

NONLINEARITY AND SEASONAL BIAS IN AN INDEX OF BRUSHTAIL POSSUM ABUNDANCE

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Abstract: Introduced brushtail possums (*Trichosurus vulpecula*) are a widespread pest of conservation and agriculture in New Zealand, and considerable effort has been expended controlling populations to low densities. A national protocol for monitoring the abundance of possums, termed trap catch index (TCI), was adopted in 1996. The TCI requires that lines of leghold traps set at 20-m spacing are randomly located in a management area. The traps are set for 3 fine nights and checked daily, and possums are killed and traps reset. The TCI is the mean percentage of trap nights that possums were caught, corrected for sprung traps and nontarget captures, with trap line as the sampling unit. We studied 1 forest and 1 farmland area in the North Island, New Zealand, to address concerns that TCI estimates may not be readily comparable because of seasonal changes in the capture probability of possums. We located blocks of 6 trap lines at each area and randomly trapped 1 line in each block in 3 seasons (summer, winter, and spring) in 2000 and 2001. We developed a model to allow for variation in local population size and nightly capture probability, and fitted the model using the Bayesian analysis software *BUGS*. Capture probability declined with increasing abundance of possums, generating a nonlinear TCI. Capture probability in farmland was lower during spring relative to winter and summer, and to forest during summer. In the absence of a proven and cost-effective alternative, our results support the continued use of the TCI for monitoring the abundance of possums in New Zealand. Seasonal biases in the TCI should be minimized by conducting repeat sampling in the same season.

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Indices of abundance, defined by Caughley (1977) as “any measurable correlative of density,” provide the basis for much decision making in wildlife management. However, indices of abundance have been criticized (e.g., Garshelis et al. 1990, Anderson 2001) for 2 general reasons. First, it has often been assumed that the relationship between an index and absolute abundance is positive and linear, with a constant slope across habitats, seasons, and years, yet such biases invalidate the use of the index for some management purposes (Thompson et al. 1998, Gibbs 2000). Non-linearity will occur if the index becomes saturated at high absolute abundance (Caughley 1977, Gibbs 2000). Second, monitoring programs involving indices of abundance have seldom demon-

strated that they had sufficient power to detect the desired changes in population abundance, if they actually occurred (e.g., Steidl et al. 1997, Thompson et al. 1998). We examined the issues of non-linearity and seasonal bias in an index used to monitor the abundance of introduced brushtail possums in New Zealand.

The brushtail possum (hereafter possum) is a nocturnal and omnivorous marsupial weighing approximately 3-kg that is now widespread in New Zealand (Cowan 1990, Clout and Ericksen 2000). The possum is considered New Zealand’s most important vertebrate pest of conservation and agriculture. Possums can defoliate and kill some tree species (Payton 2000), and prey on the eggs and nestlings of endangered birds (Sadleir 2000). Possums are also maintenance hosts of bovine tuberculosis (Tb), which poses a threat to health of domestic livestock in New Zealand. Considerable effort has been expended protecting conservation and agricultural values by controlling possums with toxins, primarily aerially sown sodium monofluoroacetate (1080; Morgan and Hickling 2000, Veltman and Pinder 2001), and leghold traps (Warburton 2000).

The National Trap-Catch Protocol, here termed the trap-catch index (TCI), was adopted by the

