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Using post-release monitoring data to optimize avian reintroduction programs: a 2-year case study from the Brazilian Atlantic Rainforest

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Abstract

Post-release monitoring data of reintroduced captive-bred birds can be utilized to help optimize future avian reintroduction programs. We present a case study of broad interest to reintroduction and conservation biologists interested in investigating movements and habitat use by reintroduced captive-bred birds. We used radio telemetry to monitor reintroduced captive-bred red-billed curassow *Crax blumenbachii* at a private reserve, Rio de Janeiro state, Brazil. During August 2006 and October 2008, 25 radio-tagged individuals (15 females and 10 males, all <30 months old) were monitored over a 25-month period. Evaluation of home-range size and habitat use revealed that captive-bred curassows should be released only into forest areas with adequate riverine habitat that are larger than the minimum home-range movements of the proposed population. Curassows also utilized pastureland, cultivated areas and secondary forests, suggesting that the proximity of release sites to such habitats may not be entirely detrimental for future reintroductions. Site fidelity for reintroduced birds was low, and there was a tendency for resident curassows to move away when new cohorts were released into the area. Determining how habitat characteristics, displacement by newly released cohorts, adjustments to their new surroundings or cohort social interactions influence post-release movements of resident birds at release sites over prolonged time frames would improve our knowledge on the impacts of releasing further captive-bred individuals into habitats with extant populations. Critically, the movement patterns of reintroduced curassows identified in this study demonstrate that avian post-release monitoring must be considered over an appropriate time frame and we highlight how different conclusions may be generated depending on the duration of post-release monitoring. It may take more than 2 years for reintroduced captive-bred sub-adults to become established following release and that post-release monitoring of similar duration may not be adequate for large avian species such as Cracids.

Introduction

Reintroduction programs attempt to reestablish species populations in areas within their historical range where they have become extirpated or extinct, through the release of wild or captive-bred individuals (IUCN, 1998; Moorhouse, Gelling & Macdonald, 2009). These programs have become important conservation tools for endangered bird species (e.g. Sanz & Grajal, 1998; Pierre, 1999) but their success has been highly divergent across different species (McPhee & Silverman, 2004) for a variety of reasons (Steury & Murray, 2004). The transition from captivity to establishment in the wild represents a formidable challenge particularly for reintroduced captive-bred individuals, as they have no prior experience of the new environment and they may be more vulnerable to both natural and feral predators (Banks, Norrdahl & Korpimäki, 2002; Parish & Sotherton, 2007). During the period immediately following release, reintroduced birds are induced to search for new territories and attempt to establish themselves over unfamiliar habitats (Stamps, 2001) – movements that may not correspond to natal or juvenile dispersal (Van Heezik, Maloney & Seddon, 2009). Significant movements away from release sites have been documented for several avian reintroductions (e.g. Clarke & Schedvin, 1997; Fancy, Snetsinger & Jacobi, 1997) and this propensity to move may eventually undermine the overall objectives of long-term population reestablishment (Van Heezik *et al.*, 2009).

These experiences have resulted in increased calls for and development of robust post-release monitoring programs for reintroduced individuals to help understand the factors that influence population reestablishment following their release (Armstrong & McLean, 1995; Sarrazin & Barbault, 1996). For them to be cost-effective and have greater conservation value, post-release monitoring programs must address key ecological questions relevant for the success of avian reintroductions (Ewen & Armstrong, 2007), such as patterns of habitat use, spatial segregation of territories and foraging behavior (e.g. Rantanen *et al.*, 2010). Despite the widespread recognition of its importance (e.g. Hean, 1997), reintroduction biology is typified by poor post-release monitoring and there exist very few examples where the conservation relevance of post-release data on movements and patterns of habitat use of reintroduced captive bred birds has been fully assessed.

In this paper, we present detailed data on the post-release movement patterns, home range and habitat use of reintroduced captive-bred red-billed Curassow in Brazil over a 25-month period using radio-telemetry. Our aim is to provide a case study of broad interest to reintroduction biologists and conservation biologists interested in investigating movements and habitat use by reintroduced captive-bred birds, and to determine how knowledge of such factors gained from post-release monitoring can help optimize future avian reintroduction programs. The red-billed Curassow *Crax blumenbachii* is a large globally threatened Cracid species restricted to the Atlantic Rainforest of Brazil – the world's most threatened biodiversity hotspot (Myers *et al.*, 2000). Formerly widespread throughout a narrow geographic area from Rio de Janeiro, Minas Gerais and extreme southern Bahia (Delacour & Amadon, 1973), the species has been extirpated throughout much of its former range due to severe habitat loss and hunting (IBAMA, 2004). The remnant wild population is highly fragmented, and estimated to range between 50 and 249 individuals, and all remaining isolated populations are not thought to exceed 50 individuals (IBAMA, 2004). Observations of wild birds suggest that the species prefer areas of undisturbed lowland forest habitat in close proximity to freshwater (streams or small rivers) but are also tolerant of secondary forest and some agricultural environments (Sick, 1970; Teixeira & Snow, 1982; Collar & Gonzaga, 1988). Thus, we expected to find the reintroduced red-billed curassows in both forest and agriculture habitats, as well as near water resources. Reintroduction using captive-bred individuals has been underway since 1991 following the methodology devised for the captive bred population held by CRAX Brazil, a private breeding center located in Minas Gerais state, Brazil (Azeredo & Simpson, 2004). The data presented here represent the first strategic post-release monitoring of the captive-bred reintroduced birds, at one of four designated release sites.

