2016

Estimates of Small Indian Mongoose Densities: Implications for Rabies Management

Shylo R. Johnson
USDA/APHIS/WS National Wildlife Research Center

Are R. Berentsen
National Wildlife Research Center, USDA, Animal and Plant Health Inspection Service, Wildlife Services, Fort Collins, CO

Christine Ellis
National Wildlife Research Center, USDA, Animal and Plant Health Inspection Service, Wildlife Services, Fort Collins, CO

Amy Davis
National Wildlife Research Center, USDA, Animal and Plant Health Inspection Service, Wildlife Services, Fort Collins, CO

Kurt C. VerCauteren
USDA-APHIS-Wildlife Services, kurt.c.vercauteren@usda.gov

The Journal of Wildlife Management 80(1):37–47; 2016; DOI: 10.1002/jwmg.998

Research Article

Estimates of Small Indian Mongoose Densities: Implications for Rabies Management

SHYLO R. JOHNSON,[1] *National Wildlife Research Center, USDA, Animal and Plant Health Inspection Service, Wildlife Services, Fort Collins, CO 80521, USA*

ARE R. BERENTSEN, *National Wildlife Research Center, USDA, Animal and Plant Health Inspection Service, Wildlife Services, Fort Collins, CO 80521, USA*

CHRISTINE ELLIS, *National Wildlife Research Center, USDA, Animal and Plant Health Inspection Service, Wildlife Services, Fort Collins, CO 80521, USA*

AMY DAVIS, *National Wildlife Research Center, USDA, Animal and Plant Health Inspection Service, Wildlife Services, Fort Collins, CO 80521, USA*

KURT C. VERCAUTEREN, *National Wildlife Research Center, USDA, Animal and Plant Health Inspection Service, Wildlife Services, Fort Collins, CO 80521, USA*

ABSTRACT The small Indian mongoose (*Herpestes auropunctatus*) is an invasive species and rabies reservoir in Puerto Rico. In the continental United States, terrestrial wildlife rabies is primarily managed by the National Rabies Management Program (NRMP) of the United States Department of Agriculture through oral rabies vaccination (ORV); the distribution of the vaccine baits is influenced by the population density of the target species. The NRMP uses a density index for estimating raccoon (*Procyon lotor*) population density to guide bait distribution. In Puerto Rico, a wildlife rabies vaccination program does not exist and vaccination of domestic animals is limited and not compulsory. To acquire information on density and other population dynamics, we compared a mongoose density index (MDI) adapted from the NRMP raccoon density index (RDI) to 3 other methods (2 types of capture–mark–recapture [CAPTURE and MARK] and spatially explicit capture–recapture [SECR]) for estimating density that incorporate modeling procedures on detection probabilities, and examined the spatial distribution of mongooses within our study plots. We used the RDI trapping protocol modified for mongooses to livetrap mongooses in El Yunque National Forest (El Yunque) and Cabo Rojo National Wildlife Refuge (Cabo Rojo) in fall of 2011 and spring of 2012 resulting in 4 trapping sessions. The MDI estimates were consistently less than those from other methods for estimating mongoose densities. The MDI detected a greater mongoose density during the wet season (0.55 mongooses/ha) than the dry season (0.34 mongooses/ha) at Cabo Rojo, consistent with all 3 other density estimation methods. Overall, the correlation coefficient between MDI and the other calculation methods was $\geq$0.68. When we examined known locations of mongooses and travel distances, we detected more mongooses in a smaller area within the study plot at Cabo Rojo than at El Yunque. The MDI provided information on the spatial distribution of mongooses, which will be needed to implement an ORV program to target mongooses in Puerto Rico. Published 2015. This article is a U.S. Government work and is in the public domain in the USA.

KEY WORDS capture–mark–recapture, *Herpestes auropunctatus*, minimum number known alive, mongoose, population density, Puerto Rico, rabies, spatially explicit capture–recapture.

The small Indian mongoose (*Herpestes auropunctatus*) was introduced to tropical islands worldwide during the 19th century as a means to control rats (*Rattus* spp.) on sugar cane plantations (Nellis 1989, Simberloff et al. 2000, Barun et al. 2011). Mongooses are diurnal and occupy almost every part of tropical islands. Although their preferred habitat is dense grasses (Pimentel 1955, Vilella and Zwank 1993), they will also inhabit mature dry forest, montane rain forest, disturbed dry forest-scrub, cattle pastures, cane fields, coastal areas, and urban areas (Pimentel 1955, Coblentz and Coblentz 1985, Vilella 1998). As opportunistic feeders, they consume a diverse diet and take advantage of anthropogenic food sources (Coblentz and Coblentz 1985, Quinn and Whisson 2005). Their successful use of diverse habitat on the Caribbean Islands resulted in mongooses being a significant public health threat where they are a rabies reservoir. These islands include Puerto Rico, Grenada, Cuba, the Dominican

Received: 6 November 2014; Accepted: 28 August 2015

[1]*E-mail: Shylo.R.Johnson@aphis.usda.gov*

Republic, and most likely Haiti (Tierkel et al. 1952, Nadin-Davis et al. 2006, Vos et al. 2013).

In Puerto Rico, approximately 6,000 reports of people bitten by animals are investigated by the Puerto Rico Department of Health annually, with approximately 10% leading to rabies post-exposure prophylaxis. Mongooses have accounted for >70% of reported rabies cases in Puerto Rico (Krebs et al. 1998, Dyer et al. 2014) and have averaged 287 bite injuries to humans/year (Irizarry-Pasaarell 2011). In 2003, 1 human died of rabies after being bitten by a dog that had apparently been bitten by a mongoose (Irizarry-Pasaarell 2011). To date, a wildlife rabies vaccination program does not exist on this island and vaccination of domestic animals is not compulsory (Blanton et al. 2010). In the continental United States, the National Rabies Management Program (NRMP) of the United States Department of Agriculture coordinates efforts to prevent the spread of terrestrial rabies using an integrated program targeting raccoons (*Procyon lotor*), coyotes (*Canis latrans*), and gray foxes (*Urocyon cinereoargenteus*; Slate et al. 2009). These efforts consist primarily of enhanced rabies surveillance and oral rabies vaccination (ORV; Slate et al. 2005).

The ORV delivery method (e.g., hand baiting or aerial broadcast) and bait density can depend on the population density of the target species (Ramey et al. 2008, Slate et al. 2008). As part of their decision-making, the NRMP implements a standard raccoon population density index (RDI) that uses minimum number known alive (MNKA) calculations (Ramey et al. 2008). However, the performance of the RDI is relatively unknown with respect to other population density estimators. It derives conservative estimates that are biased low compared to capture–mark–recapture density estimates for raccoons (Beasley et al. 2012), but it has not been evaluated with other density estimators over multiple seasons. As the name indicates, the RDI is designed for raccoons and not mongooses or other mammals. For best results, a density index should be optimized for the species of interest (Conner et al. 1983).

