The status of microbats on Norfolk Island, southwest Pacific

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ABSTRACT

No evidence for the continued existence of bats was determined during two surveys of Norfolk Island. A pilot survey for bats was undertaken on Norfolk Island in 1986 using harp trap and mist net capture techniques. A subsequent survey in 2003 was undertaken using echolocation call detection equipment. Accounts by island residents indicate that bats were present in reasonable numbers following the 2nd World War but numbers declined dramatically from the early 1960s. Eight former bat roosts were described by island residents. Five of the roosts occurred in hollow-bearing Norfolk Island Pines *Araucaria heterophylla*, two in houses and one in a large vine. Sightings of bats within the last decade suggest that bats may still persist in low numbers and further survey is warranted. Predation by rats and a gradual decrease in the number of secure roosts through tree removal are considered the most likely causes of decline, although the widespread use of herbicides could also be a factor. Provision of artificial roost boxes may assist in providing secure roosts for any remaining individuals persisting.

Key words: bat, species decline, Norfolk Island, predation, *Rattus rattus*, roost, tree hollow, *Chalinolobus gouldii*, *Mormopterus norfolkensis*

Introduction

Norfolk Island is a small isolated volcanic island situated in the southwest Pacific Ocean (Figure 1). It lies 1676 km north east of Sydney, Australia, 1065 km north northwest of Auckland, New Zealand and 772 km southeast of Noumea, New Caledonia. The island has an area of 34.6 km^2 and 32 km of coastline. Two smaller islands lie to the south; Nepean 1 km from Norfolk Island covers an area of 0.1 km^2 while the larger Philip Island 6 km to the south covers an area of 1.9 km^2. All three islands are only 3 million years old, consisting predominantly of a plateau formed from horizontal sheets of basalt that is the remnant of an elongated shield volcano.

Like many Pacific islands, the original bat fauna of Norfolk Island prior to European colonisation is unknown. Systematic fauna surveys were not carried out prior to massive disruption to the biota of the island following its settlement in March 1788. Establishment of a penal settlement resulted in over one thousand inhabitants by 1800. The island was subsequently abandoned in 1814 for eleven years. At this stage approximately one quarter of the island had been cleared of vegetation (Mueller-Dombois & Fosberg 1998). A second penal settlement was established on the island in 1825 with convict numbers reaching 2000 before the island was again abandoned in 1855. The following year, 194 people arrived on Norfolk Island aboard the "Morayshire" from Pitcairn Island. By the 1st World War 75% of the island had been cleared and the largest remaining tract of forest was in the area surrounding Mt Pitt/Mt Bates (Mueller-Dombois & Fosberg loc cit). 460 hectares of this area was declared a national park in 1984.

Vegetation in the Norfolk Island National Park can be considered to be predominantly of three subtropical rainforest community types, a palm/tree-fern forest in moister areas, a hardwood forest in semi-sheltered intermediate areas and a Norfolk Pine dominated forest on drier, more exposed areas. A high level of endemism is present in the plants. Many areas have been heavily invaded by introduced Cherry Guava *Psidium littorale*, African Olive *Olea europea africana* and Hawaiian Holly *Schinus terebinthifolius*.

Nothing is known of the bat fauna of Norfolk Island at the time of European discovery and settlement in the late 18th century. The East Coast Freetail Bat *Mormopterus norfolkensis* was described from a single specimen collected just prior to 1939, but doubts exist as to whether the specimen was actually from Norfolk Island or was a mislabelled specimen from the east coast of the Australian mainland (Strahan 1980). Gould's Wattled Bat *Chalinolobus gouldii* was recorded on the island in December 1915 from a specimen collected by J.S.P. Ramsay (Troughton 1922), (Australian Museum number M4991). The bat was one of "several roosting within the hollow spout of a small tree in scrub" in an undisclosed part of the island. Three additional specimens of *C. gouldii* from Norfolk Island were lodged in the Australian Museum collection in 1983. This included one adult female (M12760) and two adult male bats (M12758-59). No details are available regarding the circumstances of their collection. Few details are present in the museum register and it is possible the bats were collected earlier but only registered in 1983. No bat specimens from Norfolk Island have been lodged with institutions since this time.

Systematic surveys have not been undertaken on the bat fauna of Norfolk Island until the late twentieth century (Gordon 1983, this study). Additional information of the bird fauna of Norfolk Island prior to and following European settlement has been gained from sub-fossil deposits (Meredith 1985, Holdaway and Anderson 2001). These deposits are from human predation and

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microchiropteran bats were rarely used as food items. Bats are also often poorly preserved and are under represented in fossil and sub-fossil deposits as their bones are fragile and are unlikely to be preserved unless quickly separated from the elements. Those species which roost in caves are usually better represented in fossil and sub-fossil deposits than those that roost in tree hollows (eg Archer and Hand 1991).

A survey for bats was undertaken by Mary Gordon in 1983 which entailed mist netting at four sites and observing bats at dusk at nineteen sites (Gordon 1983). No bats were recorded during these surveys. This paper reports on surveys undertaken for bats on Norfolk Island in 1986 and 2003.