Methods

Study area and soft-release protocols

Red-billed curassows were monitored at the Guapiaçu Ecological Reserve (REGUA), Rio de Janeiro state, Brazil (Fig. 1). This private reserve (22°25′02″S, 42°44′18″W, elevation 20–2000 m) partially overlaps with Três Picos State Park and the Macacu Environmental Protection Area (APA Macacu), corresponding to *c.* 7200 of a 60 000 ha contiguous forest area. With a mean annual precipitation of 2600 mm and daily temperatures from 14 to 37 °C, this region is characterized by a *c.* 6-month dry season (May and October) and a wet season (November and April). Small forest fragments varying in size between <1 and 250 ha are situated in small land holdings between 100 and 200 m elevation, surrounded by areas that have been cleared for agriculture. Larger areas of continuous secondary forest habitat are mostly located up to elevations of 800 m (dominated by Juçara Palm *Euterpe edulis*, various *Ficus*, Sapotaceae and Myrtaceae species and numerous large woody vines and liana species), whereas montane forest habitat (dominated by a dense understory, along with Myrtaceae, Sapotaceae and Lauraceae species supporting prominent epiphytic vegetation) covers the landscape between 800 and 2000 m.

During August 2006 and October 2008, 53 captive-bred sub-adult birds (<30 months old) tagged with back-pack radio-transmitters provided by Biotrack® (Biotrack® Ltd, Dorset, UK; Bernardo *et al.*, 2011) and representing seven different release cohorts were transported ~450 km from the CRAX Brazil breeding center to a purpose-built 'soft-release' enclosure (15 × 8 × 9 m) at REGUA. As five birds died pre-release due to the aggressive dominant behavior of some birds, 20 individuals were released in 2006, 18 in 2007 and 10 in 2008 (Bernardo, 2010). The acclimatization period varied between 17 and 71 days (mean of 41 days) because some birds had to be released 'early' due to aggressive dominant behavior or heavy rain (Bernardo, 2010). The release site was situated in secondary forest with numerous water courses, the presence of suitable fruiting trees and easy logistical access to enable birds to adapt both to their new environment and also to the radio-transmitter (see Bernardo, 2010 for details on the origin and captive-breeding history).

Before transportation from captivity to the reserve, all curassows underwent a rigorous series of veterinary health examinations (see Azeredo & Simpson, 2004). To release the birds, the door to the enclosure was opened so that all birds were released in exactly the same place. Two people who were situated inside the enclosure then walked slowly toward the birds to gently encourage them to exit the enclosure through the opened door. Once the enclosure was empty, the door was closed to avoid the return of any birds into the enclosure. Three feeders were placed within a radius of 50 m outside the enclosure to provide supplementary food. These feeders were removed from the site *c.* 1 month post-release following a 7-day consecutive period during which no birds were observed visiting the feeders. Cohorts were always released during the dry season (August to November) to avoid confinement during periods of heavy rain. All released cohorts were subsequently monitored during the study period, which corresponded to three consecutive dry seasons and two wet seasons.

Locations of curassows

Individual radio-tagged birds were monitored during consecutive months until death, battery failure or signal loss.

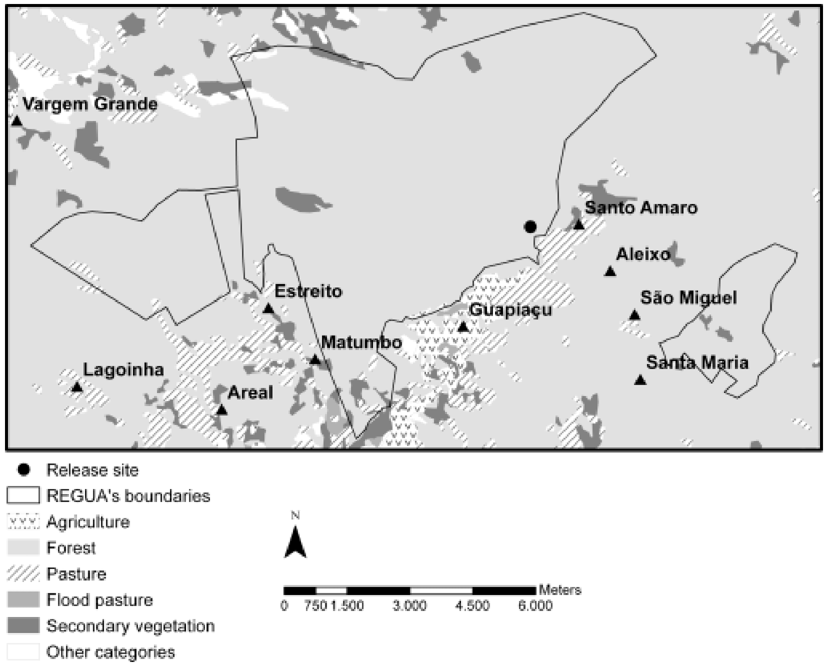

Figure 1 Location of the study area (Guapiaçu Ecological Reserve, REGUA, in Rio de Janeiro state, Brazil), showing the main local communities nearby (labeled black circles), the location of the release site of reintroduced red-billed curassows *Crax blumenbachii* (black triangle) and the land use.

