EXPLOITATION BY RATS *RATTUS* OF EGGS NEGLECTED BY GADFLY PETRELS *PTERODROMA*

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ABSTRACT

Greatwinged Petrels *Pterodroma macroptera*, incubating in the presence of Norway Rats *Rattus norvegicus*, and Cook's Petrels *P. cookii* and Black Petrels *Procellaria parkinsoni*, incubating in the presence of Polynesian Rats *R. exulans*, were studied at islands off New Zealand to determine the effect of rats on hatching success. Only unattended eggs were eaten by rats. Egg neglect by Black Petrels was rare but gadfly petrels left their egg unattended more freqently. Early in incubation more unattended eggs survived uneaten, and for significantly longer periods, than they did late in incubation, suggesting that rats learn to find and eat neglected eggs. In some years eggs of these gadfly petrels are especially vulnerable to rats at the third incubation change-over.

INTRODUCTION

All three species of rat *Rattus* that have spread to islands through human association - Norway *R. norvegicus*, Ship *R. rattus* and Polynesian *R. exulans* - prey upon petrel eggs and chicks (Murphy 1936, Bailey & Sorensen 1962, Kepler 1967, Harris 1970, Merton 1970, Norman 1970, Woodward 1972, Mougin 1975, Imber 1975, 1976, 1978, Atkinson 1978, in press, Grant *et al.* 1981). Rats have opportunities to take eggs because procellariids sometimes leave eggs unattended (Matthews 1954, Imber 1976, Grant *et al.* 1981), though not as frequently as do stormpetrels (Boersma & Wheelwright 1979). In the absence of rats, embryos often survive the chilling that results from neglect. Rats also kill young chicks, particularly soon after the guard stage which lasts only 0,5 to 3 days in many burrowing procellariids (Mougin 1975, Imber 1976). It is this latter aspect of rat predation which is most damaging to petrel populations (Harris 1970, Mougin 1975, Imber 1978).

Ultimately, rats are believed to have caused the extinctions or great reductions of the populations of petrels breeding at, for example, Tristan da Cunha and South Georgia (Murphy 1936), Campbell Island (Bailey & Sorensen 1962), Possession Island in the Crozet Group (Mougin 1975), and some northern offshore islands of New Zealand (Atkinson 1978). However, the evidence for these effects has been largely circumstantial, as in the demonstration that islands invaded by Polynesian Rats (in most cases some centuries ago) now lack or have few Whitefaced Stormpetrels *Pelagodroma marina*, Common Divingpetrels *Pelecanoides urinatrix* and Fairy Prions *Pachyptila turtur* (Atkinson 1978). It was consideration of the present distribution of rats and petrels in New Zealand that led me to conclude (Imber 1975) that a breeding population of a petrel would be endangered if exposed to a rat whose maximum body mass equals or exceeds the petrel's mean body mass.

In this paper I examine predation on eggs of two species of gadfly petrel *Pterodroma* spp. by Norway and Polynesian Rats at islands off New Zealand, and compare the findings with those obtained by Grant *et al.* (1981) who studied the effects of predation by Ship Rats on eggs of another gadfly petrel.

METHODS

I studied the winter breeding of Greatwinged Petrels *Pterodroma macroptera* at Whale Island (37 52S, 176 58E) from April 1969 to December 1972, and subsequently monitored breeding success annually to 1981, except in 1979. Norway Rats invaded Whale Island possibly early this century when rock was being taken by barge from the island to the adjacent mainland (C. Orchard pers. comm.). From November 1971 to March 1975 I studied Cook's Petrels *P. cookii* and Black Petrels *Procellaria parkinsoni*, summer breeders at Little Barrier Island (36 12S, 175 04E). The Polynesian Rat presumably arrived there about the time of Polynesian colonization, over 500 years ago (Hamilton 1961). Populations of both gadfly petrels numbered 10 000 - 100 000 pairs but there were only 200 - 300 pairs of Black Petrels. These estimates were made from sample burrow counts during the breeding studies.

The normal adult masses of rat species discussed here are: Polynesian Rat up to 120 g, Ship Rat up to 200 g, and Norway Rat up to 450 g (Atkinson 1978). The average adult masses of petrels mentioned in the text, in ascending order, are: Whitefaced Stormpetrel 44 g, Fairy Prion 115 g, Common Divingpetrel 136 g (pers. obs.), Bonin Petrel *Pterodroma hypoleuca* 180 g (Fisher 1961), Cook's Petrel 192 g, Greatwinged Petrel 533 g and Black Petrel 690 g (pers. obs.).

