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Comparative use of three methods for estimating the population size of a transferred island endemic: the endangered Seychelles White-eye *Zosterops modestus*

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Post-release monitoring is an important aspect of species transfers, providing a basis for conservation and management actions to achieve long-term survival of the species. Between 2001 and 2003, the Seychelles White-eye *Zosterops modestus* became established on Frégate Island following the transfer of 37 adult colour-ringed birds from Conception Island. Capture and colour ringing of birds was undertaken at regular intervals to keep the majority of the population banded. As the population grew, sampling methodologies became necessary to estimate its size accurately. Here, we compare the results obtained between November 2005 and January 2006 using three different methods: (1) capture–mark–relocate (NOREMARK); (2) point-transect with 'distance sampling', and (3) direct systematic surveys. Fifty point counts of 10 min each were conducted and replicated three times. The estimate by capture–mark–relocate was 77 individuals (72–83; $P < 0.05$) with better precision over distance sampling: 78 individuals (44–136; $P < 0.05$). The result from direct systematic surveys (81) indicated that estimates obtained with the two indirect methods were reliable. Based on present and previous method comparisons, we recommend using the capture–mark–relocate method for its higher precision and the NOREMARK program to determine sizes of island populations with a significant proportion of marked individuals.

Introduction

According to the IUCN, the introduction of invasive species and habitat destruction are the two principal causes of biodiversity loss in island ecosystems (IUCN 2004). Such disturbances threaten the native fauna and flora, and in some cases drive species to extinction. Among several conservation actions to safeguard the future of threatened species, population management techniques are often employed and are particularly useful for species restoration. Translocation or reintroduction, i.e. the deliberate release of wild animals in an area (IUCN 1998, Soorae 2008), is a conservation tool commonly used worldwide for this purpose. One essential aspect of all reintroduction programmes is post-release monitoring to assess status and development of the newly established population, and for determining conservation and management measures to ensure the survival of the species. A key objective is to determine the size and trends of the released population. Several methods have been developed for estimating avian population sizes, including distance sampling, territory mapping, point counts and line transects.

The capture–mark–relocate techniques first developed by Petersen (1896) and later by Lincoln (1930) have led to modern and accurate techniques (White 1996). These are widely used for estimating population sizes (Campbell 1993, Nichols and Mackenzie 2004) and to understand the evolution of population dynamics. The point count method is often used to obtain data for capture–mark–relocate techniques, and for studies on the dynamics of bird populations (Bibby et al. 1992, Thompson 2002, Buckland 2006). Distance sampling estimates the density and size of animal populations and has been used in a range of studies on terrestrial and marine species (Thomas et al. 2010).

Direct systematic surveys consist of thoroughly checking territories and other areas where the birds occur and counting the number of individuals. This method was used to survey Seychelles White-eyes *Zosterops modestus* on Frégate Island (Seychelles) between 2001 and 2003 and is useful for small populations of individually recognisable animals. As these populations grow, and become increasingly difficult and time-consuming to count directly, sampling methodologies need to be developed and assessed.

The Seychelles White-eye is a small woodland passerine endemic to the Seychelles, an archipelago of 115 islands (455 km^2) in the Indian Ocean (Collar et al. 1994, Birdlife International 2000). It was formerly known and widespread on Mahé (Newton 1867, Nicoll 1906, Vesey-Fitzgerald 1936) and was believed to have become extinct (Crook 1961) until it was rediscovered in 1961 (Lousteau-Lalanne 1962). The population was estimated at less than 100 individuals in the mid 1970s (Collar and Stuart 1985) and at 35–45 individuals in 1996 (Mellanby et al. 1997, Rocamora 1997).

In 1997, a previously unknown population, estimated at 279 individuals (242–327; $P < 0.05$) using a capture–mark–relocate method (Rocamora and François 2000), was discovered on Conception Island, bringing the global population estimate to c. 300 individuals.

To secure the long-term survival of this species and given the vulnerability of small island populations, it became imperative to translocate some individuals to other suitable predator-free islands. As a consequence, 37 Seychelles White-eyes were introduced from Conception to Frégate islands between 2001 and 2003 (Rocamora et al. 2001, 2002, 2003). The continued conservation and management of the species and its habitat led to a change in the conservation status of the species from Critically Endangered to Endangered in 2005 (IUCN 2006, Birdlife International 2007).

