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*COMMENTARY*

# Successful enhancement of Ridgway's Hawk populations through recruitment of translocated birds

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## ABSTRACT

Survival and recruitment estimates are important for predicting population viability and the efficacy of translocations. This information requires intensive monitoring postrelease, which is often economically or logistically infeasible. Since 2009, juveniles of the critically endangered Ridgway's Hawk (*Buteo ridgwayi*) have been translocated from Los Haitises National Park to Punta Cana, Dominican Republic. Here, we use multistate capture–recapture models to estimate survival and recruitment of translocated Ridgway's Hawks. We further examine whether survival or recruitment differed between sexes or translocation status (translocated vs. wild-reared birds in Los Haitises). Survival was relatively high for breeders, nonbreeders, and juveniles, and did not differ by translocation status or sex. Translocated juveniles were recruited into the breeding population at Punta Cana at more than double the rate of wild-reared juveniles in Los Haitises—likely because more unoccupied territories were available in Punta Cana. Our results show that translocation does not reduce survival, but does increase recruitment, of Ridgway's Hawks when territories are available in suitable habitat. Future work should evaluate the reproductive performance of Ridgway's Hawks in Punta Cana and determine the effects of translocations on the population in Los Haitises. Although the types of data collected during postrelease monitoring are often determined by funding, feasibility, and research objectives, our results demonstrate the importance of continued monitoring of translocated animals.

*Keywords:* monitoring, survival, recruitment, translocation, hacking, reintroduction, Hispaniola, endangered species

### Mejoramiento exitoso de la población de *Buteo ridgwayi* a través del reclutamiento de aves traslocadas

## RESUMEN

Las estimaciones de supervivencia y reclutamiento son importantes para predecir la viabilidad poblacional y la eficacia de las traslocaciones. Esta información requiere un monitoreo intensivo luego de la liberación, lo que usualmente es económica o logísticamente inviable. Desde 2009, juveniles de la especie en peligro crítico *Buteo ridgwayi* han sido traslocados desde el Parque Nacional Los Haitises a Punta Cana, en la República Dominicana. En este trabajo, usamos modelos de captura-recaptura multi-estado para estimar la supervivencia y el reclutamiento de los indivíduos traslocados de *B. ridgwayi*. También examinamos si la supervivencia o el reclutamiento difirieron entre sexos o estatus de traslocación (aves traslocadas versus criadas en silvestría en Los Haitises). La supervivencia fue relativamente alta para las aves reproductivas, no reproductivas, y juveniles, y no difirió según el estatus de traslocación o el sexo. Los juveniles traslocados se incorporaron a la población reproductiva en Punta Cana a una tasa de más del doble que los juveniles criados en silvestría en Los Haitises—probablemente porque en Punta Cana estuvieron disponibles más territorios desocupados. Nuestros resultados muestran que la traslocación no reduce la supervivencia y sí incrementa el reclutamiento de *B. ridgwayi*. Trabajos futuros deberían evaluar el desempeño reproductivo de *B. ridgwayi* en Punta Cana y determinar los efectos de la traslocación en la población de Los Haitises. Aunque los tipos de datos colectados durante el monitoreo luego de la liberación están usualmente determinados por los fondos disponibles, la factibilidad y los objetivos de investigación, nuestros resultados demuestran la importancia del monitoreo continuo de los animales traslocados.

*Palabras clave:* cetrería, especies en peligro, La Española, monitoreo, reclutamiento, reintroducción, supervivencia, traslocación

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## INTRODUCTION

Species translocation is a widely used conservation strategy, with some high-profile successes (Butler and Merton 1992, Jones et al. 1995, Cade and Burnham 2003). However, the recognition that translocation programs often fail (Griffith et al. 1989, Wolf et al. 1998) has prompted several pleas for these programs to better monitor released animals so that drivers of success can be identified and replicated (e.g., Hein 1997, IUCN 1998, Ewen and Armstrong 2007, Seddon et al. 2007). It is now considered best practice to collect demographic data on translocated animals postrelease. Demographic data are especially important because they can be used in population models to estimate population growth and viability, as well as the efficacy of proposed management actions (e.g., Sarrazin and Barbault 1996, Seddon et al. 2007, McClure et al. 2017).

