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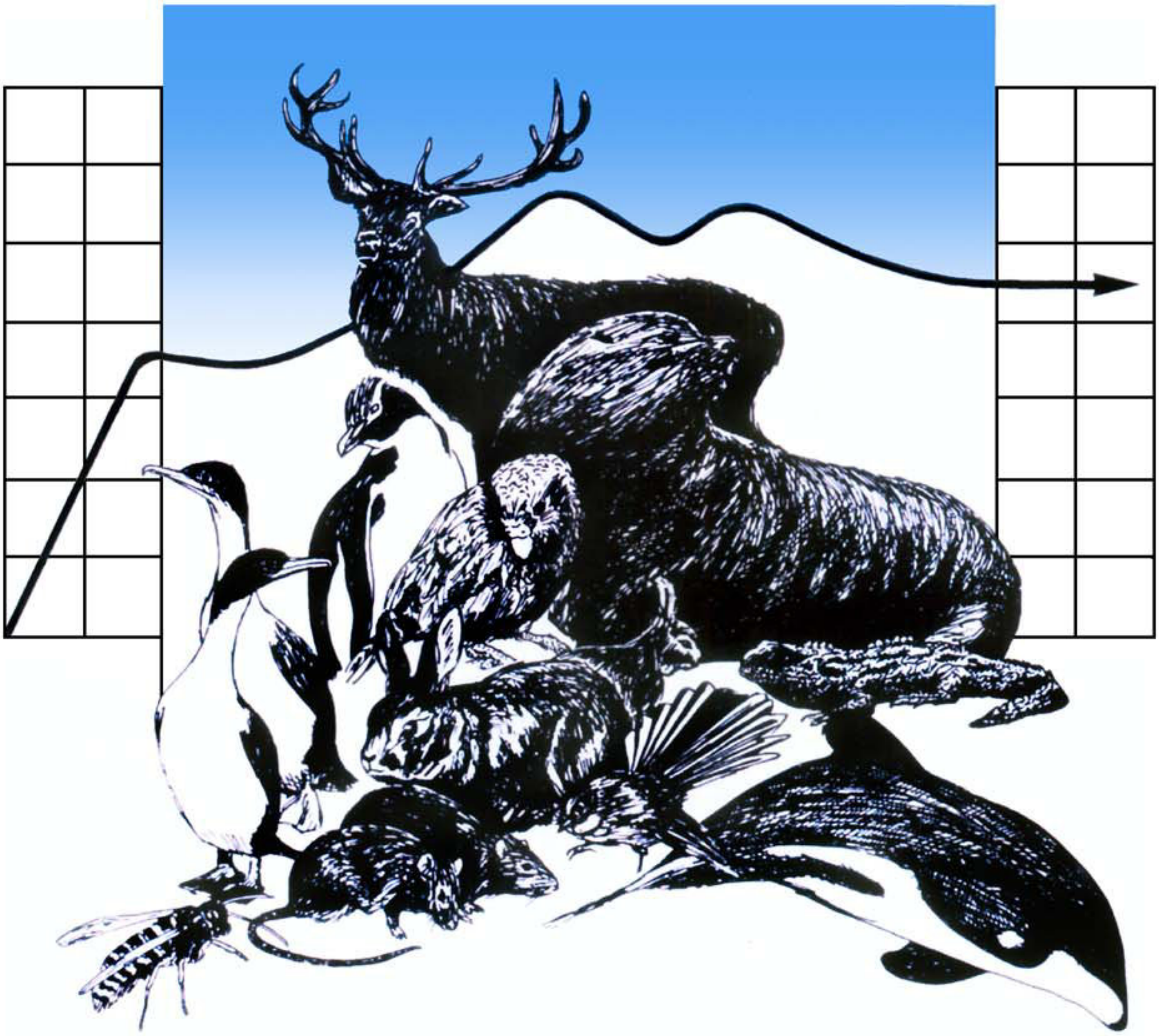

WILDLIFE MANAGEMENT

Mark-resight analysis of kaki (Himantopus novaezelandiae) sightings: a novel approach for the Kaki Recovery Programme

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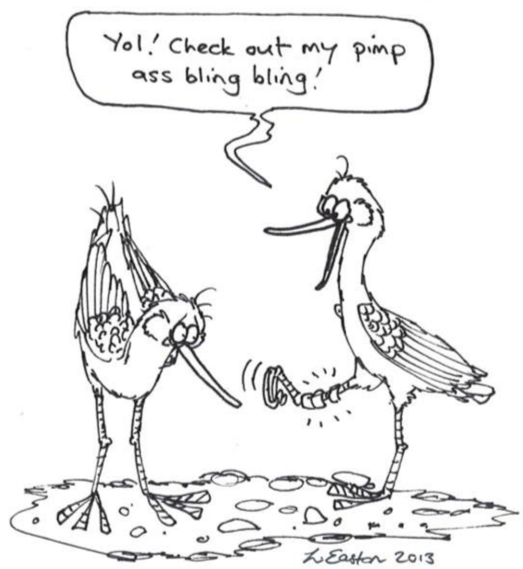