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National Possum Control Agencies in 1996 to ensure that the monitoring of possum abundance by regional councils, the Department of Conservation, and researchers was standardized (Warburton 2000). Although there have been minor changes to the protocol since 1996 (National Possum Control Agencies 2002), the key components have not changed and are as follows: (1) The number of trap lines is determined by the size of the management area; (2) Trap lines are randomly located within the management area and follow a predetermined compass bearing, except that in farmland where possum habitat is patchy, lines are subjectively located; (3) Number 1 double-coil, spring-leghold traps are used; (4) The first trap on a trap line is 20 m from the start point, and traps are set at 20-m intervals on the trap site (i.e., at the nearest tree or fence post that will hold a fence staple); (5) Traps (10 or 20 per line) are baited with a mixture of plain white flour and icing sugar (5:1 weight for weight spread behind the trap 10- to 50-cm up the tree trunk or fence post); (6) Traps are set for 3 consecutive fine nights (i.e., a night with no rain within 4 hrs of darkness); (7) Traps are checked within 12 hrs of sunrise (as required by the *Animal Welfare Act* 1999), and all possums are killed as quickly as possible and removed from the trap. Nontarget captures, escaped possums (identified from fur in the jaws of the trap), and sprung traps are also recorded. To calculate the TCI for a trap line, the total number of possums caught is divided by the number of trap nights minus 0.5 trap nights for each nontarget and sprung but empty trap (Nelson and Clark 1973), and that number is multiplied by 100%. The estimate of abundance ($\pm 95\%$ confidence interval) for the management unit is then calculated using each trap line as a sampling unit (National Possum Control Agencies 2002).

To illustrate the current importance of the TCI in the management of possums in New Zealand, during the 2002–2003 financial year (1 Jul–30 Jun) at least 941 surveys to monitor possum populations were undertaken in relation to possum control funded by the Animal Health Board, involving 23,412 TCI trap lines (P. Fairbrother, Animal Health Board, personal communication). An additional 204 surveys, involving 2,098 TCI trap lines, were undertaken by the Department of Conservation (C. Veltman, Department of Conservation, personal communication). Our study arose from concerns that TCI estimates may not be readily comparable because capture probability may vary with season. Our objective was therefore to deter-

mine whether capture probability varied among 3 seasons (summer, winter, and spring) in 2 habitat types (forest and farmland).

STUDY AREAS

We conducted our study in 2 areas in the North Island, New Zealand (Fig. 1). One area consisted of 3,200 ha of tall indigenous forest in the Maungatautari Scenic Reserve (38°00'S, 175°05'E; forest). The forest was mixed podocarp (primarily tawa [*Beilschmiedia tawa*], northern rata [*Metrosideros robusta*], rimu [*Dacrydium cupressinum*], and kamahi [*Weinmannia racemosa*]) with an understory dominated by treeferns (*Dicksonia squarrosa*, *Cyathea dealbata*, *C. medullaris*, *C. smithii*) and supplejack (*Ripogonum scandens*). Possums in the Maungatautari Scenic Reserve were controlled by aerially dropped 1,080 in June 1997. The control operation reduced possums from a mean 26% TCI to a mean 2% TCI ($n = 10$ trap lines each; G. Cochrane, AgriQuality New Zealand, unpublished data). For the 56 lines trapped for our study, the mean TCI was 7%. The abundance of possums at this area was therefore relatively low during our study.

The second area was 6,500 ha of farmland near Miranda (37°12'S, 175°15'E; farmland), approximately 200 km north of the forest area. The farmland was mainly rolling pasture interspersed with tall, indigenous forest. Some pasture adjoined *Pinus radiata* plantations or willows (*Salix* spp.). Possums at this area had not been controlled for at least 10 years, and the mean TCI was 22% for the 60 lines trapped for our study.

METHODS

Study Design

We expected possum density to vary spatially within each area, so we initially delineated 8 blocks at both study areas. We located the 8 blocks in a circular fashion at the forest site (Fig. 1). We assigned 6 trap lines of 400-m length to each block, all ≥ 250 m from the forest edge and ≥ 500 m from the nearest trap line. Radiotracking studies in tall forest habitats (Cowan and Clout 2000) indicated that a distance of 250 m would ensure that possums caught on 1 trap line would not be within the catchment of neighboring trap lines. We randomly assigned trap lines within each block to 1 of 3 seasons (summer [Jan–Mar], winter [Jul–Aug], and spring [Oct–Nov]) in 2000 and 2001.

