# Measuring mortality in short-tailed bats *(Mystacina tuberculata)* as they return from foraging after an aerial 1080 possum control operation

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**Abstract:** Lesser short-tailed bats (*Mystacina tuberculata*) feed on arthropod taxa known to consume 1080 baits. Thus, they may be vulnerable to secondary poisoning after control operations for brushtail possum (*Trichosurus vulpecula*) using aerially broadcast 1080 baits. Short-tailed bat mortality was monitored during 11 days after 1080 baits were broadcast over their winter foraging area. Monitoring involved catching a sample of 269 bats as they arrived at a roost after foraging, then holding them in captivity for 48 hours. None of the captured bats displayed any symptoms of 1080 poisoning. Power analysis indicates that there was a $\geq 0.95$ probability of detecting mortality when the actual mortality rate was above 11.1 deaths per thousand foraging flights. Uncertainties in assumptions about the bats' behaviour mean that the overall population mortality corresponding to this minimum detectable mortality rate may range from 5.4 to 28.4%, with a best estimate of 14.4%. Although it can be concluded that this 1080 operation probably did not cause major mortality of short-tailed bats, several replicate trials are required before a generalised conclusion can be drawn about the fate of short-tailed bats following aerial 1080 operations. More information about short-tailed bat population demography is required to assess the impact of 1080 operations on population viability.

**Keywords:** 1080-induced mortality; aerial broadcast 1080; non-target mortality; power analysis; secondary poisoning; short-tailed bats; sodium monofluoroacetate.

## Introduction

The lesser short-tailed bat (*Mystacina tuberculata*) is endemic to New Zealand and is the sole extant species of the family Mystacinidae. The species is ranked as a Category A threatened species, i.e. having the highest conservation priority in New Zealand (Molloy and Davis, 1994). Populations of lesser short-tailed bats occur in many of the extensive areas (i.e. >10 000 ha) of unlogged old-growth forest remaining on the North Island mainland (Lloyd, 2001). Only two populations are known on the South Island mainland (Lloyd, 2001), one in North-west Nelson, the other in Fiordland.

Since the 1970s there have been many operations to control brushtail possum (*Trichosurus vulpecula*), an introduced pest species, in forests throughout New Zealand. The principal control method is by aerial broadcast of carrot or grain-based baits impregnated with the toxin sodium monofluoroacetate, 1080 (Department of Conservation, 1994; Livingston, 1994). Daniel (1990) suggests that because short-tailed bats are omnivorous and terrestrial broadcast toxic baits may be hazardous to the species. However, the results of both bait acceptance trials with captive short-tailed bats, and a trial in which fluorescent dyed non-toxic baits were broadcast throughout an area inhabited by short-tailed bats, indicate that short-tailed bats are unlikely to consume carrot or grain-based toxic baits (Lloyd, 1994). We measured concentrations of 1080 in arthropods collected from 1080 baits after a possum control operation (Lloyd and McQueen, 2000). The results of that study indicated that a short-tailed bat can receive a median lethal dose ($LD_{50}$) of 1080 from less than 0.7% of its daily food intake of arthropods that have fed on 1080 baits. Thus, short-tailed bats may be vulnerable to secondary poisoning via arthropods because they feed on many of the arthropod taxa (Lloyd, 2001) that feed on baits (Sherley *et al.*, 2000; S.M. McQueen and B.D. Lloyd, *unpubl.*).

The behaviour of short-tailed bats makes it difficult

to measure 1080-induced mortality following aerial broadcast of 1080. During late winter, when most possum control operations are undertaken, their activity is variable, with periods of torpor lasting for up to 10 days interspersed with brief bursts of activity (Lloyd, 2001). While in torpor the bats are inaccessible, roosting deep within crevices in tree trunks. Thus it is impossible to measure changes in the population level at the time of the 1080 operation.

Population levels were monitored during the summers before and after the 1080 operation. Treatment and non-treatment areas could not be established because individual bats are extremely mobile and there is no geographic partitioning of the population (B.D. Lloyd, *unpubl.*). The results of monitoring changes in summer population levels (to be published) can only provide weak inference about the levels of 1080-induced mortality. Monitoring radio-tagged bats was not attempted as experience with radio-tracking short-tailed bats indicates that the method could not provide conclusive evidence on the effect of 1080 operations, as poisoned bats are likely to die inside tree cavities where they would be inaccessible. When a radio-tag remains stationary inside a tree there is no way of telling what has happened: the radio-tag may have dropped off, the radio-tagged bat might be in torpor, or the bat might have died from poisoning or another cause.

