	32.3 (31.1 - 33.5) n = 5881
1995	337 732 (311 848 - 363 615) n = 80	358 915 (326 322 - 394 801) n = 38	29.5 (25.6 - 33.4) n = 526	20.3 (16.9 - 23.7) n = 526	36.8 (32.6 - 41.0) n = 508

Table 2. Average estimates of chicks available and the percentage harvested on Poutama using plot and transect sampling techniques in 1994 and 1995 (lower and upper 95% Confidence Intervals given in brackets).

Year (method)	Chicks Available (95% Confidence Intervals)	No. Chicks Harvested	% Chicks Harvested (95% Confidence Intervals)
1994 (plot)	93 002 (64 544 - 124 930)	15 722	16.9 (12.6 - 24.4)
1995 (plot)	97 942 (77 962 - 119 993)	22 092	22.6 (18.4 - 28.3)
1995 (transect)	104 085 (81 581 - 130 284)	22 092	21.2 (17.0 - 27.1)

estimated. These were then expressed as averages for an area. The categories were (i) bare ground/grass; (ii) fallen stems; (iii) tupare; (iv) tete-a-weka; and (v) punawi/fern. Stems greater than 1.5m in height were counted in each transect. The average number of stems from the transects sampled within each area was calculated, and then divided by the average transect size for that area. The index was expressed as "stems m^{-2}" to account for the different average transect sizes.

Selection of chicks for harvest

Chicks harvested by one muttonbirder were weighed after having their stomach contents expelled and their % down covering estimated (50 chicks per night for seven nights) during the 1995 rama. Very few chicks had food remaining in their stomachs by the time (27 April) the first weights were obtained. Chick weights were measured using 2 kg Pesola scales (10g increments). The percentage down cover on chicks was estimated in 10% increments from 0% (no down) to 100% (fully covered in down). Chicks that were caught by the muttonbirder then discarded were also weighed and their down cover estimated. The discarded chicks are referred to as *kiaka* (skinny chicks).

The weights and % down of chicks encountered and then released by research staff moving randomly around the island were recorded on the same nights as samples of harvested chicks.

Results

Burrow density on Poutama

From the burrowscope survey it was estimated 2.3% and 2.6% of burrow systems had two entrances in 1994 and 1995 respectively. The average burrow entrance density estimate (± 95% C.I.) from circular plots on Poutama was significantly higher in 1994 (0.45 ± 0.03 burrows m^{-2}), than in 1995 (0.41 ± 0.03 burrows m^{-2} - Paired t-value = 3.47; d.f. = 79; P = 0.0008). Standard parametric procedure was used to determine 95% Confidence Intervals because transformation and non-parametric Wilcoxon Signed Rank Confidence Intervals did not improve normality or final interval estimates. There was also considerable variation between individual circular plots around the island in 1994 (C.V. = 33.5%; range = 0.08 to 0.86 burrows m^{-2}) and 1995 (C.V. = 34.4%; range = 0.08 to 0.78 burrows m^{-2}).

A marginally higher burrow entrance density of 0.45 ± 0.04 m^{-2} was measured using transect sampling during 1995. The coefficient of variation between individual transects was only 30.6% (range = 0.22 to 0.84 burrows m^{-2}), although only 38 were sampled compared with 80 circular plots. A Levene's Test of Homogeneity did not detect any significant difference in the variance between the plot and transect sampling methods (F = 0.041; d.f. = 1, 117; P = 0.8408).

In 1994 and 1995 there were 1.42 and 1.38 more burrows than burrow entrances on Poutama respectively (Table 1). Average burrow density (± 95% C.I.) using the circular plot method was 0.65 ± 0.05 m^{-2} in 1994 and 0.56 ± 0.04 m^{-2} in 1995. Burrow density was estimated to be 0.60 ± 0.05 m^{-2} in 1995 using the transect plot.

Burrow occupancy estimates on Poutama

The average percentage of burrows occupied on Poutama in 1994 and 1995 were estimated prior to the harvest using a burrowscope and during the harvest using muttonbirder strike rates (Table 1). A binomial procedure was used to determine 95% Confidence Intervals for burrow occupancy estimates. Average burrow occupancy estimates increased between the two years by 5% using the burrowscope and 4.5% using the muttonbirder strike rate technique (Table 1).