The random allocation of trap lines within blocks was impractical at the farmland study area

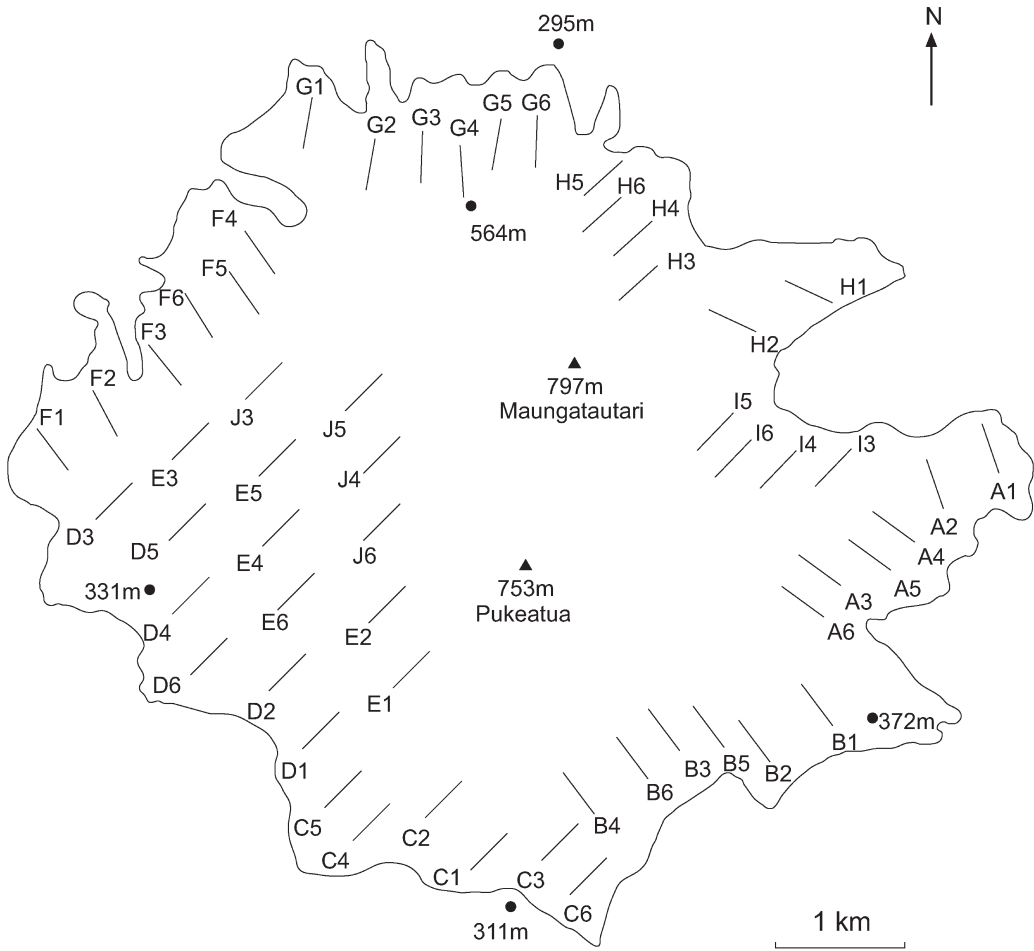


Fig. 1. The 3,200-ha forest site, North Island, New Zealand, indicating the 10 blocks (A–J) and the 6 trap lines located in each block (1–6) along which brushtail possums were trapped in summer, winter, and spring of 2000 and 2001. Two blocks had only 4 trap lines because we established them after 2 seasons (summer and winter 2000) had been completed. Numbers are spot heights (meters above sea level).

because livestock commonly trigger leghold traps, making traps unavailable to possums. Instead, we delineated large areas of similar habitat as blocks, and we located 1 line in each block (in consultation with the farm manager) at the start of each trapping session. We always placed a new trap line ≥ 500 m from a previous trap line. Following preliminary analysis of the summer and winter data in 2000, we increased the number of blocks in forest and farmland to 10 and 11, respectively.

We set each trap line with 20 Victor No. 1 traps (Montague and Warburton 2000) according to the protocol described above. We trapped all lines within each study area simultaneously, but start dates varied by up to 14 days between the forest and farmland areas. We set traps for between 9

and 12 fine nights, the first 3 of which were always consecutively fine. The end point for trapping was night 9, but if the number of possums caught on night 9 was greater than 20% of the possums caught on night 1, then we continued trapping for up to 3 more nights. We checked all traps daily and all possums were humanely killed.