Mongoose-related modifications to the RDI include the size of the density plot area because raccoons have larger and more highly variable home ranges (19.2 ha [Berentsen et al. 2013] to 244 ha [Chamberlain et al. 2003]) than mongoose home ranges (3.1–52.2 ha; Quinn and Whisson 2005). Another modification is the bait type. The standard bait used in trapping for the RDI is marshmallow and a raccoon-specific lure (Hardcore Raccoon Lure®, Wildlife Research Center, Inc., Ramsey, MN). Published examples of palatable baits for mongoose include fish, egg, hot-dogs, coconut, and beef scraps. Of these potential baits, fish, beef, and egg generated the most interest in Hawaiian environments (Pitt et al. 2015). The number of traps within a home range and bait type are just 2 factors that influence the likelihood of capturing animals.

We refer to the modified RDI we employed for mongooses as the mongoose density index (MDI). The RDI was implemented to provide a standard that could be used in different regions and provide an estimate with minimal calculations. The RDI standardizes efforts in terms of the number of traps deployed and is computationally easy. The MDI maintains these traits. The equation for density is simply the number of animals (N) divided by area (A). However, the challenge is knowing what the true N and A are (White et al. 1982). Where the capture and recapture histories are known, data can be analyzed by increasingly sophisticated calculations. For example, modeling procedures on capture and recapture probabilities are used to estimate population size N (Otis et al. 1978, Pollock et al. 2002) and then movement, home range, or other ad hoc information is used to estimate trapping area (Dice 1938, Otis et al. 1978, Wilson and Anderson 1985, Parmenter et al. 2003). Other calculations include modeling procedures based on capture probabilities and travel distance between detection events to provide a direct estimate of density (Efford 2004, Borchers and Efford 2008). These more sophisticated calculations for density estimation are established in the literature and allow a source of comparison on the performance of the MDI.

If an ORV program for mongooses on Puerto Rico is to be implemented, baseline data on mongoose population dynamics, distribution, and density will be required to effectively develop the program. For the MDI to be applicable within the ORV program framework, it needs to track density changes using simple density calculations and provide information of population dynamics and distribution when data are examined comprehensively. Our objectives were to evaluate the performance of the MDI by comparing it to other methods of estimating small-mammal densities, to examine spatial distribution of mongooses within study plots, and to incorporate these findings into a potential ORV program.

STUDY AREA

In 2011 and 2012, we worked in 2 different ecosystems: El Yunque National Forest (El Yunque) and Cabo Rojo National Wildlife Refuge (Cabo Rojo; Fig. 1). El Yunque was comprised 11,331 ha of mountainous subtropical rainforest in the Sierra de Luquillo Mountains, approximately 40 km southeast of San Juan, Puerto Rico. Average annual rainfall was 300 cm, which typically fell from May to October (Quinn and Whisson 2005). Temperatures ranged from 25.5° C to 27° C (Garcia-Martino et al. 1996). In El Yunque, our study plot was a 100-ha square located in the Palo Colorado region, and included portions of the Mina Trail and associated roads and hiking paths, which we used to access remote parts of the forest. Elevation within the plot ranged from 544 m to 820 m and contained the Mina River and tributaries. The plot encompassed several public day-use areas, which provided mongooses with access to anthropogenic food sources (Quinn and Whisson 2005), and had potential for human–wildlife interactions and disease transmission.

Cabo Rojo National Wildlife Refuge was 751 ha of subtropical dry forest in southwestern Puerto Rico dominated by forest-scrub and grassland habitats. The climate was predominantly arid, with approximately 100 cm of annual rainfall typically falling from September to November

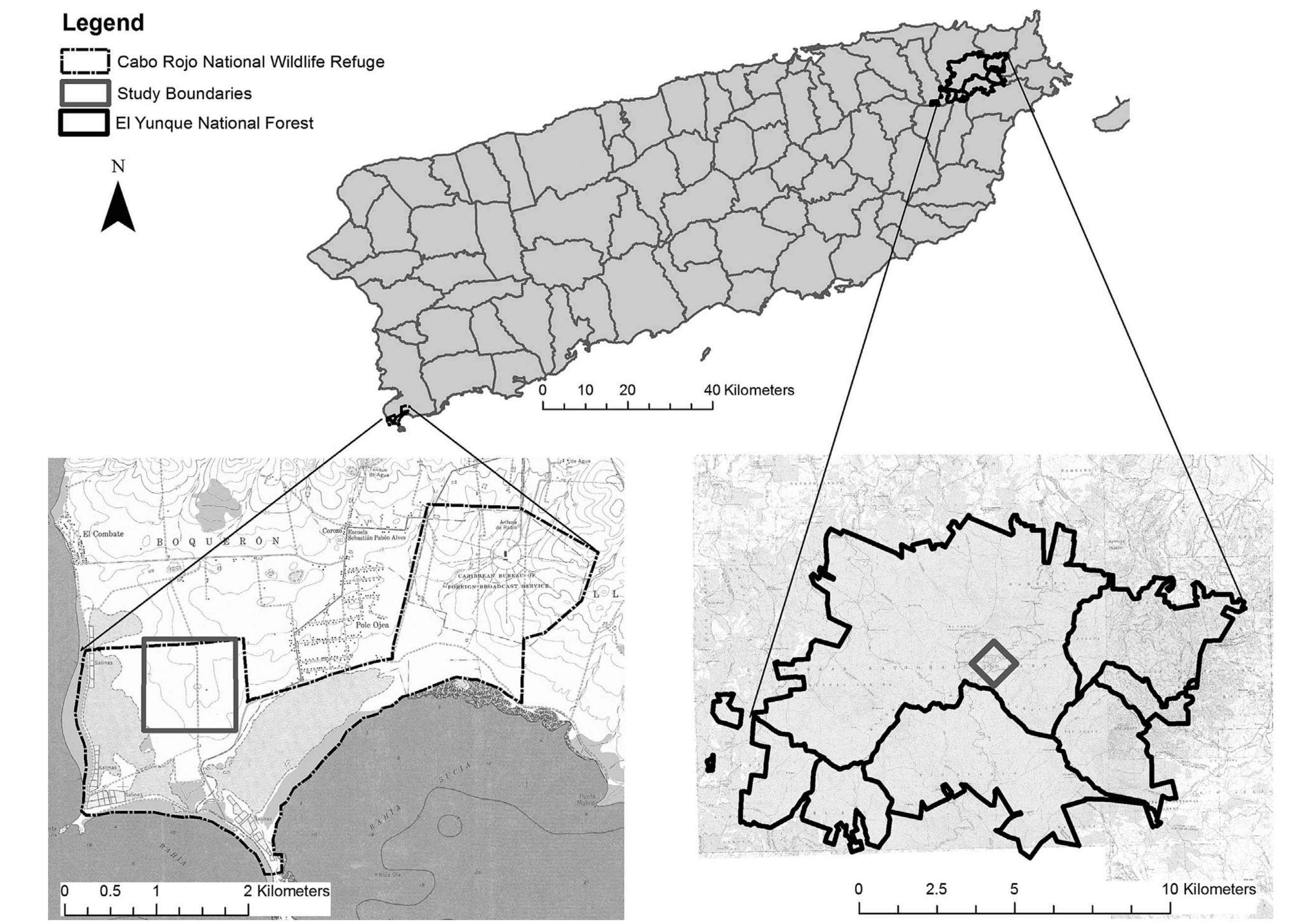

Figure 1. Study plots located in Cabo Rojo National Wildlife Refuge and El Yunque National Forest, Puerto Rico for estimating mongoose density in the fall of 2011 and spring of 2012.

