Power to detect trends in abundance of long-tailed bats (*Chalinolobus tuberculatus*) using counts on line transects

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Colin F.J. O'Donnell and Steve Langton

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Colin F.J. O'Donnell[1] and Steve Langton[2]

[1]Southern Regional Science Centre, Department of Conservation, PO Box 13049, Christchurch, New Zealand

[2]Ministry of Agriculture, Fisheries and Food, Central Science Laboratory, Sand Hutton, York, YO41 1LZ, United Kingdom

ABSTRACT

The statistical power of sampling regimes to detect significant changes in abundance has received little attention when designing bat-monitoring programmes. Put simply, power is a statistical measure of the risk of not detecting a trend in a population when one actually exists. Failure to identify trends with confidence could mean that populations heading towards extinction go unrecognised. Adequacy of monitoring programmes depends on interactions between sample size (number of counts), duration (years of monitoring), frequency of surveys, and the ability to control variability in counts because of other factors (e.g. weather). If the power of monitoring programmes is not assessed, researchers run the risk of wasting resources from the outset because the sampling regime may be inadequate to detect trends with confidence. We provide a case study of the application of power analysis to designing long-term monitoring programmes for the long-tailed bat (*Chalinolobus tuberculatus*), a threatened species from New Zealand. We calculated random variation within and between transects and years from a pilot study, and used a route-regression technique incorporating individual error terms to estimate power. Counts of *C. tuberculatus* are inherently variable, even after standardisation of counts, so obtaining sufficient power to detect changes in abundance demands large sample sizes or long-term monitoring programmes. We provide power figures that can be used by conservation managers to choose options for designing programmes. Given that resources are usually limited, in most situations we recommend that programmes should achieve 80–90% power, aim to measure population changes in the order of 3–10% per year, monitor 50–100 transects once per year per study area, and should run for >10 years.

Keywords: power analysis, monitoring, bats, transects, *Chalinolobus tuberculatus*, New Zealand

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1. Introduction

The range and abundance of the long-tailed bat (*Chalinolobus tuberculatus* Vespertilionidae) has been reduced significantly since the arrival of humans in New Zealand and the taxon is classed as Vulnerable by the IUCN (O'Donnell 2000a). Developing techniques to survey for long-tailed bats and to monitor their numbers is a priority for this threatened species (Molloy 1995). Monitoring will enable declining populations requiring active conservation management to be identified and allow the response of these populations to conservation initiatives to be evaluated (O'Donnell 2000b, 2002; O'Donnell & Sedgeley 2001).

Developing techniques for monitoring trends in bat populations is particularly challenging (Gannon & Willig 1998; O'Shea & Bogan 2000). Bats are highly cryptic and nocturnal so it is difficult to count them directly, except sometimes at roost sites (e.g. Degn 1987; Kowalski & Lesinski 1991; Weinreich & Oude Voshaar 1992). For example, long-tailed bats primarily roost in cavities in old-age trees within rainforest and both foraging areas and roost sites of colonies are widely distributed in the landscape (>100 km^2; O'Donnell 2001a; Sedgeley & O'Donnell 1999a, b). Because they move to new roosting trees virtually every day, the pool of roosts used by a colony can number in the hundreds (O'Donnell & Sedgeley 1999). It is rare for all members of a colony to occur in the same roost cavity (O'Donnell 2000c). Thus, trying to monitor mobile populations like this at their roosts is expensive and can be misleading. Consequently, bat researchers often index bat activity indirectly using ultrasonic detectors at foraging grounds (e.g. Helmer et al. 1987; Walsh et al. 1993; Boonman 1996; Walsh & Harris 1996a,b; O'Donnell 2000a,b).

The identification of statistically significant changes in animal populations can be problematic (Macdonald et al. 1998; Toms et al. 1999). Variability of counts associated with time, climate or sampling error can cloud the identification of real changes in abundance. Counts of bat passes on their foraging grounds are inherently variable so appropriate multivariate analyses are essential (Walsh & Harris 1996a,b; Vaughan et al. 1997; Verboon 1998; O'Donnell 2000b; Roche & Elliott 2000). However, the power of sampling regimes to detect significant changes in abundance has received little attention when designing bat-monitoring programmes (but see Walsh et al. 2001). Monitoring programmes should have a high probability of detecting ongoing trends in populations once all other factors influencing counts are taken into account (Taylor & Gerrodette 1993; Gibbs & Melvin 1997).

