

Testing the power of an experiment to measure predator control and habitat complexity impacts on farmland bird abundance

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Abstract: In this study I assess the statistical power to detect a significantly greater increase in bird population size on treatment farms than on control farms given that there is a substantial treatment effect. Computer simulations of bird populations on New Zealand sheep/beef farms were used to generate significant changes in bird abundance from (a) controlling predation by introduced small mammals, (b) habitat structural complexity, and (c) an interaction of both. A simplified computer model of bird population dynamics was developed that predicted a birth pulse of 357% when predators were controlled and 110% if not, and a target of detecting the experimental elevation of bird abundance at a statistically significant level ($P < 0.05$) in 75% of all attempts was set. If at least four farm pairs (treatment vs non-treatment) are monitored, this is feasible for 15 of 23 species common on farmlands for which sampling error of abundance estimation was below ~40%. A second virtual experiment measured the power of tests of whether habitat complexity and predation in combination led to added increases in bird abundance. It showed that a 75% detection of elevated benefits of predation control in complex habitats could only be achieved if at least 48 farms were monitored, and then only for species for which abundance could be estimated with <10% error. Researchers are advised to invest in increased within-site monitoring to achieve a reasonable precision in bird abundance estimation before increasing the number of replicates.

Keywords: abundance estimation; agricultural biodiversity; New Zealand; power analysis; simulation

Introduction

Enhancement of biodiversity on farmed landscapes in New Zealand undoubtedly depends on building more habitat variety and structural complexity into existing agro-ecosystems (Price 1993; Meurk & Swaffield 2000; Perley et al. 2001; Blackwell et al. 2008; Moller et al. 2008a, b; Weller et al. 2008). However, this strategy will not be sufficient in itself if the introduced mammalian predators that now inhabit New Zealand's farming landscapes suppress populations below the levels where habitat would limit their populations. Many farmers may resist planting of woody vegetation to create ecological refuges from agricultural disturbance because it potentially reduces the area of their farms that produces food, fibre and profits. The Agriculture Research Group on Sustainability (ARGOS) therefore proposed an experiment to test whether predator control was a necessary additional intervention for habitat restoration to increase bird abundance. ARGOS's overall goal is to provide incentives for the restoration of bird diversity and abundance in the production landscapes of New Zealand by demonstrating the comparative efficacy of predation control, habitat enhancement and a mixture of both. Feral cats (*Felis catus*), possums (*Trichosurus vulpecula*), feral ferrets (*Mustela furo*), stoats (*M. erminea*), weasels (*M. nivalis*), Norway rats (*Rattus norvegicus*), ship rats (*R. rattus*), mice (*Mus musculus*) and hedgehogs (*Erinaceus europaeus*) are all potentially threatening valued indigenous and introduced species on farms (Townes & Ballantine 1993; Cowan & Tyndale-Biscoe 1997; Perley et al. 2001; King 2005; Moller et al. 2008b). The greatest danger for birds is predation of eggs and nestlings, or even the incubating parent, during the breeding season (Martin 1993, 1995).

The power to measure experimental effects is partly determined by the number of replicates of each treatment, the duration of the experiment, and uncertainty in the monitoring method used to measure the response variables (in this case the abundance of birds). Large-scale field experiments are very expensive and logistically challenging to complete with adequate replication and duration. Most management of pest control operations in Australia and New Zealand does not have enough replication or monitoring of response variables in non-treatment plots to be scientifically interpretable (Reddiex et al. 2006; Clayton & Cowan 2009). A survey of field experiments published in top international ecology journals found that most had too few replicates of treatment plots, many did not even have a non-treatment comparison, and very few lasted for the generation time of the species being monitored for response to the experimental perturbation (Moller & Raffaelli 1998; Raffaelli & Moller 2000). Very few researchers conducted formal power analyses before mounting these experiments, and some that did a power analysis then ignored the result and performed the experiment even though the analysis predicted that the result would be virtually uninterpretable.

The lack of prior planning and formal power analysis of a proposed experimental design may also partly reflect a lack of knowledge of input parameters and measures of their variance before the experiment is performed. Furthermore, many proposed experiments are so complex that power analyses are difficult to conduct. One potential way to circumvent these problems is to set up 'virtual experiments' in computer simulations and systematically vary assumptions and design parameters. This paper describes a power analysis based on the simulation of two 'press perturbation' (Bender et al. 1984) virtual experiments that would test whether predator control will

significantly increase the abundance of birds in New Zealand farmland. The simulations focused strongly on uncertainty in bird abundance estimates and how this interacts with the number of replicates of the experiment to affect the ability to detect the experimental effect. My primary research goal was to assess the statistical power to (a) detect a statistically significant increase in bird abundance in 75% of all attempts, and (b) determine whether any effects of predator control were statistically significantly different in simple compared with complex habitats in 75% of attempts, depending on the number of experimental replicates and magnitude of the error in bird abundance estimates.