The objectives of our present study were to: (1) determine the size of the Seychelles White-eye population on Frégate Island using three different methods: capture–mark–relocate, point-transect 'distance sampling', and direct systematic surveys; and (2) identify the best method for such population size estimates by comparing the results obtained.

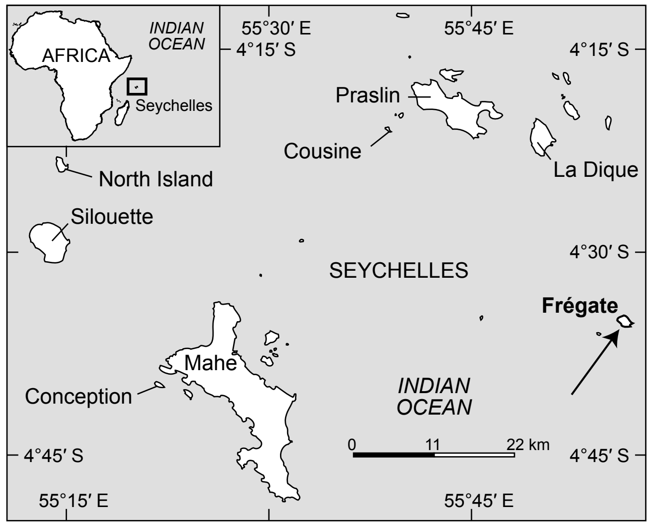

Figure 1: Map depicting the location of Frégate Island

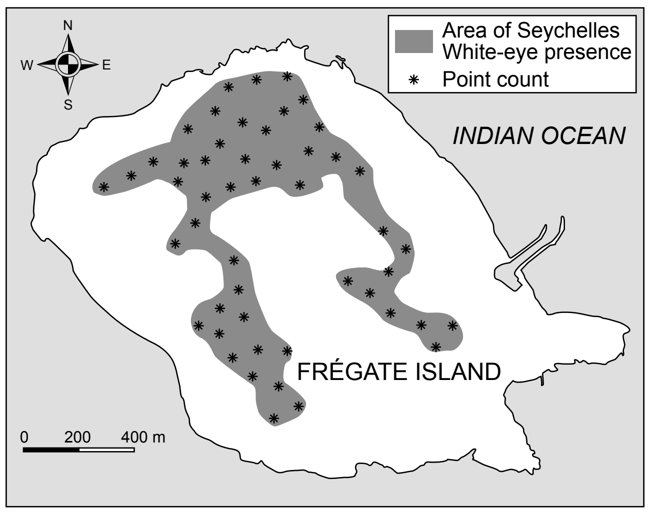

Figure 2: Seychelles White-eye distribution map and location of the 50 point counts on Frégate Island

Materials and methods

Selection of study site and data collection

Frégate is the seventh-largest island of the granitic Seychelles (219 ha, altitude of highest point 125 m), situated 55 km east of Mahé Island (Skerrett et al. 2001) (Figure 1) and an Important Bird Area (Rocamora and Skerrett 2001). Frégate's importance for conservation is because of the lack of introduced mammalian predators, such as cats and rats, which were eradicated in 1977 and 2000, respectively. In addition, intensive vegetation management and rehabilitation have created suitable habitat for many native species. The area of mixed woodland dominated by broad-leaved trees, which represents the primary suitable habitat available for the Seychelles White-eye, covers c. 90 ha. The rest of the island is covered with coconut woodland, scrubland, rocky habitats, agricultural lands and residential areas (Rocamora et al. 2001, Rocamora and Galman 2009).

Data collection for estimation of the Seychelles White-eye population size was undertaken between November 2005 and January 2006. An island-wide survey was undertaken to determine in which areas Seychelles White-eye were present or absent, as the small population was not distributed across the entire island. A distribution map of the Seychelles White-eye (Figure 2) was created and all subsequent surveys were conducted in these areas. This map was used to calculate the area occupied by the Seychelles White-eye population as well as in analyses using the program DISTANCE (see below).

