PREDATOR IDENTIFICATION FROM BITE MARKS ON PENGUIN AND ALBATROSS CHICKS

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SUMMARY

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Ferrets *Mustela furo,* Stoats *M. erminea* and feral House Cats *Felis catus* are introduced predators in New Zealand that threaten many nesting seabirds and other native species. Fifty-one Yellow-eyed Penguin *Megadyptes antipodes* chicks, four Royal Albatross *Diomedea epomophora* chicks and one Little Penguin *Eudyptula minor* adult underwent necropsy. Four Yellow-eyed Penguin chicks, three Royal Albatross chicks and the Little Penguin had puncture holes in their skin from predator bites. Three Royal Albatross chicks also had markings on their bills that were analysed separately. Only three outlying puncture hole pairs could be matched unequivocally with the species-specific inter-canine distance of each predator species. Most bites were clustered so that separate bites could not be discerned. One Yellow-eyed Penguin chick and two Royal Albatross chicks were preyed on by Stoats, but the culprits responsible for the deaths of the other 21 dead birds could not be definitely determined. There are many logistical problems and unquantified assumptions in other methods of identifying predators and in several unquantified claims that predator identity is known. Development of better diagnostics to identify predators would help conservation management by allowing better targeting of predator trapping and poisoning efforts.

INTRODUCTION

The islands of New Zealand were free of small predatory mammals until about 1000 years ago after which time people progressively introduced rats *Rattus* spp., dogs *Canis familiaris*, House Cats *Felis catus*, and mustelids *Mustela* spp. (Anderson 1990, Atkinson & Moller 1990, Fitzgerald 1990, Innes 1990, King 1990a,b, Lavers & Clapperton 1990, Moors 1990). Some of New Zealand's endemic fauna are vulnerable to these predators because they lack predator identification or defence capacities, or have inadequate reproductive rates to counteract the added predation pressure.

Chicks of two native seabirds, the Yellow-eyed Penguin *Megadyptes antipodes* and the Royal Albatross *Diomedea epomophora*, and adults and chicks of the Little Penguin *Eudyptula minor* are killed by introduced predators (Richdale 1952, Stahel & Gales 1987, Darby & Seddon 1990, Moller *et al.* 1995). All three species occur on the mainland of New Zealand where three main species of introduced predators are common: Ferrets *Mustela furo,* Stoats *M. erminea* and feral House Cats. Stoats are more abundant than Ferrets in forests (King 1990a, Lavers & Clapperton 1990). Ferrets are limited to pastoral habitat, rough grassland and scrubland (Marshall 1963) and forest margins (Moller *et al.* 1996). Cats can live in most terrestrial habitats including pasture, scrub and native forests (Wodzicki 1950, Gibb & Flux 1973, Fitzgerald 1990).

Predator-control operations to protect the native fauna are mainly by kill-trapping but poisoning methods are under development (Alterio 1996, Alterio *et al.* 1997). Trapping is very labour intensive (Moller *et al.* 1992, 1996) and emergency trapping to halt a predation outbreak is disruptive to work routines (McKinlay 1994). Different types of traps catch different predators (Moller *et al.* 1995). If the predator species responsible for an outbreak was known, the control operations could be more efficient, the most successful trap type could be used, and the operation could be ended as soon as the target predator had been killed. A tool to identify the predator responsible would remove guess-work when there is the suspicion that a new predator species has been sighted or is suspected to have been newly introduced to offshore islands. The adult Little Penguin analysed in this study was retrieved from Stewart Island where reports of an unidentified mustelid had raised alarm. Mounting a predator eradication programme is enormously expensive and problematical. So, confirmation of the predator's identity would have been very helpful. Identification of predator species responsible may also focus research on key ecological factors to assist wildlife protection and management throughout New Zealand and elsewhere. Despite the large importance of predation as a threat to New Zealand biota there are remarkably few demonstrations of which of the introduced predators are primarily responsible (Moors 1983, Brown *et al.* 1996).

One potential method of identifying predators is from analysis of the spacings between bite marks on killed individuals. This study aimed to evaluate this technique for identifying the predator responsible for the predation of Yellow-eyed Penguin chicks, a Little Penguin adult and Royal Albatross chicks. Alternative methods of identifying predators are also briefly reviewed and their assumptions assessed.