Following the completion of trapping, we used cyanide poison paste to check the reliability of our estimates of N (see below) by poisoning possums along the trap line. Although poisoning was unlikely to kill all remaining possums, we expected the number of possums killed by cyanide to increase with the number of possums estimated to be remaining along the trap line. We could not poison along all trap lines due to either proximity

to public walking tracks (forest) or the presence of livestock (farmland). We placed 2 g of peanut butter paste (Ferafeed, Feral Control, Auckland, New Zealand) on the ground at 10-m intervals along the trap line. After 2 fine nights, we laid cyanide paste (Trappers Cyanide Co., Styx Mill Road, Christchurch, New Zealand) on the remaining Ferafeed (or new Ferafeed if it had been eaten) and topped it with additional Ferafeed. Cyanide is a fast-acting, humane toxin, with death occurring in 10–26 min (Eason et al. 2000). After 2 fine nights, we recorded the number of poisoned possums on each trap line, and removed any remaining cyanide. Consumption of the prefeed and cyanide paste by rats (*Rattus* spp.) necessitated the use of a rat-proof platform at the forest study area (D. M. Forsyth et al. 2003; Contract Report LC0203/001, Landcare Research, Lincoln, Canterbury, New Zealand). Our study was conducted with the approval of the Landcare Research Animal Ethics Committee (AEC approval 99/3/6).

Statistical Analyses

The TCI estimates a function of capture probability (p) and population size (N) over the first 3 nights. For illustration, assume that p was constant over the 3 nights. It can be shown that:

$$E(\text{TCI}) = Np(1 + (1 - p) + (1 - p)^2) / K, \quad (1)$$

where K was the total number of trap nights per trap line (e.g., 60 for 1 trap line of 20 traps set for 3 fine nights). Thus, the relation between TCI and N is seen to depend on p . If there is little variation in p , TCI would be a good index to N . If variation in p is independent of N , TCI may still be a reasonable index to N . However, if p and N were correlated, the index relation may depart from linearity.

We let N_i denote the initial population size associated with line i , and X_{ij} the number of catches on night j . For notational convenience, we set $X_{i0} = 0$; then:

$$N_{ij} = N_i - \sum_{k=0}^{j-1} X_{ik} \quad (2)$$

was the population size just prior to the j th trapping occasion. We modeled the captures X_{ij} as independent binomial random variables (conditional on N_{ij}) with index N_{ij} and success rate (capture probability) p_{ij} . We note that, strictly speaking, X_{ij} cannot be a binomial random variable with index N_{ij} , since N_{ij} might be >20 , the number of traps per line. We regard this model

specification as a reasonable approximation, noting that the maximum number of captures was 12 and that on 103 of the 108 trapping occasions the number of captures was ≤ 9 .

We supposed that the logit of the capture probability, i.e.,

$$\text{logit}(p_{ij}) = \ln(p_{ij} / (1 - p_{ij})), \quad (3)$$

was a normally distributed random variable, with mean μ_{ij} and standard deviation σ_p . We modeled the effects of site-specific covariates and population size on capture probabilities by supposing that:

$$\mu_{ij} = HS_{hs(i)}^C + L_i^C + Y_{y(i)}^C + bN_{ij}, \quad (4)$$

here, HS_j^C was a factor with 6 levels representing the interactive effect of habitat and season on capture probability (forest/summer, forest/winter, forest/spring, farmland/summer, farmland/winter, farmland/spring), L_i^C was an effect specific to the i th line of traps, modeled as a mean-0 normal random effect with standard deviation σ_L^C , and Y_j^C was the effect due to year j on capture (Y_1 , for year 2000, was set to zero). We included the term bN_{ij} in (4) to model the effect of population size on counts; thus, we assumed the effect was linear on the logit scale with constant slope across sites and time.