Abstract

Monitoring is crucial for managing threatened species. Mark-resight studies in particular have been widely used to estimate population dynamics. Only recently has this approach been applied to the critically endangered kaki Himantopus novaezealandiae. The Kaki Recovery Programme intensively monitored kaki before mark-resight techniques were introduced in February 2013 because of resource restrictions. To gain confidence in this new approach we analysed sightings from 1982-2012 to estimate population dynamics of wild adults and compared the results with those derived from past intensive monitoring. Potential sex and weight effects on survival were also examined using an ANCOVA model. There was a significant interaction between sex and weight which indicated that increased persistence in the wild may be dependent on weight at banding and also that males may have a higher survival than females at an older age. The estimates for survival and recapture (resight) probabilities were congruent to previous estimations and considered constant under the selected open population model. Population size estimates using both closed and open population model approaches largely underestimated the actual population count, although the closed population model did provide similar estimates for the last three seasons despite large confidence intervals. Although major limitations present in the data prevented appropriate population size estimates being produced, using the closed population mark-resight technique does have credit for monitoring kaki and is therefore recommended. Nevertheless, comparing estimates with alternative techniques and improvements to the mark-resight model is suggested to achieve robust population parameter estimates.

Introduction

Monitoring individuals to estimate abundance and apparent survival rates is crucial for managing threatened species (Lettink & Armstrong 2003; Seddon et al. 2003; Green et al. 2004). Mark-resight studies, which are mark-recapture studies without physical contact of animals during secondary sampling, are powerful tools to gain these population parameters (Armstrong & Ewen 2000; Lettink & Armstrong 2003). Mark-resight/recapture data is often analysed by the computer program MARK as it not only produces population and survival estimates, but also identifies what factors may influence survival rates (Armstrong & Ewen 2000; Lettink & Armstrong 2003; Pryde 2003). Due to the feasibility and precision of mark-resight/recapture estimates (Seddon et al. 2003), MARK is widely utilised by studies investigating animals such as birds (e.g. Armstrong & Ewen 2000; Armstrong et al. 2001; Scofield et al. 2001; Curtis 2002; Davidson & Armstrong 2002; Brown et al. 2005), marine mammals (e.g. Shaughnessy et al. 1995; Mizroch et al. 2004), and cryptic mammals (e.g. Fisher et al. 2000; Hoyle et al. 2001; Pryde et al. 2005).

Mark-resight methods were recently applied to sightings data of the critically endangered kaki (black stilt) Himantopus novaezelandiae (first by Bulling (2008) then followed by this study). Kaki is a New Zealand endemic wader now restricted to the upper Waitaki Basin, of the central South Island (Maloney & Murray 2001; Sanders & Maloney 2002; Hutching 2004; Murphy et al. 2004). Once found throughout most wetlands of New Zealand, predation by introduced mammals and habitat loss have contributed to their decline (Reed 1998a; Maloney & Murray 2001; Sanders & Maloney 2002; Hutching 2004; Murphy et al. 2004). Since management of kaki began in 1981, population estimates have been obtained using intensive methods (Maloney & Murray 2001), but the Department of Conservation Kaki Recovery Programme could not sustain the same intensity following recent resource restrictions and changed to mark-resight techniques in February this year (Cleland S, pers. comm.). Assessing whether mark-resight techniques can produce reliable population estimates will therefore provide the Kaki Recovery Programme with confidence in utilising this new approach (Cleland S, pers. comm.). Bulling (2008) used mark-resight methods to obtain only apparent survival and recapture (resight) probabilities for the years 2003-2008. We therefore present a mark-resight analysis of sightings (provided by the Kaki Recovery Programme) of identified wild adult kaki from the years 1982-2012 in order to estimate population sizes, apparent survival, and recapture (resight) probabilities.

Precise population estimates, based on work by Seddon et al. (2003), are potentially obtained when the proportion of marked individuals reaches 30% of the entire population. Given that roughly 93% of all wild adult kaki by 2006 were captive-reared (Maloney et al. 2006) and therefore banded, estimates from this analysis should be robust. Comparing these model estimates with estimates derived from past intensive monitoring will determine how effective mark-resight methods are for the ongoing monitoring of this critically endangered species.

Methods

Data formatting

The Kaki Recovery Programme provided two excel data sets from their data base: an "alpha list" of all 2013 recorded individuals (including hybrids) since management began and a list of 56,022 sightings from 1978-2013 (for subset of data see Appendix 1-3). Sightings are weekly as each site is monitored 1-3 times per month (Green et al. 2004). There is also increased monitoring effort during the breeding season from September to February (Green et al. 2004; Cleland S, pers. comm.). We assumed that data entries of variables in the "alpha list" conformed to those present in the sightings data regarding each individual. Formatting data was carried out in both excel and R (for R code see Appendix 4).