(Weaver and Schwagerl 2008). Temperatures ranged from 21.7° C to 31.7° C (U.S. Fish and Wildlife Service 2011). In Cabo Rojo, we established a 100-ha square study plot on the western area of the refuge in relatively flat (elevation 0–15 m) forest-scrub habitat. The area contained firebreak roads and it was closed to the public.

METHODS

Field Methods

We captured mongooses with cage traps (Tomahawk Live Trap Co., Tomahawk, WI) following the RDI trapping protocol (NRMP 2011) except for 2 modifications: 1) our traps were located within 100-ha (1-km^2) plots instead of 3-km^2 plots to adjust for the smaller home ranges of mongooses (e.g., mongooses in wet season: 22 ha [Quinn and Whisson 2005]; raccoons: 73 ha [Beasley et al. 2007]) and 2) we baited traps with commercially available canned tuna packed in water (Quinn and Whisson 2005) in lieu of marshmallows and raccoon lure. We conducted 4 different MDI trapping sessions to encompass traditional wet and dry seasons at each geographical location (i.e., Cabo Rojo: 12–21 Sep 2011 fall-wet, El Yunque: 15–24 Oct 2011 fall-wet, El Yunque: 4–13 Mar 2012 spring-dry, and Cabo Rojo: 26 Apr–5 May 2012 spring-dry). However, March 2012 was the second wettest March on record. San Juan received 23.5 cm of rain, whereas rainfall in March averaged 4.0 cm over the last decade for San Juan (National Weather Service 2012). Because of this unseasonably wet weather during the dry season at El Yunque, we did not distinguish between the wet and dry seasons for the purpose of identifying our sessions for El Yunque but did do so for Cabo Rojo. Each session consisted of 10 consecutive days, which was the standard RDI duration.

During each session, we placed 50 traps within the study plots. We divided the plot into quadrants and placed 12–13 traps in each quadrant as near randomly generated locations as possible. We trapped along roads and hiking trails when we were unable to access the random point because of steep terrain or impassible water. We generated random locations using Hawth's tools (v 3.27; Beyer 2004) in ArcGIS (v 9.2, ESRI, Redlands, CA). For points in open areas, we set traps nearby in brush, grass, or trees for shade. We used random points for our initial trap placement because of the limited habitat variability originally identified in our study plots. Any trap without a unique mongoose capture within 3 consecutive days was moved $\geq$30 m from any past or present trap location (NRMP 2011). We recorded all trap locations with handheld global positioning system (GPS) units (Rhino; Garmin International, Inc., Olathe, KS).

We anesthetized captured mongooses by intramuscular injection of Telazol (tiletamine-zolazepam; Zoetis, Florham Park, NJ) at a dose of 5 mg/kg (Kreeger and Arnemo 2007). Upon initial capture, we recorded mass, body length measurements, relative age (based on mass and sexual maturity), and sex. We marked animals by injecting a passive integrated transponder (PIT) tag (Avid Identification Systems, Inc., Norco, CA) subcutaneously between the shoulder blades, and by topically applying Nyanzol D (Belmar, North Andover, MA) fur dye in a striped pattern unique to each individual. For each recapture, we documented the PIT tag and dye pattern. This study was conducted under the approval of the Institutional Animal Care and Use Committee at the National Wildlife Research Center (QA-1856).

During each session, we had motion-activated cameras (Trophy Cam, Bushnell, Overland Park, KS) operating concurrently with the trapping. The cameras were approximately 167 m apart in a 5×5 grid within the study plots. This distribution provided approximately 4 cameras/home range even during the dry season when home ranges are smallest (approx. 9.7 ha; Quinn and Whisson 2005). We placed the cameras 1 m off the ground, attached to a tree or other suitable support. The cameras were angled 45° downward toward a single 141 g (5 oz) commercial can of tuna placed 1 m from the base of the camera support. We programmed the cameras to record 3 images/trigger event with a 1-second interval between trigger events. We checked cameras and replenished bait every other day for 10 consecutive days.

Data Processing and Analysis

We recorded the date, time, camera site, number of mongooses observed, and fur-dye patterns (if present or discernable) for all camera images with mongooses present. We imported trap and camera locations along with the capture and detection history for each location into ArcGIS. For the trapping data, we used 4 calculation methods to estimate mongoose density: MDI, 2 types of capture–mark–recapture (CAPTURE and MARK), and spatially explicit capture–recapture (SECR). The calculation methods used were selected based upon their use for estimating density of closed populations from trapping data (Buckland et al. 2000, Efford 2004, Efford et al. 2009). We defined density for MDI, CAPTURE, and MARK as:

$$\widehat{\mathrm{D}} = \frac{\widehat{\mathrm{N}}}{\widehat{\mathrm{A}}}$$

where $\widehat{\mathrm{N}}$ is the estimate of population abundance and $\widehat{\mathrm{A}}$ is the estimate of the sampled area. For all the methods of density estimation, we made the assumption that no deaths, births, immigration, or emigration occurred during our 10-day sessions. For the MDI method, $\widehat{\mathrm{N}}$ equaled the number of unique individuals captured in traps in a single session and $\widehat{\mathrm{A}}$ was the 100-ha plot.

Capture–mark–recapture is a class of estimators where a model or group of models produces population abundance estimates and capture rate estimate. Thus, a separate estimate of the sampling area is needed to complete the density calculations. For our 2 capture–mark–recapture calculations, we estimated an effective trapping area using the same method but used different software programs, CAPTURE (http://www.mbr-pwrc.usgs.gov/software/capture.shtml, accessed 6 Aug 2012) and MARK (v 8.0, http://www.phidot.org/software/mark/, accessed 4 Nov 2014) for estimating population abundance. Program CAPTURE was developed in 1970s and the first to incorporate realistic variability in capture probabilities due to behavior, time, or heterogeneity (Otis et al. 1978). Program MARK (White and Burnham 1999) allows inclusion of specific covariates (i.e., sex) in modeling detection probabilities (Kendall 1999). We included CAPTURE in our analysis because of its use in previous mongoose density estimates (Corn and Conroy 1998, Guzmán-Colón and Roloff 2014). We modeled abundance while allowing detection to vary with behavior and heterogeneity in Program CAPTURE (M_{bh}; White et al. 1982). This model was selected a priori because of previous reports of low recaptures of mongooses (Pimentel 1955, Corn and Conroy 1998), the variable trap layout, and use of this model in previous mongoose density estimates. Program CAPTURE offered 2 different estimators for M_{bh}: the Pollock and Otto (1983) estimator and the generalized removal estimator. Because of documented superior performance of the former (Lee and Chao 1994), we selected it over the generalized removal estimator. We entered data separately for each session and derived a unique estimate of $\widehat{\mathrm{N}}$ for each of the 4 sessions.