Our model describes the initial population sizes N_i as overdispersed Poisson random variables, with rates λ_i influenced by habitat, site, and year. We considered the model:

$$\ln(\lambda) = HS_{hs(c)}^N + L_i^N + Y_{y(i)}^N; \quad (5)$$

we chose our notation to agree with the corresponding effects on capture probabilities but with superscript N (for population size) replacing C (for capture probability). We induced overdispersion by supposing that line effects L_i^N were mean-0 normal random variables with standard deviation σ_L^N .

We used version 1.3 of the software package *BUGS* (Spiegelhalter et al. 1996; available for free download at <http://www.mrc-bsu.cam.ac.uk/bugs/>) to conduct Bayesian analysis of our model. Bayesian inference was based on posterior distributions of parameters; these are the conditional distributions of parameters, given data. Program *BUGS* uses the Gibbs sampler (Casella and George 1992) to generate Markov chain samples of posterior distributions. Bayesian inference requires the specification of prior distributions of parameters; if the prior distribution is diffuse or if the sample

Table 1. Features of posterior distributions of model parameters modeled using the software BUGS. Data collected from brushtail possums trapped on 114 trap lines, North Island, New Zealand, in summer, winter, and spring of 2000 and 2001.

Node	Mean	SD	Precision values	2.5%	Median	97.5%
b	-1.270	0.3003	0.004585	-1.862	-1.270	-0.6818
S_1^N	2.069	0.1535	4.11E-04	1.766	2.070	2.368
S_2^N	2.163	0.1534	5.07E-04	1.861	2.164	2.461
S_3^N	2.099	0.1555	6.13E-04	1.791	2.099	2.402
S_4^N	3.296	0.1351	4.81E-04	3.030	3.296	3.561
S_5^N	3.353	0.1321	3.76E-04	3.093	3.353	3.613
S_6^N	3.576	0.1276	9.84E-04	3.325	3.575	3.827
Y_2^N	-0.0915	0.1049	3.36E-04	-0.2982	-0.0910	0.1136
S_1^C	-1.179	0.1530	0.001883	-1.487	-1.177	-0.8858
S_2^C	-1.559	0.1547	0.001915	-1.877	-1.554	-1.270
S_3^C	-1.556	0.1564	0.001989	-1.873	-1.553	-1.258
S_4^C	-1.484	0.1097	0.001169	-1.707	-1.482	-1.275
S_5^C	-1.285	0.09133	8.06E-04	-1.470	-1.283	-1.110
S_6^C	-1.837	0.1074	0.001845	-2.054	-1.836	-1.628
Y_2^C	-0.1019	0.08641	9.44E-04	-0.2743	-0.101	0.064
σ_{L^C}	0.1447	0.06937	0.001147	0.03181	0.1416	0.2859
σ_{L^N}	0.4635	0.04598	1.87E-04	0.3797	0.4612	0.5597
σ_p	0.2012	0.08375	0.001911	0.04119	0.2073	0.3517

size is large, the posterior distribution is primarily a reflection of the likelihood function, so that Bayesian inference and classical Frequentist inference will produce similar results. For a discussion of the application of BUGS to analyses in ecology and wildlife management see Link et al. (2002). We chose a standard noninformative prior for all precisions (gamma; shape = 0.001, scale = 0.001) and a standard noninformative normal distribution for all coefficients (i.e., $\mu = 0.0, 1/\sigma^2 = 0.001$; Spiegelhalter et al. 1996). We presented posterior means as point estimates, with the 2.5th and 97.5th percentiles of the posterior distribution bounds to a Bayesian 95% confidence interval. We also presented precision values (i.e., the sum of the prior and sample precisions) as a measurement of how much information was contained in each posterior mean.