Since we were only interested in wild adult kaki sightings, non-adults were removed from both lists. Captive, hybrid, unknown band combination, and unbanded individuals were also excluded from both lists where necessary. Unfortunately, inconsistent data entries (e.g. different band combinations for the same id number) were still present, thus a further filtration process was required for both data sets. Once the data had been fully filtered, only sightings from 1980-2013 remained. 'Adult' sightings were identified under the assumption that any individual seen during August in its second year or later was considered a recruit in the adult population (approximately 2 years of age as kaki reach sexual maturity at this age (Maloney et al. 2006)). Furthermore, any individuals banded as adults were assumed to be in their second year only. A matrix consisting of annual (annual sampling periods as sightings throughout the year were pooled) encounter histories (binary data of "seen"=1 and "not seen"=0) for all apparent 'adult' sightings was produced (see Appendix 5). Individuals with only one encounter period were excluded as these were assumed to have died or emigrated the following year. Additionally, as no 'adult' sightings we present in the first two years (1980 and 1981) and in the final year (2013), these years were excluded. This final filtration process left sightings from 1982-2012. The filtered matrix was then converted into an ‘inp’ file (which is compatible for the program MARK 7.1 (White and Burnham 1999)). A total of 61 ‘adults’ recorded in the “alpha list” had at least two yearly encounters. These individuals, with their respective 31 encounter periods (i.e. 31 years), were used to calculate survival and recapture (resight) estimates in MARK.

Sex and weight effects on number of years seen in wild

‘Sex’ and ‘weight (g) at banding’ acted as input variables and covariates respectively to assess any potential influence on possible survival within an ANCOVA linear regression model. The number of years each individual was seen was treated as the response variable, as persistence in the wild population was assumed to be related to survival. To obtain ‘years seen’, the number of times individuals were observed over the 34 years was summed for each ‘adult’ that had corresponding sex and weight information. Only 84 out of 122 ‘adults’ ever sighted (i.e. individuals that were sighted at least once) had both ‘sex’ and ‘weight’ information however. Two models were produced: a main effects (‘sex’ + ‘weight’) model and an interaction (‘sex’ + ‘weight’ + ‘sex:weight’) model. These models were scaled so that the covariate ‘weight’ average was centred on zero, in order to allow more appropriate statistical inferences to be made from interpreting the t-value. Models were then tested using ANOVA and selected based on AIC.

In total there were an estimated 2752 sightings of 122 ‘adults’ over 34 years. The online MARK book (Cooch & White 2013) and MARK guide (Pryde 2003) were then followed for the remainder of these methods.

Model type and assumptions

Considering the kaki population is open because of emigration and recruitment (Seber 1982; Lettink & Armstrong 2003) of released captive-reared juveniles and sub-adults, the standard Cormack-Jolly-Seber model (CJS) (Pryde 2003) was used as an open population model to estimate the population parameters. The assumptions of an open population mark-resight model are: **1)** all individuals have the same probability of apparent survival; **2)** all individuals have the same probability of being resighted; **3)** marks are not lost or missed; and **4)** all samples (i.e. resightings) are instantaneous (Seber 1982; Barker 1997; Armstrong & Ewen 2000; Linklater et al. 2001; Lettink & Armstrong 2003; Pryde et al. 2005; Bulling 2008; Cooch & White 2013). Moreover, time intervals between sampling periods do not have to be discrete (Barker 1997; White &

Burnham 1999). Based on our filtered data none of these assumptions seemed clearly violated except for assumption 4. Annual samples were not instantaneous as sightings occurred throughout the year and pooled. The assumption of constant apparent survival probability would have been violated if sub-adults and juveniles were included as different age classes often have different survival rates (Seber 1982) which is indeed the case for kaki (Maloney et al. 2006; Cline 2007).

Mark-resight model building and selection in MARK

'Apparent' survival (phi) is the probability that an individual survives and is available for resighting the following year (White and Burnham 1999; Hoyle et al. 2001; Pryde et al. 2005; Cooch & White 2013). It is not a true indication of survival as emigration cannot be differentiated from mortality (Bulling 2008; Cooch & White 2013). Recapture (resight) probability (p) is the probability that an individual is recaptured (resighted) during a sampling period. Time is denoted as t in these models (Cooch & White 2013).