Using Program MARK, we examined the Huggins closed capture model allowing for a capture effect (Huggins 1989). In this model, covariates can be modeled as functions of capture (p) and recapture rates (c). We estimated abundance for each site by year separately. We made the assumption that the covariates would affect the capture and recapture rates similarly but allowed for a difference based on behavior (i.e., additive models with behavior only, no interaction models). We examined detection rate with respect to 6 covariates: sex, age, site, year, trap movement, and proportion of traps moved per capture night. We ran all combinations of these effects to determine which covariates were most supported by the data. Using the cumulative Akaike Information Criterion correction (AIC_c) weights, we examined the relative strength of the covariates and determined that any with a cumulative weight >0.5 affected capture rates. We selected the model most supported by the data (i.e., with the lowest AIC_c) for our population abundance estimates (Burnham and Anderson 2004).

To estimate an effective trapping area to use for $\widehat{\mathrm{A}}$, we used movement data from the trap recaptures and from marked mongooses observed from the camera data to calculate the mean maximum distance moved (MMDM; Wilson and Anderson 1985). Using only movement within a session, we calculated a unique MMDM for each session. We calculated 0.5 MMDM and then used this distance as a buffer around each trap. We completed our calculation for effective trapping area specific to each session by calculating the area (ha) encompassed by merged buffers using Hawth's Tools (Beyer 2004) in ArcGIS. We then estimated density by dividing the population abundance estimates by our estimate of effective trapping area.

Our final calculation method for density used SECR (Efford et al. 2009), which combined capture probabilities with travel distance to derive a direct estimate of density (Efford 2004, Borchers and Efford 2008). The SECR derives density using 2 detection parameters, magnitude (g0) and sigma (σ; Efford 2004). The parameters are derived from capture histories and trap locations entered into the program. We conducted the majority of our analysis for SECR in R (R Core Team 2014) using the package secr (Efford 2015*b*).

To account for traps that were moved, we entered all locations where we had traps and included a usage history with each trap. Our usage history represented the availability of a location during a session (Efford 2014). When we moved a trap, its previous location was marked as not used for the remainder of the session. Because SECR uses a maximum likelihood to fit a spatial detection model, we had to identify a distance beyond the traps where the chance of a mongoose being trapped was negligible. We used 0.5 MMDM as this distance. We created a hybrid mixture model to include sex as a covariate in our model (Efford 2015*a*). We tested 8 different models with density identified as session-specific in each. In our basic model, the detection parameters were constant across all sessions, animals, and occasions. We adjusted the model so that the detection parameters could change because of a learned response to capture, sex of the individual, and differences among sessions. We compared models using AIC_c. We planned to average the models that had a difference in AIC_c from the model with the lowest $AIC_c \leq 6$ (Symonds and Moussalli 2011), but only 1 model fit this criterion. All other models had a ΔAIC_c of >6.

From our different calculation methods, we generated values for population abundance, sampling area, and density. We compared the MDI density estimates to CAPTURE, MARK, and SECR density estimates by calculating Pearson correlation coefficients as an indicator of the strength of association. We also calculated bias and reproducibility coefficients (Petrie and Watson 1999) of the MDI compared to the other density calculations. We calculated bias as the mean of the difference between MDI and the other 3 methods. The reproducibility coefficient was the standard deviation of the difference $\times 2$ and represented a value where 95% of the absolute differences were less than the coefficient.

To examine the spatial distribution, we wanted to identify the area where we actually detected mongooses (used area) and then calculate the percentage of how much the area we had covered by traps and cameras available for detecting mongooses (detection coverage area) was used. Using the same concept (0.5 MMDM is representative of the distance we were able to detect mongooses) applied to our calculation of effective trapping area, we estimated detection coverage area and used area with movement information from cameras and traps. We buffered all trap and camera locations for estimating detection coverage area, whereas we only used trap locations to estimate effective trapping area. We estimated used area by buffering cameras and traps where we trapped or observed mongooses. We calculated the percentage of area used by dividing the used area by the detection coverage area.

RESULTS

The number of unique mongooses captured ranged from 33 to 55 for the different sessions (Table 1). We captured male mongooses more frequently than females except during the fall-wet session at Cabo Rojo. The number of males/female at Cabo Rojo was 0.53 during the fall-wet session and 2.09 during the spring-dry session. At El Yunque, number of males/female was 1.29 for the fall session and 3.36 for the spring session. Recapture rates at both sites were relatively low. The spring session at El Yunque had the greatest number of mongooses recaptured in traps ($n = 7$) and the highest number of marked individuals documented on cameras ($n = 7$). During that session, 1 male mongoose was trapped 3 times; all other recaptured mongooses were only trapped twice. We had the second most recaptures ($n = 5$), along with 3 marked individuals documented on camera, during the fall-wet session in Cabo Rojo. Only 1 trap recapture occurred during the spring-dry session at Cabo Rojo; however, we observed 3 different marked individuals on cameras. The opposite occurred during the fall session at El Yunque; we recorded 3 trap recaptures and observed 1 marked mongoose from camera images. Over the course of the study, El Yunque had almost twice the number of recaptures between sessions as Cabo Rojo (Table 1).

We documented travel distances ranging from 0 m to 706.9 m from trap and camera data. The farthest travel distance was between a trap and camera (El Yunque spring), but we also recorded a trap-to-trap movement of 656.6 m (Cabo Rojo fall-wet). The resulting values for the 0.5 MMDM were 75.0 m for fall-wet in Cabo Rojo, 86.6 m for

Table 1. Mongoose capture and movement information from Cabo Rojo National Wildlife Refuge (Cabo Rojo) and El Yunque National Forest (El Yunque), Puerto Rico in fall 2011 and spring 2012. At Cabo Rojo, the seasons were distinct as wet and dry seasons but not at El Yunque.