Methods for estimating population size

Capture–mark–relocate

Catching and colour ringing of Seychelles White-eyes are regularly undertaken as part of the Seychelles White-eye post-release monitoring programme. This allows for individual identification, but also maintains a high proportion of marked birds in the population (on average 70%). Birds were captured using mist-nets set in the territories or foraging areas. The Seychelles White-eyes were attracted by playing back a tape-recorded song of the species ('tape luring'). Each bird caught was marked using a combination of a numbered metal ring from the Natural History Museum of Paris and one to three plastic colour rings. Morphometric measurements and blood samples were taken for all birds captured. After sampling and examination, the birds were released back onto their territories. Point counts (detailed below) were used to collect recapture data through relocating birds using binoculars.

Point-transect distance sampling

Distance sampling estimates the density and/or abundance of animal populations (Buckland et al. 1993, Thomas et al. 2009). This is based on accurate distance measurements of each animal from the centre of a point or line. The technique explicitly models and accounts for detection probability and was used to estimate densities and the size of the Seychelles White-eye population on Frégate. We used point counts along transects to collect data for distance sampling, hence the name ‘point-transect distance sampling’. In order to correctly and successfully apply distance sampling methods, three main assumptions must be satisfied: (1) all birds located directly on the centre of the point should be detected with certainty; (2) birds should be detected at their initial location, before they are disturbed by the observer; and (3) distances should be measured accurately (Buckland et al. 1993).

Point counts

Point counts, which are often used in studies of passerines, particularly in dense high-canopy habitats (Bibby et al. 1992, Buckland et al. 1993, Farnsworth et al. 2005, Buckland 2006), were used to collect data for both the capture–mark–relocate and distance sampling techniques used in this study. A network of nine transects was identified and point counts were conducted every 100 m along each transect (Figure 2). Within 2 weeks a total of 50-point counts were repeated three times, with a 3.5 d interval on average, to increase precision and accuracy of estimates (White 1996, Hayes and Carter 2000).

We used the method defined by Rocamora and François (2000) to estimate and monitor the size of the source population on Conception Island as part of the Seychelles White-eye Recovery Programme. At each point, a 10 min observation period is conducted and divided into 1, 2, 3–5, and 5–10 min intervals. All birds seen (marked, unmarked or unknown) from each point are recorded and colour ring combinations identified. The observer may move up to 10 m from the centre of the point to improve detection of birds and the reading of colour rings. For each Seychelles White-eye sighting, the plant species in which the bird is perched, its height in the tree and its activity (e.g. foraging, singing, preening, nest building, or feeding chick) are recorded. We used a telemeter to measure the distance projected on the ground between the bird and the observer beyond 10 m. However, data collected for the capture–mark–relocate technique considered a maximum radius of 25 m for analytical purposes only. This standardisation is useful for comparison of abundance data from one year to the next (Farnsworth et al. 2005) or between islands. All point counts were done at 07:00–11:00 and 15:00–18:00 when the Seychelles White-eyes were most active. The geographical position of all points was recorded using a GPS and the centre of each point demarcated by a ribbon.

Direct systematic surveys

Monthly, direct systematic surveys were undertaken in all territories and foraging areas of the Seychelles White-eye at 07:00–11:00 and 14:00–18:00. This method is used to census the population by thoroughly checking territories and the group composition (identity and sex of each individual). Tape luring was also used to attract birds to the observer and facilitate their identification. Direct systematic surveys are accurate but usually extremely time consuming. All marked and unmarked individuals as well as their respective activities, time and location were noted. For all nests found, further information on the number of individuals and composition of the group was obtained through follow-up monitoring.