Model selection involved the Akaike Information Criterion (AIC), which compromises between model fit (i.e. deviance) and simplicity (i.e. number of parameters), in order to achieve parsimony (i.e. a simple model representing low bias but high precision) (Anderson et al. 1998; Armstrong & Ewen 2000; Pryde et al. 2005). The model with the lowest AIC value represents the 'best' compromise (Armstrong & Ewen 2000) and thus is usually selected. Alternative models are considered if their respective delta AIC (i.e. the difference between the AICs of the 'best' model and another model) is not greater than 2 (Armstrong & Ewen 2000; Pryde et al. 2005). The quality of the model is determined by observing the deviance between the model and observed data (Gelman 2000). Thus a goodness-of-fit test using model simulations and comparing these to the observed data provides an insight into model performance (Gelman 2000). Models are adjusted for over-dispersion (i.e. inflated variation) using the c-hat variance factor (Pryde 2003; Cooch & White 2013). Adjusted models have larger 95% confidence intervals and AIC values are converted to quasi-AIC (QAIC) to accommodate for extra variance (Pryde 2003; Cooch & White 2013).

Analysis for **phi** and **p**

"Pre-defined" CJS models were ran in MARK using data which included 'adults' without 'sex' and 'weight' as input variables (n=122). The data was only slightly over-dispersed (c-hat=1.19) but still adjusted for. The adjusted phi(.) p(.) model (which meant that phi and p did not change with time (i.e. remained constant)) had the greatest QAIC weight (100%) and lowest QAIC

(Table 1.). This model was therefore selected. Estimates from this model were compared with those derived by Bulling (2008).

Table 1. CJS models of phi and p and model selection criteria (QAIC, delta QAIC, and QAIC weight).

Model	QAIC	Delta QAIC	QAIC Weight	No. Parameters
phi(.) p(.)	405.37	0	1	2
phi(t) p(.)	429.99	24.61	0	31
phi(.) p(t)	439.53	34.16	0	31
phi(t) p(t)	486.59	81.22	0	58

Population size estimation

The primary model of interest was the open population model, where population counts are divided by the recapture (resight) probability. Nevertheless, we also used the closed population model ($\tilde{N}=n_1*n_2 / m_2$) to see whether this approach could be deemed more appropriate regarding the estimates produced. The closed population model is more simplistic in that there are only two main assumptions: no marks are lost and that no births, deaths, immigrations, or emigrations take place between survey periods (Lettink & Armstrong 2003). Both population size model estimates were compared with the actual population counts previously obtained.

Results

The number of 'adult' kaki sighted over survey periods was positively skewed with a large disproportionate frequency being sighted in only one year (Figure 1).

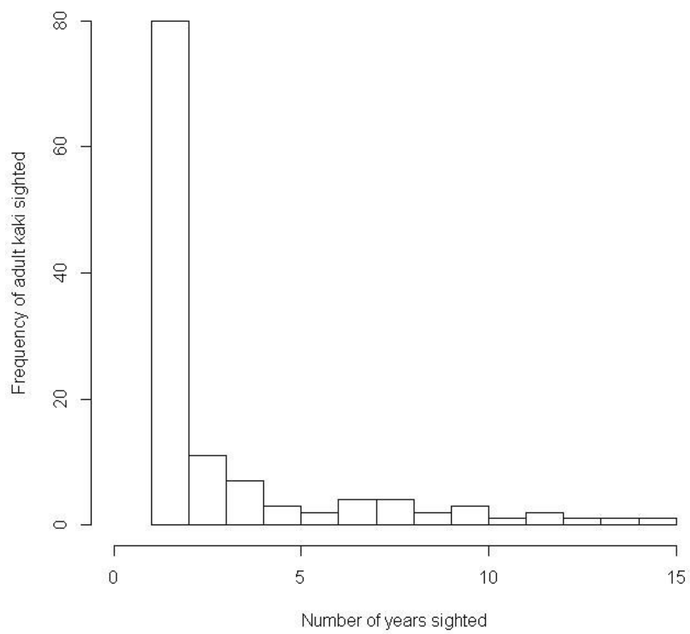

Figure 1. Number of 'adult' kaki sighted over survey periods (n=122).

Sex and weight effects on number of years seen in wild

The interaction model was considered more 'optimal' compared with the main effects model because of a lower AIC value (AIC=429.70, compared to AIC=433.84). Under this selected model, there was no effect of 'sex' on 'years seen' after controlling for the covariate 'weight' (coefficient est.=0.22, t=0.33, p=0.740). Similarly, 'weight' apparently had no effect on 'years seen' after 'sex' was accounted for (coefficient est.=0.024, t=1.71, p=0.09). The positive interaction between 'sex' and 'weight' was significant however, although the difference between male and female 'adult' kaki was small (coefficient est.=0.05, t=2.46, p=0.016) (Figure 2). The ANOVA test showed that in fact both 'weight' and 'sex:weight' were statistically important predictors in the model (F=30.4, df=1, p<0.01 and F=6.1, df=1, p=0.02 respectively) although only 31.5% of the variation was explained by the interaction model.