The farms envisaged for the experiments are a group of 36 sheep and beef farms on the South Island of New Zealand, including a subset used for intensive year-round bird abundance monitoring. They are part of the farms that are being studied by the ARGOS project (Moller et al. 2005, Weller 2009). The focal farms considered for the experiment could be broadly categorised as having 'low complexity' or 'high complexity' habitat types. 'Low complexity' farms are composed mostly of open paddocks, are of limited topographical variety and have little or no native vegetation; any introduced woody vegetation is mostly in the form of shelterbelts. 'High complexity' farms have areas of native forest, pine plantations or heterogeneous patches, and include gullies or otherwise hard-to-access terrain that provide refuges for birds and predators alike.

Simulated study system

Experimental structure

Two variants of an experiment based on the same fundamental set-up were envisaged. Over a period of several years, the nesting success of selected bird species would be monitored on replicated sets of farms. After establishing a 'baseline' value during the first breeding season (spring and summer of the first year), as many predators as is feasible would be removed by trapping from one-half of the selected farms while constantly monitoring predator numbers on all farms. This 'predator press' treatment would be maintained for 2 years. A Before-After-Control-Impact design (BACI; Stewart-Oaten & Murdoch 1986) would be used to monitor changes in bird abundance on both sets of farms, permitting a comparison of conditions before and after the experimental manipulation in one set while also providing constant comparison with a non-manipulated control set.

Experiment *A* would focus on establishing just the effect of predator control for a given complexity of habitat. 'Treatment' and 'control' farms with comparable habitats would be grouped into replicated pairs, and the change in bird population densities compared within each pair.

Experiment *B* would expand this to use groups of four farms, consisting of (1) a 'treatment'/'control' pair with low habitat diversity and a simple habitat structure, and (2) a pair with varied and complex habitats. This would allow the investigation of interaction effects of habitat quality and changes in predation pressure on bird populations.

Simulation procedure

A computer simulation was created to model the expected dynamics of the monitored bird populations. The object of this simulation was to test whether a change in bird density caused by the predator control on the 'treatment' farms (*A*), or

the difference in density change between habitat complexity levels (*B*), would be detectable by standard statistical methods; i.e. to test the statistical power of the proposed experimental set-up. The simulation program was written in Microsoft QuickBasic 7.1 (Microsoft) and provided a very simplified numerical model of a bird population over the proposed duration of the study.

The simulation created the change in a population density over 3 years. At the beginning of each year, the population went through a brief period of increase that corresponded to recruitment following a 'birth pulse' during the breeding season (following Caughley 1967). The pulse encompasses the laying of eggs, incubation, and hatching, and was set at 10% of total year duration. During the rest of the year, population size declined to minimum adult density just before the next breeding season, representing dispersal and deaths in a population at equilibrium. To ensure easy modifiability and simulation speed, only the maximum (just after the birth pulse) and minimum (just before the birth pulse) values for each year were calculated by using the population model, and the data points between were interpolated using a standardised exponential curve.

The magnitude of the standard birth pulse was simulated by predicting nesting success under different predation pressures. Since the experimentally variable part of predation pressure in this scenario consisted of predation of eggs and nestlings only, the population size at any point in the model represented the number of adult individuals. Therefore all simulated predation took place during the birth pulse and determined its peak height.

The simulations were run in two parallel streams. For experiment *A*, each stream represented a 'treatment' and 'control' (no predator control) farm as a matched pair of farms for each replication. For experiment *B*, each of the two treatment types consisted of pairs of farms with 'high habitat complexity' and 'low habitat complexity', making up farm quartets. In all scenarios I simulated a year of population fluctuation (the 'Before' phase of the BACI) and then imposed predator control on the 'treatment' farm(s) for two successive years. From the time that predator control went into effect, the estimated losses of eggs and chicks due to predation were removed on 'treatment' farms (i.e. the birth pulse increased), while the annual rate of population decrease due to dispersal and deaths from other causes was maintained at 'Before' level. This resulted in a cumulative increase of population size on treatment farms over the following years, for as long as predator control was continued (Fig. 1).

Simulation parameters

Two types of parameters entered into the models (Table 1): a model parameter set describing the modelled population (birth pulse strengths, and variability in pulse strengths and in starting population size), and the experimental parameters describing the set-up of the experiment and the monitoring process (number of replicates, simulation years, bird count samples taken per year, and introduced sampling error).

Estimating birth pulses and starting population sizes

Population model parameters estimated characteristics of bird populations and were obtained from published literature. Using data on clutch sizes and number of nestings in Heather & Robertson (2000), an average maximum reproduction rate was calculated across 23 species likely to be encountered