Survival data can be particularly informative for gauging the success of reintroduction efforts because success often rests on the ability of animals to survive in the recolonized location (Armstrong and Seddon 2008, Armstrong and Reynolds 2012, Sheean et al. 2012). Low rates of survival can doom a reintroduction program (Sheean et al. 2012). For example, efforts to reintroduce Brown Treecreepers (*Climacteris picumnus*) in Australia likely failed because of high rates of predation. The problem of translocated individuals surviving at lower rates than those in natural populations, or of low survival during a postrelease 'acclimation period,' occurs across reintroduction programs for a diverse range of taxa (e.g., Sarrazin and Legendre 2000, Bar-David et al. 2005, Bertolero and Oro 2009). For example, Kaufman et al. (2003), Brown et al. (2006), and Evans et al. (2009) found that the survival of translocated Peregrine Falcons (*Falco peregrinus*), Aplomado Falcons (*Falco femoralis*), and White-tailed Eagles (*Haliaeetus albicilla*) was lower than that of wild-reared conspecifics. Conversely, no differences were found between the survival rates of wild-reared and translocated Mauritius Kestrels (*Falco punctatus*; Nicoll et al. 2004) or Red Kites (*Milvus milvus*; Evans et al. 1999). Therefore, even within a group as narrowly defined as diurnal raptors, these divergent results preclude generalizations about the survival of translocated birds. The survival of translocated birds in the recolonized location can thus be especially important to monitor to reveal early problems with a reintroduction program. For example, in New Zealand, postrelease monitoring revealed that the survival of Stitchbirds (*Notiomystis cincta*) on Tiritiri Matangi Island was significantly lower when nectar feeders were absent (Armstrong and Ewen 2001). The researchers thus increased supplemental feeding, which increased survival (Armstrong and Ewen 2001, Armstrong et al. 2002). Beyond simple survival, there also needs to be recruitment of translocated animals into the breeding population, although this important metric is difficult to evaluate in the field (e.g., Cowardin and Blohm 1992, Carlile et al. 2012).

The Ridgway's Hawk (*Buteo ridgwayi*) is a critically endangered raptor endemic to Hispaniola in the Caribbean islands. There are ~200 breeding pairs, mostly within Los Haitises National Park (hereafter, 'Los Haitises'), Dominican Republic. The Ridgway's Hawk is best characterized by its generalist habits. Historical records place Ridgway's Hawks in nearly every terrestrial cover type on Hispaniola from sea level to 2,000 m asl (Wiley and Nethery Wiley 1981). In Los Haitises, hawks breed in a highly modified mosaic of forest patches and agricultural plots, with a high incidence of forest–edge ecotones (Thorstrom et al. 2007, Woolaver 2011). The species' diet is also diverse, including amphibians, reptiles, birds, small mammals, and insects, although snakes and lizards dominate the diet in both frequency and biomass (Woolaver et al. 2013a). Pairs are socially monogamous and defend exclusive breeding territories. Modal clutch size is 2 eggs (Woolaver et al. 2014), and average productivity per breeding attempt is 0.6 young (Thorstrom et al. 2007). Threats to the species include habitat destruction, persecution, and parasitic nest flies (*Philornis* spp.; Thorstrom et al. 2007, Woolaver et al. 2014).

To increase the long-term viability of the species, The Peregrine Fund began translocating nestlings in 2009 from Los Haitises to the privately owned 60-km$^2$ Puntacana Resort and Club within the Punta Cana region of the southeastern Dominican Republic, ~130 km from Los Haitises (hereafter, we use 'Punta Cana' to refer to both the resort and the region that encompasses it). Punta Cana hosted no Ridgway's Hawks prior to translocation. Juveniles were released by a process known as 'hacking' (Sherrod et al. 1982), then monitored to determine survival, recruitment, and productivity. In 2016, after 8 yr and 104 birds translocated, there were 12 breeding pairs of Ridgway's Hawk in Punta Cana that produced 8 fledglings.

Because we monitored marked birds postrelease, we can estimate the survival and recruitment of translocated birds vs. those remaining in the original population. Here, we use multistate capture–recapture models (Pradel and Lebreton 1999, Brown et al. 2006, Kéry and Schaub 2012) to estimate and compare survival and recruitment rates between Ridgway's Hawk populations in Los Haitises and Punta Cana.

## METHODS

### Study Areas

Los Haitises, the source of the wild population, encompasses 600 km$^2$ of rolling limestone hills ranging in elevation from sea level to 380 m asl (Wiley and Nethery



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Wiley 1981, Thorstrom et al. 2005, Gesto 2016). Substantial precipitation (2,700 mm annually) and warm temperatures (25–32°C) promote the growth of subtropical wet forests (Holdridge 1967), with >700 vascular plant species recorded. Characteristic overstory vegetation includes West Indian mahogany (*Swietenia mahagoni*), American muskwood (*Guarea guidonia*), fourleaf buchenavia (*Buchenavia tetraphylla*), and kapoktree (*Ceiba pentandra*), with a closed canopy height above 30 m (Wiley and Nethery Wiley 1981). Moderate to high levels of intervention from swidden agriculture and logging create a mosaic of primary forest patches, secondary forest, agriculture, and vegetation in various states of regrowth (Marizán 1994).