Percentage of chicks harvested

Even though the total usable burrow number was less in 1995, a higher burrow occupancy (Table 1) meant a greater number of chicks were available for harvest (Table 2). The percentage of chicks harvested on Poutama was higher in 1995 most probably because of the greater number of muttonbirders present. In 1994 four muttonbirders harvested during the nanao and 11 during the rama. In 1995 five were catching in the nanao and 13 in the rama. On average each muttonbirder was estimated to catch 2.6% of the chick population on Poutama per year. The four muttonbirders harvesting during the 1994 nanao were responsible for harvesting 4.7% of the chicks available (27.9% of the harvest for that year), while in 1995 the five muttonbirders took 5.6% of available chicks (which represented 24.7% of the harvest for that year) during the nanao.

The technique of sampling chick numbers down burrows before and after the nanao suggested 42% and 32% of the chicks were harvested during this period in 1994 and 1995 respectively (Table 1).

The average number of chicks caught in 1994 (mean = 1965 chicks; S.E. = 416, n = 8 muttonbirders) and 1995 (mean = 2762 chicks; S.E. = 509; n = 8 muttonbirders) by each muttonbirder were not significantly different (Unpaired *t*-value = -1.21; d.f. = 14; P = 0.246). Muttonbirders caught an estimated 16.9% of chicks on the island in 1994 and 22.6% in 1995 (Table 2). There was also close agreement in the estimates of the "percentage of chicks harvested" between transect and circular plot sampling methods in 1995 (Table 2).

Selectivity of areas during the nanao

Three muttonbirders between them worked on average 7.1 days (SE = 1.1; n = 16 areas; range = 1-14) in each area during the 1994 nanao (Figure 2). A highly significant difference was found in the number of days the muttonbirders worked in each area (χ^2 = 45.1; d.f. =15; P = 0.0001).

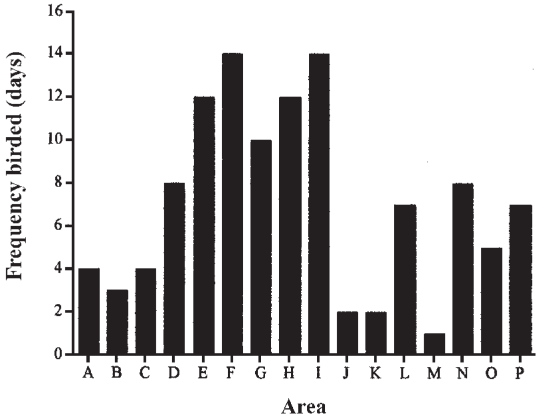

Figure 2. The frequency at which three birders worked in each area during the 1994 nanao on Poutama.

A Principal Components Analysis (PCA) was conducted with six independent variables - (i) slope, (ii) moisture content, (iii) bare ground/grass, (iv) fallen stems, (v) punawi/fern, and (vi) stems m^{-2} in an attempt to better explain "harvest frequency" (Table 3). Non-normality of variables scores required the data to be standardized [(score - μ)/σ] before analysis. Three principal components which had eigenvalues > 1 and a cumulative score of 0.854 were modelled. However, only one component grouping was significant when regressed as a predictor for "harvest frequency".

Table 3. Average "area characteristic" estimates collected from the 38 transects sampled in the 16 survey areas on Poutama in 1995.

Area	Harvest Freq.	Chick Density (chicks m^{-2})	Slope (^{o})	Moisture Index	% Fallen Stems	% Fern & Punawi	% Bare Ground & Grass	Stems m^{-2}
A	4	0.09	65	2.00	8.50	4.50	84.50	0.24
B	3	0.14	53	3.00	3.00	42.50	54.50	0.36
C	4	0.08	25	1.50	6.50	25.50	67.50	0.82
D	8	0.10	30	2.50	6.00	3.50	90.50	0.73
E	12	0.24	30	2.00	1.00	0.00	99.00	0.73
F	14	0.17	8	1.50	3.00	0.00	92.00	0.40
G	10	0.15	33	2.00	1.50	6.25	87.25	0.28
H	12	0.13	17	2.00	1.50	36.50	61.00	0.91
I	14	0.17	20	1.00	1.00	0.00	98.50	0.32
J	2	0.11	29	1.75	2.50	20.50	74.50	0.30
K	2	0.10	15	1.50	5.50	6.00	88.00	1.43
L	7	0.13	38	1.00	5.00	0.00	94.50	0.68
M	1	0.14	20	1.50	10.00	1.50	88.00	0.54
N	8	0.13	32	1.75	3.25	0.00	96.00	0.29
O	5	0.15	10	1.50	3.50	0.00	95.00	0.20
P	7	0.15	9	1.50	2.00	0.00	98.00	0.31

Table 4. Regressions using fallen stems and chick density to predict the harvest intensity frequency within areas during the nanao on Poutama, 1995. Chicks ≤ 750g are excluded.