Data analysis

The program NOREMARK was used to analyse capture–mark–relocate data collected through point counts and hence to estimate the population size. Three estimators of NOREMARK were used to compute population size: joint hypergeometric maximum likelihood estimator (JHE), Minta-Mangel estimator and Bowden’s estimator. Each of the three estimators has slightly different assumptions. The JHE estimator assumes a geographically closed population, with each bird having the same probability of being sighted on a particular occasion; and no individual is observed or counted twice during the survey for a particular occasion (referred to as sampling without replacement). In addition, JHE requires an estimate of the number of marked individuals available in the population, which is provided from the direct systematic surveys. Although a few marked birds may go undetected during the surveys, we believe that the count obtained through thorough direct surveys within the small number of existing territories was very close to the absolute number. Contrary to JHE, Bowden’s estimator allows each animal’s sighting probability to differ from the others, and sampling can be with or without replacement. The Minta-Mangel estimator relies upon the same assumptions as Bowden’s estimator, although this estimator is derived under the assumption of sampling with replacement (White 1996). Both Bowden and Minta-Mangel estimators do not require prior knowledge of the number of birds marked in the population as they are based only on the resighting frequencies of the marked animals (compared to Lincoln index models). These estimators also do not require that all birds freely mix within the entire population, unlike other capture–mark–relocate methods, whose general assumptions are detailed in Bibby et al. (1992).

Distance data were analysed using the software DISTANCE 5.2. The Conventional Distance Sampling (CDS) engine of DISTANCE was used. A preliminary analysis of all the distance data showed that truncation at 45 m ($w = 45$ m) was adequate. This was done to omit overdispersed data points and hence to improve precision and model fit. Analysis and modelling of distance data were done through consideration of several models. The four ‘key functions’ provided by DISTANCE (uniform, half-normal, hazard-rate and negative exponential) were each adjusted by the ‘series expansions’ (cosine series, simple polynomials and hermite polynomials) to improve the model’s fit to the distance data (Buckland et al. 1993, Thomas 1999). This gave a total of 12 models for consideration. Model selection criteria were applied to choose between them. The minimal Akaike’s information criteria (AIC), which is a quantitative method for model selection (Buckland et al. 1993), was used to select the best model. The goodness-of-fit tests, i.e. chi-squared (χ^2), also helped guide model selection. Using the selected model in DISTANCE, the estimates of the following parameters were generated: density of individuals per hectare, population size, effective detection radius, encounter rate and probability of detection.

Population size estimates derived from direct systematic surveys was calculated using MsExcel (Microsoft). The number of individuals per territory and foraging site was summed to produce a total count of individual Seychelles White-eyes.

Results

Population estimates using capture–mark–relocate

The results of the three estimators of NOREMARK used to estimate the Seychelles White-eye population size are summarised in Table 1. All three estimators provided similar results. The choice of estimator depends on the assumptions (see Discussion), and on the confidence interval. The JHE estimator was rejected based on its larger confidence intervals. Moreover, JHE assumes equal probabilities of sighting a given bird on a particular occasion; however, non-territorial Seychelles White-eyes, which belong to a floating population, have a lower probability of being sighted as they roam the island and are often not responsive to playbacks. Hence, the assumption of equal probability is not met.

The Bowden and Minta-Mangel estimators share the same assumptions in allowing each animal sighting probability to differ from the others. The Bowden estimator was selected as it had the narrowest confidence interval. The Seychelles White-eye population on Frégate was thus estimated at 77 individuals (72–83; $P < 0.05$).

Population estimates using point-transect distance sampling

Summary statistics for the best four models used to estimate population size are presented in Table 2. Despite using different key functions, densities, population size estimates and associated measures of accuracy (AIC) and precision (coefficient of variation [CV] and confidence intervals) were remarkably close. The Uniform key function with one cosine adjustment term provided the best-fit to the data. It had the lowest AIC and CV of the estimation was equally low (29%), as well as the difference between the minimal and maximal estimation (confidence interval). These parameters indicate the accuracy and precision of the model relative to the others. The χ^2 value was relatively high, indicating a good fit of the model to the data; the model also had the largest effective radius of detection (24.5 m).

We detected 52 individual Seychelles White-eyes at the 50 points surveyed. After truncation of the data at 45 m, the total number of observations was 44. The maximum detection distance was 107 m (before truncation). Figures 3a and b show the observed distribution of distances and the calculated densities, respectively, as well as the associated functions provided by the best-fitting model.

The data suggest that Seychelles White-eyes were not evading detection near the observer or moving evasively prior to detection, but may reflect certain attractiveness to the observer, although the model takes this into account. Despite the small population size, the detection probability of the species remained high (over 50%) up to 25 m.