This paper describes an attempt to measure the rate of 1080-induced mortality in a short-tailed bat population by monitoring the survival of samples of bats caught as they returned from foraging trips during an 11 day period immediately following a 1080 operation.

# Methods

### Study area and population

The study was undertaken within a 10 000 ha continuous tract of unmodified old growth *Nothofagus* forest on the southern slopes of Mt Ruapehu, central North Island, New Zealand (39°23' S, 175°30' E; 700-1200 m a.s.l.) (Fig. 1). The forest extends from Ohakune Mountain Road in the west, to Karioi pine plantation in the east. It is bordered by pine plantations and farmland along its southern lower edge and sub-alpine areas of Tongariro National Park in the north, and encompasses Rangataua Conservation Area and part of Tongariro National Park.

The forest is dominated by southern beeches *Nothofagus fusca* and *N. menziesii* throughout most of the area (Atkinson, 1981). At lower altitudes a variety of hardwoods and podocarps, especially rimu, *Dacrydium cupressinum*, are also present. At higher altitudes (> 1100 m a.s.l.) and on poorly drained soils in the west, the *N. fusca* and *N. menziesii* association gives way to a monotypic forest of *N. solandri* var. *cliffortioides*.

The results of simultaneous video counts of departures from all active colonial roosts during the summers of 1995-1999 indicate that a population of 6000–7000 short-tailed bats was resident in the area (Lloyd, 2001). Individual bats range widely throughout the entire forest area and there is no indication of any geographic or social partitioning within the population. In summer their activity extends into high-altitude montane forest, but during winter and early spring (i.e. June to September inclusive) when this study was undertaken, activity is restricted to low-altitude areas (< 900 m a.s.l.).

### Field methods

The work was undertaken during a large-scale possum control operation that involved aerial broadcast of 1080 baits on 30 August 1997 in the south-east of Rangataua Conservation Area. Toxic baits were broadcast over 2500 ha, encompassing almost the entire winter range of the bat population. Bait sowing rates were 5 kg $ha^{-1}$ for 1200 ha of lower altitude forest (< 900 m a.s.l.) and 3 kg $ha^{-1}$ for the remainder (Fig. 1). The baits were Wanganui No. 7 pollard (i.e. grain based) baits from Pest Control Services, Wanganui. The baits had a 0.15% toxic loading of 1080 and were cinnamon-lured and dyed green. Individual bait mass ranged from 4-6 g.

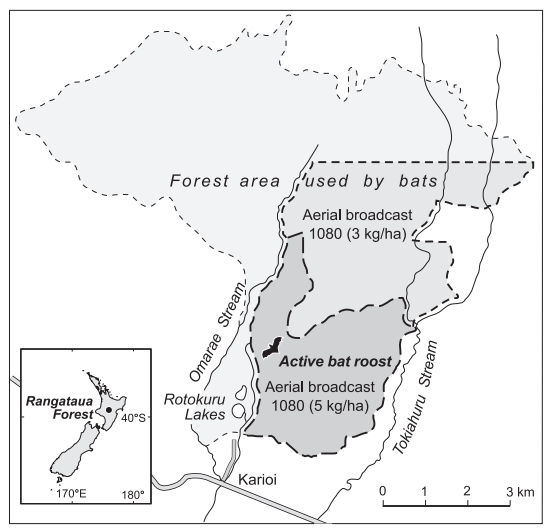


**Figure 1.** Map of the study area, which encompasses Rangataua Conservation Area and part of Tongariro National Park. The extent of the aerial 1080 operation is shown.