METHODS

Necropsy

Fifty-one Yellow-eyed Penguin chicks were investigated for cause of death after they were collected from breeding areas on the Otago Peninsula (45°50'S, 170°40'E), the Catlins (46°35'S, 169°40'E) and Stewart Island (47°00'S, 168°00'E) in the 1991/92, 1992/93 and 1993/94 breeding seasons. Four Royal Albatross chicks from Taiaroa Head, Otago Peninsula were studied after a predation outbreak in February 1994. One Little Penguin adult was found at Port Williams, Stewart Island in summer 1992/93 and it was examined to determine the predator responsible.

All dead birds were weighed, measured, carefully skinned to look for wounds (from the underside of the skin), and dissected to assess stomach contents and fat deposits for general body condition. Any wounds found were noted and the cause of death determined wherever possible. The skins were sketched to show holes and wounds.

The markings found on the bills of three albatross chicks were analysed separately in two ways because the marks were very distinct, the distances were easily measured but it was unclear which way the predator had bitten the bill. Distances between all possible pairings of holes were measured on each side of the bill; and then distances across the longitudinal axis of the bill to marks on the opposite side. Some markings appeared as if the predator's canine had torn a laceration into the bill, and the distance between parallel pairs of such rip marks were measured.

Electronic calipers were used to measure all possible distances between the puncture holes that were at least 4 mm apart (the minimum inter-canine distance for Stoats) and up to 21 mm apart (the maximum inter-canine distance for cats, the largest predator). No attempts were made to differentiate between lower and upper jaws. The puncture holes on the body that lie beyond 21 mm from the nearest cluster of puncture marks were sometimes in pairs. These pairs were assumed to belong together and have been called 'outliers'.

TABLE 1

Probabilities of inter-canine distances belonging to one of the three predators

Distance (mm)	No. of Stoats	Likelihood Stoat	No. of Ferrets	Likelihood Ferret	No. of cats	Likelihood cat
4.5	4	1		0		0
5	10	1		0		0
5.5	5	1		0		0
6	14	1		0		0
6.5	18	1		0		0
7	14	1		0		0
7.5	7	1		0		0
8	6	0.802	2	0.198		0
8.5	1	0.165	4	0.490	3	0.345
9	1	0.084	11	0.683	4	0.233
9.5		0.000	10	0.842	2	0.158
10		0	13	0.776	4	0.224
10.5		0	23	0.830	5	0.170
11		0	16	0.895	2	0.105
11.5		0	4	0.587	3	0.413
12		0	9	0.706	4	0.294
12.5		0	8	0.895	1	0.105
13		0	5	0.640	3	0.360
13.5		0	3	0.444	4	0.556
14		0		0	7	1
14.5		0		0	6	1
15		0		0	8	1
15.5		0		0	9	1
16		0		0	6	1
16.5		0		0	15	1
17		0		0	7	1
17.5		0		0	9	1
18		0		0	4	1
18.5		0		0	5	1
19		0		0	2	1
19.5		0		0	0	1
20		0		0	1	1
20.5		0		0	1	1

Predator dentition measures

Inter-canine distances for each predator species were measured from skulls held in the Department of Zoology, University of Otago. These animals were collected from throughout the Otago region by the predator/prey research team investigating protection of Yellow-eyed Penguins, and mitigation of bovine tuberculosis spread amongst farm stock.

There are no published data on growth of the inter-canine distances, so we can not directly filter out young animals by their teeth measurements. Accordingly we have indirectly excluded them by not measuring teeth of individuals that had been caught during the time of dispersal of independent young of the year (late spring) until the first predation outbreak at the albatross colony at Taiaroa Head on 12 February 1994. Accordingly, Stoats caught between mid-January and 12 February were excluded, as were Ferrets caught between mid-December and 12 February. All cats were included because young can be found throughout the year (Fitzgerald 1990).

Predation of Yellow-eyed Penguin chicks occurred predominantly in November and December when no newborn Stoats or Ferrets are yet active. In January 1992, a late (and very unusual) outbreak of predation on Yellow-eyed Penguin chicks occurred at one Otago Peninsula site (Ratz 1997) and nine chicks from this outbreak have been included in this analysis.

Comparisons of measurements on chicks and predators

Means, standard deviations and ranges of the measurements of the predator inter-canine distances were calculated to compare with distances measured between puncture holes in the skins of the chicks.