Population estimate using direct systematic surveys

Direct systematic surveys conducted between November 2005 and January 2006 identified 71 marked birds and 10 unmarked birds giving a total of 81 individuals using this method (Table 3). Unmarked birds were sighted in the territories with the same marked Seychelles White-eyes during the survey period. Hence, we assumed that it was always the same unmarked individuals that were sighted with the marked adults from one month to the next.

Discussion

Population estimate

Estimates of Seychelles White-eye population size by the three methods were remarkably similar (Table 4). The precision of the methods was evaluated by comparing the confidence intervals. The capture–mark–relocate method (with data analysis by NOREMARK) had the narrowest confidence interval and was considered more precise. The size of the Seychelles White-eye population with this method was estimated at 77 individuals (72–83; $P < 0.05$),

Table 1: Summary of the three estimators of NOREMARK used to estimate the population size of the Seychelles White-eye

Estimator	Population estimate	Confidence interval (95%)
Joint hypergeometric maximum likelihood estimator	78	74–88
Minta-Mangel estimator	78	74–90
Bowden estimator	77	72–83

Table 2: Model selection for estimating Seychelles White-eye density and abundance on Frégate Island. Akaike information criteria (AIC) is a quantitative method used to select the best model. *N* is the number of observations. The smallest AIC indicates the best model. Effective radius of detection (ERD) is the maximum distance in metres whereby the White-eye is detectable. Density (*D*) is the number of individuals per hectare, and CI of D is the confidence interval of densities. The model is more precise when the coefficient of variation (CV) is small. A χ^2-test is used to test the fit of the model for probability of detection to the distance data. The larger the χ^2 value, the better the model. *P* is the probability of recording a White-eye in the surveyed area. The total surveyed area was 50 ha

Model	Adjustment	*N*	AIC	ERD (m)	*D* (individuals ha^{-1})	CI of D	CV (%)	Population size	$P < 0.05$	χ^2	*P*	Encounter rate
'Uniform'	Cosine	44	341.34	24.54	1.55	0.88–2.72	29.00	78	44–136	0.12	0.30	0.88
'Half Normal'	Hermite polynomial	44	341.58	22.84	1.79	0.95–3.36	32.00	89	48–168	0.01	0.26	0.88
'Half Normal'	Cosine	44	341.58	22.84	1.79	0.95–3.36	32.00	89	48–168	0.01	0.26	0.88
'Uniform'	Hermite polynomial	44	343.34	25.80	1.40	0.77–2.54	30.00	70	39–127	0.04	0.33	0.88

whereas point-transect distance sampling produced an estimate of 78 birds (44–136; $P < 0.05$). The direct systematic survey gave a population size of 81 individuals, and this result was used to validate those of the capture–mark–relocate and point-transect distance sampling methods. Based on the results of the direct systematic surveys, it can be concluded that the estimates of both NOREMARK and DISTANCE are reliable for this species.

Evaluation of methodological assumptions and survey design

Interpretation of the above population estimates is largely based on whether the fundamental assumptions have been met by each method (Bibby et al. 1992, Buckland et al. 1993, Mattice et al. 2005). Every effort was made to respect these assumptions and the survey was designed so as to ensure that key assumptions were satisfied. Some capture–mark–relocate estimators (JHE NOREMARK) assume a geographically closed population, which was the case for the Seychelles White-eye on Frégate, where it is sedentary. Frégate is 20 km from the nearest island, so it was realistic for us to assume no dispersal to nearby islands.