	Cabo Rojo		El Yunque	
	Fall-wet	**Spring-dry**	**Fall**	**Spring**
Unique captures	55	34	33	49
M	17	23	18	37
Ad	11	14	21	36
Juv	6	4	2	1
F	32	11	14	11
Ad	24	9	9	7
Juv	8	2	5	4
Unidentified	6	0	1	1
Recaptures within session	5	1	3	7
Marked animals at cameras within session	3	3	1	7
Recaptures between sessions	NA	3	NA	5
Mean maximum distance moved (m)	150.0	173.3	182.1	308.8
SE	89.0	54.8	95.7	46.1

Table 2. Mongoose abundance, area sampled, and density estimates derived from 4 different calculation methods based on the same trap and camera information collected from Cabo Rojo National Wildlife Refuge (Cabo Rojo) and El Yunque National Forest (El Yunque), Puerto Rico in fall 2011 and spring 2012. At Cabo Rojo, the seasons were distinct as wet and dry seasons but not at El Yunque. The methods for deriving density estimates were the mongoose density index (MDI), Program CAPTURE for abundance estimates and an estimation of effective trapping area (CAPTURE), Program MARK for abundance estimates and an estimation of effective trapping area (MARK), and spatially explicit capture–recapture (SECR).

	Cabo Rojo		El Yunque	
	Fall-wet	Spring-dry	Fall	Spring
MDI				
Abundance	55	34	33	49
Area (ha)	100	100	100	100
Density (no. mongooses/ha)	0.55	0.34	0.33	0.49
CAPTURE				
Abundance	59	43	41	84
Area (ha)	82	98	74	111
Density (no. mongooses/ha)	0.72	0.44	0.55	0.75
CI	0.63–1.19	0.36–0.84	0.45–1.08	0.56–1.28
MARK				
Abundance	165.4	73.2	61.5	74.3
Area (ha)	82	98	74	111
Density (no. mongooses/ha)	2.02	0.75	0.83	0.67
CI	1.00–6.14	0.46–1.77	0.52–2.33	0.49–1.42
SECR				
Abundance	55	34	33	49
Area (ha)	29.7	45.2	35.0	50.2
Density (no. mongooses/ha)	1.85	0.75	0.94	0.97
CI	0.59–5.8	0.29–1.95	0.35–2.54	0.44–2.14

spring-dry in Cabo Rojo, 91.0 m for fall in El Yunque, and 154.4 m for spring in El Yunque.

Our lowest density estimate was 0.33 mongooses/ha calculated by MDI from the fall session in El Yunque, whereas our highest estimate was 2.02 mongooses/ha calculated by MARK from the fall-wet session in Cabo Rojo. Of the 4 methods of estimating density, the MDI derived the lowest estimates (Table 2). Density estimates in Cabo Rojo were higher in the fall-wet session than the spring-dry session across all methods. This uniformity was not observed for El Yunque; the MARK density estimate was lower in the spring session than the fall session, whereas other methods showed the opposite trend. In the fall, Cabo Rojo consistently had higher density estimates than El Yunque, but in the spring neither site consistently had higher or lower density estimates than the other site.

From tests comparing MDI to the other density calculations, the greatest bias occurred with SECR and the highest reproducibility coefficient occurred with MARK (Table 3). Program CAPTURE had the greatest level of agreement with MDI; it had the lowest bias, the lowest reproducibility coefficient, and the highest Pearson's r (Table 3). From the covariates examined in MARK, 3 models had a cumulative $AIC_c > 0.5$: site, sex, and age. These covariates were in our model with the lowest AIC_c. For the MARK models, changes in capture probability due to behavior were an inherent feature of the models. In SECR, we selected among models with the covariates sex, behavior, and session; sex and behavior were the covariates in our model with the lowest AIC_c.

When we examined spatial distribution, the session that had the highest number of mongoose captures, fall-wet in Cabo Rojo, had the smallest used area. Our estimation of used area was 49.6 ha for fall-wet in Cabo Rojo, 65.7 ha for spring-dry in Cabo Rojo, 64.1 ha for fall in El Yunque, and 111.0 ha for spring in El Yunque spring. The corresponding values we calculated for detection coverage area were 88.8 ha, 102.2 ha, 84.4 ha, 115.2 ha compared to our plot size of 100 ha for each site and session, respectively. Our calculated percentages of area used were 55.9% for fall-wet in Cabo Rojo, 64.3% for spring-dry in Cabo Rojo, 76.6% for fall in El Yunque, and 96.3% for spring in El Yunque (Fig. 2), indicating a difference in the distributions of the mongooses in the different study plots.

DISCUSSION

Our study represents the first attempt to use unstructured (vs. grid or linear) trap placement and trap movements as a means to estimate mongoose density. It is also the first to our knowledge to use multiple capture–recapture calculation

Table 3. Bias, reproducibility coefficient, and correlation coefficient Pearson's r derived from comparing the mongoose density index (MDI) to 3 other calculation methods of estimating mongoose density in Puerto Rico: Program CAPTURE for abundance estimates and an estimation of effective trapping area (CAPTURE), Program MARK for abundance estimates and an estimation of effective trapping area (MARK), and spatially explicit capture–recapture (SECR). Bias is the direction and degree of distortion of the MDI from the selected density estimator. Reproducibility coefficient is an indication of the maximum difference likely to occur between MDI and the other density estimators over multiple repetitions. Pearson's r is a measurement of the dependence of MDI on changes in density as estimated by the 3 different methods.

Density estimation method	Bias	Reproducibility coefficient (mongooses/ha)	Pearson's r
CAPTURE	−0.19	0.14	0.89
MARK	−0.64	1.14	0.68
SECR	−0.70	0.82	0.8