During the month before the poison operation, we identified sites within the proposed operational area where large numbers of bats could be caught easily (e.g. major flight paths or active colonial roosts). Areas with high levels of bat activity were sought by widespread survey with automatic bat monitoring systems (ABMS) (O'Donnell and Sedgeley, 1994). These systems can be left in place for several nights and will record echolocation calls from any short-tailed bat flying within 20 m. Active colonial roosts were sought both by tracking radio-tagged bats to their daytime roosts, and by inspecting known traditional colonial roosts. Nine bats were caught, radio-tagged, released, and radiotracked to their daytime roosts. The bats were caught in mist-nets at three sites in the operational area and released with miniature radiotransmitters (Holohil BD2A) attached to their backs using contact adhesive. Two days after being radiotagged, the bats' approximate daytime locations were determined by radiotracking from a Cessna 172 aircraft. The exact roost sites were found by radiotracking on the ground later on the same day. Crevices occupied by radiotagged bats, as well as all known traditional colonial roosts in the operational area, were monitored for bat activity by inspecting the roost entrances for fresh droppings and using hand-held bat detectors to detect activity within the roost during the late afternoon. Where there was any doubt whether a site was an active colonial roost it was monitored for a number of nights with either a night-time video surveillance system or an ABMS.

A target sample size of 500 bats was chosen using the power analysis method discussed below. The bats were caught as they returned from foraging during the period after the 1080 operation when toxin was available for consumption by the bats (i.e. the exposure period). They were caught both in mist-nets close to an active colonial roost, and using a harp-trap at the roost entrance. Capture efforts began in the evening 90–120 minutes after the end of civil twilight, when most bats are returning to roost after foraging. Mist-nets were placed at two sites. A single rig with three 6 m long nets was 10 m from the roost, and two rigs, each with three 12 m long nets were *c.* 100 m from the roost. The harp- trap was hung in front of the roost entrance, orientated radially to the main trunk of the tree. This is the best orientation for catching short-tailed bats entering a roost, as before entering, bats usually fly across the roost entrance several times. The harp-trap was modified to make it suitable for trapping large numbers of bats at a roost entrance. The trap was smaller (catch area 1 x 1.2 m) than standard harp-traps, making it easier to haul, and the vertical tubes were bolted to the frame's base so that hanging did not affect the mono-filament tension. The catch-bag (Fig. 2) was designed to reduce handling time when removing bats. It was made from thick transparent plastic with the base sloping at 45º to a 100 mm diameter tube in the centre. Bats slide through the tube into a detachable holding-bag, which can be quickly replaced with minimal interference to trapping.

After capture, the bats were held for 48 hours to monitor them for symptoms of 1080 poisoning. Two enclosures were used to keep bats caught on different nights separate. Each enclosure comprised a flight cage 1.2 m x 2.4 m and 2.15 m high with an adjoining roost area 1.2 m x 0.8 m and 2.15 m high. The walls and ceiling of the flight cages had internal linings of nylon fly-mesh to avoid damage to the bats' wings. Fresh food (mealworms, i.e. *Tenebrio* larvae, and 30% honey water solution) and water were provided each night. The bats were released into the enclosure at night, between 2 h and 5 h after capture. They were released individually so that each bat could be observed for unusual behaviour. The flight cage and the roost area were inspected on the following day for any dead bats or bats behaving abnormally. On the second day the bats were recaptured, their individual details (sex, age and reproductive status) recorded and each bat was marked with black hair-dye (Wella Bellalady) to identify the date of capture. The bats were released close to the

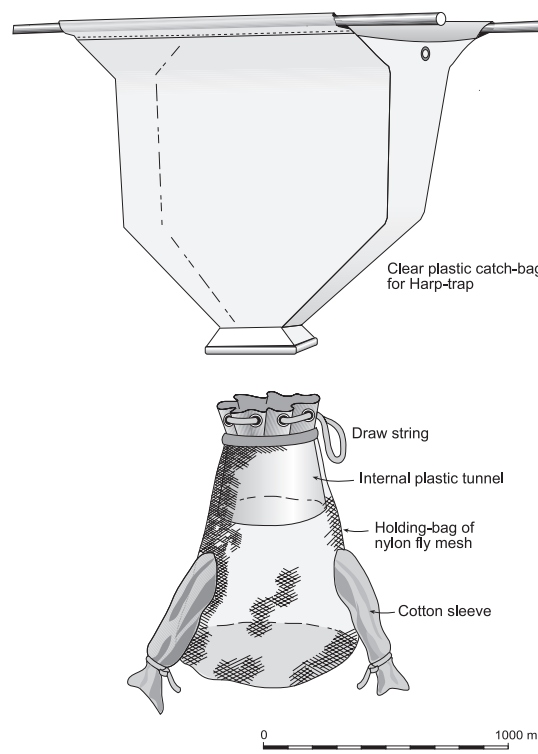


**Figure 2.** Modified catch-bag and holding-bag for a harp-trap, to allow continuous trapping at roost entrances.

original capture location on the evening of the second day, approximately 48 hours after capture.