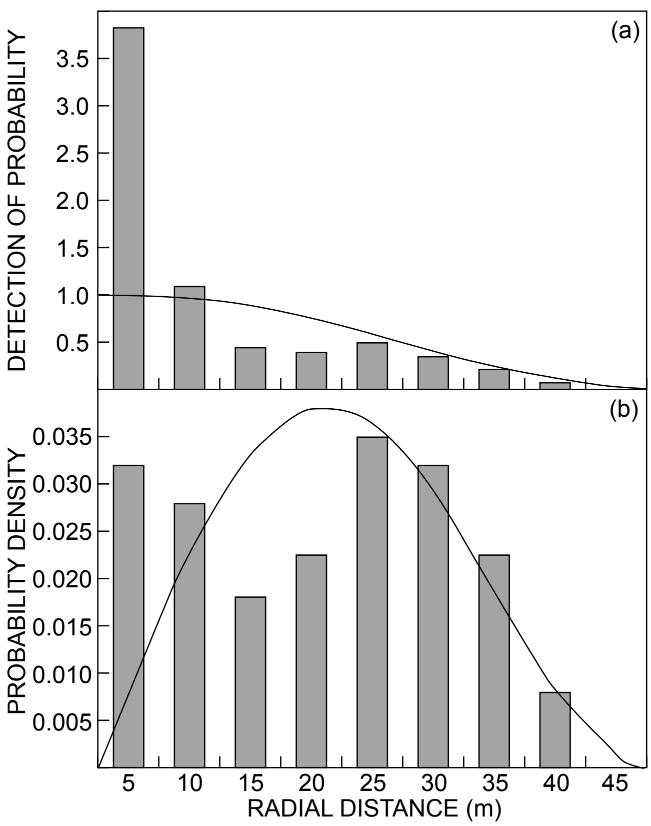

Figure 3: (a) Histogram of radial distance and detection probability of Seychelles White-eyes based on point-transect data collected on Frégate Island in January 2006. The Uniform key function with one cosine adjustment term provided the most parsimonious fit to the distance data. Data truncation was 45 m. (b) Density function expressed as the probability density of Seychelles White-eyes with radial distance from the centre of the point

As part of our efforts to respect the main assumptions of distance sampling, bird disturbance was minimised by a careful and slow approach to the point to be surveyed. Once the survey had begun, movements were minimised by looking well ahead as the area was searched. Some Seychelles White-eye territories are located in habitats with dense and high canopy vegetation, and the small size of the bird (10 cm in length), cryptic colouration (olive grey) and secretive behaviour especially when preening or resting may inhibit their detection. The area around the centre of each point was therefore actively searched as per the standardised method described by Rocamora and François (2000). Perched birds were often detected at their initial locations by their vocalisation, as Seychelles White-eyes almost always emit contact calls before flying away. As birds' detectability varies with time of day (Buckland et al. 1993), our surveys were carried out during mornings and late afternoons, when Seychelles White-eyes are most active and vocal, and thus more easily detected. The use of a telemeter appears essential to estimate accurately distances beyond 10 m, and we occasionally used a measuring tape or pacing to check distance estimates of less than 10 m.

Direct systematic surveys depend on the identification of all territories and accurately counting all individuals. Hence, the distribution of the Seychelles White-eye population on Frégate was determined prior to this study with an island survey that identified presence and absence of the species in different habitats and areas around the island, and also allowed for the identification of territories. On Frégate, most Seychelles White-eyes live in social groups of two to nine individuals, five on average (Henriette 2007), which facilitated counting during the surveys.

Contrary to the recommendations of Buckland et al. (1993), not all transects were randomly distributed. Some transects followed existing trails because this was the only way to access impenetrable areas. In some areas, vegetation was so dense that points had to be relocated. Many surveys are often conducted along existing trails, especially in inaccessible terrain (Rivera-Milan et al. 2003, 2005, Butler et al. 2007, Giunchi et al. 2007). Though this is likely to be unrepresentative (Buckland et al. 1993), it is often the only way to collect data in difficult places. These conditions could lead to bias, but this did not appear to be the case here as estimates from sampling methods were similar to results from direct systematic surveys.

Table 3: Determination of the Seychelles White-eye population size using direct systematic surveys

Parameters	Number of individuals
Number of marked (64) and unmarked individuals (7) surveyed in November 2005	71
Number of marked (37) and unmarked individuals (1) surveyed in December 2005	38
Number of marked (49) and unmarked individuals (3) surveyed in January 2006	52
Number of marked (71) and unmarked individuals (10) surveyed between November 2005 and January 2006	81

Table 4: Comparison of the population size estimates from the three methods

Method	Model	Population estimate	Confidence interval (95%)
Capture–mark–relocate	Bowden estimator of programme NOREMARK	77	72–83
Point-transect distance sampling	Uniform + cosine of programme DISTANCE	78	44–136
Direct systematic surveys	Direct systematic surveys	81	

Choice of method for estimating population size

Population parameters such as density and population size can be estimated by a range of different methods, which often have to be adapted to meet numerous limitations and constraints such as reduced visibility, difficult terrain and impenetrable vegetation. It is crucial to use a method that does not violate underlying assumptions. Moreover, choice of methods may depend on simplicity of the method, experience and availability of observers, physical and logistical constraints, and characteristics of the study population.