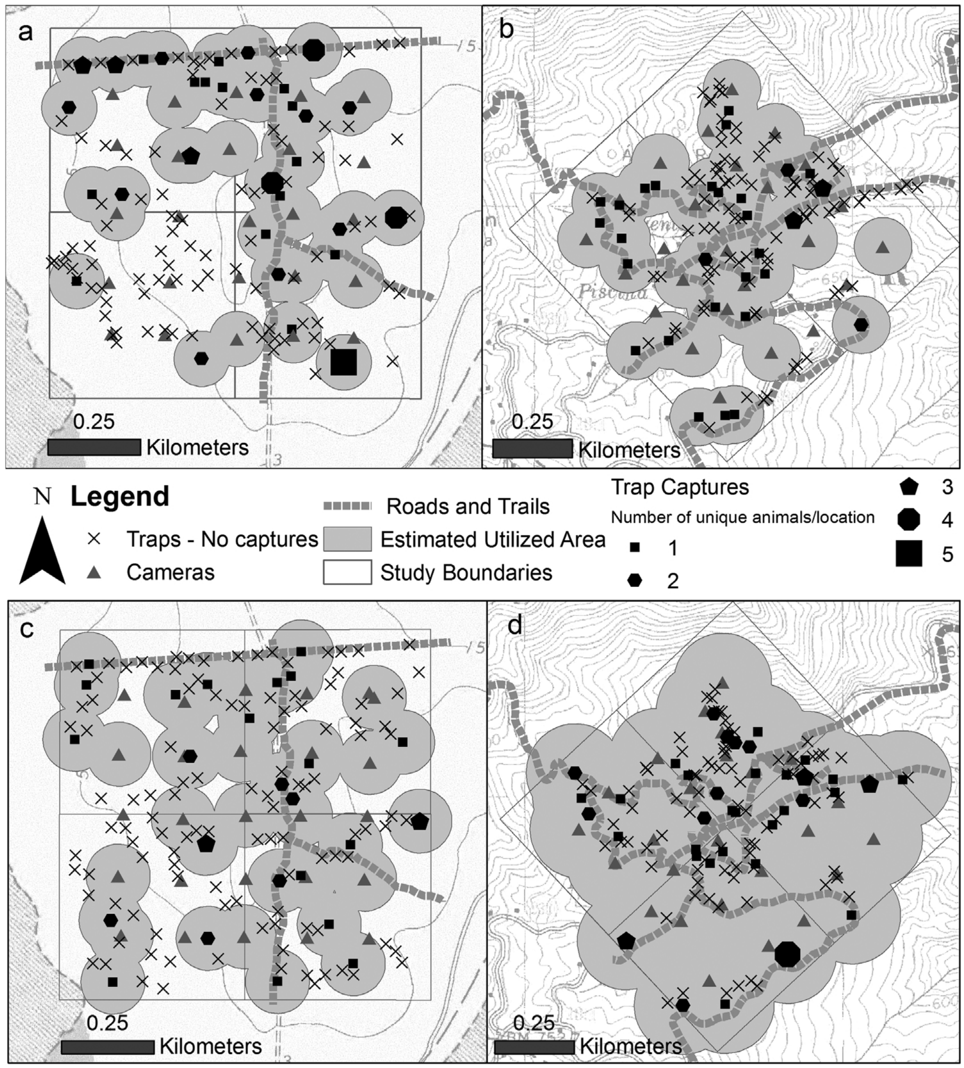

Figure 2. Distribution of traps without captures, traps with captures, and cameras located in density study plots along with the estimated area used, which represented areas with mongoose detections in Puerto Rico for each session: (a) Cabo Rojo Wildlife Refuge (Cabo Rojo) in 2011 fall-wet season, (b) El Yunque National Forest (El Yunque) in fall 2011, (c) Cabo Rojo in 2012 spring-dry season, and (d) El Yunque in spring 2012. Seasons are not indicated at El Yunque because of atypical rainfall in the dry season.

methods of estimating density to evaluate the performance of a density index. This research provided information on the performance of the MDI and information on factors to consider when developing an ORV program for mongooses.

The MDI yielded estimates ranging from 0.32 mongooses/ha to 0.55 mongooses/ha, which is lower than most previously reported estimates for Puerto Rico (Table 4) and lower than our density estimates that used the same data and included a modeling component. Estimates from MNKA calculations, which we used in the MDI, are typically biased low (Hilborn et al. 1976, Nichols and Pollock 1983, Pocock et al. 2004). With the exception of SECR estimates from the spring-dry session in Cabo Rojo and spring session in El Yunque, the MDI estimates were even below lower limits of confidence intervals for the capture–recapture density estimates. For the capture–recapture calculations, we had movement based or spatial components in the density calculations. These movement-based components provided a better representation of the area trapped than square boundaries used in the MDI because sections of our 100-ha plot were likely not sampled because of the trap placement but were still included as part of our total area. This could cause our estimate to be biased low. For example, our study plot encompassed 100 ha, but during our first sessions at Cabo Rojo and El Yunque, our effective trapping areas were only 82.3 ha and 74.0 ha, respectively. Also in the El Yunque fall session, we detected mongooses at a camera where the nearest traps were greater than 0.5 MMDM (Fig. 2).

The unstructured trap placement and movements may contribute to under- or oversample areas and could further bias a density estimate if the traps are exclusively clustered within a few areas or habitats. Initial placement in our study occurred by distributing traps equally among 4 quadrants within the study boundaries and using randomly generated points. This mitigated the likelihood of clustering traps on

Table 4. Published mongoose density estimates for Puerto Rico including estimates from Cabo Rojo National Wildlife Refuge (Cabo Rojo) and El Yunque National Forest (El Yunque).

Location	Density (no. mongooses/ha)	Density range	Source
Cabo Rojo (eastern)	4.6		Horst et al. (2001)
Semi wooded		<8	
Heavily wooded		2–5	
Grasslands		0–2	
Cabo Rojo (western)			This study
Forest-scrub fall	0.55		
Forest-scrub spring	0.34		
Luquillo experimental forest (in El Yunque)			Vilella (1998)
Tree plantations	2.0		
Palo Colorado	2.0		
Tabonuco forest	1.5		
El Yunque			Quinn and Whisson (2005)
Palo Colorado	0.57		
Tradewinds	0.19		
El Yunque			This study
Palo Colorado fall	0.33		
Palo Colorado spring	0.49		
Puerto Rico	2.5		Pimentel (1955)

only a few hectares. However, the unstructured trap placement does have some logistic advantages.

The intent behind the density index is to use it in multiple regions on public and private land. An unstructured arrangement allows a trapper to trap adjacent to areas where access is limited because of safety concerns or landowner permission. Safety was a concern at El Yunque where ravines and high water levels prevented access to some pre-selected random points. Mongooses used the trail and road system at El Yunque (Quinn and Whisson 2005) providing a safer method for trap placement that would allow us to detect mongooses. Thus, we had a heavier reliance on the roads and trails to distribute traps within the study boundaries at El Yunque than at Cabo Rojo.

Alternately, unstructured trap placement, in combination with periodic moving of traps, may improve trapping success. If we assume that preferred habitat or resources have a higher capture rate, targeting these locations in initial trap placement would improve trapping success. We did not use this assumption to guide our trap placement simply because the dominate landscapes, forest-scrub and grassland, of Cabo Rojo are both used by mongooses and El Yunque was dominated by only forest. Based on this assumption that preferred locations may increase capture success, we moved traps that were not capturing animals to new locations to maximize the number of unique animals captured within the study plot. This strategy may have influenced our overall trapping success.

Unlike other studies (Corn and Conroy 1998, Vilella 1998, Quinn and Whisson 2005), we had relatively consistent trapping success during the 10-day trapping periods at both study sites, likely as a result of moving traps out of low use areas. Future research should quantify habitat metrics (e.g., percent canopy, grass height) and other resources to identify high and low use areas. For example, when we examined spatial distribution within our study plots, we detected mongooses only in 55.9% of the area we were sampling during the fall-wet session in Cabo Rojo and it increased to 64.3% in the spring-dry session suggesting that some feature existed on our site that mongooses avoided during the wet season but not during the dry (Fig. 2).