Put simply, power is a statistical measure of the risk of not detecting a trend in a population when one actually exists. Failure to identify trends with confidence could mean that populations heading towards extinction go unrecognised. Adequacy of monitoring programmes depends on interactions between sample size (number of counts), duration (years of monitoring), frequency of surveys, and the ability to control variability in counts because of other factors (e.g. weather). Specifically, power is defined as $(1 - \beta)$ where β is the probability of wrongly accepting a null hypothesis when it is actually false

(Type II errors; Gerrodette 1987; Fairweather 1991). Increasing power creates a trade off against the possibility of a Type I error (i.e. saying a trend exists [$P = \alpha$] when it does not). Setting conservative α levels ($p < 0.05$) lowers the power to detect trends, but guards against wrongly alerting managers to significant population declines, which might not exist.

Power is often expressed as a percentage. For example, if power = 90%, this means the statistical power of the monitoring programme is 90% to detect a population trend of a specified magnitude. Put another way, this means a Type II error (failure to detect a biologically significant trend) will be avoided with a probability of 0.9. A good introduction to power analysis can be found on the United States Geological Survey web site http://www.mp1-pwrc.usgs.gov/powcase/.

Monitoring programmes must aim to maximise accuracy and minimise the possibility of wrong conclusions being drawn about trends. Type II errors can be costly for conservation managers. If a significant decline in a threatened species is not identified, then the population may decline beyond a threshold where recovery is possible. In contrast, if managers respond to a perceived decline that is not real (managing a species that is not endangered), then resources may be wasted in the short term, but the 'false alarm' is likely to be recognised. If sample sizes and survey frequencies are insufficient, a monitoring programme will fail to provide the precision needed to detect population changes over time (Walsh et al. 2001). In short-term studies based on few years data there is only a small probability that a trend would be detected even if an actual trend existed (Hayes & Steidl 1997). If the power of monitoring programmes is not assessed, researchers run the risk of wasting resources from the outset because the sampling regime may be inadequate.

This study provides a case study of the application of power analysis to designing long-term monitoring programmes for bat populations. Specifically, the study uses indices of activity levels of long-tailed bats on their foraging grounds to investigate the ability of the programme to detect significant changes in abundance. Recommendations are made regarding (a) sampling intensity and frequency, (b) duration of the monitoring programme, and (c) expected levels of population change such a programme could detect.

2. Study area

The study was conducted in the lower Eglinton Valley, Fiordland, in the South Island, New Zealand (44°58′S, 168°01′E). Long-tailed bats are common throughout the valley (O'Donnell 2000a,b). The valley is long and narrow, with a road down the centre and mountains up to 2000 m high on either side. Temperate rainforest dominated by beech (*Nothofagus* spp.) covers gentle terraces, outwash fans on lower hill-slopes, and steeply rising mountain slopes up to the timberline at 1000–1200 m a.s.l. (Sedgeley & O'Donnell 1999a).

3. Methods

3.1 TRANSECT SURVEYS

A preliminary monitoring programme was conducted from 1992 to 2000. A series of 50 transects throughout the study area were surveyed biannually (October and February) Transects followed representative routes that crossed each 1000 m grid square (NZ Map Series 260) in the valley. Consequently most transects were c. 1 km in length, although a few were shorter because a safe route across the grid square could not be found. Transect placement was not random, but followed accessways (roads and tracks) across the grid squares. Transects were undertaken in blocks of 4–6 per night per observer. The aim was to sample a large geographic area in a relatively short time span. Transects were undertaken in summer during the first two hours after sunset while the weather was fine (clear, partly cloudy, or overcast, but no rain or strong winds) and the temperature was >7°C. Transects were walked slowly (c. 3 km/hr). Number of "bat passes" on each transect was recorded. A bat pass was defined as a sequence of greater than two echolocation calls as a bat flew past the microphone (Furlonger et al. 1987). A sequence of audible clicks followed by a pause delineated each bat pass. There was little probability of detecting short-tailed bats (*Mystacina tuberculata*), the only other bat present in the valley, on transects, or getting their call confused with long-tailed bats if they were detected because their calls were different (O'Donnell et al. 1999; O'Donnell 2000b).