In the years 1969-71 I studied 108, 92, and 87 pairs respectively of Greatwinged Petrels during incubation. From 1971 to 1973 I observed 45 pairs of Cook's Petrels each year but study of their incubation in 1971 was very brief. In 1972 and 1973 I studied 16 and 11 pairs respectively of Black Petrels.

I prepared burrows for study before laying began by digging observation shafts to the nest chambers and covering the shaft entrances with slabs of rock. Birds were sexed by cloacal examination soon after laying, and colour-ringed for sex identification. I observed incubating birds and nest contents daily over intermittent study periods of two to three weeks. To minimize disturbances of incubating birds, burrow entrances were routinely screened with leaves or twigs. However, some desertions of eggs were caused by handling of incubating birds. Such eggs were included in comparisons of predation rates through the incubation period. In this paper the terms "unattended" and "neglected" are synonymous and imply a temporary state of affairs.

Rat predation of an egg was determined by finding its shell with the characteristic opening in the side (Fig. 1). Usually the shell was still in the nest chamber but Norway Rats often carried, or rolled, the egg along the burrow or outside. Unless the rat was interrupted at its meal by a returning petrel, the entire egg contents were eaten between one day's observation and the next day's. Rarely a petrel returning to find its egg partially-eaten attempted to resume incubation.

Where I considered that handling a petrel had caused its desertion, the departure usually occurred the night immediately after first handling, the petrel was heavy enough to incubate longer and was not relieved by its mate or displaced by a competitor for that burrow. Intraspecific competition was a factor to be considered in the neglect of an egg when more than two birds were known to be using the same nest. Possible immaturity (of the male only) may have caused some egg neglect. In such cases, the male would visit the burrow at nights, or sometimes for a day or two, but would not incubate the egg.

RESULTS

Intermittently throughout incubation eggs were left unattended, and rats preyed only upon such eggs. Whereas eggs of Black Petrels were rarely unattended, neglect by gadfly petrels was more common (Table 1). The main cause of neglect (Table 2) was failure of the relieving bird to arrive before the incubating partner was forced to return to sea to feed, because its mass was becoming critically low (Imber 1976). Feeding difficulties presumably caused this, affecting either the time of the relieving bird's arrival, or its condition, or both. Although egg-neglect occurred throughout incubation, Greatwinged Petrels suffered this problem mainly at the first relief after egglaying, and Cook's Petrels at the third relief in the years studied (Table 2). Both species complete most of their incubation periods (Greatwinged Petrel, 55 days; Cook's Petrel, 49 days; pers. obs.) in three long shifts.

Both in terms of the proportion of eggs eaten, and the number of

TABLE 1

PROPORTION OF THE INCUBATION TIME DURING WHICH EGGS WERE LEFT UNATTENDED BY GREATWINGED PETRELS AT WHALE ISLAND IN THREE YEARS, AND BY COOK'S AND BLACK PETRELS AT LITTLE BARRIER ISLAND IN TWO YEARS. EGGS NEGLECTED BECAUSE OF DISTURBANCE CAUSED BY THE OBSERVER ARE EXCLUDED. EGG-DAYS = NUMBER OF EGGS STUDIED X NUMBER OF DAYS OF OBSERVATIONS

Species	Year	Eggs observed		Eggs neglected		Percent of days neglected
		No.	Egg-days	No.	Egg-days	
Greatwinged Petrel *P. macroptera*	1969	106	978	8	29	3,0
	1970	71	1 335	13	67	5,0
	1971	61	1 063	17	107	10,1
Cook's Petrel *P. cookii*	1972	35	376	3	5	1,3
	1973	36	332	13	27	8,1
Black Petrel *Procellaria parkinsoni*	1972	8	76	1	5	6,6
	1973	8	62	0	0	0

TABLE 2

CAUSES OF EGG NEGLECT BY GREATWINGED PETRELS AT WHALE ISLAND, AND BY COOK'S AND BLACK PETRELS AT LITTLE BARRIER ISLAND

Species	Greatwinged Petrel	Cook's Petrel	Black Petrel
No. of eggs observed	257	72	16
No. of eggs neglected	57	17	1
No. neglected because of:			
discontinuity at first change-over	15	1	-
discontinuity at second change-over	5	-	-
discontinuity at third change-over	3	12	-
possible immaturity of male	2	-	1
death or disappearance of mate	3	1	-
intra-specific competition	8	1	-
flooding of nest after rain	2	1	-
disturbance of observer	19	1	-