Recognizing that MNKA estimates are biased low and our unique trapping arrangement (random trap placement and trap moves), we placed cameras in a grid-layout on the landscape with the intent of having a capture–recapture model based on trap captures and camera detection. Unfortunately, some recaptured mongooses had no observable dye pattern present, possibly because of dye failure due to qualities of the hair coat, or removal of the dye before staining as the animals moved through the dense wet vegetation (Melchior and Iwen 1965). Also, capture and handling at traps possibly resulted in a camera shyness because we used the same bait at the cameras and traps (White et al. 1982). Because maintaining marks is a basic requirement for capture–recapture, we limited our use of the camera data to calculate travel distances of mongooses with a discernable dye pattern and to identify locations where we did or did not detect mongooses. Thus, all of our capture–recapture density estimates are from capture data solely based on the MDI trap arrangement, which may account for some difference in our density estimates and other studies. However, our CAPTURE estimates from El Yunque (0.55 mongooses/ha and 0.75 mongooses/ha) were comparable to a previously published density estimate (0.56 mongooses/ha) from the same region (Quinn and Whisson 2005). The density estimation technique used by Quinn and Whisson (2005) was similar to ours in that they used the same model (M_{bh}), placed traps near trails, and used mongoose movement to determine effective trapping area. They, however, did not move traps.

Even our highest estimate at Cabo Rojo (2.02 mongooses/ha) was lower than the density estimate (4.6 mongooses/ha) published by Horst et al. (2001). However, Horst et al. (2001) used a different location within Cabo Rojo Wildlife Refuge (U.S. Fish and Wildlife Service 2011), and the estimation methods differed based on area sampled. The previous study used a 50-m-wide belt over the trap line to estimate area sampled (Hoagland et al. 1989, Horst et al. 2001). By comparison, the lowest MMDM by mongooses recorded in our study was 150 m. Corn and Conroy (1998) reported MMDM as 224 m in Antigua, West Indies, and Pitt et al. (2015) documented travel distances of up to 1,200 m in mongooses in Hawaii. These travel distances are considerably greater than the width used by Horst et al. (2001). Thus, they could have been sampling animals from a much wider area than they estimated for calculating density, which would result in an overestimate of density.

Though the MDI had low estimates, we observed that it had an ability to track changes; we measured a strong correlation ($r \geq 0.68$; Taylor 1990) between the MDI and the other density estimates. All capture–recapture calculation methods concurred with the MDI estimation of a higher density in the fall-wet session than the spring-dry session in Cabo Rojo. At El Yunque, not all of the capture–recapture density estimates concurred with the MDI estimation of a higher density in the spring session than the fall session. The weather for the spring session was atypical; we had expected to be trapping in the dry season, but this session received more rainfall than when we were trapping at the end of the wet season (National Weather Service 2011, 2012). The MARK estimate for the El Yunque spring session had the lowest density of all the sessions even though the MDI estimate was the second highest. This session had the greatest MMDM of all the sessions, suggesting that mongooses were traveling farther. This travel may have been for mating or in search of food. If the damp weather decreased tourist visitation, it would have decreased anthropogenic food sources, which mongooses used (Coblentz and Coblentz 1985). Alternatively, density may have remained unchanged at El Yunque because of wet weather in both sessions or site-specific traits; SECR estimates were 0.94 mongoose/ha and 0.97 mongoose/ha in the spring and fall sessions, respectively.

We did observe a change in the male/female sex ratio at Cabo Rojo; we caught almost 2 females for every male in the fall and had the opposite in the spring, 2 males for every female. The expected ratio of males to females is 1:1 (Hoagland et al. 1989). Some trapping studies are very close to the expected (1.06:1; Pimentel 1955), whereas others may be biased toward males (2.6:1; Vilella 1998) or females (0.31:1; Pitt et al. 2015). Sex was an important covariate in MARK and SECR. Although a bias in 1 sex being more trap shy than the other could result in sex being an important covariate on capture rates, this does not appear to be the case with mongooses because of the inconstant trend in the sex ratios. Instead, we conclude that it is sex-specific factors, such as breeding and maternal behaviors, affecting movement and home range size and ultimately affecting the capture rate of males and females. During the breeding season, multiple males may occupy the same home range (Hays and Conant 2003) and at El Yunque females had smaller home ranges than males in both dry and wet seasons (Quinn and Whisson 2005) increasing the likelihood of catching males. However, home ranges size and seasonal effects on home range size at Cabo Rojo are unknown. Pitt et al. (2015) attributed the higher number of females they captured to female movement in search of mates. Depending on the island, the mongoose breeding season can vary from a few months to year-round (Hays and Conant 2007). For Puerto Rico, Pimentel (1955) noted that the breeding season ranged from January to October and observed 2 peak times for the birth of litters: March–April and July–August.

Age was another important covariate in the MARK estimates. Adults had a different probability of being captured than juveniles. Though a difference in trap shyness may contribute to a different probability of capturing juveniles, it is more likely a reflection of fewer juveniles on the landscape. We used 2 criteria to estimate mongoose age: mass and appearance of sexual maturity. Pups start traveling with their mothers when they weigh about 200 g corresponding to 6-weeks of age and they reach sexually maturity between 4 months and 6 months (Hays and Conant 2007). We captured more juveniles in the fall than spring and these juveniles may have been born during the March–April pulse and recently separated from their mother. Although the juveniles captured could have been dispersing through our plots, we do know that some were not dispersing because we recaptured them as adults. We had 7 recaptures between fall and spring sessions and 4 were juveniles when we initially caught them in the fall. Because we documented juveniles remaining within our study plots, including them in our analysis did not violate our assumption of a closed population. Future research should examine how breeding and maternal behaviors could affect detection rates.

The primary limitations of the MDI are that the study plots misrepresent the areas sampled and the trap arrangement may result in an additional bias toward low-density estimates if traps are set in poor locations. More elaborate calculations, such as use of capture models and effective trapping area, help reduce the inherent low bias in MDI calculations but require extra time and more expertise than the MDI. Furthermore, without the camera data (cameras are not used in the MDI) for calculating movement distance, the information for calculating effective trapping area or starting distance in SECR may be sparse or not exist for the more sophisticated calculations. Changes in trapping procedures, such as trapping until a significant decline in captures occurs, may be useful in providing a better representation of density. A simple calculation, such as increasing the abundance estimate to a 1:1 male/female ratio to represent the expected ratio, may be useful in providing a better representation of density and should be explored with further research.

MANAGEMENT IMPLICATIONS

Overall, the MDI provided information needed to develop a mongoose rabies management and ORV program for the island of Puerto Rico. The MDI met ORV program criteria in that it approximated other density estimators and provided information on population dynamics and spatial distribution along with identifying what information still needs to be collected. Even without the modifications we recommend in our discussion, the MDI can be used to detect differences between seasons and to identify areas of high or low use within plots, informing bait distribution to maximize probability of uptake. The difference in spatial use between the 2 study sites indicates that an even bait distribution would result in baits remaining undetected by mongooses in Cabo Rojo, whereas this would be less likely to happen in El Yunque. Difference in seasonal density observed at Cabo Rojo is useful data for timing the implementation of ORV. Future work developing a mongoose ORV program should involve acquiring additional information on mongoose dynamics, such as birth pulses and population turnover rates, and identifying the habitat characteristics influencing spatial distribution in the different regions of Puerto Rico.