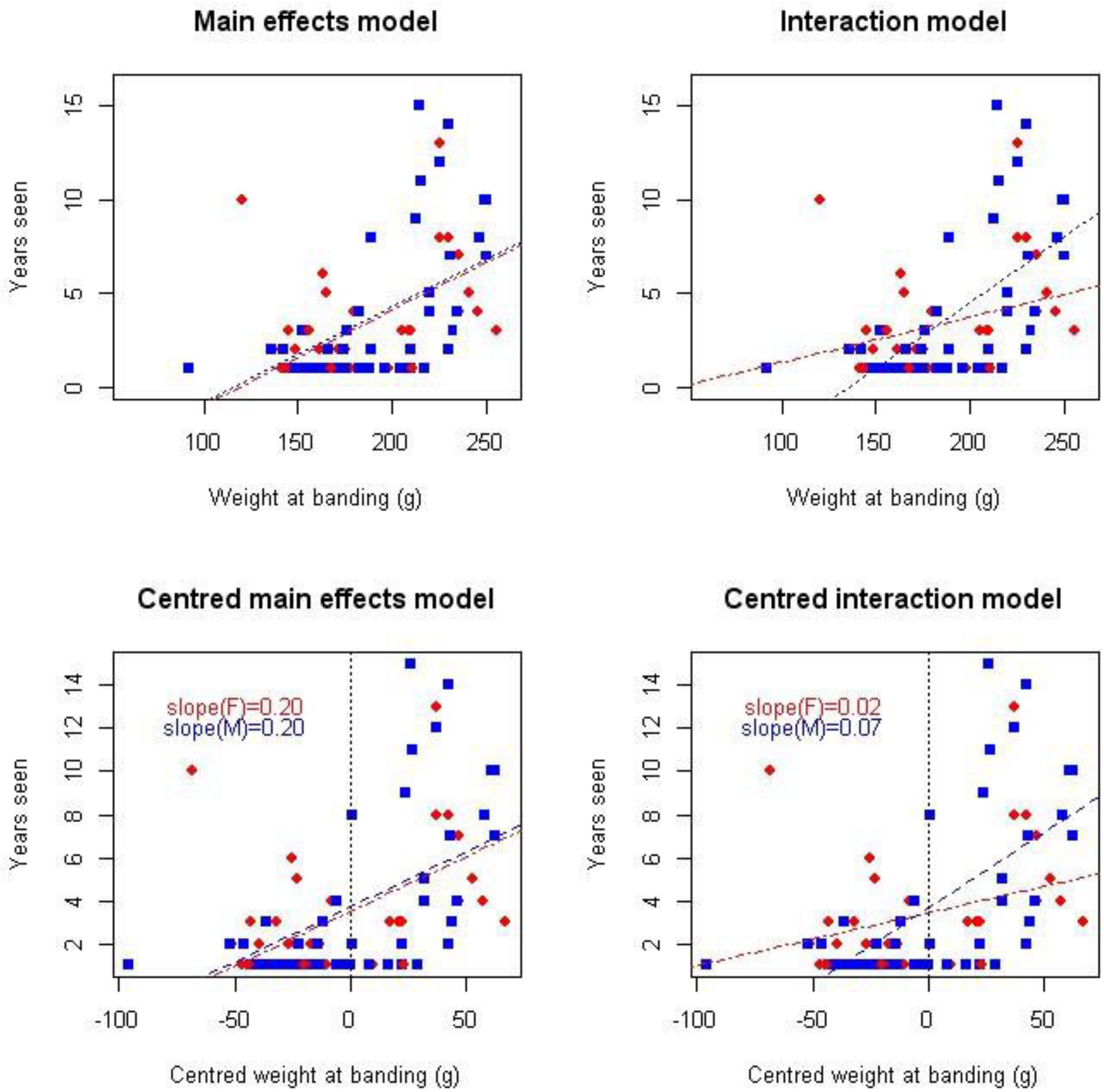

Figure 2. Main effects and interaction model (non-centred and centred) plots showing positive relationship between 'years seen' and the predictors 'sex' and 'weight' (males=squares; females=diamonds) (n=84).

Analysis for **phi** and **p**

For the years 1982-2012 phi was considered constant at 0.84 (95% CI: 0.79-0.88). Similarly, p was constant at 0.87 (95% CI: 0.81-0.91). Comparatively, Bulling (2008) estimated phi for two groups (based on location) of 'adult' kaki: 'Tasman'= 0.78 (95% CI: 0.61-0.89) and 'non-Tasman'= 0.56 (95% CI: 0.41-0.69). P was constant at 0.87 (95% CI: 0.69-0.95) for both groups. Note: Bulling used two attribute groups (g) based on location and selected the model phi(g) p(.) (meaning that phi changes between groups, but not p).

Population size estimation

Both population models underestimated the actual population size as indicated by intensive population counts (Figure 3a). Closed population model estimates for the last three seasons, however, were more congruent with actual population counts despite the large 95% confidence intervals (Figure 3b).