We chose Punta Cana as the release site because, within the resort, hawks would be protected from persecution, which is thought to be a primary threat to the species (Thorstrom et al. 2007, Woolaver et al. 2014), and because we deemed the resort to possess suitable habitat within the historic range of the species (Wiley and Nethery Wiley 1981, Woolaver et al. 2013b, 2014). The Punta Cana region in the southeastern sector of the island differs markedly in topography, rainfall, vegetation, and land use from Los Haitises. Punta Cana has a flat topography near sea level, where warm annual temperatures (mean = 26.5°C), comparatively less annual precipitation (800–1,200 mm), and high evapotranspiration potential sustain a subtropical dry forest with an open canopy to 10 m (EcoMar 2012, MIMARENA 2012). Characteristic trees of the overstory include tietongue (*Coccoloba diversifolia*), holywood (*Guaiacum sanctum*), false mastic (*Sideroxylon foetidissimum*), and lancewood (*Nectandra coriacea*), among others (EcoMar 2012). In Punta Cana, there are 5 luxury residential communities, multiple hotels, and 2 golf courses that combine to create an open, urban landscape, with patches of dry forest and scrubby second growth among large swaths of manicured lawns.

### Translocation and Monitoring at Punta Cana

In 2014 and 2015, we removed nestlings aged 1–2 weeks from Los Haitises and hand-reared them in a laboratory setting to 5 weeks of age. Under this protocol, we removed all nestlings from a given nest so that adult birds in Los Haitises could attempt a second clutch. From 2009 to 2013 and in 2016 we removed single nestlings at ~5 weeks of age from broods of 2–3 young, allowing adults to raise the remaining nestling(s). We placed the ~5-week-old nestlings in an enclosed box (hack box) on an elevated platform and provided them with a constant food supply. Translocated female nestlings were fitted with VHF transmitters to aid relocation and the determination of recruitment. When nestlings were ~6 weeks old, we opened the hack box and allowed them to come and go at liberty, while still providing food at the hacking platform. During a period of up to 4 mo, the young hawks steadily decreased their dependence on the provided food and dispersed from the hacking area. We attempted to relocate released birds each nesting season (January to July). As breeding territories were established, we climbed to occupied nests weekly to monitor nestling development and survival, and to mark young with unique alphanumeric, colored leg bands. In total, 104 (53 male, 51 female) Ridgway's Hawks were translocated from Los Haitises to Punta Cana.

### Monitoring at Los Haitises

Between 2011 and 2016, Peregrine Fund biologists monitored from 36 to 110 nesting Ridgway's Hawk pairs each year in the Los Haitises population. Occupied nests were monitored using methods similar to those used in Punta Cana. Resighting of marked birds, mostly (>95%) during the breeding season, forms the basis for our estimates of recruitment and survival in Los Haitises. We were unable to survey some territories in Los Haitises every year, and therefore censored birds with incomplete capture histories from analysis. There were 144 males and 154 females in Los Haitises with complete capture histories.

### Analysis

Our final analysis included >400 Ridgway's Hawks monitored in Los Haitises and Punta Cana (see Supplemental Material Appendix A for survival data). We used the state–space formulation of a Cormack-Jolly-Seber capture–recapture model to estimate survival using a Bayesian framework (Cormack 1964, Jolly 1965, Seber 1965). Our models examined apparent survival (hereafter, 'survival'), meaning that our survival estimates are the probability that a hawk survived and was within the study site the following year. We used a categorical distribution, which is a special case of the multinomial, to create a multistate model incorporating age and breeding status (juvenile, nonbreeder, and breeder) as alternative states (Pradel and Lebreton 1999, Kéry and Schaub 2012). The observation and state equations are fully described elsewhere (Kéry and Schaub 2012, chapter 9). We defined the state-transition matrix that describes the state of an individual at time $t + 1$ given its state at time $t$ as:

$$
\begin{array}{c} \\ \text{State at } t \end{array}
\begin{array}{c}
\begin{array}{cccc} \text{State at } t+1 & & & \\ \text{juvenile} & \text{nonbreeder} & \text{breeder} & \text{dead} \end{array} \\
\begin{bmatrix}
0 & \phi_J(1-\Psi_{JB}) & \phi_J\Psi_{JB} & 1-\phi_J \\
0 & \phi_N(1-\Psi_{NB}) & \phi_N\Psi_{NB} & 1-\phi_N \\
0 & 0 & \phi_B & 1-\phi_B \\
0 & 0 & 0 & 1
\end{bmatrix}
\end{array}
\begin{array}{l} \text{juvenile} \\ \text{nonbreeder} \\ \text{breeder} \\ \text{dead} \end{array}
$$

where $\phi$ is survival and $\Psi$ is recruitment. We specified the observation matrix, which maps true states (rows) to observed states (columns), as:



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$$\begin{array}{r} \\ \text{juvenile} \\ \text{nonbreeder} \\ \text{breeder} \\ \text{dead} \end{array} \begin{array}{c} \begin{array}{cccc} \text{juvenile} & \text{nonbreeder} & \text{breeder} & \text{not seen} \end{array} \\ \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & p_N & 0 & 1-p_N \\ 0 & 0 & p_B & 1-p_B \\ 0 & 0 & 0 & 1 \end{bmatrix} \end{array}$$

where $p$ is the detection probability for a given state. Juveniles in our dataset were all banded as juveniles and thus were observed perfectly. The model allows false-negative errors to occur during surveys, that is, the model accounts for the fact that an individual may not be observed due to imperfect detection probability. However, model assumptions include that there are no misidentifications of individuals, no state assignment errors, and no emigration (i.e. given emigration, the model estimates apparent survival, not true survival; Kéry and Schaub 2012).

We first created a global model that included factors for sex (male or female) and translocation status (translocated or wild-reared) for all estimated parameters. To determine whether survival, recruitment, and detection varied by sex and translocation status, we derived a posterior distribution for the average of each group and then subtracted samples of one group from another to derive a distribution for the differences between groups (Kéry 2010, Kruschke 2015). For example, to estimate the difference in survival between the translocated and the wild-reared population, we added the samples of posterior distributions from the different sexes together within each group and divided each group by 2, then calculated the difference between averages. We determined significance when 95% credible intervals from the resulting distribution did not include zero. After determining which groups differed in survival, recruitment, and detection, we built a post hoc model that excluded factors for groups with nonsignificant differences.

To determine support for the post hoc model vs. the global model and a null model, we used the product space method for model comparison (Tenan et al. 2014, Kruschke 2015). We did not average model estimates because a priori models are needed for model-averaged estimates to be appropriate (Kass and Raftery 1995). The product space method is described in detail elsewhere (see Carlin and Chib 1995, Tenan et al. 2014); we provide a brief description here. This method uses Markov chain Monte Carlo (MCMC) simulations to determine posterior model probabilities (Carlin and Chib 1995). At each iteration, the MCMC sampler simulates the parameters for all models, but only those from one model are allowed to affect the likelihood. We used a categorical distribution to select 1 of the 3 possible models to affect the likelihood, while deactivating the likelihood for all other models. We tuned the model selection index using pseudopriors for the parameters (survival and recruitment in this case) of deactivated models to prevent autocorrelation within chains, because chains can become stuck on individual models without pseudopriors when deactivated models with vague priors are evaluated as less likely (Tenan et al. 2014). Pseudopriors do not inform the model likelihood directly, and increase mixing of the model selection index, thus decreasing autocorrelation among chain iterations (Tenan et al. 2014). We ran our analysis iteratively, gradually updating pseudopriors based on the posterior distributions of the previous model run as chain mixing improved and provided improved parameter estimates for the model selection index. The global model likelihood was activated infrequently by the categorical model selection index, so we ran this model separately to estimate pseudopriors, and we updated detection covariates to be consistent with other models. For all models, we allowed the detection probability of nonbreeders to vary by group (translocated or wild-reared) because this variable was significant in the global model.

For pairwise comparisons of models ($M_i$, $M_j$), we calculated the relative probability of each given the data, $\boldsymbol{y}$, as the posterior model odds:

$$\frac{p(M_i|y)}{p(M_j|y)} = \frac{p(M_i)}{p(M_j)} \frac{p(y|M_i)}{p(y|M_j)},$$

where $p(M_i|\boldsymbol{y})$ is the posterior model probability. The Bayes factor ($BF_{i,j}$) is the second ratio on the right-hand side (i.e. the ratio of the 2 marginal likelihoods $p(\boldsymbol{y}|M_i)$ / $p(\boldsymbol{y}|M_j)$), and $p(M_i)$ / $p(M_j)$ is the ratio of the assigned prior model probabilities (Tenan et al. 2014). A Bayes factor describes the change in model odds resulting from observing the data (Lodewyckx et al. 2011). We considered values of 2 $\log_e(BF_{i,j})$ for $M_i$ over $M_j$ as follows: 0–2 = little support; 2–6 = substantial support; 6–10 = strong support; and >10 very strong support (Kass and Raftery 1995).

We calibrated the model selection index to further promote mixing within chains by running the MCMC sampler several times and adjusting the model weights as priors to achieve relatively even sampling of the models in posterior draws (Link and Barker 2010, Tenan et al. 2014). Priors influencing model weights are distinct from pseudopriors, but are similarly used to promote chain mixing of the model selection index. We corrected posterior model probabilities for assigned model weights (Lodewyckx et al. 2011, Tenan et al. 2014); therefore, Bayes factors were not influenced by these model weights (Tenan et al. 2014). The null model ($M_1$) was assigned a prior probability of 2/1,000,000, while the intermediate model ($M_2$) was assigned 1/1,000,000, and the global model ($M_3$) was assigned 999,997/1,000,000.