The inter-canine distances were used to calculate the probability that an observed bite distance was made by a Stoat, Ferret or cat (Table 1) by:

1. converting the frequency distributions of inter-canine distances in Figure 1 to proportions (to allow for differing numbers of each predator sampled),
2. summing the proportions for each interval of inter-canine distance, and
3. calculating the proportion of the sum calculated in 2. above that was made up of Stoat, Ferret or cat. This was put through a three-point running mean to smooth it.

Percentage of matches between bite distances and inter-canine distances for each predator species (Table 2) were calculated by:

1. summing the pairings where either a Stoat, Ferret or cat was the most likely to have inflicted the bite (using Table 1), and
2. expressing the sum as a percentage of the total for all ‘most likely’ matches on each chick.

RESULTS

Necropsy

Predation was characterised by the presence of either one or more flesh wounds, or when puncture holes in the skin were discovered after skinning. Typically such birds were in good condition with healthy organs, the stomach and guts usually contained food, and some subcutaneous fat deposits were present. Chicks assumed to have died from trampling characteristically had internal bleeding and/or bruising, the trachea and/or oesophagus often contained blood and they were between one and 16 days of age, with a mean age of nine days. Chicks older than 16 days have not been found trampled (however, the age of one chick from Stewart Island was unknown and it may have been older). Chicks assumed to have died from starvation had no food in the stomach (some had stones) or in the gut, the area around the gall bladder was often discoloured green with excess bile, and typically no subcutaneous fat deposits were present. Some chicks had the symptoms of starvation and trampling and predation or combinations thereof (Table 3).

Of the 51 recovered Yellow-eyed Penguin chicks, 37.7% were preyed upon, 27.5% died from starvation and 21.5% died from trampling. The cause of death was not clearly distinguishable in 13.7% of cases (Table 3). Two Yellow-eyed Penguin chicks were found to have mauled legs with torn muscles, and the left tibia of chick no. 33 was broken. The Little Penguin adult and the four Royal Albatross chicks died of predation (Table 3).

Inter-canine distances

The inter-canine distances were measured for 80 Stoats, 108 Ferrets and 116 cats. The mean distance was 6.4 mm for Stoats (standard deviation (SD) = 1.0, range: 4.4–9.0 mm), 10.7 mm for Ferrets (SD = 1.3, range 7.8–13.6 mm) and 14.7 mm for cats (SD = 2.9, range 8.3–20.6 mm).

Identification of predators from inter-canine distances

The presence of many comparatively short inter-canine distances of young cats means that it is effectively impossible to separate cat from Ferret bite marks using inter-canine distances

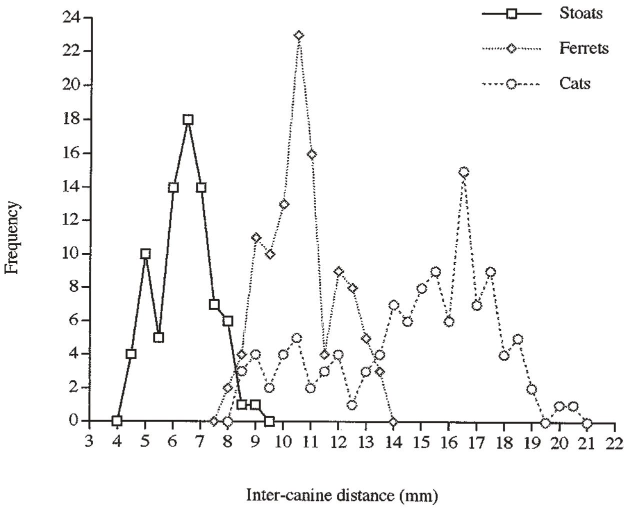

Fig. 1 *Frequency distribution of inter-canine distances of Stoats, Ferrets and cats (sexes and upper/lower jaws combined)*

TABLE 2

Percentage of spacings (a) between bite marks and (b) between parallel rip marks on the bills of three Albatross chicks that were most likely to be made by each predator species