Predictor	Coefficient	SD	*t*-ratio	*P*-value
Constant	11.21	1.56	7.17	0.000
Fallen Stems	-1.04	0.33	-3.17	0.007
Constant	-2.16	3.39	-0.64	0.535
Chick Density	67.65	24.01	2.82	0.014

A greater proportion (0.834) of this grouping was attributed to fallen stems. When modelled with chick density in a multiple regression none of the principle components were significant and only 43% of the variation was explained. Therefore, the PCA procedure was abandoned for the simpler standard regression model.

Fallen stems and chick density were significant predictors of "harvest frequency" in each area explaining 42% and 36% of variation respectively (Table 4). Muttonbirders targeted areas with lower fallen stem density and higher chick density.

Selection of chicks by muttonbirders

The maximum weight of chicks discarded by the muttonbirder was 750 g so this was used as a cut-off point for defining harvestable chicks. No chicks were kept for consumption less than this weight by the one muttonbirder monitored (Figure 3). Of the 371 randomly encountered chicks in 1995, 12.9% weighed less than 750 g. If this percentage of the chick population was not considered for harvest, then only 85 307 chicks would have been potentially at a harvestable standard in 1995. Therefore, 25.9% (21.1-32.5%) of the chick population, rather than 22.6% (18.4-28.3%), would have been harvested in 1995.

The distribution of chick weights (> 750g) were significantly dependent on whether they were harvested or randomly encountered ($\chi^2 = 46.3$; d.f. = 7; $P < 0.0001$ - Figure 3). Only 8.9% (n = 350 chicks) of harvested chicks were in the 750 g to 899 g weight range, while 27.2% (n = 323 chicks) of randomly encountered chicks were in this lower weight category. This left 91.1% of harvested chicks in the mid and upper weight ranges (900 g-1499 g), compared with 72.8% of randomly encountered chicks. The average weight of harvested chicks was 1037 g (S.E. = 6 g; n =350) compared with 986 g (SE = 7 g; n = 323) for randomly encountered chicks (excluding those ≤ 750 g). The difference between the means is highly significant (Unpaired *t*-value = -5.57; d.f. = 671; $P = 0.0001$).

The rama was divided into three stages (i) "early" - 27 April to 30 April; (ii) "mid" - 1 May to 5 May; and (iii) "late" - 6 May to 15 May. The 27 April was the first day harvested chick weights were collected, so weights from randomly caught and released chicks were used starting from this date as well. A two-factor Anova indicated a significant difference between randomly encountered and harvested chick weights ($F = 27.4$; d.f. = 1, 667; $P = 0.0001$), but not between stages in the rama ($F = 1.01$; d.f. = 2, 667; $P = 0.363$) nor in the interaction between the two ($F = 1.57$; d.f. = 2, 667; $P = 0.209$) (Table 5).

The distribution of % down on chicks was also shown to be significantly dependent on whether they were harvested or randomly encountered ($\chi^2 = 66.2$; df = 10; $P < 0.0001$) (Figure 4). Collectively 69.7% of harvested chicks had percentage down estimates of between 0% and 50%, compared with 43.3% of randomly encountered chicks. As before all chicks less than 750 g were excluded from this analysis.

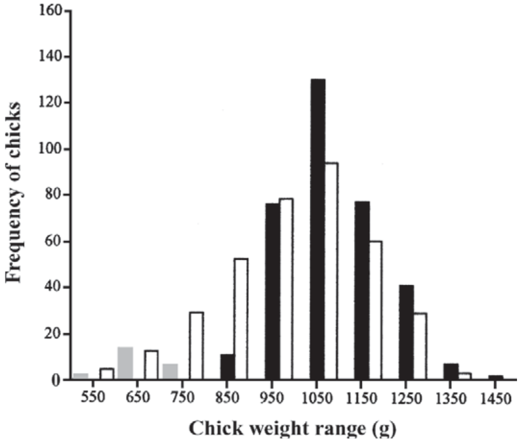

Figure 3. Frequency distribution of harvested (black bars), randomly encountered (white bars) and kiaka chicks (stippled bars) from the 1995 rama in their respective weight classes. Each bar represents the frequency of chicks between 451-550, 551-650g etc.