We implemented the analysis (Supplemental Material Appendix B) in JAGS 4.2.0 (Plummer 2003) using jagsUI package version 1.4.4 (Kellner 2016) in R 3.2.3 (R Core



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Team 2016). We ran 3 chains for 200,000 iterations for each chain after a 10,000-iteration burn-in, and retained each iteration for a total of 600,000 posterior draws. To assess chain convergence, we calculated the Gelman-Rubin statistic (Gelman and Rubin 1992), and determined convergence when parameters had an $\hat{R} < 1.1$. We also visually assessed trace plots of parameter chains to check for convergence. We used vague priors for survival, recruitment, and detection (Kéry and Schaub 2012) on logit-transformed parameters to approximate a vague uniform prior on the probability scale, $Normal(\mu = 0, \tau = 0.37)$. Models using the product space method require a sensitivity assessment of the effect on Bayes factors of priors on survival, recruitment, and detection parameters (Tenan et al. 2014). To test sensitivity to an alternative prior, we ran the model and converted survival, recruitment, and detection parameters to the probability scale and specified the priors as $Uniform(a = 0, b = 1)$, where $a$ and $b$ were minimum and maximum values. We also provide Bayes factors from this model for comparison.

## RESULTS

Rates of survival were similar between translocated and wild-reared Ridgway's Hawks, with the global model revealing that credible intervals for differences in survival between all groups overlapped zero (Figure 1). There were significant differences between the recruitment of juveniles into the breeding population in Punta Cana vs. Los Haitises (Figure 1), with the probability of juvenile recruitment in Punta Cana 2.30 times (95% CI = 1.10–4.28) higher than that in Los Haitises. The only significant difference in detection was for nonbreeding hawks, which were 4.51 (95% CI = 2.39–8.27) times more likely to be detected in Punta Cana than in Los Haitises. We did not detect any differences by sex in any state for any parameter (Figure 1). Our post hoc model therefore assumed that survival was equal for all states, that recruitment varied by translocation status only for juvenile hawks, and that detection varied by translocation status only for nonbreeding hawks.

Ranking of the 3 models—global, post hoc, and null—revealed substantial support for the post hoc model over the global and null models, with the post hoc model receiving 73% of the support, the global model receiving 0%, and the null model receiving 27%. Direct model comparisons of $2 \log_e(BF_{i,j})$ showed strong support for the post hoc model over the global model ($2 \log_e(BF_{2,3}) = 29.2$), strong support for the null model over the global model ($2 \log_e(BF_{1,3}) = 27.2$), and some support for the post hoc model compared with the null model ($2 \log_e(BF_{2,1}) = 2.03$). Our conclusions using Bayes factors were relatively robust to the alternative model specification using uniform priors on survival parameters, and showed similar model comparisons as those described above: $2 \log_e(BF_{2,3}) = 14.2$, $2 \log_e(BF_{1,3}) = 12.1$, and $2 \log_e(BF_{2,1}) = 2.1$. We present parameter estimates from the post hoc model because it was considerably more parsimonious than the other 2 models.

Estimates from the post hoc model revealed that survival was relatively high across all sexes, sites, and states, with mean breeder survival of 0.93 (95% CI = 0.90–0.96), overall nonbreeder survival of 0.73 (95% CI = 0.59–0.86), and overall juvenile survival of 0.45 (95% CI = 0.36–0.55; Figure 2). Recruitment of juveniles into the breeding population was higher in Punta Cana (mean = 0.39, 95% CI = 0.24–0.56) than in Los Haitises (mean = 0.19, 95% CI = 0.10–0.29; Figure 2). Mean detection probability for breeders was 0.98 (95% CI = 0.96–1.00), and was higher for nonbreeders in Punta Cana (mean = 0.90, 95% CI = 0.73–0.99) than in Los Haitises (mean = 0.21, 95% CI = 0.12–0.33; Figure 2). Trace plots showed adequate mixing of chains, with $\hat{R} < 1.1$ for all parameters. The model selection index showed adequate mixing after model priors were tuned, with 199,353 iterations for the null model, 275,116 iterations for the post hoc model, and 125,531 iterations for the global model.