Methods

1986 Survey

Harp traps were placed at three sites for two consecutive nights in remnant forest surrounding Mt Pitt and Mt Bates in the north of the island (H1–H3, Figure 2). Traps were set along tracks and were inspected each morning for captured bats. Two 10 metre long mistnets were erected for one night at three sites (M1–M3) and monitored for four hours from dusk. Mistnets were then furled to prevent the capture of bats while the nets were unattended. The nets were located over freshwater bodies where any remaining bats may come to feed or drink.

The sky was observed at dusk for flying bats while mistnets were set until visibility waned with fading light. On two nights, several of the tracks at Mt Pitt were traversed holding a 55 watt spotlight to observe flying bats.

Weather conditions were generally fine for the duration of the survey. No rain fell, winds were moderate and minimum temperatures did not fall below 16.9°C.

2003 Survey

A second survey utilising Anabat detectors at 30 sites for a total of 260 hours of sampling was undertaken in February/March 2003 (D1–D30, Table 1 & Figure 3). Sites were distributed throughout the island including residential areas, rural settings and remnant forest. No sampling was undertaken on Phillip Island due to constraints on accessing the island during the survey. Anabat 1 detectors (Titley Electronics, Ballina) were coupled to a voice activated tape player or storage zcaim and directed into openings in forest, over open pasture and water bodies. Sites were also selected where bats had been observed over recent decades. Sampling was undertaken throughout the night at each site except in two localities where insects triggered the voice activated tapes restricting sampling time. A number of island residents were questioned regarding their knowledge of bats, particularly elderly residents whose memories extended beyond the 2nd World War. Details of any sightings including the location, date, number of bats and behaviour were recorded. Where residents recalled diurnal roosts of bats, these were inspected and photographed if still in existence.

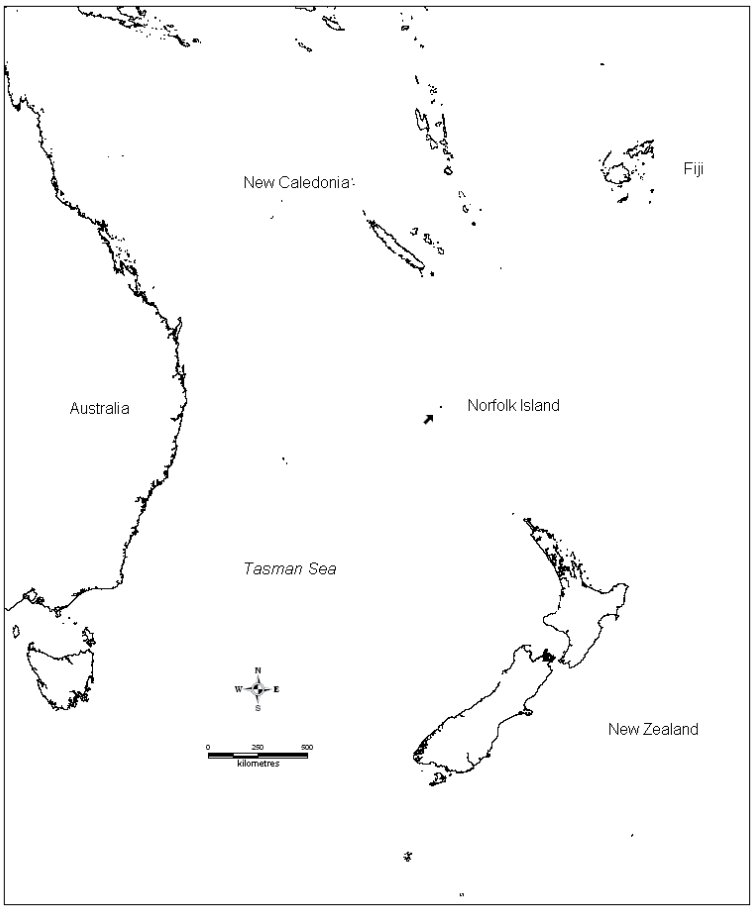

Figure 1. The location of Norfolk Island in the southwest Pacific Ocean.