Lcation positions were obtained three times per week during systematic searches conducted during 06:00–17:00 h. The locations of individuals were recorded using triangulation (White & Garrott, 1990) with locations estimated from two or more compass bearings for each individual recorded within a 60-min search period. Marking location over periods >60 min increases the likelihood that birds will change their location while consecutive bearing are being recorded, and consequently generating bias with inferring interaction between individuals. All locations were recorded using LOCATE III software (Nams, 2006) on a handheld palmtop (palmtop Zire 22®, Palm Inc., Sunnyvale, CA, USA). Where three or more bearings were considered, error ellipse (with 95% CI) was assessed using a maximum likelihood estimator. Angles were corrected ($-23°$) due to magnetic declination, estimated with information from a map by the Brazilian Institute of Geography and Statistics (Teresópolis and Nova Friburgo cities, 1974). If an individual appeared to remain stationary during a 7-day period, we purposely verified whether the bird was alive or dead.

Post-release distance movements

Of 53 radio-tagged individuals, we considered data from 25 radio-tagged individuals (15 females and 10 males) over the 25-month survey period. Birds that died within 1 month post-release were excluded from the analysis ($n = 7$), as well as birds monitored for <3 months due to signal loss or battery failure ($n = 4$). We did not consider the birds released in 2008 ($n = 10$) to avoid comparing the values of home range possibly related only to the initial movements. Five birds died pre-release and two further females were removed from the sample following their release because they exhibited tame behavioral traits.

Distance (m) from the release site to each individual location fix was measured, and repeated measures ANOVA was used to test for significant differences between the movements of males and females over time. Location data were analyzed using RANGES 8 v2.2 software (Kenward *et al.,* 2008). Four different home-range estimators were calculated for the reintroduced red-billed curassow, to choose the most appropriate one objectively, avoiding the subjective selection of methods: minimum convex polygon (100% MCP and 95% MCP); fixed kernel (95% FK); adaptive Kernel (95% KA); Neighbor Linkage (95% NL). Differences between home-range estimations were examined using non-parametric Kruskal–Wallis tests. The method that presented the lowest amplitude in home-range estimates was selected as the most appropriate home-range estimator, to which we subsequently applied the outlier restricted edge polygon outlier exclusion method (Kenward *et al.,* 2008). The furthest locations were excluded based on nearest-neighbor distances (NNED) or kernel exclusion distances using two methods: exclusion of 5% of farthest locations or an iterative process that excluded locations where the most extreme linkage distances was $>0.1\%$ (α-level) of the normal distribution estimated by the remainder. This iterative process was repeated until all distances were within the chosen α-level, which excludes only the most extreme outliers (Kenward *et al.,* 2008).

We used ANCOVA to examine the relationships between home-range size, gender, age of birds and period of post-release monitoring. All continuous variables were log-transformed following examination for normality using Kolmogorov–Smirnov tests. We examined whether reintroduced curassows used the same home-range area (site fidelity) following two principal events: (1) after individuals reached sexual maturity; (2) following the release of groups in the subsequent year. For the first event, we selected five males and five females that could be followed from when they were sub-adult (<30 months) and also into adulthood (older than 30 months). Strong site fidelity was assumed if more than 50% of locations of the individual's sub-adult home range overlapped with its adult home range. For the second event, we considered six individuals that were released in 2006 (of a total of 20 released) and eight individuals released in 2007 (of a total of 18 released). Strong site fidelity was assumed if more than 50% of the locations of an individual (before any releases) overlapped with its home range after the release of additional birds into the same area in the following year.

Post-release behavior

Time-series data of each individual were examined to determine whether two different individuals moved independently from each other (e.g. White & Garrott, 1990). Jacobs index (Jacobs, 1974) was used to identify positive interaction between individuals (social cohesion, couple formation) or negative association (territorialism). An interaction was considered when at least two of the three measures, arithmetic mean, geometric mean or median, were $> +0.75$ or < -0.75 (e.g. Kenward, 2001). We also compared the Jacobs index of both radio-tagged sub-adults (<30 months old) and radio-tagged adults (>30 months old) to identify possible association with individuals since they were young.

Habitat use

Compositional analysis (Aitchison, 1986; Aebischer, Robertson & Kenward, 1993) was conducted at two levels to assess whether different habitats were used in the same proportions as they occurred in the study area. We used a classified habitat-type map (donated by the State Environmental Institute of Rio de Janeiro) to calculate habitat coverage using ArcGIS software (ESRI, 2006). First, we compared the proportion of each habitat in the study area (e.g. the sum of all home ranges) with the proportion of habitats within each individual home-range area. Second, we compared the proportion of each habitat within an individual's home range with the proportion of locations of the individual in those habitats. Where habitat selection (non-random use) was detected, we ranked habitat according to the relative use. All statistical procedures followed Aebischer *et al.* (1993) and were conducted using the excel macro function COMPOS ANALYSIS v. 6.2 standard (Smith, 2005).