3.2 POWER ANALYSIS

Counts from the preliminary monitoring programme in the Eglinton Valley were used as a basis for power analysis. Bat passes per kilometre were log-transformed and Residual Maximum Likelihood (REML, Genstat 5 Committee 1993; Robinson 1987; Verboom 1998) was used to estimate different sources of variability in the data (Table 1). Four sources of variability were examined: (a) variation between transects that was consistent among years (Site); (b) variation in trend between transects (Site.trend interaction); (c) year-to-year variation within sites (Site.year interaction); and (d) variation in transect counts within years within sites (Residual variation). The variance components from REML analyses were used to calculate the expected variation in the estimate of

TABLE 1. ESTIMATED VARIANCE COMPONENTS AFTER RESIDUAL MAXIMUM LIKELIHOOD (REML) ANALYSIS OF EGLINTON VALLEY TRANSECT SURVEYS, 1992–2000.

RANDOM TERM	COMPONENT ± SE	EXPLANATION OF VARIATION[1]
Site	0.0329 ± 0.0103	= transect
Site.trend	0.0017 ± 0.0011	Variation in trend between sites
Site.year	0.0000 ± 0.0155	Variation between years within sites
Residual	0.2822 ± 0.0194	Transects within years within sites

[1] See Section 3.2 for greater detail.

linear trend using the standard rules for calculating the variance of a linear combination of random variables (Walsh et al. 2001). Variance components used in the power analysis were those calculated from analysis of combined results from October and February surveys.

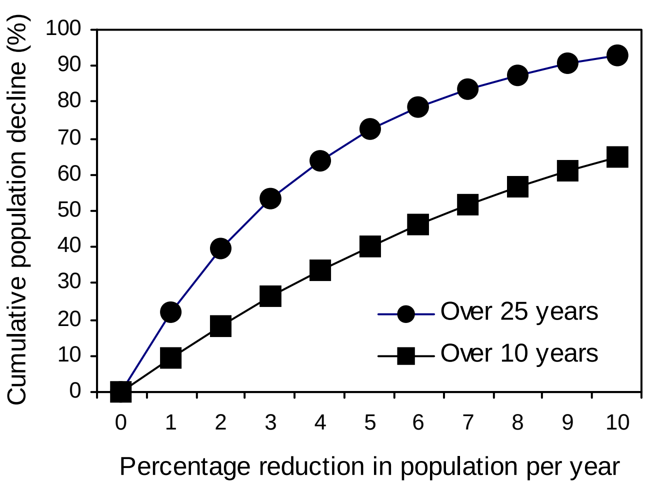
We used route regression (Sauer & Drogue 1990; Gibbs & Melvin 1997), to calculate the power of long-tailed bat transect counts to detect population changes. All sites were weighted equally and two-sided tests (to examine either upward or downward trends) were used, with a more liberal α level of 10% (P = 0.1). MacDonald et al. (1998) considered P = 0.1 an 'early-warning' significance level. The probability (power) of detecting a trend was then assessed using the t-distribution function. These results were confirmed for a subset of the factor combinations by direct simulation of data from a log-normal distribution with variances equal to the REML estimates at each level of variation. The technique differed from other power analyses that involve route regression (e.g. Program MONITOR, Gibbs 1995) in its ability to examine the influence of different sources of variation in the counts, such as the possibility of variation in trend within sites, calculated from pilot studies. In contrast, MONITOR simulates the situation where all sites follow exactly the same linear increase or decline.

Variance components were incorporated into an easy-to-use Microsoft Excel 97 spreadsheet developed by S. Langton (Batpower2.xls, Version tr2.1). Variance components and their interactions were easily manipulated to investigate their relative effects on power through simulations. We explored the influence of variability of counts and interactions of sample size and frequency of surveys, on power to detect population changes of different magnitudes.

3.3 LEVELS OF POPULATION DECLINE

Power of monitoring programmes varies depending on the level of population decline that conservation managers wish to detect (e.g. Gibbs & Melvin 1997; Van Strien et al. 1997). In this paper we examine power to detect a range of population declines based on general conservation practice (Fig. 1). Mace & Lande (1991) proposed that population declines in the order of >1–2%/yr equated to unacceptable probabilities of extinction in many animals and IUCN (1999, 2001) uses declines of >10% over 10 years to identify alert levels for threatened species. In this paper we examine the influence of sample sizes required to detect annual declines of 1.14% (= 25% cumulative decline over 25 years), 2.73% (= 50% cumulative decline over 25 years), and more catastrophic annual declines of 5% (= 72% decline over 25 years), and 10% (= 93% decline over 25 years) (Fig. 1).