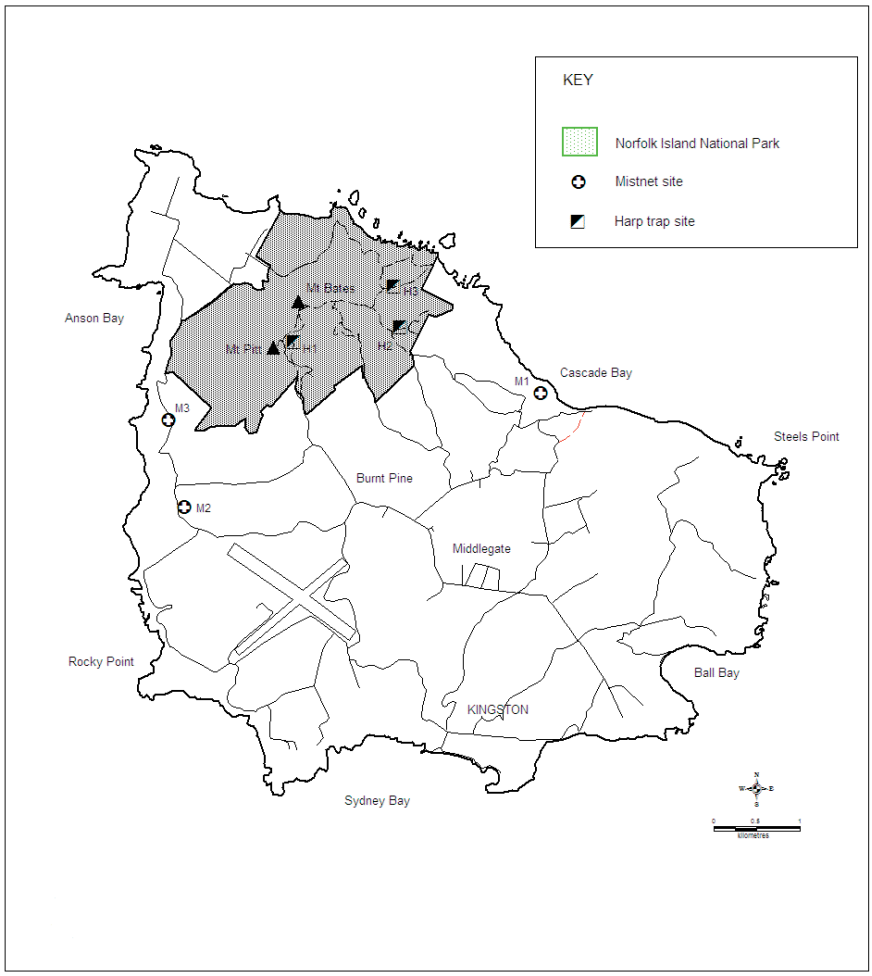

Figure 2. The location of mistnet and harp trap sites sampled during February 1986.

Table 1. The location of sites sampled by mistnets and harp traps during the 1986 survey.

Site	Date	Location	Latitude	Longitude
H1	9&10/02/1986	Track to Mt Pitt, Norfolk Island National Park.	–29.015849°	167.935588°
H2	11&12/02/1986	Track to Palm Glen, Norfolk Island National Park.	–29.014344°	167.948245°
H3	13&14/02/1986	Track to Bird Rock, Norfolk Island National Park.	–29.010043°	167.947505°
M1	8&9/02/1986	Over creek Cascade Reserve.	–29.021106°	167.965031°
M2	10&11/02/1986	Over dam off Anson Bay Road, near Mission Road.	–29.033000°	167.922575°
M3	12&13/02/1986	Over creek off Anson Bay Road, near Puppys Point.	–29.023967°	167.920708°

Table 2. Weather condition during the 1986 survey. (Norfolk Island Aero, Latitude: 29.03°S, Longitude: 67.93°S, Elevation: 110m.)

Date	Daily maximum temperature (°C)	Daily minimum temperature (°C)	Maximum sustained wind speed (Km/h)	Total daily precipitation (mm)
7/02/1986	25.1	19.3	7.1	0
8/02/1986	24.3	20.3	9.8	0
9/02/1986	24.8	19.9	13.8	0
10/02/1986	23	16.9	13.8	0
11/02/1986	24	18.2	13.8	0
12/02/1986	24.6	17.2	12.4	0
13/02/1986	24.1	17.2	12.4	0
14/02/1986	24.3	19.6	8.4	0
15/02/1986	25.4	21	11.2	0

Results

1986 Survey

No bats were captured in harp traps or mistnets during the 1986 survey. There were also no bats observed at dusk at any of the sites.

2003 Survey

No bat calls were recorded at any of the thirty sites sampled by echolocation call detection during the 2003 survey.

Survey of residents and tourists

Eighteen residents were questioned regarding their observations of bats. All the older residents remembered

Table 3. The location of sites sampled through echolocation call detection during the 2003 survey.

Site	Date	Location	Latitude	Longitude
D01	26/02/2003	Water Mill dam off Country Road.	–29.049402°	167.951201°
D02	26/02/2003	Mission Church of St Barnabas Church.	–29.034307°	167.924703°
D03	26/02/2003	Dam off Anson Bay Road Headstone Point.	–29.044148°	167.921874°
D04	26/02/2003	Mobile Transect around Kingston.	–29.055967°	167.9598440°
D05	26/02/2003	Ponderosa Apartments off Country Road.	–29.052050°	167.944878°
D06	27/02/2003	Captain Cook Memorial at the end of Dunscombe Road.	–29.002969°	167.941499°
D07	27/02/2003	House of Margaret & Ken Christian near Point Vincent.	–28.998942°	167.9208686°
D08	27/02/2003	H.I. Pottery north of Anson Bay.	–29.002891°	167.9177840°
D09	27/02/2003	Anson Bay Picnic Area.	–29.009160°	167.920553°
D10	27/02/2003	Selwyn Reserve, south of Anson Bay.	–29.014775°	167.920392°
D11	28/02/2003	Off Mt Pitt Road north of Mission Road intersection.	–29.024826°	167.938407°
D12	28/02/2003	Mt Bates.	–29.011234°	167.935013°
D13	28/02/2003	Below Mt Pitt.	–29.015837°	167.934861°
D14	28/02/2003	Broken Bridge Creek east of crossing with JE Road.	–29.027590°	167.953314°
D15	1/03/2003	Fig Gully off Rocky Point Road.	–29.053197°	167.929861°
D16	1/03/2003	Bumbora Reserve near Cresswell Bay.	–29.057737°	167.9384190°
D17	1/03/2003	Large figs at edge of Rocky Point Reserve off New Farm Road.	–29.047834°	167.922781°
D18	1/03/2003	Near Airport terminal.	–29.036293°	167.940528°
D19	3/03/2003	Dam in paddock off Cascade Road.	–29.027984°	167.966035°
D20	3/03/2003	Cascade Reserve.	–29.018781°	167.962009°
D21	3/03/2003	House of Dave Smith end of JE road.	–29.016529°	167.949230°
D22	3/03/2003	Palm Glen in Norfolk Island National Park.	–29.014997°	167.940245°
D23	3/03/2003	Picnic area start of Palm Glen walk.	–29.015782°	167.943565°
D24	4/03/2003	House at start of Steeles Point Road.	–29.032021°	167.988438°
D25	4/03/2003	Point Blackbourne picnic area.	–29.039649°	167.990353°
D26	4/03/2003	"White Oaks", Point Blackbourne.	–29.047312°	167.987006°
D27	4/03/2003	House of Jack Hayes, off Collins Head Road.	–29.049482°	167.972647°
D28	5/03/2003	House of Judith & John Lorking off JE Road.	–29.029009°	167.954476°
D29	5/03/2003	Pasture west of Cascade Road at Middlegate.	–29.036111°	167.963181°
D30	5/03/2003	Facing over gully west of Stockyard Road.	–29.040923°	167.978272°