Results

Location positions

A total of 2834 locations were recorded from 25 red-billed curassows (mean 123 ± 57 SE for male locations, and 106 ± 34 SE for female locations). The mean size of ellipse error was 0.98 ha (0.8–1.1 ha), with a mean bearing standard deviation of 9.7° (range 8.3–11.1°). Locations for all individuals were autocorrelated even when data were simulated to be collected every 300 h (12 days intervals), with only one male showing no significant correlation when location data were truncated at 96 h (4 days intervals). Overall, curassow locations were concentrated between 20 and 1350 m elevation where slopes varied between 0 and 70°. However, curassows were more frequently (98%) found at 20–500 m, where the degree of slope in 79.5% of locations varied between 0 and 20°. Rarely did individuals move over steep, higher elevational areas: 1.7% of locations of 12 individuals were recorded at 500–800 m elevation (where the degree of slope in 20% of locations varied between 21 and 40°), and 0.3% of locations of another six individuals were recorded at elevations 800–1350 m (0.5% of locations between 41 and 70°). Reintroduced curassows were more commonly found close to streams or rivers, with most (57.8% of locations) occurring <100 m from the nearest stream or river, 30.8% of locations occurring between 101 and 300 m and 11.4% of locations occurring between 301 and 740 m from water resources.

Post-release distance movements

All 25 focal individuals continued to move away from the release site during the first 11 months post-release, after which the distance stabilized. Reintroduced curassows moved significantly less (~500 m) during the first 2 months post-release (Fig. 2) in comparison with other periods throughout the study, when new birds joined others already living in the area. During the first 11 months post-release, 27% of the locations were of individuals situated on average 2–2.5 km from the release site. All individuals had moved >2 km from the release site during 12–25 months post-release, with half of all location records showing that individuals were on average 3–3.5 km from the release site (Fig. 2). Males and females showed no significant differences in distances moved from the release site over the 25-month period ($F = 0.67$, $P = 0.65$). By the end of the study period (October 2008), 40% of birds had reached sexual maturity, and individuals maintained a mean distance of 2.8 km (CI = 0.9) from the center of each other's home ranges, with only adult females (not males) showing overlap between home ranges. The maximum distance from the release site reached by any individual was 12 km, by up to five individuals after 16 months post-release.

Home range and site fidelity

Incremental analysis revealed that 160 locations were a necessary minimum sample size to generate an accurate estimation of home-range size for the study period of 25 months (Fig. 3). NL (95% NL) estimator presented the least amplitude in home-range size estimation (median = 364.7 ha: 25% quartile = 209 ha, 75% quartile = 615 ha), whereas the 100% MCP estimator (Fig. 4) presented the greatest (median = 1457 ha: 25% quartile = 969 ha, 75% quartile = 2549 ha). There was a significant variation in home-range size estimated by the different methods ($H = 37.4$, $P < 0.01$) and significant

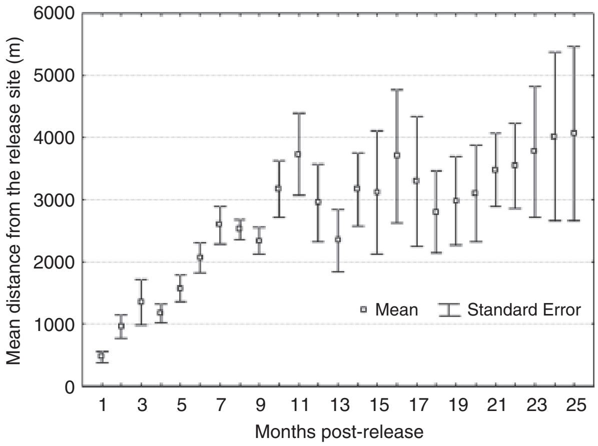

Figure 2 Mean distance (m) ± standard error moved by 25 reintroduced red-billed curassows *Crax blumenbachii* from the soft-release site over the 25-month post-release monitoring period at Guapiaçu Ecological Reserve (Rio de Janeiro state, Brazil).

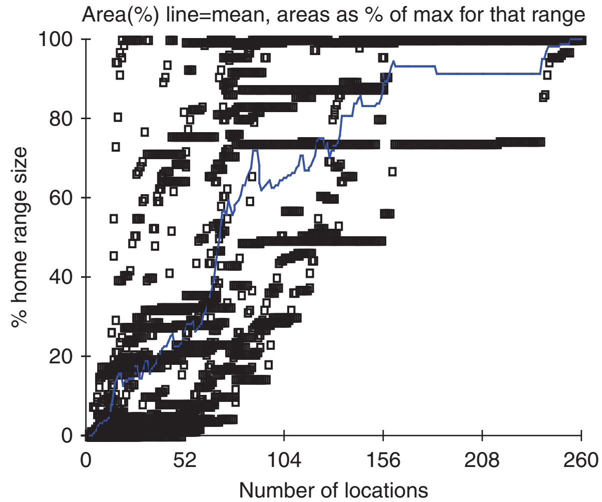

Figure 3 Incremental analysis of percentage home-range size against the number of consecutive locations of 25 captive-bred reintroduced red-billed curassow *Crax blumenbachii* at Guapiaçu Ecological Reserve (Rio de Janeiro state, Brazil), provided by RANGES software. The black line corresponds to the connection of the mean area for all the home ranges. Around 160 locations were needed on average to define the home ranges. The maximum value of the *Y*-axis corresponds to the maximum value of a home range obtained for a curassow.

differences in the outlier exclusion methods applied in the 95% NL method ($H = 68.9$, $P < 0.01$). Subsequently, we selected the NNED procedure for outlier exclusion due to the lowest variability of results (Fig. 5).