Figure 1. Potential cumulative population decline by 10 and 25 years of annual population declines of 0–10% per year.



4. Results

4.1 INFLUENCE OF SAMPLE SIZE, FREQUENCY OF SURVEYS, AND YEARS OF MONITORING ON POWER

Indices of bat activity from the pilot study were variable despite standardising transect counts (Fig. 2) and the estimated variance components and standard errors of all components were high (Table 1).

Number of years of monitoring needed to obtain sufficient power to detect population trends was dependent on sample size. The greater the sample size achievable, the greater the power to detect trends over shorter time frames. Monitoring could detect 5% and 10% annual declines in long-tailed bat populations with 90% power with samples of <100 transects per study area in <10 years (9–10 years and 5–6 years respectively; Fig. 3A). In contrast, much larger sample sizes (>500 transects) were required to obtain 90% power to detect declines of 2.73%/yr in a similar time period (Fig. 3A). If monitoring in a study area was limited to <100 transects then it would take >15 years to attain 90% power to detect declines of 2.73% per annum. However, if number of transects were doubled (n = 200), it should take 9–10 years (2 surveys/yr) or 12–13 years (1 survey/yr) to achieve 90% power. Very large samples were required to attain 90% probability of detecting 1.14% annual declines (e.g. n = 9840 over 5 years monitoring to n = 281 in 25 years).

Sample sizes for achieving lower power (80%; Fig. 3B) were smaller, though the difference with Fig. 3A was negligible. For example, if 100 transects were surveyed annually, the programme would achieve 80% power to detect declines of 2.73% per annum in 13–14 years (two surveys/yr) compared with >18 years to achieve 90% power.

Undertaking two surveys per year increased the power to detect declines (Fig. 3). However, if monitoring continues for >15 years, then this difference became negligible.

Figure 2. Mean number of long-tailed bat passes/km (± 95% Confidence Intervals) for (A) October and (B) February surveys, Eglinton Valley, 1992–2000.