The incidence of 1080 poisoning in the sample of bats caught during the exposure period provides an estimate of the mortality rate per foraging flight. Overall mortality from 1080 poisoning depends on the number of foraging flights bats make during the exposure period. Overall mortality ($d$) was calculated from the mortality rate per foraging flight ($m$) using $d=1-(1-m)^f$, where $f$ is the average number of foraging flights by bats that survive the exposure period. Direct estimation of the number of foraging flights is difficult because of the bat's intermittent activity during the hibernal period (Lloyd, 2001) and was not undertaken. Indirect estimation was undertaken by determining the length of the exposure period and monitoring night-time weather conditions to identify nights suitable for foraging. The length of the exposure period was determined by measuring the concentrations of 1080 in samples of baits collected from the study area at intervals following the 1080 operation (Lloyd and McQueen, 2000). During their hibernal period bats will not forage when night-time temperatures drop to 0°C or lower, or during persistent rain. Temperatures were recorded with a temperature logger placed 1.5 m above the ground in a shady spot in the forest within the operational area. Rainfall was measured with a tipping bucket rain gauge and datalogger located in open farmland approximately 9 km west of the study area at a site with similar aspect and altitude to the operational area.

**Data analysis**

Power analysis was used both to determine the target sample size and as an aid to interpreting the results of the trial. Data from this trial were analysed using a one-tailed binomial test. The null hypothesis is that no bats died of 1080 poisoning, i.e. $H_0$: $m = 0$, where $m$ is the 1080-induced mortality rate per foraging flight. The alternative hypothesis is $H_A$: $m > 0$. The $\alpha$ error is zero, because $H_0$ will never be rejected if it is true. The power of the trial (the probability of correctly rejecting $H_0$ when it is false) is the probability of catching one or more poisoned bats. This can be calculated as $Power = 1 - P(0)$, where $P(0)$ is the probability of not catching any poisoned bats. If $n$ is the sample size, $P(0) = (1 - m)^n$ and $Power = 1 - (1 - m)^n$. Rearranged as $m = 1 - (1 - Power)^{\frac{1}{n}}$, the equation can be used to calculate minimum detectable mortality rates for different powers and sample sizes.

# Results

Eight days before the poison operation, 200 mm of snow fell. Although most of the snow-cover melted within four days, patches persisted in shady spots throughout the study area until three days after the operation. The implications of the snowfall are discussed later in this paper. The aerial broadcast was successful with good coverage throughout the operational area (John Luff, Department of Conservation, Ohakune, N.Z., *pers. comm.*).

At the time of the poison operation, large numbers of bats were using a traditional colonial roost tree within the operational area (Fig. 1). Monitoring with a night-time video surveillance system showed that when the roost was occupied and weather conditions were suitable around 200 bats left the roost during early evening and began returning about 1h later. Radiotelemetry of radio-tagged bats indicated that over a period of several days the roost was visited by a much larger number of individuals. The identity of bats occupying the roost during the day varied from day to day, and on warm evenings bats using the roost during the day and others roosting elsewhere congregated at this roost after foraging. Radiotracking also demonstrated that bats using this roost dispersed over a wide area of forest, both for foraging and to use other daytime roosts. All trapping for the trial was undertaken at, or close to, this roost as bats caught there are likely to be a representative sample of bats active in the operational area.

**Table 1.** Numbers of short-tailed bats caught during 11 days after the 1080 operation.

| Nights after the 1080 operation | Number of bats caught |
|---|---|
| 1 | 52 |
| 2 | 90 |
| 4 | 68 |
| 9 | 0 |
| 11 | 65 |
| Total | 269 |

Trapping was undertaken on five of the first 11 nights after the poison operation. A total of 269 bats were caught and held in captivity for at least 48 hours (Table 1). All 269 bats survived and were released without any unusual behaviour being noted. The estimated mortality rate is zero, with the 95% confidence interval enclosed by an upper limit of 11.06 deaths per thousand flights. The null hypothesis that no bats died of 1080 poisoning ($H_0$: $m = 0$) is not rejected, and the minimum detectable mortality rate is 11.07 deaths per thousand flights with $Power = 0.95$ (Table 2). The difference between the minimum detectable mortality rate and the 95% confidence limit arises from inaccuracies in the tables used to compute the confidence limit (Zar, 1984).