Across the 25-month study period, the mean home range size ± SE for reintroduced red-billed curassow was 125.8 ± 12.3 ha ($P = 0.1$ for 95% NL and outlier exclusion through NNED) and the mean distance between the home-range center of two neighboring areas was 2.8 ± 0.9 km. Home-range size among all 25 focal individuals was greater during the 7–12 months post-release period (mean-117.6 ± 22.2 ha), but showed very little variation (remaining around 60 ha) during 0–6, 13–18 and 19–25 months post-release. Individuals from the 2006 release cohort occupied larger home ranges (mean = 117 ha, 82–152 ha) than those from the 2007 release (mean = 74 ha, range 43–104 ha). Adults utilized a larger home range (201–250 ha) than sub-adults (51–100 ha). Thus, variation in home-range size was influenced by the age of the reintroduced birds ($F = 15.9$, $P < 0.01$). Although both adult (241 ± 63 ha) and sub-adult males (109.9 ± 20 ha) presented larger values of home-range sizes than adult (146 ± 40 ha) and sub-adult females (96 ± 15 ha), the variation in home-range size was not significantly influenced by gender ($F = 0.14$, $P = 0.700$). There were also no statistical differences when considering the period of monitoring ($F = 0.83$, $P = 0.360$).

Reintroduced curassows showed no evidence of site fidelity. Individuals from the earlier released cohorts showed a tendency to move into new areas (not previously occupied) following subsequent reintroduction of further cohorts into the reserve (Fig. 6). All 2006 cohort individuals moved on average 3.3 km from the post-release area into new, previously unoccupied areas following the release of the 2007 and 2008 cohorts, with only 16–20% of 2006 cohort locations occuring within their previous home range. Following the release of the 2008 cohort, individuals from the 2007 cohort moved on average 2.8 km to new areas and occupied *c*. 10% of their previous home range. Only 8% of locations of sub-adult birds ($n = 10$) showed evidence of home-range fidelity upon reaching adulthood, and the percentage home-range overlap varied between 0 and 17%.

Post-release behavior

The movements of the majority of reintroduced curassows (21 individuals comprising 13 females and eight males) were associated over time (Jacobs index ≥ +0.75), whereas the remaining four birds showed no social interactions (Jacobs index~0). Furthermore, there were no negative interactions between sub-adults or adults during the study period, suggesting that reintroduced birds did not avoid each other over time (e.g. no evidence of displaying territoriality). Reintroduced curassows tended to move in groups of up to seven individuals, consisting of four females and three males before reaching sexual maturity. On eight occasions, pairing occurred before reaching sexual maturity. After reaching sexual maturity, three pairs were formed: only one of the pairs formed while sub-adults remained together after reaching sexual maturity and only two new pairs were formed once all birds were sexually mature.

Habitat use

We detected significant patterns in the use and selection of forest habitat at both the home range ($\Lambda = 0.35$, $\chi^2 = 25.8$, $P < 0.0001$) and the location level ($\Lambda = 0.23$, $\chi^2 = 36.2$, $P = 0.002$), suggesting non-random habitat use for both levels. The simplified