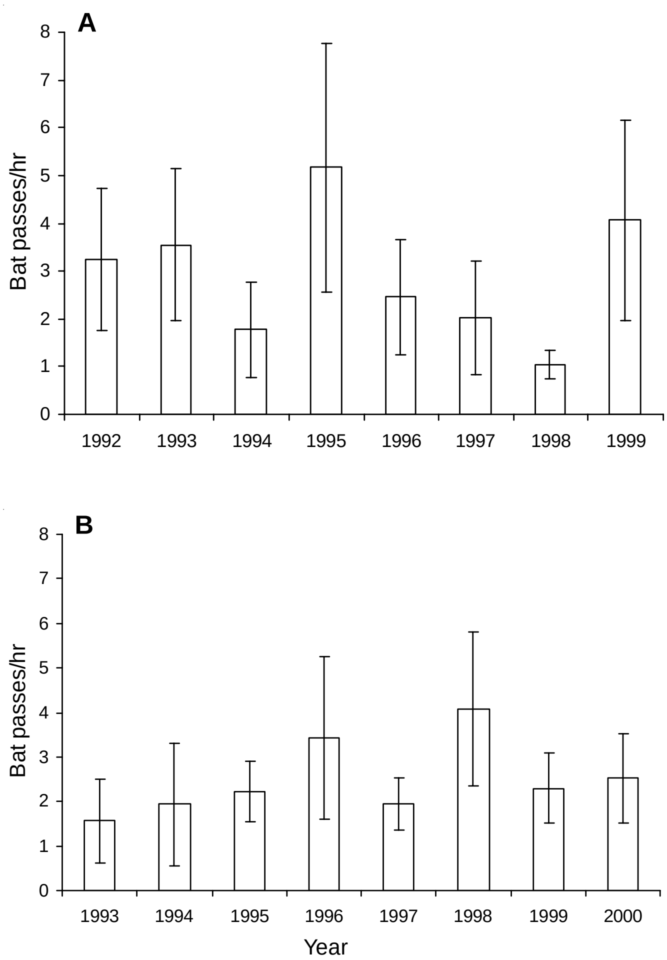
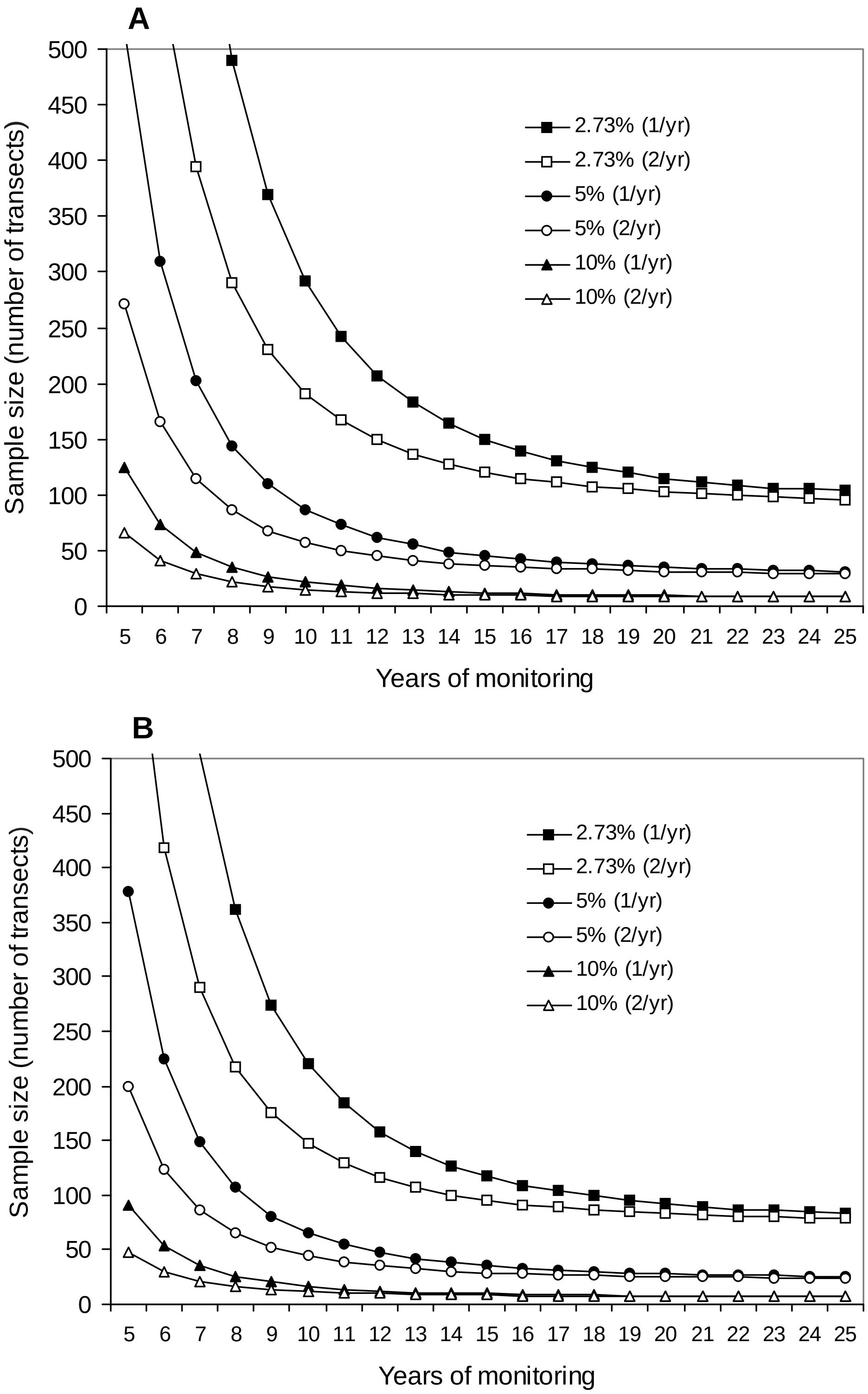


Figure 3. Relationship between number of years of monitoring and minimum sample size needed to achieve (A) 90% power and (B) 80% power to detect existing declines of 2.73%, 5% and 10% per annum in long-tailed bat populations.



5. Discussion

5.1 ADEQUACY OF THE POWER ANALYSIS TECHNIQUE

It is important that appropriate power analyses are available as easy-to-use computer programmes if conservation managers are to be encouraged to use them as tools for designing their monitoring programmes. Precision of power analysis depends on the technique and variance estimates used, as well as the interactions of sample sizes, sampling frequency and number of years of monitoring used in simulations (Taylor & Gerrodette 1987; Peterman 1990a,b; Beier & Cunningham 1996; Hatfield et al. 1996; Gibbs & Melvin 1997; Hayes & Steidl 1997). Because it is not possible to standardise all aspects of surveys between years, statistical modelling procedures are used that distinguish between variation in counts resulting from environmental variability or sampling conditions and the actual variation in activity levels of bats between years (Walsh & Harris 1996a,b; Vaughan et al. 1997; Verboom 1998; O'Donnell 2000b; Roche & Elliott 2000).