Table 5. Average weights (± SE) of randomly encountered and harvested chicks from the early, mid and late stages of the 1995 rama on Poutama. Note: harvested chicks were weighed after having stomach contents expelled.

Capture Method	Stages within the rama		
	Early stage weights (g)	Mid stage weights (g)	Late stage weights (g)
Randomly caught and released chicks	1001 (± 13) (n = 86)	994 (± 11) (n = 106)	971 (± 11) (n = 131)
Harvested chicks	1029 (± 12) (n = 100)	1044 (± 11) (n = 100)	1038 (± 9) (n = 150)

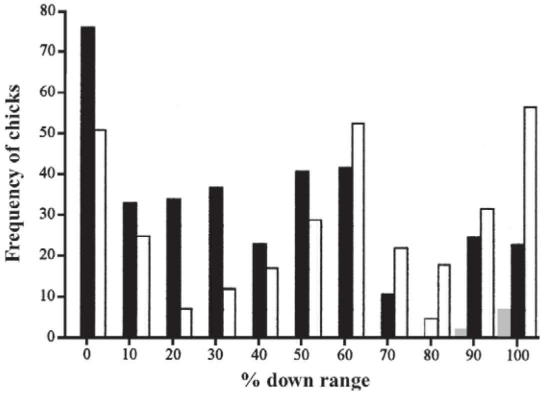

Figure 4. Frequency distribution of harvested (black bars), randomly encountered (white bars) and kiaka chicks (stippled bars) from the 1995 rama in their respective percentage down categories.

Discussion

Burrow density and occupation

The estimated number of burrow entrances was similar for the two sampling techniques (plot and transect) used in 1995 (confidence intervals overlapped considerably). However, the greater coverage of areas using the 80 circular plots would be expected to give a more reliable estimate and a greater range of densities.

Burrow occupancies from both years on Poutama were lower than the pre-harvest range of 35-49% for short-tailed shearwaters for two harvested islands in Tasmania (Skira and Wapstra, 1980). However, they were more comparable with the 26-41% range of wedge-tailed shearwater (*Puffinus pacificus*) burrow occupancy estimates (Floyd and Swanson, 1983).

Using the plot sampling method it was estimated that 213 129 and 151 979 burrows lacked chicks on Poutama in 1994 and 1995 respectively. These numbers are minima because they do not include burrows of "unknown" occupancy. It was not possible to tell whether 21% and 25% of burrows in 1994 and 1995 respectively had chicks present or not.

The number of unoccupied burrows suggests that density dependence may not be a factor affecting breeding on Poutama, unless a major early season breeding failure occurred. Burrow occupancy would need to be assessed earlier in the season to confirm this hypothesis. Muttonbirders have reported a decreasing density of usable burrow entrances in recent decades i.e., more burrow entrances are becoming filled in (Birders A and B, *pers. comm.*). In past years during the nanao muttonbirders would crawl or roll to the next burrow entrance because of their close proximity of entrances to each other (Birders A, B and C, *pers. comm.*). More recently muttonbirders report having to stand to find the next burrow, which suggests density may be decreasing and lack of space is not a limiting factor of breeding.

Both burrowscope and muttonbirder strike rate estimates increased by similar amounts between 1994 and 1995. This indicates that monitoring harvest rate during the nanao could provide an accurate index of chick occupancy and population trends. Burrow occupancy estimates obtained using a burrowscope are likely to be most reliable because all usable burrows in a survey area and all areas of the island are assessed. However, a small scale sooty shearwater burrow excavation experiment showed that the burrowscope failed to detect 14% of the eggs present and 6% of young chicks (Hamilton, *et al.* 1997). The experiment was conducted on the Snares which is believed to have extremely complex burrow systems (e.g. one area had over 35 burrow entrances connected together). In contrast, the percentage of successful strikes by muttonbirders may be an over-estimate because burrows are generally only prospected if they are thought to contain a chick. It is not known if muttonbirders can reliably identify occupied *vs.* unoccupied burrows. However, analysis showed that muttonbirders target areas of the island where the density of chicks is higher (Table 4). Stomach contents from chicks are expelled into burrow entrances when they are caught. This sign is used by other muttonbirders to avoid burrows from which a chick has already been taken so strike rate is not reduced by former removal of chicks by other muttonbirders.