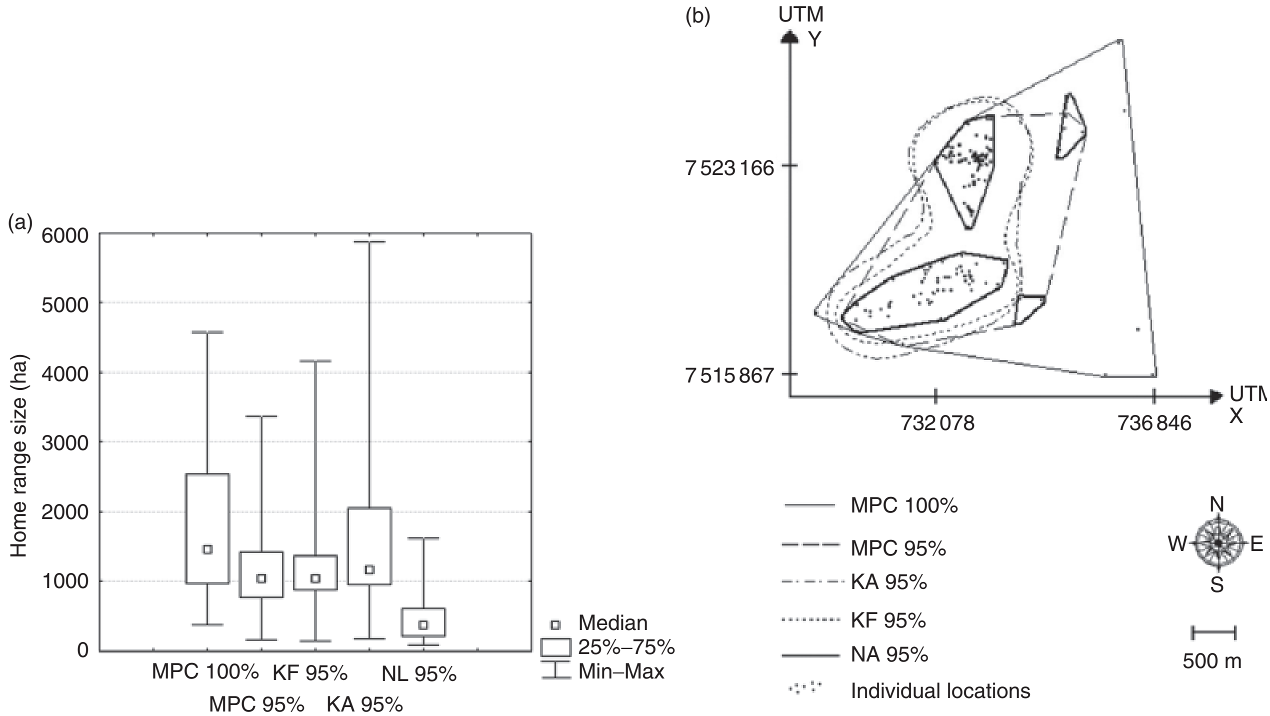

Figure 4 Comparison between different methods used to determine the home-range size of reintroduced red-billed curassows *Crax blumenbachii* at Guapiaçu Ecological Reserve (Rio de Janeiro state, Brazil). (a) Box-plot showing the median, quartiles and amplitude (Min–Max, minimum and maximum values) of home-range sizes of 25 individuals over the 25-month post-release monitoring period; (b) data of a male (ring number 8) reintroduced in August 2006 (MPC 100% = minimum convex polygon, including 100% locations, MPC 95% = minimum convex polygon, including 95% locations, KF 95% = fixed kernel includng 95% locations, KA 95% = adaptive kernel, including 95% locations, NL 95% = neighbor linkage including 95% locations).

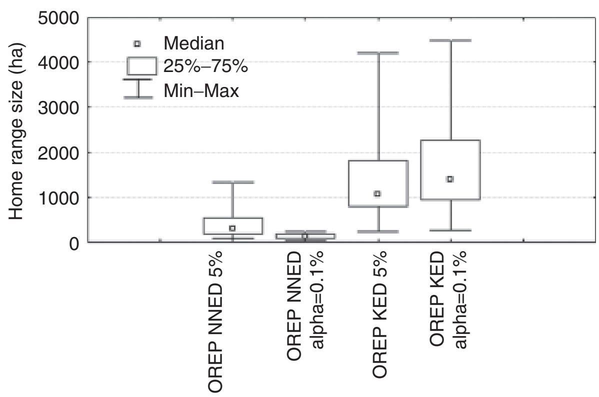

Figure 5 Comparison between different outlier exclusion methods, used to determine the home-range size of red-billed curassows *Crax blumenbachii* using the Neighbor Linkage method (OREP, outlier restricted edge polygons; NNED, nearest-neighbor distances; KED, kernel exclusion distances; 5% = percentage of excluded locations, alpha 0.1% = α-level of normal distribution).

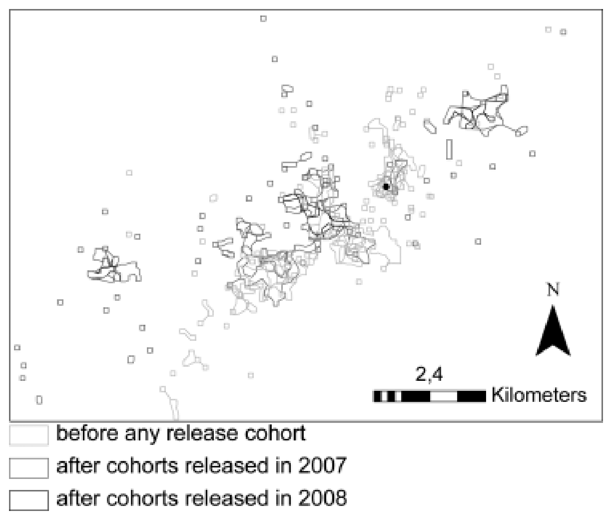

Figure 6 Change in home-range positions of individual red-billed curassows *Crax blumenbachii* released in 2006 at Guapiaçu Ecological Reserve (Rio de Janeiro state, Brazil), before and following the release of 2007 and 2008 cohorts. The black dot corresponds to the release site.

ranking matrix (Table 1) identified a distinctive pattern of curassow habitat use, in which forest habitat was used disproportionally more than all the other habitats considered, firstly at the home-range level (significant deviation from random at $P < 0.05$ is represented by the triple symbol $>$): forest $\ggg$ agriculture $>$ pasture $>$ flood pasture $>$ secondary vegetation, and secondly at the location level: forest $\ggg$ pasture-secondary vegetation $>$ agriculture $>$ flood pasture.

Table 1 Simplified ranking matrices of habitat selection of reintroduced red-billed curassows *Crax blumenbachi* at REGUA (RJ, Brazil) for (a) home-range level and (b) location level

	Agriculture	Forest	Pasture	Flood pasture	Secondary vegetation	Rank
(a) Home-range level						
Agriculture		—	+	+ + +	+ + +	3
Forest	+ + +		+ + +	+ + +	+ + +	4
Pasture	–	—		+	+	2
Flood pasture	—	—	–		+	1
Secondary vegetation	—	—	–	–		0
(b) Location level						
Agriculture		—	–	+ + +	–	1
Forest	+ + +		+ + +	+ + +	+	4
Pasture	+	—		+ + +	+	3
Flood pasture	—	—	—		–	0
Secondary vegetation	+	–	–	+		2

The highest value in the rank corresponds to the most selected habitat. The signals indicated that the habitat type in the row was more (+) or less (–) used than the habitat in the column (triple signals denote non-random habitat use, for example $P<0.05$).