## DISCUSSION

We found no differences in survival between Ridgway's Hawks that were translocated to Punta Cana and those that remained in Los Haitises. All estimates of differences between survival of the sexes or translocated vs. wild-raised birds had credible intervals that overlapped zero. Moreover, the post hoc model that assumed no differences in survival between classes was much more supported than the global model, further supporting the hypothesis of similar rates of survival between wild-reared and translocated Ridgway's Hawks. Both Los Haitises and Punta Cana populations had high rates of survival. Newton et al. (2016) reviewed more than 40 studies of raptor survival and found that rates for medium-sized hawks, such as the Ridgway's Hawk, were in the range of ~0.70–0.90. With an average survival rate of 0.93 for breeders, populations of Ridgway's Hawk in both Punta Cana and Los Haitises had a relatively high survival rate for a bird of their size. Note that because our survival estimates represented the probability of a hawk both surviving and returning to the study site, our estimates might have been affected by emigration. It is possible for rates of dispersal to be density dependent (Matthysen 2005), and they therefore likely differed between our study sites, probably causing differing rates of emigration. Future research should therefore examine the dispersal of individuals in both Los Haitises and Punta Cana.

There are several reasons why the birds that we translocated apparently survived at a similarly high rate



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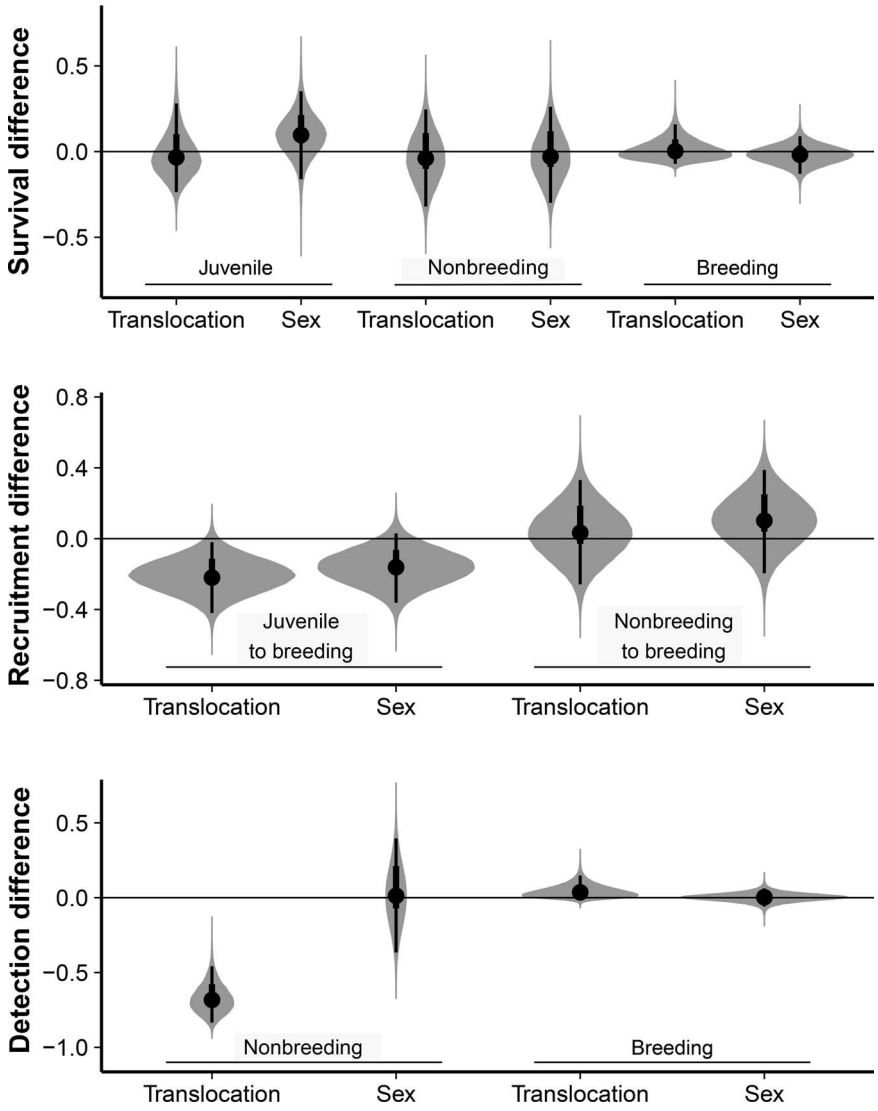



**FIGURE 1.** Derived differences of rates of survival, recruitment, and detection based on sex or translocation status (either translocated from Los Haitises National Park to Punta Cana, Dominican Republic, or remaining in the national park) for Ridgway's Hawks, 2009–2016. Points represent medians of posterior probability distributions, thick lines represent 68% credible intervals, and thin lines represent 95% credible intervals. Gray shading represents violin plots of posterior distributions. Differences are for translocated birds minus wild-reared birds or males minus females, such that negative values indicate higher rates for translocated or female birds.

as those in the source population. Wild-caught animals tend to survive at higher rates than captive-reared animals when translocated (e.g., Griffith et al. 1989, Wolf et al. 1996, Rummel et al. 2016). Brown et al. (2006) suggested that captive-reared Aplomado Falcons had lower rates of survival than wild-hatched conspecifics because of a lack of parental influence, which might have led to a reduction in foraging efficiency, socialization, and predator avoidance. However, the birds that we translocated were all taken from the source population as nestlings. Therefore, although they were wild-caught, the birds that we released lacked parental influence during a portion of the brood-rearing period and thereafter.