		% of puncture pairs matching			
		n	Stoat	Ferret	cat
(a)	Albatross chick no. 2	248	27.0%	30.7%	42.3%
	Albatross chick no. 3	91	40.6%	33.0%	26.4%
	Albatross chick no. 4	72	45.8%	45.8%	8.4%
(b)	Albatross chick no. 2	15	66.7%	26.7%	10.6%
	Albatross chick no. 3	14	71.4%	7.1%	21.5%
	Albatross chick no. 4	21	71.4%	28.6%	0.0%

TABLE 3

Causes of death of all recovered and necropsied Yellow-eyed Peguin chicks, Royal Albatross chicks and Little Penguin adult

Species	Cause of death	Catlins	Otago Peninsula	Stewart Island
Yellow-eyed Penguin chicks				
	predation	6	13	
	starvation	10	4	
	trampling	5	5	1
	starvation/trampling	1	2	
	starvation/predation		1	
	unknown	1	1	1
Little Penguin adult				
	predation			1
Royal Albatross chicks				
	predation		4	

(Fig. 1). If bites from upper and lower canines are equally represented by holes on the carcasses, 10% of Stoat bites will be indistinguishable from those of Ferrets'; 30% of cat bites will be indistinguishable from Ferrets'; and 16% and 98% of Ferrets' bites cannot be distinguished from Stoats' or cats', respectively (Table 4).

Puncture holes on the body

Only four of the 19 Yellow-eyed Penguin chicks preyed upon had puncture holes in the skin (Table 5). The others had large wounds at the back of the neck that were interpreted as being caused by a predator attack rather than by scavenging because starvation and/or trampling could be ruled out. One Yellow-eyed Penguin chick was recovered with only two marks on the right foot which match the inter-canine distances of a Stoat (Table 5).

TABLE 4

The percentage overlap of the inter-canine distances of the three predator species

Predator	% overlap with other predators		
	Stoat	Ferret	cat
Stoat	x	10%	2.5%
Ferret	16%	x	98%
Cat	6%	30%	x

None of the four Yellow-eyed Penguin chicks with puncture holes had outliers. The Little Penguin and the four Royal Albatross chicks all had puncture holes but only two Royal Albatross chicks had outliers. Both matched the inter-canine distances of a Stoat. Large clusters of bite marks on the body were mapped and all possible distances between holes measured. However, these were largely uninterpretable because bites overlaid one another.

Analysis of bites on bills of albatross chicks

The majority of the marks on the bill of albatross chick no. 2 matched cat distances, thus making a cat the more likely source of these marks (Table 2). 40.6% of the marks on the bill of chick no. 3 matched Stoat distances, but marks on the bill of chick no. 4 matched Stoat and Ferret distances equally well (Table 2). These scores in themselves have little discriminating power, and any or some combination of the three predators could have inflicted the bites.

TABLE 5

Number of puncture holes and outliers in the killed Yellow-eyed Penguin chicks, Royal Albatross chicks and Little Penguin adult

Species	Location	Body part with puncture holes	No. of puncture holes	No. of outlier pairs	Distance (mm)	Predator responsible
Yellow-eyed Penguin no. 36	Otago Peninsula	foot	0	1	8.00	Stoat
Yellow-eyed Penguin no. 33	Otago Peninsula	neck	43			
Yellow-eyed Penguin no. 32	Otago Peninsula	neck	37			
Yellow-eyed Penguin no. 34	Otago Peninsula	neck	15			
Yellow-eyed Penguin no. 13	Catlins	neck	12			
Little Penguin adult	Stewart Island	neck	38			
Royal Albatross Chick no. 1	Taiaroa Head (Otago Peninsula)	head & neck body bill	16 19 0	 1	 6.06	 Stoat
Royal Albatross Chick no. 2	Taiaroa Head (Otago Peninsula)	head & neck bill	22 29			
Royal Albatross Chick no. 3*	Taiaroa Head (Otago Peninsula)	neck bill	0 16	1	5.39	Stoat
Royal Albatross Chick no. 4	Taiaroa Head (Otago Peninsula)	head & neck bill	98 13			

* The neck of chick no. 3 was not mapped but these two outlier puncture holes were the only ones found in the region.

When only parallel rips were considered the majority matched the inter-canine distance of Stoats (Table 2). Only a few could potentially be attributed to Ferrets or cats. None of the pairings for chick no. 4 was made by cats (Table 2).