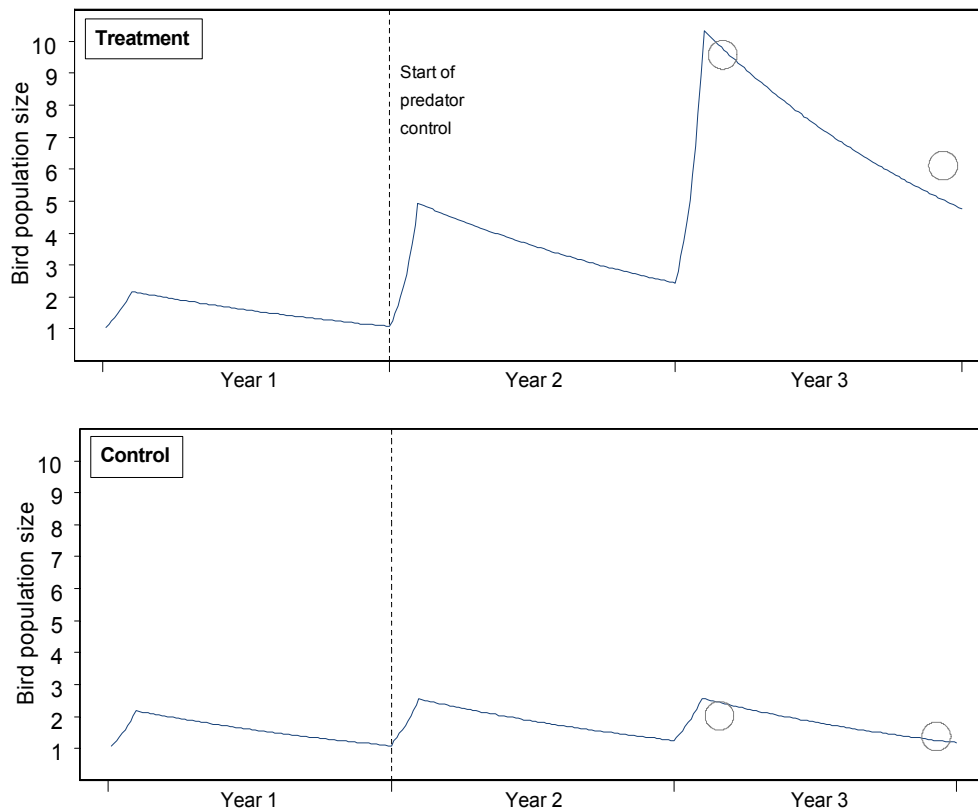


Figure 1. Simulation of bird population size over the course of 3 years, on the ‘treatment’ (top) and ‘control’ (below) farm. Equilibrium populations increase in a short ‘birth pulse’ during nesting season and then decline back to the starting value over the rest of the year. The vertical line marks the onset of predator control on the ‘treatment’ farm, resulting in a reduction of nest predation and an increase in birth pulse strength. The taking of virtual bird count samples to represent sampling errors in the field is shown in year 3 (circles). Samples are generated by adding a random error (between -10% and 10% in this example) to the calculated population size.

Table 1. Population model parameters and experimental parameters used in the simulations, with sources as applicable.

Simulation A			Experimental parameters	
Population parameters	Value	Sources	Parameter	Value
Standard birth pulse strength (reduced by nest mortality)	+109%	Heather & Robertson (2000)	Replicate farm <i>pairs</i>	2, 3, 4
Treatment birth pulse strength (reduced only by nest mortality that is not predation-related)	+308%	Flack (1978); Martin (1993, 1995); Elliott (1996); Matthews et al. (1999); Heather & Robertson (2000); Whyte et al. (2005); Boulton et al. (2008)	Years monitored before and after start of treatment	1 before, 2 after
Maximum variation in birth pulse strength each year	50%	Heather & Robertson (2000)	Samples taken per year	2
Maximum variation in starting population size between paired farms	50%	ARGOS unpubl. data	Introduced sampling error of abundance estimation (percentage CV)	0, 5, 10, 15, 20, 25, 50, 65, 75, 85, 100, 150, 200%
Simulation B (additional parameters)			Experimental parameters	
Parameter	Value	Sources	Parameter	Value
Treatment birth pulse strength difference between ‘high’ and ‘low complexity’ farms	10, 20, 30, 40%	Same as above	Replicate farm <i>quartets</i>	4, 8, 12
Starting population bonus on ‘high complexity’ farms	+40%	Weller (2009)	Introduced sampling error of abundance estimation (percentage CV)	0, 5, 10, 20, 40%

on the monitored farms in sufficient numbers for abundance estimation (Table 2). This value was halved for simulation purposes to account for a population of breeding pairs. The list of species was based on the results of previous ARGOS bird surveys on the intended properties (Blackwell et al. 2005; Green et al. 2005).

These reproduction rates predicted an average birth pulse of +375% of the basal adult population just before breeding began if no eggs or chicks were lost (Table 2). A standard birth pulse strength (i.e. under nest predation) was then calculated as +109% of the pre-breeding adult population size, this being the proportion of individuals successfully hatched after factoring in an average 71% of nest losses reported in the literature (various sources, see Table 1). Birth pulse strength when predators were controlled was then calculated as +308% by removing the estimated 75% of these total nest losses that were attributable to nest predation (leaving a residual nest mortality of 18%) (Martin 1993). A maximum random variation of 50% of starting population sizes within a farm pair was inferred from the ARGOS results and a maximum random variation of 50% of annual birth pulse from Heather & Robertson (2000).