As shown by this study, all three methods produced similar population estimates. The capture–mark–relocate method is labour intensive, time consuming and requires skilled personnel with bird-ringing experience. It is likely to be most useful for estimating total population size in studies that require intensive ringing to meet other study objectives (Dunn et al. 2006), which was the case under the Seychelles White-eye post-release monitoring programme. Other studies having used capture–mark–relocate methods on birds in small islands of the Seychelles include Rocamora (1997) on Seychelles Fody and the Seychelles Cave Swiftlet, and Rocamora and François (2000) and Rocamora et al. (2006) on the Seychelles White-eye.

The advantages of direct systematic surveys for species monitoring, compared with point counts and transect counts, are that observers can concentrate their efforts in areas where birds are most abundant and can track down elusive individuals to confirm identification. The disadvantages are that, as with capture–mark–relocate, this approach is time consuming and can become more difficult to implement as the population and distribution expands. These drawbacks highlight the need to employ other sampling methods rather than exhaustive ones at any given time.

The advantage of distance sampling is that density and population size can be estimated even when a relatively small percentage of individuals are detected within the sampled area. It is also efficient for sampling large areas (Powlesland and Barraclough 2001). Its disadvantages lie in being able to meet the assumptions. Although in this study distance sampling provided relatively robust estimates and performed fairly well under our sampling conditions, this was not the case for the Seychelles White-eye study conducted on Conception Island where distance sampling provided poor results and was shown to overestimate Seychelles White-eye densities (Rocamora and François 2000). The method was biased owing to the violation of assumptions concerning bird movement and also possible attraction of birds to the observer. The same study concluded that the capture–mark–relocate method produced density measurements that were much closer to those observed in two study areas compared to distance sampling.

Based on its higher performance, capture–mark–relocate with NOREMARK is thus confirmed as the most reliable method yet tested for estimating the size of newly established Seychelles White-eye populations on small islands such as North and Cousine islands (Henriette 2006, Rocamora and Henriette Payet 2008). Point counts are a good way of providing standardised resightings of individually marked birds within the population as part of a random and independent sampling strategy. However, *ad hoc* resightings of (both marked and unmarked) White-eyes distributed all over Conception also provided good population estimates with capture–mark–relocate methods (Rocamora et al. 2006).

Conservation implications

Conservation and management of endangered species requires an adequate knowledge of their distribution and population sizes. The acquisition of reliable population estimates, amongst other demographic, biological and ecological data, is directly relevant to the Seychelles White-eye Recovery Programme. These are not only essential to evaluate the number of individuals, but also to follow their temporal and spatial fluctuations to analyse the causes and consequences of these trends. Post-release monitoring of the Seychelles White-eye since their translocation to Frégate permitted collection of such data. Reliable population estimates are also indispensable in assessing the species' status, population growth and development, determining conservation priorities, and detecting the species' response to management and conservation activities. Knowledge of the status of the Frégate Seychelles White-eye population contributed to the downlisting of the species in 2005 from Critically Endangered to Endangered (IUCN 2006, Birdlife International 2007). Results from such studies have taken the conservation of the species further by contributing to conservation introductions to North and Cousine islands in 2007, the elaboration of the 2009–2013 Seychelles White-eye Conservation Assessment and Action Plan (Rocamora and Henriette 2009), thus have direct conservation applications.

Conclusion

There have been substantial developments in methods for estimating animal population size in the last two decades. Each study can adapt these methods to the specificity of the species and/or study area concerned. The results of our study suggest that capture–mark–relocate, point-transect distance sampling and direct systematic surveys are viable and efficient methods for estimating Seychelles White-eye population size on the conditions that assumptions are met. In cases where habitat is dense and impenetrable, point-transects give clear advantage compared to line transects. Our study strongly supports the use of the capture–mark–relocation approach (using NOREMARK) as a reliable method for determining the size of island passerine populations, which contain a significant proportion of marked individuals.

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