Two bats were released without details being recorded. Of the remaining 267 bats 64% were female and 36% male. Most (67%) of the females were

**Table 2.** Estimates of the detectable mortality rate and detectable overall mortality for actual (269) and target (500) sample sizes when the power of the trial is 0.95.

| Sample size | Detectable mortality rate (deaths per 1000 flights) | Detectable overall mortality (%) for different numbers of foraging flights (*f*) | | | | |
|---|---|---|---|---|---|---|
| | | *f* = 5 | *f* = 10 | *f* = 14 | *f* = 20 | *f* = 30 |
| 269 | 11.07 | 5.4 | 10.5 | 14.4 | 20.0 | 28.4 |
| 500 | 5.97 | 3.0 | 5.8 | 8.0 | 11.3 | 16.5 |

nulliparous and were therefore young bats, probably less than three years old. Weighing individuals at capture was impracticable because of the large numbers of bats caught, but during initial handling all bats produced copious droppings which indicated they had already fed that evening. There was only one recapture: a parous female, originally caught on the second night and released on the fourth night, was recaptured on the eleventh night.

Levels of 1080 in the baits declined slowly from 0.156% at the time of broadcast to 0.07% 17 days after broadcast, when a period of sustained rain accelerated bait breakdown and detoxification (Lloyd and McQueen, 2000). High concentrations of 1080 can persist in arthropods for 4 days after they consume 1080 baits (Booth and Wickstrom, 1999; Eason *et al.*, 1993). The estimated exposure period to secondary consumption of 1080 via arthropods was therefore 21 nights.

There were only 14 nights during the 21 nights of the exposure period when weather conditions were suitable for foraging: activity was curtailed by low temperatures on six nights, and heavy rain on one night (Fig. 3). Echolocation call rates recorded on an ABMS 500 m from the active roost tree confirmed this pattern of activity for the first 11 nights of the exposure period (Fig. 3). Radiotelemetry shows that at this time of year (early spring) individual bats usually only leave their roosts to forage once a night. Thus, the best estimate of the average number of foraging flights by bats that survive the exposure period (*f*) is 14. With *f* = 14 the overall mortality level corresponding to the minimum detectable (*Power* = 0.95) mortality rate of 11.07 deaths per thousand flights is 14.4% (Table 2). Unfortunately, because of inadequate knowledge about the proportion of the population active and the number of foraging flights on each night, even the best estimate for *f* is not reliable. Values of *f* may range from 5 to 30, the corresponding overall mortality levels range from 5.4% to 28.4% (Table 2).

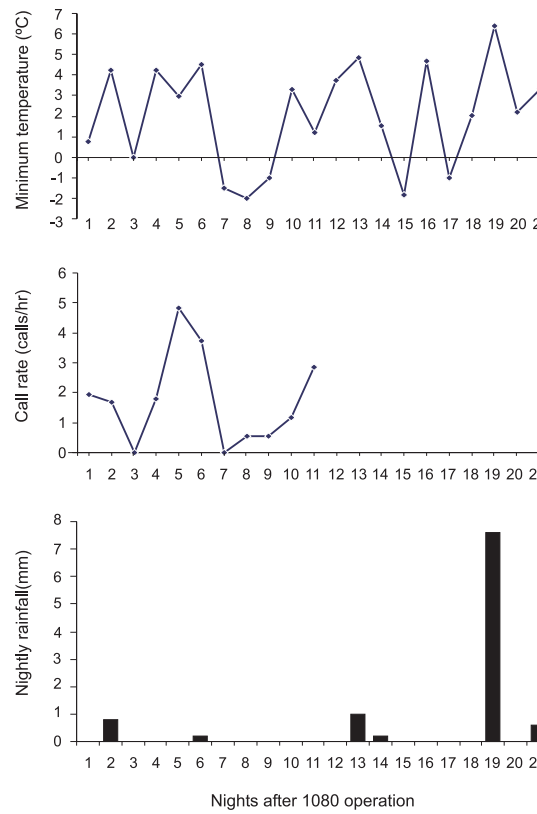


**Figure 3a.** Minimum overnight forest temperatures during the 21-night exposure period following the poison operation.
**Figure 3b.** Short-tailed bat echolocation calls per hour for the first 11 nights of the exposure period.
**Figure 3c.** Total overnight rainfall during the 21-night exposure period following the poison operation.