Table 4. Weather condition during the 2003 survey. (Norfolk Island Aero, Latitude: 29.03°S, Longitude: 67.93°S, Elevation: 110m.)

Date	Daily maximum temperature (°C)	Daily minimum temperature (°C)	Maximum sustained wind speed (Km/h)	Total daily precipitation (mm)	Weather event reported
25/02/2003	23	19.6	21	0	
26/02/2003	24	20	18.2	0	
27/02/2003	23	19.8	21	0	
28/02/2003	24	17.9	12.4	0	
1/03/2003	25	21	25.3	0	Rain (or Drizzle)
2/03/2003	24	20	26.6	0	Fog Rain (or Drizzle)
3/03/2003	24.4	19.1	21	0	
4/03/2003	22.5	19.5	21	0	Rain (or Drizzle)
5/03/2003	23	19.3	22.2	0	Rain (or Drizzle)

bats being common in their childhoods up until the 2nd World War. A number knew of roosts where bats occurred or regularly observed bats flying at dusk. From this time, observations of bats decreased and by the 1980s only individual bats were sighted. Sporadic sightings of individual bats have continued from this time until at least 2002 when a bat was seen flying at dusk near Watermill Dam (Figure 4).

Bat Roosts Identified

Eight previous bat roosts were recorded from discussions with residents of the island during the 2003 visit to the island. Five of the roosts were within hollows in large senescent Norfolk Island Pines *Araucaria heterophylla* in scattered locations across the island (Figure 5).

Bats were known to roost in the roof of a building at Steeles Point prior to the 2nd world war (Roost 1 Figure 5, O. Evans, pers. com.). *Chalinolobus gouldii* regularly utilises the roofs of buildings as roosts in eastern Australia (Dixon 1995). Colonies often number from fifty to several hundred individuals and many of these roosts are used for breeding by females during the summer months. *Mormopterus norfolkensis* less frequently roosts in buildings (Allison and Hoye 1995).

Five of the roosts were in mature or senescent Norfolk Island Pines *Araucaria heterophylla*. This is now the most widespread and abundant tree on the island with individuals present in otherwise cleared land. Two senescent pines in close proximity were used as roosts by bats at Ball Bay from least 1941 (Roosts 2 &3, Figures 4, 6 & 7, J. Hayes pers. com. 2003). Bat numbers in the roosts dropped dramatically in the 1960s. Both trees were removed in 2002 as they were considered dangerous, with only the stumps remaining in March 2003. Roost 2 had a diameter at 0.5 metres of 2 metres (Figure 5). From the remaining stump, this tree had a hollow centre of 300 millimetres diameter at the base. Roost 3 has a diameter at 0.5 metres of 2.8 metres and was extensively hollowed (Figure 7). The remaining stump has a hollow near ground level of 1.8 metres diameter and has two vertical slit entrances at this point. A search of debris within the centre of the stump did not reveal any bat remains.

A mature *Araucaria heterophylla* in a paddock adjacent to Rocky Point Road north of Bumbora Reserve was used as a roost by a large number of bats until the 1960s (Roost 4, Figure 5 & 8 H. McCoy pers. com.). A bat was observed flying down Bumboras Lane in August 1987 not far from the roost (McCoy 1987). A detector was placed adjacent to the tree at site D16 during the 2003 survey with no bat calls being recorded.