The key issues for assessing the performance of Markov chain Monte Carlo simulation are starting values, convergence, and autocorrelation (Spiegelhalter et al. 1996, Link et al. 2002). We evaluated the performance of our model by examining 4 diagnostics for the posterior distributions: (i) convergence of the Markov chains, (ii) the estimated autocorrelation function, (iii) the mean, median, and mode values of the posterior distributions, and (iv) the precision values (Anderson et al. 2001). Markov chains produced by Gibbs sampling can be highly transient when the starting value lies outside the range of the stationary distribution. We estimated our parameters using 105,000 iterations after thinning by a factor of 10, with a burn-

in of 5,000 (see Link et al. 2002). The key inference we intended to make was whether capture probability varied with population size, year, habitat, or season.

RESULTS

The nightly sum of sprung and nontarget captures for a trap line ranged from zero to 4 (mode = 0) at both study areas. We used data from all trap lines except for 2 on which no possums were trapped.

In the parameter estimates for the fitted model (4), σ_{L^N} , σ_{L^C} , and σ_p were standard deviations estimated from the precision values defined above (Table 1). There was a 95% chance that the slope for the relationship between actual population size \hat{N} and actual capture probability \hat{p} was between -1.862 and -0.682. We interpreted this result as strong evidence that capture probability declined with increasing population size. The relationship between N and p (Fig. 2) generated a positive but nonlinear relationship between TCI and possum abundance (Fig. 3). There was little evidence that either capture probability (Y_2^C) or population size (Y_2^N) varied be-

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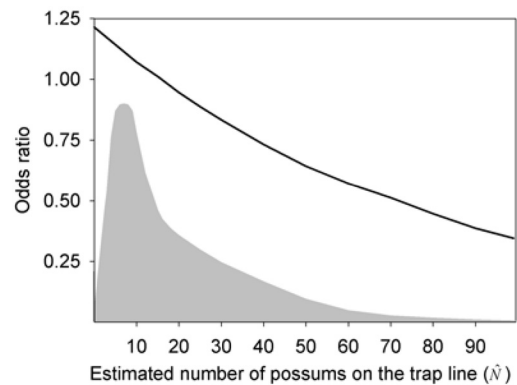


Fig. 2. Change in odds of capture as brushtail possum population size (N) increases (solid line) relative to the estimated median population size $\hat{N} = 16$, North Island, New Zealand. The value $\hat{N} = 16$ is the median fitted value across habitats and seasons and the shaded region is the distribution of fitted population sizes across habitats and seasons. Data collected from brushtail possums trapped in summer, winter, and spring of 2000 and 2001.

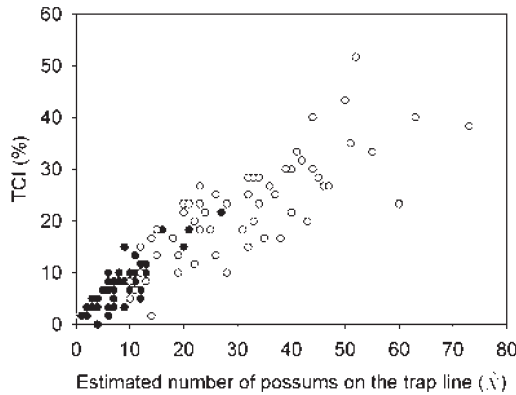


Fig. 3. Relationship between trap catch index (TCI) and estimated brushtail possum population size, North Island, New Zealand. Data were collected in summer, winter, and spring of 2000 and 2001. Estimated population size (\hat{N}) must be >0 . The open circles are trap lines at the forest study area ($n = 54$), and the closed circles are trap lines at the farmland study area ($n = 60$).

tween years 2000 and 2001, with the confidence intervals for both parameters including zero.

For all but 3 of the 15 contrasts for the odds ratios of capture probability between habitat and season (Table 2), the 95% confidence intervals enclosed 1. The odds of capturing a possum were lower during spring in farmland relative to both summer and winter in farmland and to summer in forest. However, all of the 95% confidence intervals were large, indicating that our sampling effort was likely to detect only large differences in capture probability.

We conducted poisoning along 37 of the 54 trap lines at the forest study area and along 36 of the 60 trap lines at the farmland study area. We used the posterior median value of \hat{N}_i as a point estimate of

the actual population size at site i , denoting this estimate by N_i .