Methods of estimating the intensity of harvest

Using a burrowscope to assess burrow occupancy before and after the nanao will have greatly over-estimated the harvest. This method suggests that 40% and 29% of the available chicks were taken in the 1994 and 1995 nanao respectively. If generalised over the entire area of Poutama it would suggest that 37 201 and 28 403 chicks were harvested over the nanao in 1994 and 1995 respectively. These totals were far greater than the total number of chicks taken by the muttonbirders (Table 2), so the method should be dismissed as unreliable. The bias may have arisen from chicks observed by the burrowscope being more accessible to muttonbirders and most likely to be harvested, or because chicks may have begun to fledge before the second burrowscope survey was completed. The proportion of chicks leaving before the 22 April (final burrowscope survey date) was thought to be minimal because 0% of chicks left Putauhinu Island before 28 April in the years between 1997 and 1999 (C. Hunter, University of Otago, Dunedin, N.Z., *unpubl. data.*).

The "pre-nanao" *vs.* "late nanao" survey method is enormously time consuming. Accordingly the simpler method of comparing harvest totals with the estimated number of chicks present each season (using the single pre-nanao survey of burrow occupancy) is recommended for future studies. Its accuracy is critically dependent on a reliable count of the total number of chicks harvested by all the muttonbirders present. It is believed harvest totals obtained from Poutama, especially in 1994, were reliable which renders the second more intensive method redundant. However, obtaining these counts at the outset of the study was not assured.

It is possible the burrowscope survey may have caused an over- or under-estimation of the number of chicks present each year. In both 1994 and 1995 a quarter of burrows surveyed were of unknown occupancy. It is possible chick occupancy could have been higher or lower in these longer more complex burrows than the average occupancy of known burrows. Also, once a chick was found the burrowscope was not pushed past it to check for other chicks further down the burrow. The burrow excavation experiment of Hamilton *et al.* (1997) confirmed these inferences that the burrowscope fails to detect some eggs (14%) and chicks (6%). In the 1994 and 1995 seasons 18% and 19% of chicks respectively were located before the end of the burrow was reached. If burrowscoping has under-estimated the occupancy of these burrows, it is possible there could have been an even greater number of chicks present than suggested by my calculations.

Harvest intensity

No management limits are placed on the harvest, so the levels of cropping depends on the number of chicks available to muttonbirders, their harvest rate and effort, and the number of people catching. The greater number of chicks harvested in 1995 may have been directly related to the increase in muttonbirders harvesting on Poutama that year. One additional muttonbirder during the nanao and two during the rama increased the overall percentage of chicks harvested by 5.7%. Averaged over all the muttonbirders on Poutama, the expected harvest increase would have been 3.8% for these three additional muttonbirders. However, the additional muttonbirders were considered very experienced and harvest intensity could have increased by 5.7% because of their presence in 1995.

Shearwaters are generally more resilient to exploitation because of their large populations (Skira and Wapstra, 1980). However, muttonbirders on Poutama and other islands have noticed a decline in harvests over the years. Harvest rates (chicks caught per day) on Poutama have decreased by half between 1989 and 1998 (Lyver *et al.*, 1999). A similar decline in chick occupancy was observed between 1986 and 1996 on the nearby unharvested island of Whenua Hou (Codfish Island) (Lyver *et al.*, 1999.). It is possible predation by kiore (*Rattus exulans*[3]) may have contributed to the decline in burrow occupancy on Whenua Hou. However, this does not explain the similar decline in harvests on the predator-free island of Poutama. It is thought therefore that outside influences such as climatic perturbations could be affecting the sooty shearwater breeding population by reducing adult survival and that harvest alone is not a sufficient explanation for the decline. Large scale events such as climatic perturbations have been suggested as a possible cause for the decrease in harvests (Lyver *et al.*, 1999).

Selectivity of areas for harvest

Areas of higher chick density around Poutama were significantly more likely to be targeted for harvest by muttonbirders in the nanao than areas of low chick density. This indicates that muttonbirders have developed knowledge of the areas where they will get the best return for their efforts. From 45 years of experience, one muttonbirder on Poutama knew which areas produced the best chick yields at particular times of the nanao. Muttonbirders describe the island as being "patchy", with areas renowned for producing good numbers of chicks while others continually produce fewer or smaller chicks. One flatter interior region on Poutama is historically known as *manu kiaka* (a birding area where chicks are skinny - Birders B and F, *pers. comm.*).