For simulation *B*, the starting population size in 'high complexity' habitats was assumed to be 140% of that in 'low complexity' habitats, due to greater availability of nesting and feeding sites (based on a 2-year study carried out on ARGOS farms; Weller 2009). The identical 'before' (and continuous 'control') birth pulse value was assigned to both complexity levels, as the source data that were used to calculate the reproduction rates (Heather & Robertson 2000) did not allow segregation between habitat types, and

no information is available at this time to adjust this value in the case of New Zealand farmland birds. Since the purpose of this simulation was to assess detection power in the case of a hypothetical differential effect of predator removal on nesting success being present, populations on 'high complexity' 'treatment' farms were assigned an increased reaction to the release from predation pressure, based on the assumption that benefits from predation release would be all the more realised in complex habitats (Begon et al. 1996; Whittingham & Evans 2004). Series were produced for differences of 10%, 20%, 30% and 40%. Half of each value was subtracted from the 'low complexity' 'treatment' birth pulse strength and half added to the 'high complexity' one since the reproduction rates averaged from literature were sourced from a variety of habitat types (Table 1); e.g. for a difference of 20%, the treatment pulse strength of 308% would be modified to 298% for the 'low complexity' site and 318% for the 'high complexity' site.

Simulation *A* runs were performed with 2, 3 and 4 farm pair replicates, which would allow implementation on the ARGOS core farms. Simulation *B* proved to require a substantially larger amount of replication and was performed with 4, 8 and 12 replicates of farm quartets.

Incorporating uncertainty from monitoring bird abundance

To simulate uncertainty from field monitoring of bird abundance, sampling error in abundance estimation was simulated rather than assuming perfect knowledge of the number of birds present. Simulated bird count samples were taken twice a year, at the beginning and end of the post-birth-pulse period. A variable error (percentage CV) was applied to the current state value of the model to simulate sampling errors

Table 2. Population model parameters used to calculate magnitude of reproduction rates, for all species where abundance estimates could be produced in the ARGOS surveys (Blackwell et al. 2005; Green et al. 2005). Species where abundance could be estimated with an error below 40% (percentage CV) are marked with an asterisk *. Data are sourced from Heather & Robertson (2000). The reproduction value is the annual average percentage population increase *per parent bird* based on number of broods and eggs.

Common name	Scientific name	Avg. broods	Avg. eggs	Avg. reproduction %
Bellbird*	<i>Anthornis melanura</i>	2	3	300
Blackbird*	<i>Turdus merula</i>	2.5	3	375
Chaffinch*	<i>Fringilla coelebs</i>	2	4	400
Dunnoek	<i>Prunella modularis</i>	2.5	4	500
Fantail*	<i>Rhipidura fuliginosa</i>	2.5	3	375
Feral pigeon	<i>Columba livia</i>	2.5	2	250
Goldfinch*	<i>Carduelis carduelis</i>	1.5	4	300
Greenfinch*	<i>Carduelis chloris</i>	2	5	500
Grey warbler*	<i>Gerygone igata</i>	2	4	400
Australasian harrier*	<i>Circus approximans</i>	1	3	150
House sparrow*	<i>Passer domesticus</i>	3	4	600
Australian magpie*	<i>Gymnorhina tibicen</i>	1	3	150
Mallard duck	<i>Anas platyrhynchos</i>	1.5	9	675
Paradise shelduck	<i>Tadoma variegata</i>	1	8	400
Pied oystercatcher	<i>Haematopus finschi</i>	1	2	100
Red poll*	<i>Carduelis flammea</i>	2	4	400
Silvereye	<i>Zosterops lateralis</i>	2	3	300
Skylark*	<i>Alauda arvensis</i>	2.5	3	375
Song thrush*	<i>Turdus philomelos</i>	2.5	3	375
Spur-winged plover*	<i>Vanellus miles</i>	2.5	4	500
Starling	<i>Sturnus vulgaris</i>	1.5	4	300
Welcome swallow	<i>Hirundo tahitica</i>	2.5	4	500
Yellowhammer	<i>Emberiza citrinella</i>	2	4	400
			Average	375

incurred in the field, and this adjusted value was recorded (Fig. 1). Runs used random values from a range of simulated error maxima between 0% and $\pm 200\%$. In accordance with actual bird monitoring practice on the sheep/beef farms intended for the experiment, where data from several surveys would be pooled for distance modelling of an annual abundance estimate, the two samples per year were averaged into single annual values before analysis.

Testing power to detect virtual experimental effects

The samples taken from a simulation run of a unit of farms were analysed with SPSS 10.0 (SPSS Inc. 1999) (A) and GenStat 9.1 (Lawes Agricultural Trust 2006) (B). 'Before' values were subtracted from 'After' values of the equivalent part of the year, and the differences used in modelling. For simulation A, a repeated-measures general linear model (identity link function, normal errors) of the form $year * treatmentType$ was used, where $treatmentType$ was either 'treatment' or 'control'. Since interest lay in the ability to distinguish population size changes on 'treatment' farms after implementation of predator control from those on 'control' farms over the same period, the frequency of significant effects (at the 0.05 level) of the interaction factor $year.treatmentType$ were noted. Thus, the abundance difference was modelled as $\alpha_f + \beta_i * t$, where α_f was the intercept depending on starting population size of farm f , t was the year, i was either 'treatment' or 'control', and the tested null hypothesis was $\beta_{treatment} = \beta_{control}$. Similarly, for simulation B, the model had the form $year * treatmentType * complexity$, where $complexity$ was either 'high' or 'low', and significant effects of the three-way interaction $year.treatmentType.complexity$ were tested. The simulation run for a unit of farms was repeated 100 times, and the percentage of replicates that showed a significant interaction effect was recorded. For simulation A, this process was carried out for each of 13 different introduced sampling error sizes, and the resulting series was