DISCUSSION

Penguin predators

Trampling of Yellow-eyed Penguin chicks by their parents is assumed to be a 'natural' mortality, and sometimes it was not possible to determine whether the chick first starved to death and was then trampled by its parents or whether it was first injured by the parents and then could not beg for food and so died of starvation. Starvation and trampling may therefore be closely related outcomes.

A Stoat was identified as the predator with a reasonable certainty in only one (no. 36) of the 19 eaten Yellow-eyed Penguin chicks. Chick no. 33 and no. 34 also had mauled legs, a possible sign of a dog attack (C. Lalas pers. comm.). Both had puncture holes as well, but no outliers for a definite predator identification. Dogs are not allowed in the majority of Yellow-eyed Penguin breeding areas, but chicks no. 33 and no. 34 were from an area with public access and a dog cannot be ruled out as the cause of death.

The Little Penguin had no conclusive outliers to judge which predator killed it. It was collected from Stewart Island where only feral cats are potential predators, but recent unconfirmed reports of mustelids there make clear identification impossible.

What killed the albatrosses?

Stoats were probably responsible for the four albatross deaths. The analysis of parallel marks on the bill (Table 2) provided the least confused interpretation because the bill was less affected by decomposition, the marks were clearer than those on the body and pairing only parallel rips allowed better discrimination. No inferences whatever should be taken from Table 2 because of the crowded nature of the bill marks, the bias referred to below and the lack of information used by matching parallel marks. The parallel bill marks suggest that Stoats were the most likely culprits; and in one case it is virtually certain that it was not a cat (Table 2). Albatross chicks nos. 1 and 3 were the only chicks with outliers, and all of them would have been inflicted by Stoats alone (Table 5). Evidence for the chicks nos. 2 and 4 is less conclusive: it is possible that any of the three species was involved, but most likely that it was one or more Stoats. The observed pattern of a sudden predation outbreak followed by ongoing losses of chicks on consecutive nights is quite typical of the pattern of Stoat predation of Yellow-eyed Penguin chicks in the Catlins (Ratz 1997), and of penguin chick losses on Otago Peninsula (J.T. Darby pers. comm. in Ratz *et al.* 1992). It is likely that an individual (sometimes termed 'rogue') predator 'locks onto' the chicks as targets after having killed its first one. If so, all the albatross chicks killed at Taiaroa Head during this emergency are most likely to have been killed by the same individual. This further suggests that a Stoat was responsible for killing chicks nos. 2 and 4, as well as the two (chicks nos. 1 and 3) for which evidence is unequivocal.

One of the nests where albatross chicks nos. 2 and 3 were killed had clear signs of a tunnel through long grass reaching the edge of the nest (McKinlay 1994, H. Moller pers. obs.). Such a sign is uncharacteristic of a cat whereas Stoats move throughout long-grass areas and Ferrets tend to use tracks through it (Ratz 1997). A single long hair was recovered from the bill of a dead chick and described as 'gold with a black tip' (P. Lyver pers. comm.). Unfortunately it was lost before positive identification. It was inferred that it was most likely to have been a long coarse guard hair with a black end such as from Ferrets; but it could also have been a hair plucked out of the black tail tip of a Stoat. The detailed analysis of the bites presented here suggests that the latter interpretation is the more likely.

Difficulties with using bite marks to identify predators

The mapping of the three-dimensional skins from chick carcasses onto two-dimensional paper will result in some distortion of the distances between the puncture holes. Also, the skins were flexible and unintentional stretching may have added error in the measurements. In addition to chew marks, flesh had also been removed by fly maggots from areas of chicks where they were fly-blown. The combination of these two factors made complete analysis of marks on the carcasses very difficult. Puncture holes could only be found where the skin had been left intact and the carcasses had not reached an advanced stage of decay. More rapid recovery and immediate freezing of the carcass is recommended.

The numbers of puncture holes found on some skin pieces were large and clustered (Table 5). Simple matches of distances between all puncture holes will be biased toward cat inter-canine distances because these are largest. Any clustering of bites will compound this false apparent signal that a cat was responsible. If all possible measurements are taken of all pairings of holes up to 21-mm distance, then by chance alone there would be disproportionately more measurements of the larger distances that match cats. An approach that could allow for this is a discriminatory signal in the distribution of nearest neighbour distances from clustered bites for each predator species. The only way to check and calibrate such bite mark signatures will be to film predation events and match computer simulations and predictions with observed bite mark distributions. If a signature can be found, the bite marks method will become much more valuable. Without it most of the bites on killed birds are clustered and the analysis is confounded to such a degree that it is of little use in identifying the predators responsible.