TABLE 4

SURVIVAL OF EMBRYOS IN GREATWINGED AND COOK'S PETREL EGGS LEFT UNATTENDED FOR VARYING PERIODS DURING INCUBATION

No. of days unattended	Petrel species	Days of incubation	No. of embryos	Pecent surviving
up to 2	Greatwinged	6 to 52	3	100
	Cook's	6 to 35	3	100
6 to 9	Greatwinged	10 to 26	3	0
5 to 6	Greatwinged	43 to 55	2	100

days of neglect per predation, rats took more eggs more quickly late in incubation (Table 3).

In 1973, approximately 30 % of Cook's Petrel eggs in study burrows were left unattended at the third incubation changeover. Though periods of neglect were mainly only a day or two, all eggs I saw unattended were eaten by rats. In the most abrupt case of predation, the egg was regularly attended during the day but the female, whose mass became critically low, evidently left before, but the same night as, the male returned, the egg being partly eaten in the intervening period. Many incubating females were decreasing to critically low masses by the time of relief. Five females weighed just before leaving their egg unattended (156 - 185 g, mean 173 g) were the lightest of any group of adults weighed during my study. The mean mass of 11 females during courtship was 187 g (range 175 - 208 g), and of 16 females that had just laid it was 202 g (range 180 - 214 g). Similar minimal masses were recorded for female Greatwinged Petrels leaving eggs unattended (Imber 1976).

During my three-year intensive study of Greatwinged Petrels, breeding success (chicks fledged per eggs laid) ranged from c. 20-35 % and neglect of eggs was infrequent (Table 1). However, breeding success decreased considerably in later years. In 1972, 1975 and 1981, when 0-10 % of breeding pairs reared chicks, I found evidence of high rates of predation of eggs. Examination of shells of rat-eaten eggs showed very well developed air-sacs in most, indicating that predation had occurred when incubation was well advanced, and most likely at the third incubation changeover.

I also examined the survival rates of embryos in eggs left unattended that were not eaten by rats (Table 4). Data were very limited but showed that embryos survived chilling for one or two days at any stage of incubation. However, embryos chilled for five or more days survived only late in incubation. The data were inadequate to show effects of chilling for three to five days in the earlier part of incubation, or the stage at which embryos could survive five or more days' chilling. Apparently resistance to chilling increases through incubation, as may happen with Manx Shearwater *Puffinus puffinus* embryos (Matthews 1954).

DISCUSSION

There could be three explanations for the increasing rate of egg predation by rats through the incubation season:

(1) rats were learning that petrel eggs were becoming available as a potential food source, and were learning to eat them;

TABLE 3

PREDATION RATE (PROPORTION OF EGGS EATEN BY RATS AND NUMBER OF DAYS' NEGLECT PER PREDATION) FOR GREATWINGED AND COOK'S PETREL EGGS EARLY AND LATE IN INCUBATION. EGGS NEGLECTED BECAUSE OF DISTURBANCE OF SOME INCUBATING BIRDS BY THE OBSERVER ARE INCLUDED

Species	Period	No. of eggs neglected	Total days' neglect	Rat-eaten No.	Rat-eaten %	Days of neglect per predation
Greatwinged Petrel	22 June to 15 July	29	89	12	41,4	7,4
					1	3
	16 July to 6 September	13	30	10	76,9	3,0
Cook's Petrel	31 October to 12 November	7	16	1	14,4	16,0
					2	4
	1 December to 22 December	13	14	11	84,6	1,3

1 X^2 = 4,546, P <0.05 3 X^2 = 5,867, P <0.05

2 X^2 = 6,676, P <0.01 4 X^2 = 13,398. P <0.001

(2) rat populations were increasing during incubation, thus increasing the demand for food;

(3) alternative food supplies were diminishing during incubation, thus increasng the demand for eggs.