repeated for 2, 3 and 4 pairs of farm replicates. Simulation B used five different error levels within the range shown to yield interpretable results for simulation A (0% – 40%), and 4, 8 or 12 farm quartet replicates (Table 1).

Simulation results

As expected, in both simulations statistical power to detect the effect of the predator control treatment declined with increasing bird count uncertainty (Figs 2 & 3). A higher number of farm pair replicates strongly increased the power to detect the effect, especially if the sampling error of abundance estimation was also low. Over the parameter space explored by the simulation, the sampling error at first had a much greater effect on experimental power than did the level of replication; below an error level of $\sim 100\%$, additional replications rapidly increased in their effect on power in simulation A (Fig. 2).

However, in the case of simulation A, even if estimation techniques were very certain (e.g. sampling error was $< 10\%$), having just two replicates will only detect the experimental effect in around 40% of cases (Fig. 2). Setting a target minimum percentage of detections at 75%, the simulation shows that at least four farm pairs must be monitored provided that the maximum sampling error of the density estimates does not exceed $\sim 40\%$ (Fig. 2).

Simulation B showed that power to detect effects of habitat complexity on the strength of benefit from predator control was much lower for a given number of replicates than for the detection of the predator control effect alone. Four replicates of farm quartets yielded a detection probability of only 30% even assuming perfect accuracy in bird population size estimation and the largest hypothetical habitat-related difference in birth pulse strengths (40%) (Fig. 3). At the sampling error maximum for simulation A of 40%, detection probability in B was below

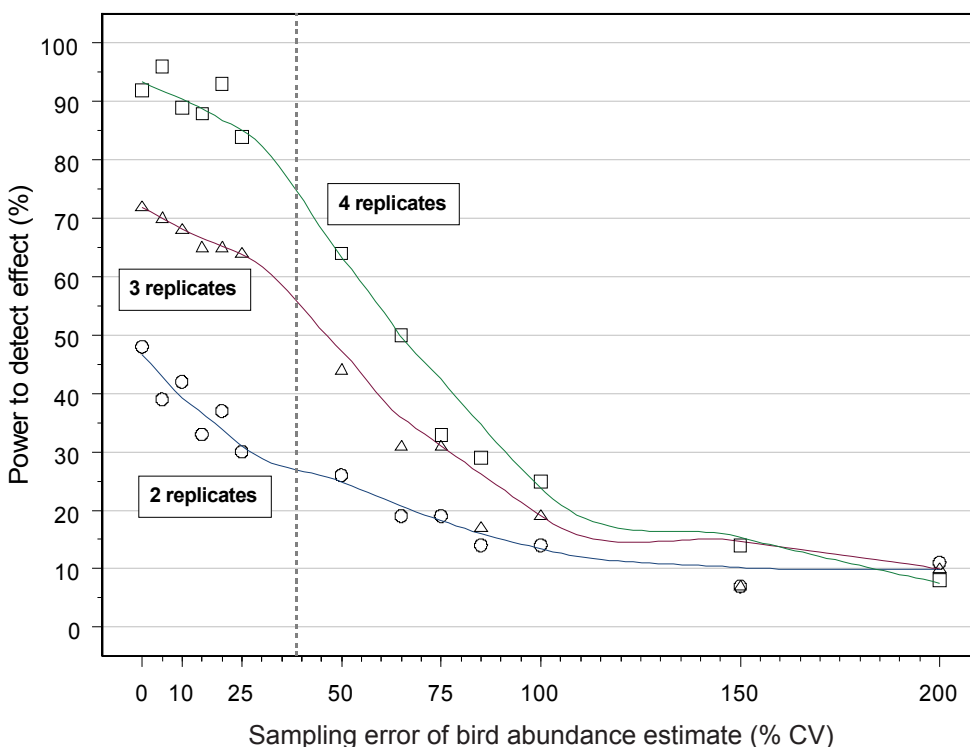


Figure 2. Power to detect the effects of predator control under an increasing size of sampling error for bird abundance estimates. X-axis displays maximum simulated sampling error, y-axis displays percentage of 100 simulation runs using that error where a significant (0.05) effect of predator control was detected. Run series with 2, 3 and 4 replicate farm pairs are represented by individual data series (smoothed splines). Maximum sampling error to achieve a power of 75% using four farm pair replicates is marked by a dashed line.