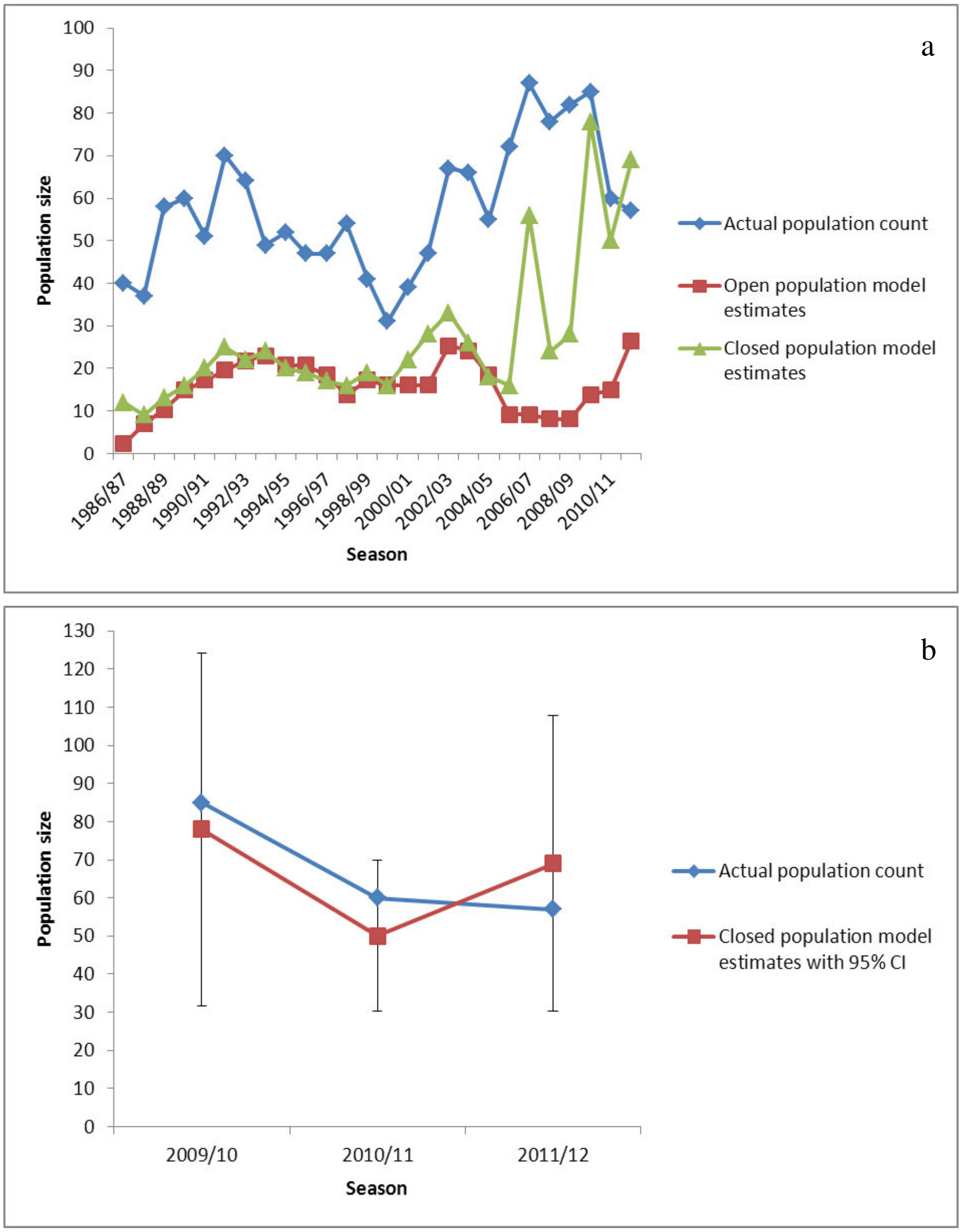

Figure 3. a) Population size estimates for both closed and open population models, in comparison to actual population counts; b) subset of population estimates derived from closed population model for the seasons 2009/10-2011/12 with 95% CI, in comparison to actual population counts.

Discussion

Quality of data

Given that our long-term data set consisted of a high proportion of marked individuals (Maloney et al. 2006), we were confident that population estimates derived from this mark-recapture analyses would be robust and precise. Indeed, Scofield et al. (2001) demonstrated that mark-recapture techniques can work successfully on large data sets by re-analysing banding data of titi (Puffinus griseus) collected by Lance Richdale between 1940 and 1957. Furthermore, Davidson and Armstrong (2002) analysed long-term data of saddlebacks, where they were able to obtain precise estimates of survival because of no confounding seasonal variation. Linklater et al. (2001) also had precise estimates due to the high proportion of their feral horse population being marked. For kaki, population counts that included captive-reared birds began in 1988 which meant that by 1990 observations began to become more robust as the kaki population was becoming disproportionately represented by captive-reared individuals (Reed 1998b). By 1995, 46% of the population was captive-reared (Reed 1998b), which is higher than the threshold proportion of 30% set by Seddon et al. (2003) to obtain precise estimates. A combination of long term data and high proportion of marked individuals (like the kaki sightings (Maloney et al. 2006)) should therefore be an optimum data set to apply mark-recapture (resight) methods to.