In the wild, the annual mortality of Ship Rats in New Zealand has been found to exceed 90 % (Daniel 1978). Assuming a similar rate for other species, most rats at Whale and Little Barrier Islands are likely to be exposed to petrel eggs during only one incubation season. Neither island has large populations of other ground-nesting birds that may leave their eggs unattended. On Whale Island only a few hundred pairs of Sooty Shearwaters *Puffinus griseus* breed in summer in small, scattered colonies. On Little Barrier Island, because of feral cat predation, there are now no winter-breeding petrels. Therefore, each year a new generation of rats must learn that eggs are laid in petrel burrows, that petrels do not permanently cover the eggs and that eggs are edible once the shell is broken. As incubation progresses, rats apparently learn to visit regularly most petrel burrows in their territories. Evidence that rats may not know instinctively that eggs are edible is provided by one instance where a female Greatwinged Petrel died at laying. Norway Rats completely scavenged her carcass but her egg lay unattended but intact for eight days, after which her mate began incubation.

It seems improbable that rat populations were increasing during the incubation season of either Greatwinged or Cook's Petrels. At Whale Island, Bettesworth (1972) found none of 46 female rats pregnant in May 1971, and only one of 34 pregnant in July. Therefore it is more likely that the rat population was static or decreasing at Whale Island when the petrels were incubating. Though few data are available on breeding of rats at Little Barrier Island, pregnant Polynesian Rats were trapped on a nearby island only from November to February (Craig & Moller 1978), so the annual rat population increase should not occur until after incubation by Cook's Petrels.

Less is known about variation in the food for these omnivorous rodents. Incubation by Greatwinged Petrels takes place from winter to early spring, and by Cook's Petrels from late spring to summer. In a warm temperate climate the food supply for these rats seems unlikely to be decreasing at such seasons. Therefore, I conclude that the increasing rate of predation on petrel eggs by rats through incubation can best be explained by learning.

Grant *et al.* (1981) suspected that some Ship Rats were learning not only to eat Bonin Petrel eggs but also to take attended eggs. However, one aspect of their study that differs from mine is that the difference in mass between rats and petrels is least at Midway Atoll (see above). Thus Ship Rats may be able to intimidate Bonin Petrels into exposing their eggs.

Grant *et al.* (1981) suggested that, since most petrels incubated with their tail towards the nest chamber entrance, rats might be able to startle them and take their egg before they had turned around. However, petrels sleep most of the time while incubating with head tucked into the scapulars, and are actually facing the chamber entrance (pers. obs.). Thus they have merely to open their eyes to see anything entering the nest chamber, which I have seen them do when I checked their nests. Furthermore, even if they were startled by a rat, they are quite capable of pivoting on the nest to face an enemy whilst continuing to cover the egg, which is well tucked into the "brood pouch". I see little prospect of a rat getting an attended egg other than by menacing the petrel itself.

An alternative explanation for some of the high egg loss witnessed by Grant *et al.* (1981) is that egg neglect by Bonin Petrels occurred more frequently than they were able to discover because rats were taking eggs promptly after desertion. Bonin Petrels are winter-breeders. It is possible that many rats on Midway Atoll had already learned to take eggs from summer-breeders, such as Wedgetailed Shearwaters *Puffinus pacificus* which are abundant there (Grant *et al.* 1983). Thus the initial learning period I observed may have been absent during the Midway Atoll study.

Egg neglect by Greatwinged and Cook's Petrels is most likely to occur during two periods. The first is during the first 20 days after laying, when all of the natural causes of neglect listed in Table 2 operate, except discontinuity of incubation at the second and third change-overs. The second period is at the third change-over, about two-thirds through incubation. Before incubation begins male and female have been at sea continuously for about two months in the case of Greatwinged Petrels (Imber 1976), or for one month in the case of Cook's Petrels (pers. obs.). Normally the female incubates for only three to four days after laying before the male takes over, and she leaves to feed while still above average mass. The male carries out the first of the three main incubation shifts which have an average duration of 17 days for Greatwinged Petrels and 14 days for Cook's Petrels (pers. obs.). The female is usually able to gain enough mass during the male's first incubation shift to accomplish her single main shift. Problems arise in some years, presumably because of feeding difficulties, when the male, having decreased to an average or lesser mass during his first shift, is unable to gain mass fast enough during the female's shift to return in time to relieve her. The female is obliged to leave the egg when her mass becomes critically low. Where rats are present, therefore, this is a particularly vulnerable stage in the incubation routine of these gadfly petrels.