Roost 7, a senescent *Araucaria heterophylla* at Cutters Corn was used as a roost until at least the late 1960s

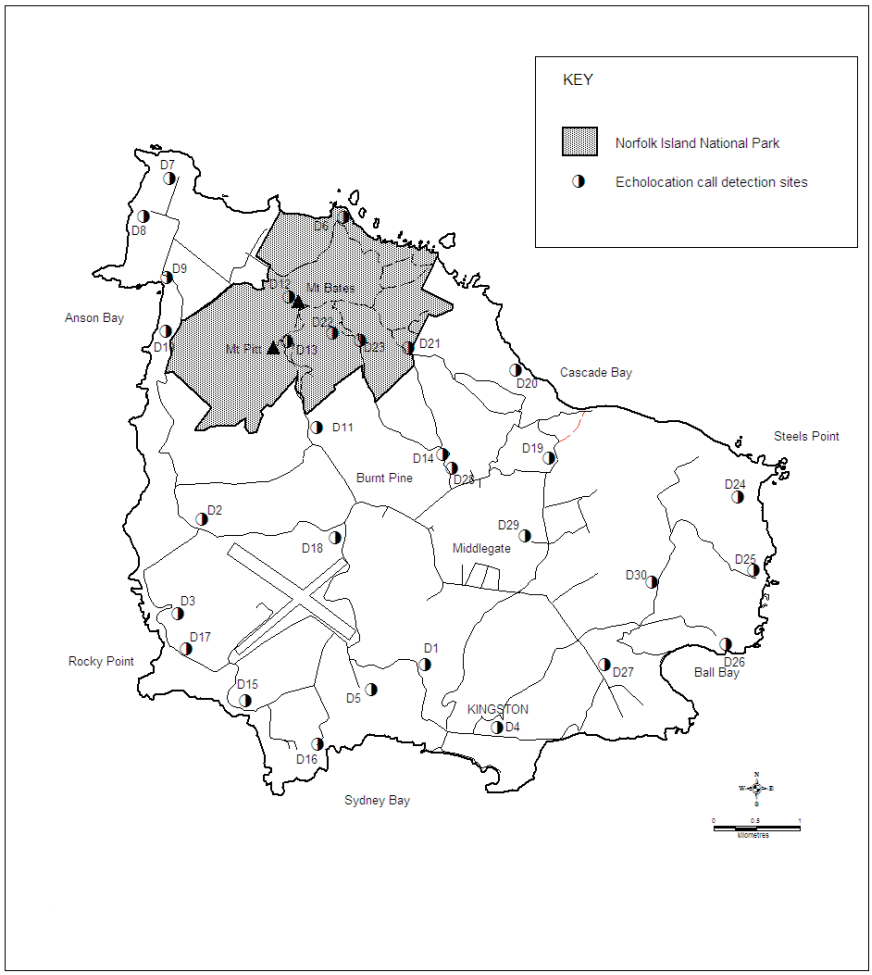

Figure 3. The location of detector sites sampled during February/March 2003.

(H. Knapton pers. com. 2003). The pine, which has been removed, had a hollow centre. Another senescent pine adjacent to the towers on Mt Bates was used as a roost until at least the late 1960s (Roost 6, Figures 4 &9 O. Evans pers. com. 2003). The top of the tree was subsequently snapped off in a storm and the roost would have been unsuitable after this. The tree has extensive hollowing and a large split now extends down the trunk. A detector was placed adjacent to the tree at site D12 during the 2003 survey with no bat calls being recorded.

From 1945 to 1976 bats roosted in a Cape Honeysuckle Vine at the home of Owen Evans at Burnt Pine (Roost 5, Figure 5 O. Evans pers. com. 2003). Judith Lorking observed bats flying from under her house also near Burnt Pine in 1997 (Roost 8, Figure 5 J. Lorking pers. com. 2003).

Records of an additional roost in a sea cave in an undisclosed location on Norfolk Island were subsequently provided by Harry Parnaby (H. Parnaby pers. com. 2008). An acquaintance who grew up on Norfolk Island, Charlie McCoy, recounted seeing a large number of bats in a sea cave as a boy prior to his leaving the island permanently during the 2nd World War.

Discussion

While no bats were captured on the island during the 1986 survey, the low level of survey intensity during this visit to the island made the capture of bats problematical. However, failure to observe bats flying at dusk during 1986 as well as a similar result in more widespread observations at dusk by Mary Gordon a few years earlier (Gordon 1983) suggested that by the 1980s bats were in very low numbers. No bat calls were recorded during the 2003 survey despite widespread sampling throughout the night across the island. This result also indicates that bats are in very low densities but does not prove that bats are extinct on the island. The detectors, while sampling all night, record bat calls over a small volume of space.

Table 5. Observations of bats by island residents and tourists.