Areas which had a higher proportion of fallen branches or trees were generally avoided by muttonbirders or targeted less frequently during the nanao. Areas where you have to continually climb over and through branches to find, reach into burrows and then recover the birds are much more difficult to harvest in than clear areas. Thickly vegetated areas are generally left to last, and are used once the productive available clear ground has been covered. In "good" years these areas of rough ground may not even be harvested (Birder B, *pers. comm.*). In 1994, which was perceived as a season with low chick numbers, almost all areas of the island were harvested, although at varying intensity.

The areas with thick and fallen vegetation may be acting as "chick reservoirs" for the sooty shearwater population on Poutama. If these areas are not being harvested as intensively as others, a chick's chance for survival may be higher than those from elsewhere on the island. Muttonbirders report that towards the end of the season there is sometimes "a flurry of chicks from

[3]Nomenclature of mammals follows King (1990).

the thick" (Birders A, B, C and D, *pers. comm.*). This is when large numbers of chicks emerge from these thickly vegetated areas on the island at one time and head towards the island's edge to take-off.

Selectivity of chick characteristics

Muttonbirders caught larger and developmentally more advanced chicks than a random selection during the rama. Chicks harvested had already been "spewed" (stomach contents forcibly expelled by the muttonbirders) by the time they were weighed, although at this time of the season chicks have comparatively less stomach contents. Nevertheless, the increased weight of harvested compared with random caught and released chicks would have been even greater than suggested by the data in Table 5.

Rejection and release of chicks less than 750 g means that the number available for harvest is actually less than what is indicated by the burrowscope survey. These smaller chicks probably have a much lower chance of survival (Sagar and Horning, 1998). Even if chicks smaller than 750 g are not considered for harvest the estimated proportion removed (25.9%) was still well below the approximate 37.5% maximum sustainable yield proposed for short-tailed shearwaters (Skira *et al.*, 1985). It is recognised however that more baseline breeding data (burrow occupancy) are required before a MSY could be estimated particularly for Poutama.

In poor growth years the percentage of chicks below 750 g would increase, reducing the number available to muttonbirders for harvest. In these years muttonbirders could be catching a much higher percentage of the larger chick population that has potential to survive and return to breed. Years with larger and heavier (fatter) chicks are also years with larger harvests of chicks (P.O'B. Lyver, *unpubl.*). In poor seasons muttonbirders may also increase their take of smaller chicks. Muttonbirders report the number of chicks that can be fitted into the standard 10 litre bucket, increases in "poor" years relative to "normal" or "good" years (Birder A, B and C, *pers. comm.*).

Muttonbirders succeed in selecting above average-sized and advanced chicks by targeting areas of the island where they have traditionally caught good quality chicks, or times when larger chicks emerge such as in windy or wet conditions (P.O'B. Lyver, *unpubl.*). Birders from the Outer Hebridean Isle of Lewis harvesting on the island of Sula Sgeir select "guga" [gannet (*Sula bassana*) chicks] for harvest on the basis of their down coverage (Beatty, 1992). The favoured "guga" or "tre-tim" (three tufts) is identified by down tufts on its head, back and legs. They are selected because of their optimum quantity of meat and ease of capture (Beatty, 1992). Rakiura muttonbirders assess a chick by it's size, it's behaviour or reaction to their approach, the thickness of it's neck or whether the sternum bone can be felt protruding (Birders A, B and F, *pers. comm.*). Kiaka chicks are often less responsive to a muttonbirders approach, have very thin necks and their sternum protrudes because of poor subcutaneous fat and muscle development.

Birder B reported that in some years there is differential emergence behaviour of chicks based on their condition (i.e. weight). Birder B believed chicks emerging earlier in the rama were generally lighter and needed to fledge in order to feed and maintain condition. Muttonbirders also reported to Richdale (1954) that fledglings were lighter at the start of the rama than those caught later in the season. However, no significant difference could be detected in the weight-related emergence behaviour of chicks in 1995. Nevertheless, if such differential behaviour does occur the "random" selection of emerged chicks presented in Figures 3 and 4 may differ from the distributions of weight and % down of all chicks present on the island (including emerged and non-emerged chicks).

Whatever, the mechanism of selectivity, higher proportionate harvest of larger and more advanced chicks is potentially very important for modeling population impacts of harvest. Larger sooty shearwater chicks were more likely to return to breed on The Snares (Sagar and Horning, 1998). A simple demographic model using only the number of chicks harvested is likely to be inadequate. We are is now pursuing the formulation of a demographic predictive model that incorporates quality measures of chicks harvested and escaping harvest.

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