As we predicted, the number of possums killed by cyanide increased with the number of possums estimated to be remaining along the trap line after we finished trapping (Fig. 4).

Assuming that the total number of animals trapped and poisoned at site i was in fact N_p , we noted that on 17 trap lines $\hat{N}_i < N_p$, on 24 trap lines $\hat{N}_i = N_p$, and on 32 trap lines $\hat{N}_i > N_i$ (Fig. 4). No possums were poisoned on the 2 trap lines on which no possums were trapped.

DISCUSSION

Our results demonstrated that the TCI is a non-linear index of possum abundance (Table 1) that can vary seasonally (Table 2). Although the potential for nonlinearity has long been recognized in indices of abundance (Caughley 1977), to our knowledge this is the first study to explicitly test for seasonal variation in the capture probability of an index of animal abundance (Gibbs 2000). The nonlinearity arose because capture probability declined with increasing population size (Table 1; Fig. 2). Hence, the ability of the index to discriminate abundances decreased as abundance increased. Other constant removal techniques in which the number of individuals that can be captured per unit of effort is small relative to the absolute population size can also be expected to have a nonlinear relationship with absolute abundance (Gibbs 2000).

Capture probability in farmland was lower during spring relative to both winter and summer in farmland, and also to forest during summer (Table 2). There was no evidence of seasonal variation within the forest

Table 2. The 15 contrasts in the odds ratios of capture probability by habitat and season modeled using the software BUGS. Data collected from brushtail possums trapped on 114 trap lines, North Island, New Zealand, in summer, winter, and spring of 2000 and 2001.

Contrast	2.5th percentile	Median	97.5th percentile
Forest summer–forest winter	0.996	1.458	2.147
Forest summer–forest spring	0.975	1.442	2.132
Forest summer–farmland summer	0.955	1.345	1.870
Forest summer–farmland winter	0.795	1.106	1.527
Forest summer–farmland spring	1.306	1.893	2.729
Forest winter–forest spring	0.663	0.991	1.459
Forest winter–farmland summer	0.651	0.923	1.280
Forest winter–farmland winter	0.539	0.760	1.042
Forest winter–farmland spring	0.898	1.298	1.870
Forest spring–farmland summer	0.652	0.933	1.315
Forest spring–farmland winter	0.543	0.766	1.066
Forest spring–farmland spring	0.903	1.310	1.897
Farmland summer–farmland winter	0.651	0.822	1.040
Farmland summer–farmland spring	1.094	1.406	1.840
Farmland winter–farmland spring	1.355	1.711	2.195

habitat. Further work throughout New Zealand is required to determine the consistency of seasonal bias. Until such data are available, a sensible approach would be to restrict repeated sampling to as similar a time period as possible. Seasonal changes in the capture probability of possums might be a consequence of seasonal changes in the behavior of possums. For example, male possums are

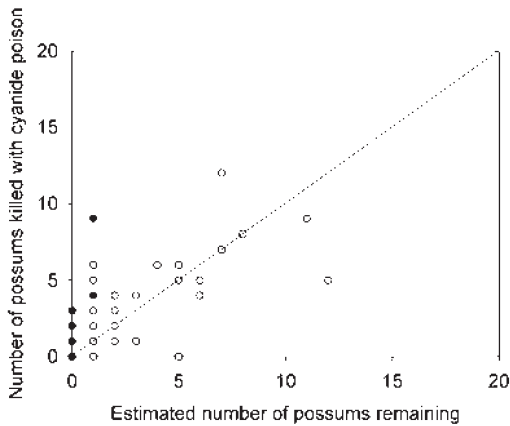


Fig. 4. Number of brushtail possums killed with cyanide poison compared with the number predicted to be remaining after trapping, North Island, New Zealand, in summer, winter, and spring of 2000 and 2001. The open circles are trap lines at the forest study area ($n = 37$), and the closed circles are trap lines at the farmland study area ($n = 36$). The solid line is the 1:1 line of perfect fit.

more active during summer and autumn (Cowan and Clout 2000), possibly increasing the probability they will encounter a trap during those seasons.