Year of Observation	Observer	Comments
1930	Amy Bathie	Remembers bats at Cascade.
1935–1940	Owen Evans	Children took bats to school when he was a child.
1935–1945	Charlie McCoy	Large numbers of bats in see caves prior to 2nd World War.
1941	Jack Hayes	Lots of bats in two hollow pines at Steeles Point.
<1945	Owen Evans	Told by older person that bats roosted in the roof of a house at Steeles Point.
1948	Herbert "Wiggy" Knapton	Bats in hollow pine near Cutters Corn around 1948.
1960	Ken Christian	Bats observed flying at Anson Bay.
1955–1965	Honey McCoy	Many bats at Rocky Point Reserve in late 1950s and early 1960s.
–1965	Honey McCoy	Bats roosting in pine tree north of Bumbora Reserve until early 1960s.
1948–1969	Owen Evans	Bats roosting in hollow pine at Mt Bates.
1960s	Jack Hayes	Bat numbers dropped in 1960s.
1970	Wayne Boniface	Observed 6 bats west of Bumbora Reserve in 1970 when 10 years old.
1975	Wayne Boniface	Several bats observed at Ferny Lane near end of airport runway.
1958–1962	Yarm Menzies	Saw bats from 1958 to 1962 but doesn't remember bats from 1975.
1975	John McKean	Bats observed at Anson Point at dusk (observation related by Ken Christian).
1945–1976	Owen Evans	Bats roosting in a Cape Honeysuckle vine at family home.
1982	Lee Christian	Bats observed flying at dusk at Anson Bay Picnic area.
1985	Corn (?) Christian	Bats observed flying near Palm Glen.
1987	Honey McCoy	Bat flew past shoulder at Bumboras Road.
1995	Owen Evans	Saw and heard bats flying at dusk near campsite, Upper Long valley, Phillip Island.
1997	Judith Lorking	Bats roosting under house in 1997 seen flying out at dusk.
1997	Muchsin Russ	Bat flew along verandah of building at Quality Row, Kingston.
2002	Lisa Plant	Bat flying at dusk at Watermill Dam.
	Peter Davidson	Has been on Norfolk Island for 10 years without seeing any bats.
	Tom Greenwood	Has never seen bats.
	Lisle Snell	Has never seen bats.
	Ian Keiman	Has never seen bats.
	John Quintal	Has never seen bats.

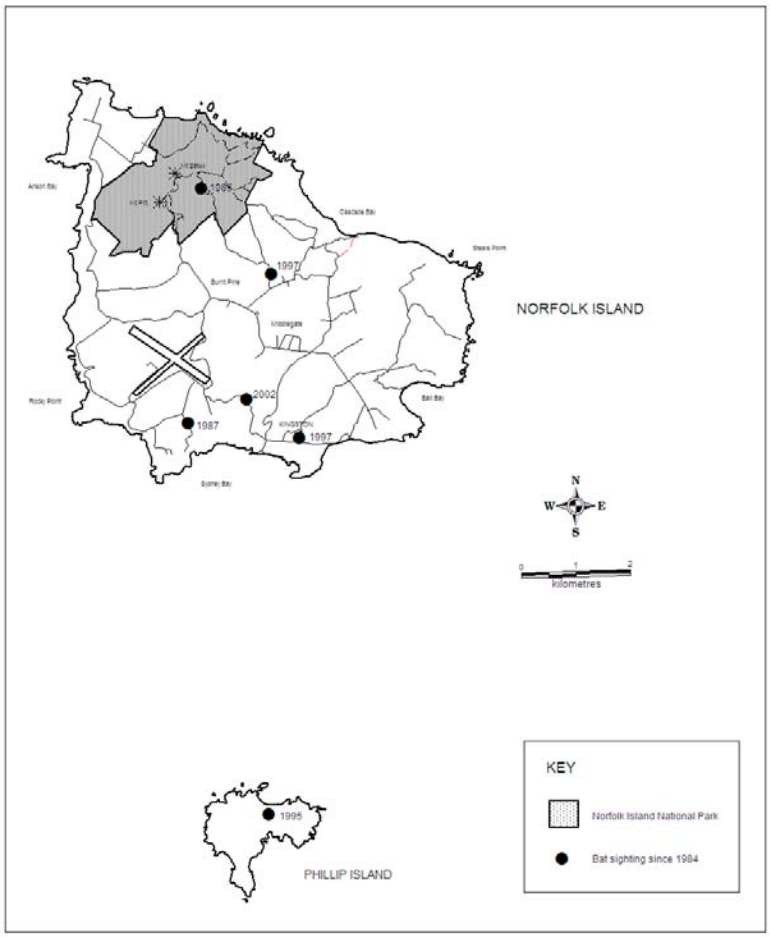

Figure 4. Recent sightings of bats by residents and tourists.

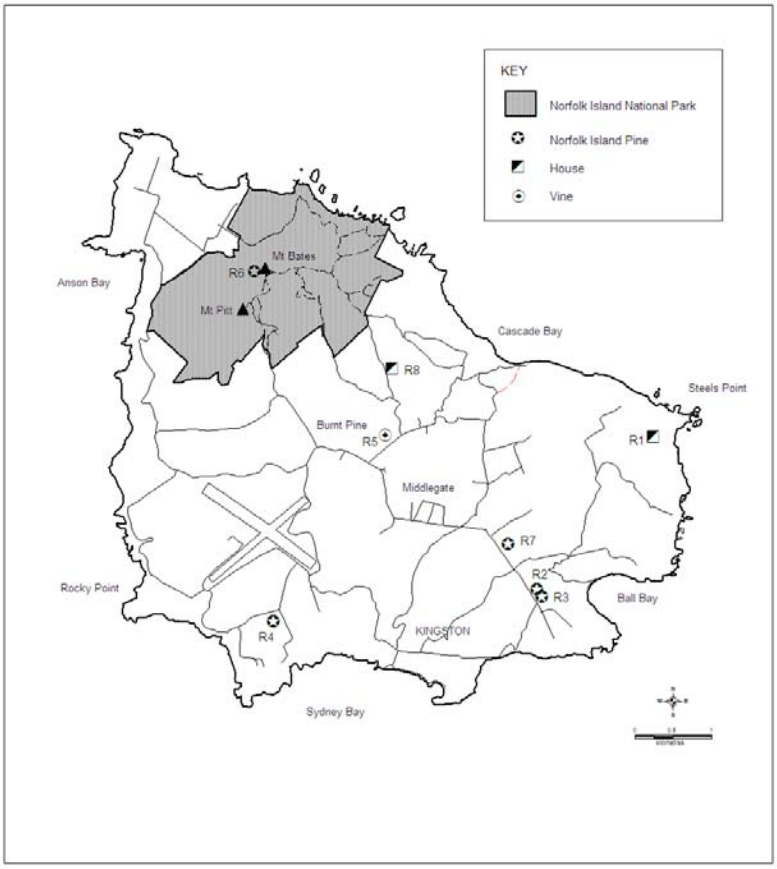

Figure 5. The location of bat roosts identified by island residents.