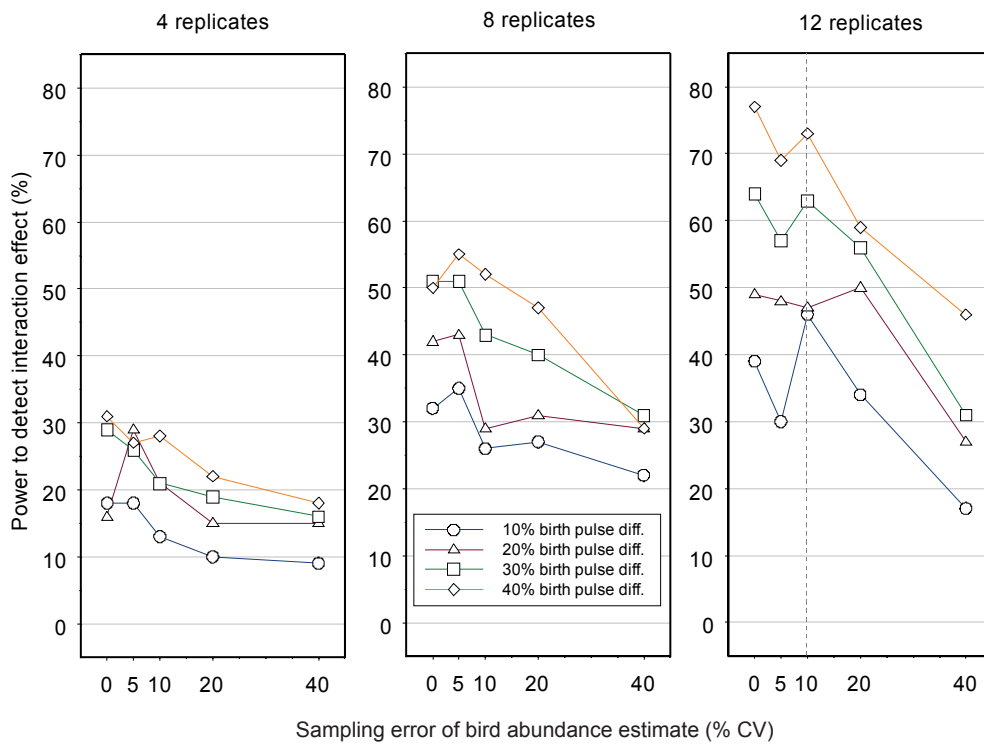


Figure 3. Power to detect the interaction effects of predator control and habitat complexity under an increasing size of sampling error for bird abundance estimates. X-axis displays maximum simulated sampling error, y-axis displays percentage of 100 simulation runs using that error where a significant (0.05) interaction effect was detected. Run series with 10%, 20%, 30%, and 40% difference in ‘treatment’ birth pulse between ‘high’ and ‘low complexity’ farms are represented by individual data series. Panels represent results for 4, 8 and 12 farm quartet replicates. Maximum sampling error to achieve a power of 75% using 12 farm quartet replicates is marked by a dashed line.

50% for every parameter combination. The power threshold of 75% could be achieved only with 12 replicates (48 farms), but only if a birth pulse strength difference of 40% and a sampling error not larger than 10% were assumed (Fig. 3).

Discussion

The very simplified nature of my simulation needs to be taken into account when considering its reliability. Using two deterministic population targets per year, the program makes no allowance for more complex aspects of dynamics that are frequently present in bird populations, such as density dependence (Begon et al. 1996) or the possibility of renesting if one clutch or nest is lost (Thompson et al. 2001), nor for any kind of seasonal population fluctuations other than a generalised diminishing of numbers from the breeding season onwards. Nevertheless, the actual impact of inaccuracies in density distribution across a year should be small, as neither the sampling nor the analysis process make any assumptions about the temporal correlation between bird count samples within a year. Also, my main interest lay in the relative difference in abundance between reference and experimental farms, not the absolute values. Errors in assumptions will apply equally to both groups and are therefore less likely to have affected my predictions of necessary replication.

A potentially more serious bias could result from miscalculation of the magnitude of the effect of predation (or its lack). I used averaged values from the literature. Repeating this analysis for a specific species, with more accurate population parameters should they be available, should give better information for individual cases and might result in modified conclusions for measuring the response of a particular species to predator control, while this study was primarily concerned with examining the general feasibility of the proposed experiments.

The simulation results obtained for experiment *A*, assessing the detectability of the effects of predator removal irrespective of habitat type, indicate that for an experiment aiming to restore any of the species potentially present in New Zealand farmland, using generalised assumptions, a satisfactory degree of statistical power could be achieved if density estimates are sufficiently accurate. The best available estimates of the actual sampling errors when monitoring bird numbers on these farms can be derived from three recent annual monitoring studies carried out on the ARGOS farms (ARGOS, unpubl. data). In these surveys, the abundance of 15 of the 23 most commonly encountered bird species could be estimated with less than 40% sampling error (using line transect distance sampling; Buckland et al. 2001, 2004) (Table 2). If four farm unit replicates were used, this level of estimation error would be within the desirable power of detection range. The 75% power threshold chosen is appropriate, given the expense of undertaking a press-perturbation experiment. While this means that the putative experimental test of the benefits of predator control could not be reliable for about a third of these common species, power could be increased by working with ecologically sensible species groupings sharing similar detectability and/or life history traits. Collectively, my results (Fig. 2) suggest that a considerable proportion of the investment in any predator experiment should go into increased frequency and therefore accuracy in the bird monitoring itself. A high number of replicates will not suffice to raise the power of the experiment to interpretable levels if a reasonable accuracy of estimates cannot be achieved. This is also procedurally more sensible, in that a well-designed, accurate monitoring programme can be extended to new areas more easily than a widespread, inaccurate one can be upgraded to better estimates.