The application of route regression to calculating power is justified for use with bat counts. Other approaches such as using negative binomial distributions (O'Donnell 2000b) or non-linear nonparametric route regression (James et al. 1996) involve extensive simulation and it would be difficult to examine the full range of parameter combinations. The log-normal distribution allows calculation of approximate power without simulation and is widely used with population data and should be robust against minor departures from the distribution. The advantage of the REML technique we have used over other techniques is its ability to incorporate a variety of variance components from pilot studies that simulate random sampling errors more realistically. Variance components and their interactions could be manipulated easily to investigate their relative effects on power through simulations.

Undertaking power analysis gives researchers some indication of the potential usefulness of a monitoring programme before significant resources are spent. Because of the problem of skewed data distributions from bat counts, power analysis utilising log-linear regression techniques should always be viewed as an approximation of power and as an indicative tool for exploring and designing sampling programmes.

5.2 WHAT LEVEL OF DECLINE DO WE NEED TO IDENTIFY?

The design of an adequate monitoring programme for long-tailed bats depends on the level of population decline that needs to be identified to trigger conservation action. We provide four scenarios (1.14–10%/yr) for level of population decline in long-tailed bats. Each provides markedly different power estimates. Undertaking monitoring requiring identification of 5% decline per annum requires much smaller sample sizes than those required identifying declines of 1.14% per annum. Sample sizes for detecting more catastrophic declines (>5%/yr) were considerably lower, but still required monitoring to continue for 5–8 years. Unless resources allow studies with very large numbers of counts (>500) then transect counts will not have the power to detect changes in the order of 1–3%/yr unless a monitoring programme lasts >15 years. However, there will be sufficient power to identify more catastrophic declines of >5% per annum.

Statistical tests should in principle aim to detect biologically significant population declines (Reed & Blausten 1997). The potential cumulative effects of annual declines (Fig. 1) are thought to be significant (Mace & Lande 1991; IUCN 1999, 2001). However, their precise impact will depend on the demographic characteristics of the declining population, particularly as they relate to recovery potential and rate of recovery. Population viability analysis using precise productivity and survival data provides a means of identifying biologically meaningful alert levels. However, few data are available for long-tailed bats (O'Donnell 2001b), and bats generally (Tuttle & Stevenson 1982; Racey & Entwistle 2000), for constructing useful population models. Future research should aim to develop recommendations for the level of population change in bats that should alert managers to the need for conservation action. Population viability analysis is now a well-developed tool for predicting risk of extinction (e.g. Boyce 1992), and techniques are being developed to use it for determining general alert levels for threatened species (IUCN 1999). We need to develop techniques to assess thresholds at which declines impact on long-term viability of long-tailed bat populations. There may be substantial time lags between onset of threatening processes and changes in density or viability (DeSante & Rosenberg 1998), and threatening processes may vary among populations (Green 1995; O'Donnell 2000a).

In reality, setting alert levels must consider resource availability as well as biological considerations. Conservation programmes designed to recover populations of endangered species have commenced after declines of >70–90% have already occurred (e.g. Butler & Merton 1992; O'Donnell et al. 1996; Colbourne & Robertson 1997; Elliott et al. 2001). Late initiation of conservation actions is far from ideal, yet may be necessary because declines could not be identified early enough or sufficient resources were not available to undertake the recovery programmes. In New Zealand, catastrophic declines of >5% per annum are more likely to trigger a conservation management response than smaller yet biologically significant declines, largely because >2300 taxa are listed as threatened and resources for species conservation are limited (Hitchmough 2002).