Limitations of data

Despite the apparent good quality of data used, there are some limitations largely due to some individual database information not being updated, inconsistent sighting entries, uninformative sighting entries, or details left incomplete. A large proportion of potentially valuable information could therefore not be used thus excluded from the analyses. The data required rigorous filtering before any analyses could commence. These limitations could have easily been avoided had data been entered consistently, with any unknowns entered as just a single condition (e.g. “unk”), and ensuring that all required information was filled out completely. Recommendations for mitigating these limitations have been made below.

Sex and weight effects on survival

The significant interaction between ‘sex’ and ‘weight’ suggests that adult male kaki may survive longer in the wild than females after about 7 years since recruitment if their weight at banding exceeds ~175g. Males may therefore have a higher survival rate than females at an older age (i.e. at least 9 years). The optimal weight range at banding seems to be between 200-250g in order to increase persistence in the wild for both sexes. There are two main confounding variables however: age at banding and age at release. Individuals have not been banded at the same age (some are banded as adults whereas most are banded as juveniles), thus of course weight would depend on age at these stages. Moreover, survival rates vary between age classes (Maloney et al. 2006; Cline 2007) thus long-term persistence in the population may be due to individuals being released as adults for instance. Adding these parameters into the ANCOVA model, along with increasing the sample size, would definitely improve the reliability of our interpretations of this model.

Survival and recapture (resight) estimates

The estimate for survival probability was relatively accurate and precise as the estimate and associated 95% CI was congruent with the survival range of 75-88% inverse to the mortality range indicated by Maloney et al. (2006) for all managed years until 2006. Our 95% confidence intervals were narrower and over-dispersion approximately five times lower than that obtained by Bulling (2008). Recapture (resight) probability was also similar to Bulling's. Filtering sightings to meet certain criteria was more intensive in this study which may have contributed to lower variation observed. Moreover, Bulling only looked at relatively short-term data in proportion to the data available. Adult mortality, inverse to survival, was similar to the ~10% adult mortality observed per year during the years 1979-1994 (Reed 1998a). This suggests that mark-resight techniques are indeed suitable for estimating kaki population survival and recapture (resight) parameters.

Population size estimates

Although the population size estimates using both mark-resight models underestimated actual population size, there were indications that the closed population model is indeed appropriate as estimates for the last three seasons were similar to actual counts. The most recent survey during February this year using the closed population mark-resight approach also produced a precise estimate congruent to previous population counts (61 adults (95% CI: 58-64)) (Cleland S, pers. comm.). Improved data quality and sampling effort in recent years is likely to contribute to these more appropriate estimations. Actual population counts were produced using similar methods to this study such as removing unknown or unbanded individuals (Cleland S, pers. comm.), thus the main reason as to why underestimations were observed is assumed to be the assumption regarding individuals banded as adults. 35 out of 39 individuals which were banded as adults were sighted from the filtered "alpha list" and used in the analyses. As we had no way of determining actual age from the data provided, these individuals were assumed to be in their first year of recruitment. This assumption can easily be violated however as these individuals are likely to be older and possibly sighted as an unbanded adult earlier on. All unbanded individuals were removed from the analyses as individual identification cannot be linked with a particular encounter history, but consequently this leads to the potential loss of adults recorded as actually present in the wild population at the time of the survey. Not enough resightings the following year due to detection error may also be a factor, although the decrease in individuals seen over subsequent survey periods is likely to be expected as adult mortality is a major limiting factor of population growth due to predation by introduced pests (Maloney & Murray 2002). Detection error is also expected to be low for kaki due to the experienced observers of the Kaki Recovery Programme conducting the surveys.

Limitations of models

The open and closed mark-recapture/resight models, like all models, have limitations. Firstly, some assumptions can be easily violated, such as the assumption regarding constant resighting probability especially when different age classes or sex is concerned (Seddon et al. 2003). Secondly, any individual that may permanently disperse out of the area or not detected due to sampling bias after the initial sighting would be considered dead (Brown et al. 2005). This would lead to an underestimation of population estimates and is a particular problem for estimating open populations (Brown et al. 2005). Moreover, uncertainty is always associated with population estimates because of imperfect detection (e.g. bad weather), observer bias, spatial and temporal variation, and sampling error (Thompson et al. 1998; Skalski et al. 2005; Brown & Robinson 2009). In particular, spatial and temporal variation may be promoted by a small proportion (~10% annually) of kaki migrating to post-breeding estuaries during autumn/winter (Reed 1998b; Maloney & Murray 2001). Careful monitoring practices including near-simultaneous surveys of populations are therefore essential for robust estimation (Skalski et al. 2005). Multiple surveys across years decrease uncertainty (Curtis 2002; Brown & Robinson 2009) and increases inference from results (Anderson et al. 1998; Pryde 2003), but as sample size increases, more unknown effects (e.g. temporal or spatial effects) may influence the data (Anderson et al. 1998; Bayarri & Berger 2000). This can lead to overdispersion (Anderson et al. 1998), but fortunately there are (although complex) Bayesian methods that can eliminate these unknown parameters (Bayarri & Berger 2000; Bayarri & Castellanos 2007).