Outliers affect the best opportunity to avoid bias, but such well-spaced bites occurred in only 14% of the 21 chicks examined in this study. Even where outliers are present, they are unlikely categorically to separate cats from Ferrets as the predator responsible (Table 4).

The proportions of the inter-canine distances of each predator species allow estimation of the probability that a bite was made by each species provided

1. all sizes of each predator are equally likely to have bitten the chicks, and
2. our estimated inter-canine distance frequencies represent those present in the population (Table 1). This latter assumption is dependent on all sizes of a species being equally trappable.

An overriding assumption of the bite marks method is that only one species was involved in each predation. Predation sign is often subsequently altered or obliterated by subsequent scavenging by other species (Major 1991, Brown *et al.* 1996). Some of the dead Yellow-eyed Penguin chicks had muscles, brains and internal organs removed and may thus have been scavenged, possibly by rats and/or Brushtail Possums *Trichosurus vulpecula*. For some of these chicks the cause of death could not be determined definitely.

Alternative methods of identifying predators

Identification of predators is an essential first step in achieving effective control of introduced mammalian predators in New Zealand and other islands. The above analysis of the puncture holes in the skin of the prey has proved inconclusive at this stage because of the difficulties discussed. Accordingly we now briefly review the utility of alternative methods and their assumptions.

Some Yellow-eyed Penguin chicks were X-rayed to determine any markings on the bones underneath the extensive flesh wounds. However, this proved to be impossible because the neck vertebrae in the X-ray picture were overlying each other and potential markings on the bones were impossible to distinguish.

There are presently only two ways of positively identifying a predator species: direct observation (through watching or filming) and recovery of feathers or egg shell fragments from gut contents.

Direct observation

Direct observations are few and depend on chance encounters where the observer may frighten the actual or potential predator away or interfere with the predation event (Nolan 1963, Skutch 1966, Thompson & Nolan 1973, Best 1974, Morgan 1981, Wilcove 1985). Cameras were used in some studies to film or photograph the predator robbing a nest (Custer 1973, Dunn 1977, Savidge & Seibert 1988, Major 1991) but this is normally restricted to few nests (Custer 1973, Dunn 1977, Major 1991, Brown *et al.* 1993, pers. obs.), is extremely expensive to set up and time consuming to service. However, it gives an unequivocal identification of the predator responsible.

Gut contents

Kill-trapping in an area where predation occurs and subsequent necropsy of the predators and analysis of the stomach and gut may reveal feathers and/or bones and/or egg shells for proof. The disadvantage is that a scavenger cannot be distinguished from a predator. McLennan & MacMillan (1985) used poisoned eggs and found a substance similar to yolk in the stomach of a dead rat near the depredated nests. Stanton (1944) found egg remains in the stomach of Douglas Ground Squirrels *Citellus beecheyi douglasii* and Innes (1979) found egg shell fragments and feathers in Black Rat *Rattus rattus* stomachs and guts. The only direct evidence available for Yellow-eyed Penguin chicks comes from chick feathers found in the stomach of a Ferret caught after a predation outbreak (R. McKay pers. comm.). There is no direct evidence for any predator species of Little Penguins or Royal Albatrosses.

Indirect evidence

The identification of a predator could be determined by indirect evidence, including:

1. Predation stops when kill-trapping is initiated. Predation of Yellow-eyed Penguins stopped in the Catlins when trapping was initiated and Stoats were mainly caught (Ratz 1997). A Stoat was caught shortly after the last albatross chick was killed at Taiaroa Head. No other Stoats were trapped before then in the reserve area and no further predation events occurred (McKinlay 1994). However, this by itself provides no proof that this Stoat killed the albatross chicks.

2. If predation ceases when selective trapping for one of two or three species is initiated, the selected predator species is implicated as the originator of the predation. In January 1992, a very late Yellow-eyed Penguin chick predation outbreak occurred on the Otago Peninsula and after selective removal of Stoats, predation ended (Ratz 1997). It remains possible that the predator responsible left the area, and predation is sporadic, so there is no guarantee that the trapping in 1. or 2. was the reason why predation stopped.