Testing the interaction effect of predator removal and habitat quality, as proposed for experiment *B*, appears to be far less feasible. Carrying out sustained predator control on 24 farms, and monitoring bird populations on twice as many, for

the duration of 3 years would represent a high investment of effort even if there was a high chance of successfully measuring the sought effect. However, the parameters chosen for the simulation already represent almost a best-case scenario for the detection of an interaction effect. Assuming that there is a higher base population in 'high complexity' farms even under predation pressure is supported by the results of surveys on representative farms (Weller 2009), but may not represent the general case. Repeating the simulation run with the highest detection power (40% treatment birth pulse difference, 12 replicates, no estimation error) without a bonus applied to 'high complexity' starting populations yielded a power level of only 15% instead of 77%, showing that in the absence of this supposition the interaction effect would be at least five-fold harder to detect. As noted above, the error present in estimates of bird abundance is also unlikely to consistently be as low as 10% even using comparatively accurate distance sampling methods (Weller 2009; ARGOS, unpubl. results). Additionally, the set of 36 farms where these estimates were taken would not be large enough to carry out the experiment at the needed rate of replication.

Most importantly, the strength of the hypothetical effect difference between complexity levels being unknown, there would be a high probability of not detecting the sought interaction if the difference in relative population increase was smaller than the assumed 40%. A negative effect size, i.e. a relatively reduced increase of the birth pulse on 'high complexity' farms, for example caused by the population size already being closer to the habitat's carrying capacity, would similarly be much harder to detect.

Conclusion

Power analyses based on simulated bird population dynamics showed that experimental investigations of the effect of predation on the breeding success of farmland birds would require four replicated pairs of farms to obtain 75% certainty of results, which would be feasible using the bird surveying techniques already tested on the intended experimental farms. An expanded variant of the experiment that would investigate the interaction effect of predator control and habitat quality on bird breeding success is not feasible due to expectations of low power to detect the effect even at high replication. Simulations to estimate experimental power of large-scale field manipulations have considerable scope for improving wildlife science and gaining more reliable knowledge.

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References

- Begon M, Harper JL, Townsend CR 1996. Ecology: individuals, populations and communities. 3rd edn. Oxford, UK, Blackwell. 1068 p.
- Bender EA, Case TJ, Gilpin ME 1984. Perturbation experiments in community ecology: theory and practice. *Ecology* 65: 1–13.
- Blackwell G, O'Neill E, Buzzi F, Clarke D, Dearlove T, Green M, Moller H, Rate S, Wright J 2005. Bird community composition and relative abundance in production and natural habitats of New Zealand. ARGOS Research Report 05/06. Online at http://www.argos.org.nz/research_results.shtml. 59 p.
- Blackwell G, Fukuda Y, Maegli T, MacLeod CJ 2008. Room for everyone? Refugia and native biodiversity in New Zealand's agricultural landscapes. *New Zealand Journal of Agricultural Research* 51: 473–476.
- Boulton RL, Richard Y, Armstrong DP 2008. Influence of food availability, predator density and forest fragmentation on nest survival of New Zealand robins. *Biological Conservation* 141: 580–589.
- Buckland ST, Anderson DR, Burnham KP, Laake JL, Borchers DL, Thomas L 2001. Introduction to distance sampling: estimating abundance of biological populations. Oxford University Press. 432 p.
- Buckland ST, Anderson DR, Burnham KP, Laake JL, Borchers DL, Thomas L 2004. Advanced distance sampling. Oxford University Press. 416 p.
- Caughley G 1967. Parameters for seasonally breeding populations. *Ecology* 48: 834–839.
- Clayton RI, Cowan PE 2009. Best practice operational and outcome monitoring for pest management – a review of existing council approaches and activity. Landcare Research Contract Report LC0809/085 for Horizons Regional Council. Envirolink Report 494, online at <http://www.envirolink.govt.nz/Envirolink-reports/>. 43 p.
- Cowan PE, Tyndale-Biscoe CH 1997. Australian and New Zealand mammal species considered to be pests or problems. *Reproduction, Fertility, and Development* 9: 27–36.
- Elliott GP 1996. Productivity and mortality of mohua (*Mohoua ochrocephala*). *New Zealand Journal of Zoology* 23: 229–237.
- Flack JAD, Lloyd BD 1978. The effect of rodents on the breeding success of the South Island robin. In: Dingwall PR, Atkinson IAE, Hay C eds *The ecology and control of rodents in New Zealand nature reserves*. Information Series 4. Wellington, Department of Lands and Survey. Pp. 59–66.
- Green M, O'Neill E, Wright J, Blackwell G, Moller H 2005. Interspecific interaction and habitat use by Australian magpies (*Gymnorhina tibicen*) on sheep and beef farms, South Island, New Zealand. ARGOS Research Report 05/07. Online at http://www.argos.org.nz/research_results.shtml. 44 p.
- Heather B, Robertson H 2000. *The field guide to the birds of New Zealand*. Auckland, Viking/Penguin.
- King CM ed. 2005. *The handbook of New Zealand mammals*. 2nd edn. Melbourne, Oxford University Press.
- King CM, Edgar RL 1977. Techniques for trapping and tracking stoats (*Mustela erminea*); a review and a new system. *New Zealand Journal of Zoology* 4: 193–212.
- Lawes Agricultural Trust 2006. GenStat 9.1. Rothamsted