As mentioned before, only about 1990 did population estimates before more precise because of increased monitoring effort, thus caution must be used when addressing 1980s population estimates in this data set. Pre-cautionary use of earlier population estimates, in particular, were clearly illustrated by Linklater et al. (2004) where they determined that historical estimates of population growth of feral horses may have been overestimated by ~50% because of improvements in monitoring techniques. It is unlikely that the 1980s kaki counts were overestimated by this extreme, but there is a possibility that they were underestimated especially when captive-reared individuals were excluded from the population counts until 1988 (Reed 1998b). Lastly, with regards to determining whether 'sex' and 'weight' input variables influence survival, another limitation is that only sex is a fixed input variable. Mark-recapture (resight) models assume that input variables remain constant over the survey period (Brown et al. 2005), but of course weight fluctuates over time. Covariates thus tend to be continuous (Pryde 2003). Unfortunately, no practical method is available to obtain a covariate that can change geographically and temporarily using a multistate approach (Pradel & Lebreton 2002) in the field as it requires multiple measurements of the same individual (Brown et al. 2005).

Improvements to model and possible alternatives

Both improvements in the models produced by this study and alternative techniques would ensure reliable estimates are obtained. Firstly, comparing sampling techniques (e.g. Distance sampling (Seddon et al. 2003; Preston 2008) or single-encounter approach (Sólymos et al. 2012)) to that of mark-resight is essential to ensure estimate robustness. For instance, mark-resight sampling was shown to be the most precise and effective method when estimating population size for the Arabian oryx (Seddon et al. 2003). Secondly, Barker (1997) proposed a model with resightings obtained from marked animals continuously between survey periods and throughout their home range. This model is particularly relevant to this study and many others as by pooling resightings into a single encounter (usually annual (Lettink & Armstrong 2003)) important information may be lost. The 'Barker model' has also been shown to reduce variation in model estimations (Mizroch et al. 2004). More recently, Sólymos et al. (2012) suggested using a single-encounter approach to estimate population size, based off the zero-inflated Poisson model proposed by Joseph et al. (2009) and Wenger and Freeman (2008). All three studies highlight that presence and absence data actually includes a third parameter regarding detection error. Recording an individual as absent during a particular survey may in fact be a 'false absence', as detection error may be high depending on the weather or observer (i.e. an individual may actually be present but not detected). Inflating this ‘zero encounter’ to a possible detection using conditional likelihood is dependent on additional covariates (such as time of day, observer, weather, etc.,) within the model. Most importantly, this approach only requires a single survey of the area.

Conclusions

Utilising cost-effective techniques when resources are increasingly becoming restrictive is essential for the persistence of any conservation management programme. Even though this attempt at estimating population size was limited by the data at hand, there were indications that the mark-resight technique will work successfully. Survival and recapture (resight) estimates were congruent with previous estimates and several population size estimates using the closed population model were also similar to actual population counts. The most recent survey of kaki during February this year using the closed population mark-resight approach provided a precise estimate similar to past population counts, adding confidence in using mark-resight as a new monitoring technique. Lastly, investigating potential effects on survival such as sex and weight provide important insights into how to best manage this species. It is suggested that improvements to the models be made or alternative monitoring methods be explored using a subset of data recently collected to achieve robustness in population estimates. Until further investigation however, the mark-resight closed population technique is indeed a good candidate for monitoring kaki.

Recommendations

Overall, this study has highlighted a number of strengths and weakness associated with the data sets available and how the quality of data influences the validity of mark-recapture (resight) models produced. From this we can make the following recommendations:

1) always enter data consistently and correctly

2) use R code to tidy up data sets by removing any incorrect and therefore uninformative data entries

3) update data sets regularly.

We have also illustrated that mark-resight analyses do provide appropriate survival and resight estimates. Additionally, indications of relatively appropriate population size estimates using the closed population model highlight the need to implement these two recommendations:

4) modify R code to enable survival and resight estimates to be obtained for sub-adult and juvenile kaki also

5) use the closed population mark-resight model as a monitoring technique.

Finally, this study can be improved in four main ways, and hence forms the final recommendations:

6) have someone with an advanced R background re-examine the R code to simplify it or make justifiable changes where necessary

7) compare mark-resight method with other techniques like Distance sampling or single-encounter approaches to increase robustness of estimates produced

8) seek further mark-recapture (resight) models (e.g. the Barker model) to reduce uncertainty and therefore increase precision of population estimates.

9) account for potential confounding variables in the ANCOVA model and/or assess input variable effects on survival in MARK.

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