5.3 HOW POWERFUL SHOULD A MONITORING PROGRAMME BE?

Deciding on the level of power required to make decisions about population trends with confidence involves some risk assessment. Choice of power is an arbitrary decision that reflects the degree of certainty that managers wish to achieve (and a trade off between α, power and number of sites/years monitored). If power is >95% and $P < 0.05$ there is a very high probability of undertaking correct assessments of population trends, but sample sizes to achieve this confidence may be unrealistic. If power is <80% and $P > 0.1$, then there is a lower probability of identifying trends. Species recovery groups often take a precautionary approach. Cohen (1988) recommends a minimum of 80% power as adequate. For long-tailed bats we preferred setting the power to 90% for our simulations but a more liberal power (80%) may be adequate. For more critically endangered species conservation managers may seek higher power, but this would then be associated with a more liberal α (say $P = 0.1$). In this scenario managers are less concerned by false alarms because it is very important to identify possible declines and act on them at the earliest. Potentially, conservation resources may be spent on lower priority projects in retrospect, if accepting 80–90% power misidentifies further declines of already threatened species like long-tailed bats. For less endangered species α should be lower ($P < 0.05$) to reduce the risk of false alarms wasting resources.

5.4 INFERENCE TO OTHER BAT POPULATIONS

We consider the sample sizes identified for monitoring long-tailed bats in the Eglinton Valley are of an order of magnitude applicable to other bat populations. Similar results were gained for bats counted along transects in the United Kingdom, though sufficient power was obtained with smaller sample sizes (Walsh et al. 2001). For example, 90% power to detect 2.73% annual declines using 100 transects was achieved after nine years in the common pipistrelle (*Pipistrellus pipistrellus*) compared with 18 years for long-tailed bats.

Study design depends on the scale of the monitoring programme. The monitoring programme in the United Kingdom presently aims to assess changes at a national level (Walsh et al. 1993), whereas the New Zealand programme aims to assess trends in individual populations (O'Donnell & Sedgeley 2001). The distribution of bat foraging habitats may differ between sites, resulting in animals being distributed differently in the landscape. For example, in the Eglinton Valley, where food availability is limited, a population of >350 long-tailed bats ranges over >110 km^2 (O'Donnell 2001a,b). In contrast a smaller population of c. 150 bats near Geraldine is concentrated in a much smaller area (<30 km^2) (Griffiths 1996; O'Donnell 2000d).

6. Conclusions and recommendations

6.1 APPLICATION OF POWER ANALYSIS

- Power analysis is a useful statistical tool for assisting in planning long-tailed bat monitoring programmes, particularly for choosing appropriate sample sizes and programme duration.
- Managers need to decide on the level of certainty (relative power of a monitoring programme to detect significant changes) they require to make decisions about whether conservation action is required and risks associated with not identifying trends. Decisions are ultimately arbitrary and often political, but it is far better to attach confidence limits provided by power analysis to decisions.
- Power analysis techniques do not provide absolute measures of power and should be viewed as approximations to power. Numerous possible scenarios could be investigated using the power analysis software.
- We consider analysis using REML and route regression approaches a good first approximation for estimating power to detect changes in long-tailed bat populations. The alternative would be to fit a variance component model with negative binomial errors. However, difficulties in calculating appropriate variance components and the amount of simulation required in estimating power suggest this approach would be impractical (S. Langton unpubl. data).

6.2 RECOMMENDED MONITORING PROGRAMME DESIGN

- We recommend that monitoring programmes for long-tailed bat populations that use line transects as the sampling unit should follow the standardised methods outlined by O'Donnell & Sedgeley (2001).
- Simulations highlighted the overall importance of time in influencing the number of transects required to provide sufficient power to detect changes.
- The power figures (Figs 3A and 3B) can be used to choose options for designing monitoring programmes. In most situations we recommend that programmes:
  - — aim to achieve a minimum of 80% power, and preferably 90% power, to detect population trends
  - — aim to measure population changes in the order of 3–10%/yr
  - — monitor 50–100 transects surveyed once or twice per year per study area
  - — should run for >10 years.

- Considerably larger sample sizes (>500 transects) would be required to measure population changes in the order of 1%/yr in less than 15 years of monitoring.
- Repeating samples within the same survey period does not improve power markedly. If variability is low–moderate then successive samples are repeating the same information (Macdonald et al. 1998).
- Ten people, each with a bat detector, and using 5 vehicles could survey 50 1-km transects in one 2–3 hour evening (O'Donnell & Sedgeley 2001).

6.3 FUTURE RESEARCH

- Research is needed to determine alert levels that reflect biologically significant population declines in long-tailed bats (e.g. using Population Viability Analysis).
- Cost-benefit analysis techniques that balance biological needs, resource availability, and competing priorities, need to be incorporated into the design of appropriate alert levels for long-tailed bats.

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