Our model allowed for variation in local population size and capture probability. Since we chose noninformative priors, the Bayesian analysis we presented produced estimates similar to those that would be obtained under a Frequentist analysis. The advantage of the Bayesian analysis is its simplicity and integrity; classical approaches would require complex calculations of marginal distributions or dubious reliance on asymptotic results. A Bayesian analysis treats all quantities in the statistical model as random variables, with uncertainty expressed relative to parameters that could have produced the identical set of data (Link et al. 2002).

The removal method of estimating population abundance relies on several key assumptions being met (Seber 1982). First, the sampled population is assumed to be closed. Since trapping occurred over a maximum of only 21 nights in a season (i.e., 12 fine nights interrupted by 9 wet nights, when traps were closed), any recruitment or natural mortality would have been negligible. Efford et al. (2000) observed that shifts and extensions in the home range of possums neighboring experimentally culled animals on a forest-farmland margin occurred in a matter of weeks. Such movements may have violated the assumption of a closed population, but we had no means of assessing this possibility. Second, it is assumed that all animals in the population can be sampled. This assumption would be violated if some pos-

soms exhibited a behavioral aversion to entering traps. However, the distribution of the numbers of possums poisoned along trap lines after trapping had ceased (Fig. 4) suggests that the proportion of nontrappable animals was sufficiently low not to bias our estimate of N_i . Third, it is assumed that capture efficiency remains constant during the sampling period. Since traps were checked daily, and reset or replaced if necessary according to a protocol (National Possum Control Agencies 2002), capture efficiency was unlikely to have changed. We did not attempt to account for sprung traps and nontarget captures because the percentage of traps made unavailable to possums was very low at both study areas.

An index of abundance that is to be used by many people in different agencies, as is required for the management of possums in New Zealand, needs to be simple to implement and must yield information relevant to the management objective. Until recently, the TCI was primarily used for estimating kill rates in control operations aimed at reducing populations at high abundance (i.e., >20% TCI) to low abundance (i.e., <5%; termed knocking down). Veltman and Pinder (2001) assessed how operational and environmental factors affected kill rates in 48 aerial 1080 operations throughout New Zealand. The kill rates were determined using TCI estimates from before and after control, and they were found to increase with decreasing air temperature, a result that was consistent with the role of temperature in clinical trials of 1080 toxicity in possums (Veltman and Pinder 2001). The majority of possum control in New Zealand changed from reducing populations to maintenance control. Maintenance control aims to maintain populations at a TCI of $\leq 5\%$ because empirical data indicate that this strategy can substantially reduce the annual Tb reactor incidence in associated livestock herds (Coleman and Livingstone 2000). A target TCI is stipulated in the control operation contract, and the contractor is paid only when that TCI (or lower) is attained. Given that the index is approximately linear at such low possum abundance, and that the seasonal bias is small, the TCI appears adequate for such monitoring. The number of trap lines required to estimate a TCI with a desired level of precision can be calculated using several methods (review in Thompson et al. 1998). R. A. Webster and P. Caley (2001; Contract Report LC0001/46, Landcare Research, Lincoln, Canterbury, New Zealand) illustrate how such methods can be applied to the TCI.

Finally, we note that the advantages and disadvantages of the TCI must be weighed against competing methods of estimating the abundance of possums. Capture–mark–recapture techniques can generate precise estimates of absolute possum abundance (e.g., Efford 1998), but they are considered too expensive to implement at the management scale in New Zealand. Fecal pellet counting has been used to index the abundance of possums (Hickling and Pekelharing 1989), but the method has not been formally evaluated. Provided its limitations are recognized, the TCI therefore appears adequate for the purposes of the majority of possum management in New Zealand.

MANAGEMENT IMPLICATIONS

In the absence of a proven and cost-effective alternative, our results support the continued use of the TCI for monitoring the abundance of possums in New Zealand. However, whenever possible, we recommend minimizing seasonal biases in the TCI by conducting repeat sampling in the same season.

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