3. The predator species responsible for a predation event can sometimes be deduced by the information on the predator guild locally present. Brushtail Possums have not been considered as a potential predator in the management of Yellow-eyed Penguins, but they have been observed taking eggs and nestlings of other bird species (Morgan 1981, Brown *et al.* 1993). Stewart Island has only cats and no mustelids (Fitzgerald 1990, King 1990a, b, Lavers & Clapperton 1990); therefore it was assumed that predation of Yellow-eyed Penguin chicks on Stewart Island was always caused by cats without considering possums (Marchant & Higgins 1990).

4. Characteristic sign of a predator species from which its identity could potentially be deduced has been considered for some species (Moors 1983, Brown *et al.* 1993, Brown 1994). Others use sign from observed predation events to characterise the sign produced by each predator (Nelson & Handley 1938, Skutch 1966, Thompson & Nolan 1973, Best 1974). However, differences in sign left by individual predators have been found (Sooter 1946) and, more importantly, sign overlaps between different species. Major (1991) photographed rats carrying off Scarlet Robin *Petroica multicolor* nestlings, leaving clean nests attributable to mustelids using Moors' (1983) criteria.

5. Markings on eggs have been used to identify the predator responsible. Teeth marks have been found on eggs and used to identify the predator responsible (Anderson 1969, Morris 1976, Moors 1978, 1983, Clout *et al.* 1995) but only Rearden (1951) mentioned skulls for comparison but did not elaborate or provide a key. Møller (1987, 1989) used stuffed specimens of aerial predators to imitate the markings on plasticine eggs and compared those with the ones obtained from eggs in the field. He claims that the bill markings differed clearly from each other but he does not present any data or evidence of this comparison.

6. Predators have been identified by their droppings (Dunn 1977, Flack & Lloyd 1978), footprints (Sooter 1946, Rearden 1951, Moors 1978, McLennan & MacMillan 1985, Wilcove 1985, Angelstam 1986) and by hair (Rearden 1951, Yahner & Wright 1985, McLennan 1988, Major 1991) left behind at nests. These studies assumed that the originator of the sign was the predator. However such signs are no definite proof because the originator of the sign may have passed before or after the predation event

and/or was scavenging remains at the nest. All that can be said about the species identified is that they visited, not what they did.

7. Many studies identify the putative culprits without evidence or even reference to other studies; for example Rearden (1951), Perrins (1965), Rowley (1965), Skutch (1966), Anderson (1969), Thompson & Nolan (1973), Klimstra & Roseberry (1975), Best (1974) and McLennan (1988). It is impossible for others to assess the methods used and the identification of the predators can not be validated. In some studies the methods and assertions stay undeclared and it is reported that predator identifications were based on consultation with colleagues, or on the work undertaken by others who presented no direct evidence: For example Henry (1969) identified some predators 'from descriptions obtained through correspondence with prominent biologists'; Gottfried & Thomson (1978) quoted Nolan (1963) and Thomson & Nolan (1973) and neither presented concrete evidence for their identification of the predator. Chesness *et al*. (1968) and Yahner & Wright (1985) both quote Rearden (1951) who reported his conclusions without presenting evidence. The only caveats issued in these citations circuits were from Angelstam (1986) who reported that an individual predator species may treat bird eggs in different ways, and that Rearden (1951) needs to be looked at with caution.

8. The predator is identified by 'typical' behaviour such as caching of prey by Stoats (King 1990a). This assumes that there is not species overlap for this behaviour. Cats also cache their food (Stahel & Gales 1987) and live in the same areas as Stoats do in New Zealand (King 1990a, Fitzgerald 1990, Alterio *et. al* 1998). So the signal is potentially too confused for predator identification.

CONCLUSIONS

Painstaking and detailed analysis of bite marks on penguins and albatross chicks has failed categorically to identify the predator that killed them in the vast majority of cases. Stoats definitely killed two albatross chicks and one Yellow-eyed Penguin chick. Computer simulations of bite distributions will be needed to extend the value of the technique but first, matches of bite mark distributions with filmed predation events will be necessary. Indirect methods used to identify predators are problematical, and filming is expensive and so will usually only provide small sample sizes. A brief review of the literature challenges many assertions that the identity of predators is known. Definite measures of the relative importance of different potential predators could greatly assist seabird conservation management, but are not immediately available.

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