The probability of recording bats present in low densities during the survey would have been relatively unlikely. The weather deteriorated towards the end of the survey and this also is expected to have decreased the probability of detecting bats.

From the recollection of island residents, bats were still present on Norfolk Island in reasonably high numbers up until the Second World War, but by the 1960s, bats were in serious decline. By the mid 1980s bats were either extinct in most areas or in very low numbers on the main

Figure 6. The remaining stump of roost 2.

Figure 7. The remaining stump of roost 3.

Figure 8. Roost 4 in a paddock off Bumboras Road.

Figure 9. Roost 6 is at the summit of Mt Bates.

Table 6. Bat roosts identified by island residents and tourists during the 2003 survey.

Roost	Location	Informant	Type	Time of last use	Colony Size	Fate
1	Steeles Point	Owen Evans	Roof of house	<1945	?	Removed
2a	Ball Bay	Jack Hayes	Norfolk Island Pine	1960s	>50	Removed 2002
2b	Ball Bay	Jack Hayes	Norfolk Island Pine	1960s	>50	Removed 2002
3	Rocky Point Road	Honey McCoy	Norfolk Island Pine	Early 1960s	>50	Present
4	Burnt Pine	Owen Evans	Cape Honeysuckle Vine	1976	<50	Present
5	Mt Bates	Owen Evans	Norfolk Island Pine	Late 1960s	>50	Present, damaged in storm
6	Cutters Corn	Herbert Knapton	Norfolk Island Pine	?	?	Removed
7	JE Road	Judith Lorking	Under house	1998?	<50	Present

island. Sporadic sightings of small numbers or individual bats continued through the 1980s until 2002, when Lisa Plant observed a bat flying at Watermill Dam (Appendix 1). Sightings of bats within the decade prior to 2003 included individuals observed flying at dusk in Upper Long Valley, Phillip Island by Owen Evans in 1995, individuals roosting under the house of Judith Lorking north of Burnt Pine in 1997 and an individual observed hawking along the veranda of a building at Quality Row, Kingston in 1997 (O. Evans, J. Lorking & M. Christian local residents, pers. com. 2003). The sightings on Phillip Island are compelling as Owen Evans is a dedicated naturalist who had regularly encountered bats during his early years. While black rats *Rattus rattus* colonised Norfolk Island from a shipwreck in 1943 (Schodde *et al.* 1983), they did not reach Phillip Island. If rats are a major factor in the decline of bats on Norfolk Island, the continued presence of bats on Phillip Island until at least the mid 1990's is feasible. It is only 6.5 kilometres south of Norfolk Island and it likely to have been colonised by bats prior to European disturbance. While it escaped invasion by rats, the island was almost denuded by pigs, goats and rabbits. On this basis it would seem a poor candidate to support remaining bats. Some remnant trees do, however, remain on Phillip Island and may provide roosting and foraging habitat for a small microchiropteran bat population. Regeneration of the island following the removal of rabbits, pigs and goats continues and much of the island now has some form of vegetative cover.

Another potential impact raised by Jack Hayes (local resident, pers. comm. 2003) is the widespread use of herbicides to kill exotic plants after the Second World War. From the late 1950s, 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) were used extensively to kill guava and other invasive plants (J. Hayes pers. comm.). A dioxin, 2,3,7,8-tetrachlorodibenzo-para-dioxin (TCDD), is produced as a by product of the manufacture of 2,4,5-T, and was present in any of the herbicides that used it. Insectivorous bats are susceptible to the accumulation of a range of pollutants including DDT, DDE, Lindane and mercury (Boyd *et al* 1988, Clarke and Krnitsky 1983, Jeffries 1972). The effects of dioxin on bats has not been investigated, but its exposure to humans is increasingly considered detrimental. The National Toxicology Program has classified TCDD to be a human carcinogen, frequently associated with soft-tissue sarcoma, Non-Hodgkin's lymphoma, Hodgkin's disease and chronic lymphocytic leukemia (CLL). It is also considered an endocrine inhibitor, effecting reproduction in a range of species. Maruta *et al.* (2005) determined a 15% decrease in population of cormorant numbers over the period of their study due to the effects of dioxin and dioxin like PCBs. The period of use of the herbicides 24D and 245T in commercial use date from the late 1960s. This is also when a serious decline in bat numbers on Norfolk Island occurred. It is possible that the decline of bats after the 2nd World War is not solely due to rat predation.