The method by which we released young birds may have increased their initial survival rate. 'Soft releases' are often assumed to increase the initial survival of translocated animals (Kleiman 1989, Bright and Morris 1994), but some experiments have questioned this assumption (Armstrong and Seddon 2008). The hacking method that we used has been effective for the establishment of other populations of translocated raptors (e.g., Cade et al. 1988, Cade and Jones 1993, Jones et al. 1995, Hunt et al. 2013), although the survival of hacked raptors can be lower than that of wild-



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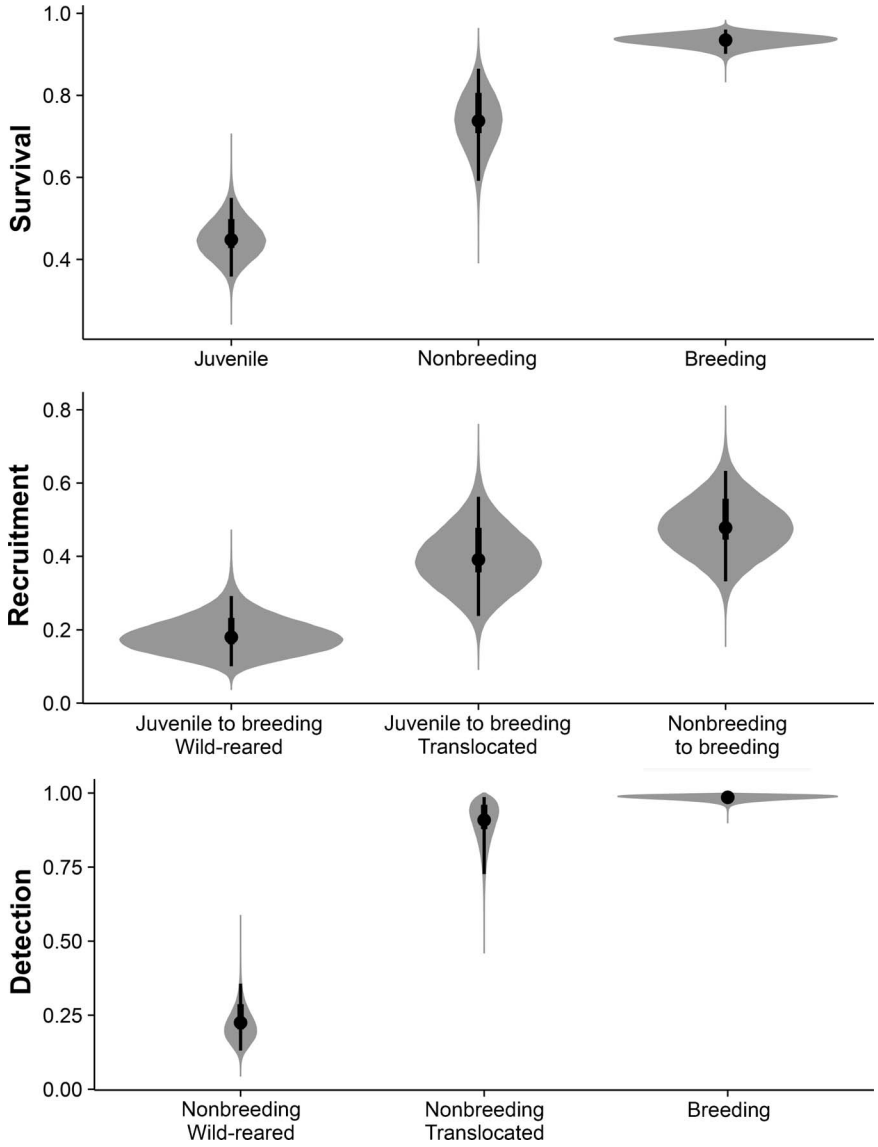



**FIGURE 2.** Rates of survival, recruitment, and detection based on breeding status and translocation status for Ridgway's Hawks, Dominican Republic, 2009–2016. Wild-reared birds were reared and remained in Los Haitises National Park, whereas translocated birds were reared in the national park but translocated to Punta Cana. Points represent medians of posterior probability distributions, thick lines represent 68% credible intervals, and thin lines represent 95% credible intervals. Gray shading represents violin plots of posterior distributions.

reared birds (Kauffman et al. 2003, Brown et al. 2006). Regardless, because we only released juveniles, the translocation of wild-caught individuals and our use of hacking likely served to increase only juvenile survival. Release effects tend to diminish over time (Bar-David et al. 2005, Brown et al. 2006). Therefore, for birds released as juveniles in Punta Cana to maintain levels of survival equal to those in Los Haitises suggests that, although the landscapes differed, the habitat available to both populations was of similar quality (Johnson 2007), at least for survival.