# Discussion

Failure to detect 1080 poisoning in any of the 269 bats caught during this trial is surprising. We have previously found strong, though inferential, evidence for the occurrence of secondary poisoning of short-tailed bats after aerial 1080 operations (Lloyd and McQueen, 2000). Before concluding that there was no 1080-induced mortality in the bat population in Rangataua Forest, it is necessary to consider the assumptions underlying the method as well as the power of the trial to detect 1080-induced mortality.

The most important assumption is that the latent period for 1080 (the time between ingestion of 1080 and the onset of symptoms) is long enough for bats to be captured at the roost after foraging, but less than the period the bats were held in captivity (48 h). Under this assumption bats would show symptoms or die during captivity but not during the period before capture. There are no estimates of the latent period for 1080 for any bat species. McIlroy (1986), in a comparison between major groups of animals, concludes that there is considerable inter- and intraspecific variability in latent periods for 1080. The best available predictor of the short-tailed bat's latent period is the range of latent periods published for eutherian mammals, 0.4-48 h, derived from 250 individuals belonging to 22 species (McIlroy, 1981 1982a, b, 1983). These latent periods were determined using orally administered solutions of 1080 in distilled water, and are likely to be shorter than the latent periods for 1080 ingested in arthropods because of faster absorption of 1080 from water than arthropod tissues. The results of video monitoring at the roost entrance and radiotelemetry indicate that individual short-tailed bats usually forage for about 1 h in the early evening before returning to roost. Thus, available information indicates that although the 48 h holding period is sufficient to identify any cases of poisoning in the captured bats, symptoms of 1080 poisoning may occasionally begin before poisoned bats return to the roost.

Failure to reject the null hypothesis, i.e. no bats died of 1080 poisoning, does not mean it should be accepted as true. In this trial the minimum detectable mortality rate (*Power* = 0.95) was 11.07 deaths per thousand flights. Thus, there is a 0.05 probability (i.e. the $\beta$ error) of failing to detect any mortality when the true mortality rate was 11.07 deaths per thousand foraging flights. This corresponds to an overall mortality of about 14.4% (range 5.4-28.4%). The probability of failing to detect lower levels of mortality is greater than 0.05. If the target sample size of 500 had been achieved the magnitude of the minimum detectable mortality rate and corresponding overall mortality would have been halved (Table 2).

For conservation management purposes the important question is not whether any bats died of 1080, but whether 1080 had a significant impact on the viability of the population. The results of this trial mean this question should be recast as: would a mortality level less than the minimum detectable mortality rate have a significant impact on the population's viability? The paucity of demographic data on short-tailed bats precludes rigorous treatment of this question. It seems likely that a single mortality episode of 14.4% (the best estimate for the minimum detectable overall mortality) will not have a major impact on a viable population of short-tailed bats. Multiple mortality episodes of this magnitude resulting from repeated 1080 operations at short intervals could have consequences on the population's viability. A single episode of 28.4% mortality (the higher end of the range of overall mortality estimates) would be of concern. More information about short-tailed bat population demography is required for rigorous assessment of the impact of 1080 operations on population viability.

Although it is reasonable to conclude that this 1080 operation probably did not cause major mortality of short-tailed bats in Rangataua Forest, the trial was unreplicated. Several replicate trials would be required in a variety of circumstances before a valid generalised conclusion could be drawn about mortality of short-tailed bats during aerial 1080 operations. The results of this trial might be atypical as the heavy fall of snow 8 days before the poison operation reduced arthropod activity markedly for most of the trial period (S.M. McQueen and B.D. Lloyd, *unpubl.*).

The method described here provides a reliable method for measuring 1080-induced mortality rates in short-tailed bat populations when 1080 operations are undertaken during the bats' hibernal period. Larger sample sizes, and direct measurement of both the average number of foraging trips during the exposure period and the length of early-evening foraging sessions would provide a more robust basis for the method. When 1080 operations are undertaken outside of the hibernal period direct measurement of changes in the population by video counts of roost departures may be a more appropriate method.

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