It is unfortunate for the petrels that learning by rats leads to increased egg predation as incubation progresses. Since most eggs left unattended for more than two days early in incubation seem less likely to hatch, rats eating such eggs may do no harm, and perhaps even some good, in relieving pairs of unnecessary incubation efforts. Resistance to chilling of older embryos, which is of greatest value to gadfly petrels in tiding embryos over the occasional hiatus between the female's main incubation shift and the male's second shift, is made futile by rats.

With regard to the timing of control of rats in a petrel colony, there seems little advantage in controlling rats until incubation has begun. An annual, intensive application then of an anticoagulant rodenticide such as brodifacoum mixed into grain-based baits, which has proved to be very effective on Whale Island (pers. obs.), will probably protect hatchable eggs and young chicks.

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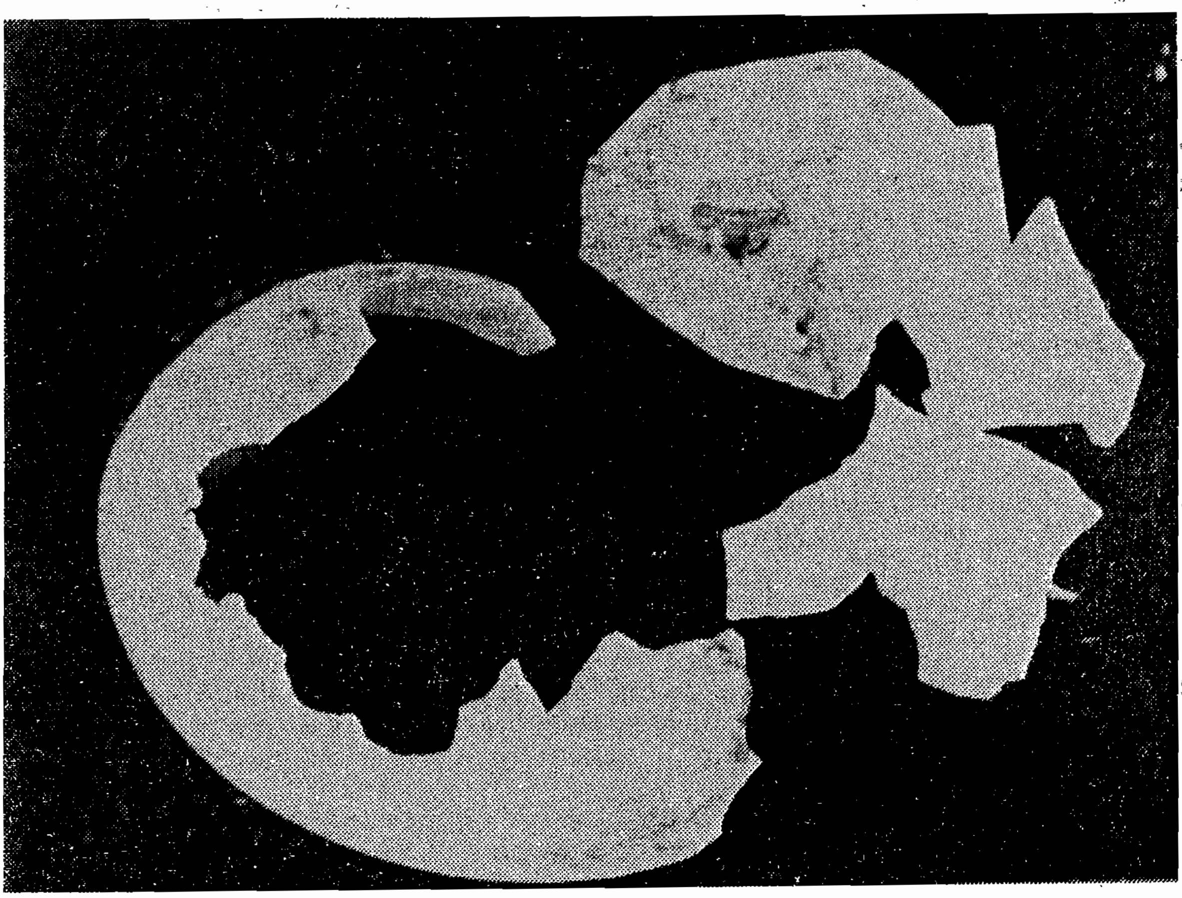

Figure 1

Shell of a Greatwinged Petrel *Pterodroma macroptera* egg eaten by Norway Rats *Rattus norvegicus* on Motuhoropapa Island, New Zealand in August 1978.

Photographed by P.J. Moors