The first record in 1915 of *C. gouldii* from Norfolk Island was an individual found roosting with others in a small tree in scrub (Troughton 1922). Eight roosts scattered across the island were identified by island residents during the 2003 survey. Of these, five were in mature or senescent pines. The bat utilising these roosts is presumed to be *C. gouldii*. Confirmed records of this bat date from the time of use of these roosts but it is possible *M. norfolkensis* or as yet unrecorded bat species were using some or all of the roosts. Long-eared bats *Nyctophilus* sp. occurred previously on Lord Howe Island to the southwest of Norfolk Island and currently exist on New Caledonia to the northwest (McKean 1975, Parnaby 2002). Nyctophiline bats use passive hearing, sight and smell to locate much of their prey through gleaning (Grant 1991), unlike *M. norfolkensis* and *C. gouldii* which catch all their prey on the wing. This behaviour results in less frequent and softer echolocation signals by *Nyctophilus sp*. than by those species that are constantly foraging in free space. Even if present they would be much less likely to be detected than *C. gouldii* or *M.norfolkensis* during a call detection survey such as the one I conducted during 2003. Without further concerted survey, we will probably never know the true situation unless bats are brought in by the public. The continued presence of bats on Norfolk Island is uncertain given the results of this study. It is recommended that further island wide surveys utilising harp trapping and ultrasonic call detection be undertaken as a matter of urgency. Sites should be surveyed across the island to maximise the probability of encountering individuals from small relict colonies. This should include Phillip Island where possible sightings were made of microbats in 1995.

Old Norfolk Island Pines were clearly an important communal roost resource for bats on the island until the 1960s. Many of these roosts would have been accessible to *R. rattus* and their use by bats ceased within two decades of the arrival of rats in the 1940s. A decline was also observed in a number of bird species and subspecies endemic to the island during this period (Schodde *et al.* 1983). The number of hollow-bearing pines that would be suitable as roosts on Norfolk Island has diminished dramatically since settlement of the island in 1788. An indication of the size of some of the trees at this time can be gained by the observations of Jacob Nagle who visited the island in March 1790 (Dunn 1988):

> The wood that groes on the island is in general pine, and they grow to a mazen highth and thickness. One tree was found, though but short, the top being blown off and sprouted again and hollow, which measured 25 fathom around.

If the measurement is accurate, this was an immense tree almost 46 metres in circumference, and probably the largest girthed tree ever recorded. The largest Kauri Pine recorded in New Zealand had a circumference of only 23 metres (Salmon 1996) while the largest girthed tree currently recognised on earth is a Montezuma Cypress in Mexico with circumference of 42.7 metres (Pakenham 2003). One of the largest pines currently in existence on Norfolk Island is conserved in the national park and has a circumference of 11 metres. Few mature or senescent pines now exist on the island as extensive clearing and logging over the past two hundred years has all but removed this age class of pines. While a significant area of forest is reserved in the national park, large pines are still removed in other areas when deemed a safety hazard. This was the case with the two past roost trees at Ball Bay which were cut down in 2002. All four pines identified as

former bat roosts were large senescent trees. Their exact age is unknown but it is likely they were growing prior to settlement of the island in 1788. The selection of suitable pines for roosting by bats has been diminishing yearly as mature trees are removed. This is likely to have placed additional stresses on bat populations on the island and may have impeded successful breeding.

No caves were inspected on the island during either of the surveys. The rugged nature of most of the coastline made such an undertaking unfeasible in the time available. The account of Charlie McCoy of bats being present in large numbers in a sea cave when he was a boy prior to the 2nd World War, if valid, would indicate that caves were used to some degree as roost sites. With the possible exception of isolated individuals neither *C. gouldii* nor *M. norfolkensis* use caves as roosts on mainland Australia (Hoye *et al*. 2008, Dixon & Lumsden 2008). Cave roosting would represent an island adaptation by either of these two species or alternatively the observations were of another unrecorded bat species. The Polynesian Sheathtail-bat *Emballoneura semicaudata* was previously widely spread across islands of the South-west Pacific including Fiji and Tonga (Flannery 1995). It is possible this or another unrecorded bat species utilised sea caves on Norfolk Island without specimens being collected and lodged in an institution. This, like many other facets of previous bat presence on Norfolk Island will probably never be known with any certainty.

A lack of secure roosts is likely to be a limiting factor on any remaining bats on Norfolk Island. If future surveys locate bats on the island, the provision of artificial roost boxes may be a means of increasing the number of available roosts. Both *C. gouldii* and *M. norfolkensis* are known to readily utilise artificial roosts on mainland Australia (Irvine and Bender 1995, Hoye 2004). Boxes could be placed on poles or trees that have metal skirting to prevent rats from climbing and accessing the boxes. Such a strategy may be sufficient for populations to recover if rats are indeed a significant cause of mortality.

If bats are determined to be no longer present on Norfolk Island or Phillip Island, a last resort could be the introduction of mainland Australian sourced *C. gouldii* and/or *M. norfolkensis*. The re-introduction of *C. gouldii* to Norfolk Island has previously been proposed (Tidemann 1986). This should not be considered until it is established with certainty that endemic populations are no longer present. While this would not establish a population of the same genetic structure as original populations, it may be beneficial from an ecological perspective. During the 2003 survey, high densities of an introduced moth species were present in pasture throughout the island. Increasing bat densities on Norfolk Island may assist in controlling this and other insect pest species.

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