Discussion

Improvements to reintroduction science can be made by utilizing post-release monitoring data so that the maximum conservation value can be derived from the case studies being conducted (Armstrong & Seddon, 2008). The movement patterns of reintroduced red-billed curassows identified in this study have a much broader relevance for reintroduction projects because they demonstrate that post-release monitoring must be considered over an appropriate time frame, and highlighting how different conclusions may be generated depending on the duration of post-release monitoring. For example, the cessation of post-release monitoring after only 11 months (or less) may have led us to conclude that reintroduced birds have a poorer propensity to move as they tended to remain <2.5 km of the release sites. The lowest movement rates were detected during the first 2 months of the study and these were almost certainly related to some of the reintroduction soft-release protocols used specifically for the adjustments of the birds to their new surroundings (before and following release) and supplementary food provision (e.g. Bright & Morris, 1994; Van Vuren, 1998). Utilizing data solely from this period may have undermined future reintroductions by impacting decision-making regarding changes to these key components of the release strategy or by drawing erroneous conclusions on how lower movement rates may impact the population dynamics and spatial synchrony of the reintroduced population.

By the end of the 25-month study period, all reintroduced curassows had moved ~3.5 km from the vicinity of the soft-release enclosure. In addition, we detected no differences in the mobility between males and females, suggesting that both sexes have an equal probability for moving some distance from the soft-release enclosure. Interestingly, five individuals had moved 12 km away from the release site, which is a distance similar to that reported for captive-bred white-winged Guan *Penelope albipennis* (13 km) reintroduced into Tumbesian forests of north-west Peru (Pratolongo, 2004). The presence of reintroduced birds 12 km away from the enclosure suggests that captive-bred red-billed curassows are able to explore different areas, at least at REGUA. However, the majority of birds avoided more distant locations during the study period. This implies that additional efforts must be incorporated into avian soft-release protocols to counter any unfamiliarity species may have with more distant locations that are perhaps linked to perceptions in predation risk or difficulties in finding a mate.

Reintroduced curassow home range and site fidelity

Assuming that our assessment of home-range size is reasonably valid, we can conclude that red-billed curassows utilize minimum home ranges of 100–200 ha, and that of adult males do not overlap and are often separated by distances of 3 km. Unfortunately, we cannot attest how representative our home-range data are of wild born curassow behavior simply because of the lack of studies on wild populations. Our estimations are much lower than known home ranges for other Cracids, which vary from 150 to 200 ha, except for Salvin's Curassow *Mitu salvini*, which utilizes a smaller home range of 70 ha (Parra *et al.*, 2001). Variation in reintroduced curassow home-range size at REGUA was related to the age of the birds and was far greater for adults than for sub-adults, although the sub-adults moved with greater frequency than adults. We also found no relationship between estimated home-range size and gender or the duration of monitoring. Previous authors have suggested that variation in Cracid home-range size may be related to reproductive activities (e.g. Badyaev, Martin & Etges, 1996) or to variations in food availability (e.g. SantaMaria & Franco, 1994; Bernal & Mejía, 1995). Further research on the diet and resource partitions between conspecifics would be extremely beneficial for guiding future reintroductions for the species.

From the subset of birds followed after releases of more individuals, it appears that side fidelity is low for red-billed curassow at REGUA. In general, there was a tendency for

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reintroduced curassows to move to other areas when new individuals were released into the area in subsequent cohorts. These movement patterns are of significant interest for reintroduction practitioners in that it is the resident birds that move. We do not know what factors are driving these movements from the release site over such prolonged time frames. It could purely be the influence of subsequent cohort releases changing the abundance and displacing resident birds. Alternatively, reintroduced birds may simply require a long time to habituate to the wild, and to explore and settle within a home range. The 25 focal captive-bred reintroduced curassows had no previous knowledge of the REGUA area before release, and such unfamiliarity with the release site is known to influence the site fidelity of translocated animals (Lande, 1988), particularly translocated Galliformes (e.g. Terhune *et al*., 2010). Social or competitive interactions also appear important in reintroduced curassow dispersal behavior. We observed frequent interactions between reintroduced curassows, with some individuals even mixing with conspecifics from different released cohorts with no negative interactions recorded or evidence of established territoriality. Distinguishing between these factors would be of significant interest for future avian reintroductions and would contribute to the poor information base on the impacts of releasing further captive-bred individuals into habitats with extant populations, topics noted variably as top-up reintroductions, supplementation, restocking and genetic rescue.