Although the quality of habitat available to the 2 populations seems equivalent with respect to survival, the difference in recruitment rates indicates that there were more unoccupied territories available in Punta Cana than in Los Haitises and highlights the potential benefits of translocation. The probability of a juvenile becoming a breeder more than doubled if we translocated it from Los Haitises to Punta Cana. This probably resulted from a saturation of territories in Los Haitises, compared with there being no Ridgway's Hawks in Punta Cana when we began releases. As the Punta Cana population grows, future research should determine whether recruitment or average population productivity declines as high-quality territories become saturated and hawks begin occupying



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lower-quality territories (Fretwell and Lucas 1969, Rodenhouse et al. 1997, Hunt and Law 2000).

The similar survival rates that we found in 2 such disparate landscapes lead us to speculate on the relative contributions of different sources of mortality in Los Haitises and Punta Cana. Hispaniola, like most small oceanic islands, has a depauperate mammalian fauna, and the Ridgway's Hawk is the apex predator in its forested habitats. Predation is therefore probably not a significant source of mortality for juvenile or adult hawks. Because of the Ridgway's Hawk's generalist preferences for edge habitats and diverse prey, habitat and prey abundance also seem unlikely to limit survival. However, we have observed that anthropogenic sources of mortality differ greatly between sites. Shooting has been a major source of mortality of mature hawks in Los Haitises (Thorstrom et al. 2007), whereas in Punta Cana we have observed deaths mostly due to electrocutions from power lines and from vehicular strikes (T. Hayes and R. Thorstrom personal observation). Therefore, although survival was equal across sites, sources of mortality likely differed. We have been working to reduce sources of anthropogenic mortality through retrofitting power poles in Punta Cana and environmental outreach conducted by The Peregrine Fund, Fundación Grupo Puntacana, and Fundación Propagas in local communities at both sites.

Our estimates of detection likely reflect the ease with which different-sized populations of territorial hawks are surveyed, use of radio-telemetry, and logistical differences of surveying the 2 sites. The detectability of breeding hawks was high across both study sites, likely because of high site fidelity of breeding Ridgway's Hawks. However, nonbreeding hawks were more easily detected in Punta Cana than in Los Haitises, perhaps because it was easier to monitor a much smaller population. Further, Los Haitises is larger, more densely forested, and has fewer roads than Punta Cana, making surveys in Los Haitises logistically far more difficult.

Postrelease monitoring did not reveal problems with the ability of Ridgway's Hawks to survive and obtain breeding territories in Punta Cana. However, establishing a self-sustaining population also requires individuals to reproduce at a rate high enough to maintain a positive or stable growth rate. Population models are essential for reintroduction programs to estimate population viability and the efficacy of management options (Griffith et al. 1989, Armstrong and Seddon 2008, McClure et al. 2017). For example, Evans et al. (2009) used a model to determine that White-tailed Eagles no longer needed to be released to maintain a population in Scotland. In the same manner, our estimates of survival and ongoing estimation of fecundity of Ridgway's Hawks in Punta Cana will inform future population modeling, allowing us to gauge the viability of the Punta Cana population while also determining the effect of translocations on the source population in Los Haitises.

By monitoring translocated Ridgway's Hawks we were able to evaluate our program, highlighting emphasis by other authors on the importance of monitoring translocated animals following their release (e.g., IUCN 1998, Ewen and Armstrong 2007, Seddon et al. 2007, Pérez et al. 2012). Although demographic data can require intensive effort to collect, researchers should consider whether these data sufficiently increase the accuracy of population projections and accomplish research objectives (Sutherland et al. 2010, IUCN/SSC 2013), and then plan for such effort when securing project funding. In the case of the Ridgway's Hawk, postrelease demographic monitoring has been, and will continue to be, a valuable tool for gauging success and driving conservation efforts.

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**Ethics statement:** This research was conducted in compliance with the *Guidelines to the Use of Wild Birds in Research* and with permission granted by the Ministry of the Environment and Natural Resources of the Dominican Republic.

**Author contributions:** C.J.W.M., T.I.H., C.D.H., R.T., M.C., and D.L.A. conceived the study. T.I.H., C.D.H., M.C., and R.T. designed and implemented the field protocols. C.J.W.M. and B.W.R. conducted analysis. All authors contributed to the writing and editing of the paper.

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