- Experimental Station, UK, Lawes Agricultural Trust.
- Martin TE 1993. Nest predation and nest sites. *BioScience* 43: 523–532.
- Martin TE 1995. Avian life history evolution in relation to nest sites, nest predation, and food. *Ecological Monographs* 65: 101–127.
- Matthews A, Dickman CR, Major RE 1999. The influence of fragment size and edge on nest predation in urban bushland. *Ecography* 22: 349–356.
- Meurk CD, Swaffield SR 2000. A landscape ecological framework for indigenous regeneration in rural New Zealand–Aotearoa. *Landscape and Urban Planning* 50: 129–144.
- Moller H, Raffaelli D 1998. Predicting risks from new organisms: The potential of community press experiments. In: Fletcher DJ, Kavalieris L, Manly BFJ eds *Statistics in ecology and environmental monitoring 2: Decision making and risk assessment in biology*, Dunedin, University of Otago Press. Pp. 131–156.
- Moller H, Wearing A, Pearson A, Perley C, Steven D, Blackwell G, Reid J, Johnson M 2005. Environmental monitoring and research for improved resilience on ARGOS farms. ARGOS Working Paper 6. Online at http://www.argos.org.nz/working_papers.shtml. 136 p.
- Moller H, Blackwell G, Weller F, MacLeod CJ, Rosin C, Gradwohl M, Meadows S, Perley C 2008a. Social-ecological scales and sites of action: keys to conserving biodiversity while intensifying New Zealand's agriculture? *New Zealand Journal of Agricultural Research* 51: 461–465.
- Moller H, MacLeod CJ, Haggerty J, Rosin C, Blackwell G, Perley C, Meadows S, Weller F, Gradwohl M 2008b. Intensification of New Zealand agriculture: implications for biodiversity. *New Zealand Journal of Agricultural Research* 51: 253–263.
- Perley C, Moller H, Hutcheson J, Hamilton W 2001. Towards safeguarding New Zealand's agricultural biodiversity: research gaps, priorities and potential case studies. Ecosystems Consultants contract Report 23 (project EI-30/2000). Wellington, Ministry of Agriculture and Forestry. 230 p.
- Price LW 1993. Hedges and shelterbelts on the Canterbury Plains, New Zealand: transformation of an antipodean landscape. *Annals of the Association of American Geographers* 83: 119–140.
- Raffaelli D, Moller H 2000. Manipulative field experiments in animal ecology: do they promise more than they can deliver? *Advances in Ecological Research* 30: 300–338.
- Reddiex B, Forsyth DM, McDonald-Madden E, Einoder LD, Griffioen PA, Chick RR, Robley AJ 2006. Control of pest mammals for biodiversity protection in Australia. I. Patterns of control and monitoring. *Wildlife Research* 33: 691–709.
- SPSS Inc. 1999. *SPSS Base 10.0 for Windows user's guide*. Chicago IL, SPSS Inc.
- Stewart-Oaten A, Murdoch WW, Parker KR 1986. Environmental impact assessment: "pseudoreplication" in time? *Ecology* 67: 929–940.
- Thompson BC, Knadle GE, Brubaker DL, Brubaker KS 2001. Nest success is not an adequate comparative estimate of avian reproduction. *Journal of Field Ornithology* 72: 527–536.
- Towns DR, Ballantine WJ 1993. Conservation and restoration of New Zealand island ecosystems. *Trends in Ecology and Evolution* 8: 452–457.
- Weller FG 2009. Monitoring bird abundance on New Zealand pastoral farms. Unpublished PhD thesis, Department of Zoology, University of Otago, Dunedin, New Zealand. 190 p.
- Weller FG, Meadows S, Gradwohl M 2008. Retaining adaptive capacity in New Zealand's ecological systems. *New Zealand Journal of Agricultural Research* 51: 477–479.
- Whittingham MJ, Evans KL 2004. The effects of habitat structure on predation risk of birds in agricultural landscapes. *Ibis* 146 (Suppl. 2): 210–220
- Whyte BI, Didham RK, Briskie JV 2005. The effects of forest edge and nest height on nest predation in two differing New Zealand forest habitats. *New Zealand Natural Sciences* 30: 19–34.

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