Patterns of habitat use by reintroduced curassows

At REGUA, reintroduced curassows predominantly used forest habitat at the home range and location level, while to a lesser degree, also used a range of agricultural, degraded or regenerating habitats. The use of agricultural habitat types is of particular interest as wild red-billed curassows have been observed foraging in papaya plantations *Carica papaya*, cocoa *Theobroma cacao* and rubber tree plantations *Hevea brasiliensis* in nearby Descobrimento National Park (Alvarez & Develey, 2010) and Fazenda Cupido, in the State of Espírito Santo (F. Olmos pers. obs.). Reintroduced birds were observed either alone or as single pairs, and are not currently considered as an agricultural pest due to their very low density. Several Cracid species (e.g. *Penelope superciliaris*, *Crax daubentoni, Crax alberti* and *Crax alector*) and other Galliformes also exhibit a similar pattern of habitat use that includes agricultural plantation habitats (e.g. Ayeni, 1983; Mikich, 2002; Iqubal *et al*., 2003; Rios, Londoño & Muñoz*,* 2005; Moreno-Palacios & Molina-Martinez, 2008). These results are encouraging and suggest that both reintroduced captive-bred and wild Cracids are, to a degree, tolerant of agricultural habitats as part of a larger heterogeneous landscape.

Reintroduced captive-bred curassows showed a preference for topographically flatter, lowland riparian forest habitats, but were occasionally recorded on accentuated slopes such as river banks and at higher elevations up to 500 m. The majority of curassow locations were <100 m from water sources, with few locations ($\sim$11%) further than 300 m. This association with freshwater streams or small rivers has been previously suspected by a number of authors (e.g. Sick, 1970) and there are anecdotal records of wild red-billed curassows constructing nests in trees above water (e.g. Teixeira & Snow, 1982; Collar & Gonzaga, 1988). The species' preference for riparian habitats at REGUA complements what is known for other curassow species. Wild populations of Cozumel curassow *Crax rubra griscomi* (Martinez-Morales, 1999), wattled curassow *Crax globulosa* (Begazo, 1997) and razor-billed curassow *Mitu tuberosa* (Hill, Aranibar-Rojas & Macleod, 2008) are all known to prefer flooded forest habitats and establish territories within close proximity to lowland rivers and large streams. The number of locations at which reintroduced curassows were recorded at higher elevations is also important and suggests that the species is capable of movement within higher elevational habitats, which may be significant if there is to be natural dispersal between different reestablished populations in the region.

Analytical considerations for avian post-release monitoring

Our study highlights the importance of evaluating a range of home-range estimation methods for reintroduced birds. We found that all four home-range estimator methods were highly sensitive to outliers, even when considering 95% of locations, with the exception of the NL method (which we ultimately selected). Sensitivity to outliers is well known for MCP (e.g. Kenward, 2001) while Kernel estimators also typically incorporate non-used areas into their estimations particularly if animals exhibit non-random movements (Hemson *et al.,* 2005). The advantage of selecting the NL method is that it does not ignore distant or 'rare' locations used by curassows but considers such data points as independent isolated locations (Kenward *et al.,* 2001).

Although a considerable effort was made to collect $\sim$3000 location fixes for the 25 reintroduced curassows at REGUA, we found that they were strongly autocorrelated. Choosing to locate birds within a maximum interval of 3 days was a compromise between movement details and a larger sample size of monitored birds. Incremental analysis also revealed that sample sizes for location data were not enough to comprehensively estimate home ranges, and consequently, our home-range values corresponded only to a minimum home-range size. We therefore encourage a more experimental approach to resolve such issues for avian post-release monitoring by varying the intervals (number of days) between the collection of location fixes and that researchers use a triangulation protocol for marking location positions of reintroduced birds. This will provide a suitable balance between tracking more birds over a suitable shorter period of time and may be more efficient as observers often have to follow birds off trail in dense vegetation.

Optimizing avian reintroduction programs

Our findings have a number of implications relevant for optimizing avian reintroduction programs, and more specifically, for the proposed reestablishment of a self-sustaining red-billed curassow metapopulation in the Atlantic Rainforests of Rio de Janeiro state. Our post-release monitoring data reveal that reintroduction using captive-bred red-billed curassows should only be envisaged in areas of forest larger than the minimum home-range movements (*c.* 125 ha) of the proposed population. Proposed reintroduction sites must contain adequate lowland, flatter riparian (riverine) habitat. The proximity of these release sites to agricultural habitats may not be detrimental for reintroduction as curassows are able to partly utilize these habitats, although they may increase their exposure to predators such as domestic dogs (see Bernardo, 2010).

The propensity of reintroduced birds to move during the immediate post-release period will in part depend on soft-release protocols, specifically the timing and number of release cohorts, supplementary feeding and the proximity of the soft-release enclosure to freshwater sources. Captive-bred birds will be unfamiliar with the release site and this will also influence home-range establishment and site fidelity. Reintroduced sub-adults captive-bred curassows did not form a self-sustaining (breeding) population at REGUA up to 25 months post-release, although we did observe nest construction by one male and some coupling. Newly hatched juveniles have been observed within a previously reintroduced red-billed curassow population at Macedonia Farm, Minas Gerais State, more than 4 years following reintroduction (Azeredo & Simpson, 2004). Conservation managers of reintroduction programs must be acutely aware that reintroduced captive-bred populations using non-breeding sub-adults may take several years (at least >2 years) to become established following release. We stress the importance of considering post-release monitoring over an appropriate time frame, avoiding different conclusions that could be generated depending on when monitoring stops. Post-release monitoring programs of at least 25 months' duration may not be adequate for larger avian species such as Cracids and this should be factored into the budgets for reintroduction programs.

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