ACKNOWLEDGMENTS

We extend thanks to all the people that provided technical and logistical support to this study, especially P. F. Quinones, F. L. Boyd, O. A. Diaz, J. Padilla, F. J. Cano, R. Lopez-Ortiz, E. L. Blizzard, N. L. Mooers, B. Fuentes, A. Gomez, and J. D. Chinea. We also thank N. J. Crider and 2 anonymous referees for review of this manuscript. The research was funded by National Wildlife Research Center.

LITERATURE CITED

Barun, A., C. Hanson, K. Campbell, and D. Simberloff. 2011. A review of small Indian mongoose management and eradications on islands. Pages 17–25 *in* C. R. Veitch, M. N. Clout, and D. R. Towns, editors. Island invasives: eradication and management. IUCN, Gland, Switzerland.

Beasley, J. C., W. S. Beatty, T. C. Atwood, S. R. Johnson, and O. E. Rhodes. 2012. A comparison of methods for estimating raccoon abundance: implications for disease vaccination programs. Journal of Wildlife Management 76:1290–1297.

Beasley, J. C., T. L. Devault, and O. E. Rhodes. 2007. Home-range attributes of raccoons in a fragmented agricultural region of northern Indiana. Journal of Wildlife Management 71:844–850.

Berentsen, A., M. R. Dunbar, C. E. Fitzpatrick, and W. D. Walter. 2013. Spatial ecology of urban raccoons in northeastern Ohio: implications for oral rabies vaccination. Prairie Naturalist 45:39–45.

Beyer, H. L. 2004. Hawth's analysis tools for ArcGIS. http://www.spatialecology.com/htools. Accessed 14 May 2011.

Blanton, J. D., D. Palmer, and C. E. Rupprecht. 2010. Rabies surveillance in the United States during 2009. Journal of the American Veterinary Medical Association 237:646–657.

Borchers, D. L., and M. G. Efford. 2008. Spatially explicit maximum likelihood methods for capture-recapture studies. Biometrics 64:377–385.

Buckland, S. T., I. B. J. Goudie, and D. L. Borchers. 2000. Wildlife population assessment: past developments and future directions. Biometrics 56:1–12.

Burnham, K. P., and D. R. Anderson. 2004. Multimodel inference understanding AIC and BIC in model selection. Sociological Methods and Research 33:261–304.

Chamberlain, M. J., L. M. Conner, B. D. Leopold, and K. M. Hodges. 2003. Space use and multi-scale habitat selection of adult raccoons in central Mississippi. Journal of Wildlife Management 67:334–340.

Coblentz, B. E., and B. A. Coblentz. 1985. Control of the Indian mongoose *Herpestes auropunctatus* on St John, US Virgin Islands. Biological Conservation 33:281–288.

Conner, M. C., R. F. Labisky, and D. R. Progulske Jr. 1983. Scent-station indices as measures of population abundance for bobcats, raccoons, gray foxes, and opossums. Wildlife Society Bulletin 11:146–152.

Corn, J. L., and M. J. Conroy. 1998. Estimation of density of mongooses with capture recapture and distance sampling. Journal of Mammalogy 79:1009–1015.

Dice, L. R. 1938. Some census methods for mammals. Journal of Wildlife Management 2:119–130.

Dyer, J. L., P. Yager, L. Orciari, L. Greenberg, R. Wallace, C. A. Hanlon, and J. D. Blanton. 2014. Rabies surveillance in the United States during 2013. Journal of the American Veterinary Medical Association 245:1111–1123.

Efford, M. 2004. Density estimation in live-trapping studies. Oikos 106:598–610.

Efford, M. G. 2014. Adjustment for varying effort in secr. http://www.otago.ac.nz/density/pdfs/secr-varyingeffort.pdf. Accessed 12 Feb 2015.

Efford, M. G. 2015*a*. secr 2.9-spatially explicit capture-recapture in R. http://www.otago.ac.nz/density/pdfs/secr-overview.pdf. Accessed 12 Feb 2015.

Efford, M. G. 2015*b*. secr: spatially explicit capture-recapture models. R package version 2.9.3. http://CRAN.R-project.org/package=secr. Accessed 22 Jan 2015.

Efford, M. G., D. L. Borchers, and A. E. Byrom. 2009. Density estimation by spatially explicit capture-recapture: likelihood-based methods. Pages 255–269 *in* D. L. Thomson, E. G. Cooch, and M. J. Conroy, editors. Modeling demographic processes in marked populations. Springer, New York, New York, USA.

Garcia-Martino, A. R., G. S. Warner, F. N. Scatena, and D. L. Civco. 1996. Rainfall, runoff and elevation relationships in the Luquillo Mountains of Puerto Rico. Caribbean Journal of Science 32:413–424.

Guzmán-Colón, D., and G. J. Roloff. 2014. Small Indian mongoose (*Herpestes auropunctatus*) population abundance and effects of habitat features on trapping success in protected areas of eastern Puerto Rico. Caribbean Naturalist 19:1–12.

Hays, W. S. T., and S. Conant. 2003. Male social activity in the small Indian mongoose *Herpestes javanicus*. Acta Theriologica 48:485–494.

Hays, W. S. T., and S. Conant. 2007. Biology and impacts of Pacific Island invasive species. 1. A worldwide review of effects of the small Indian mongoose, *Herpestes javanicus* (Carnivora: Herpestidae). Pacific Science 61:3–16.

Hilborn, R., J. A. Redfield, and C. J. Krebs. 1976. On the reliability of enumeration for mark and recapture census of voles. Canadian Journal of Zoology 54:1019–1024.

Hoagland, D. B., G. R. Horst, and C. W. Kilpatrick. 1989. Biogeography and population biology of the mongoose in the West Indies. Pages 611–634 *in* C. A. Woods, editor. Biogeography of the West Indies, past, present and future. Florida Museum of Natural History, Sandhill Crane Press, Gainsville, Florida, USA.

Horst, G. R., D. B. Hoagland, and C. W. Kilpatrick. 2001. The mongoose in the West Indies: the biogeography and population biology of an introduced species. Pages 409–424 *in* C. A. Woods, and F. E. Sergile, editors. Biogeography of the West Indies: patterns and perspectives. CRC Press, Boca Raton, Florida, USA.

Huggins, R. M. 1989. On the statistical analysis of capture experiments. Biometrika 76:133–140.

Irizarry-Pasaarell, E. L. 2011. Rabies situation in Puerto Rico. Inception meeting of the CaribVet Veterinary Public Health Working Group, 12–14 December 2011, San Juan, Puerto Rico.

Kendall, W. L. 1999. The robust design for capture-recapture studies: analysis using program MARK. Proceedings of the Second International Wildlife Management Congress, Godollo, Hungary, The Wildlife Society, Bethesda, Maryland.

Krebs, J. W., J. S. Smith, C. E. Rupprecht, and J. E. Childs. 1998. Rabies surveillance in the United States during 1997. Journal of the American Veterinary Medical Association 213:1713–1728.

Kreeger, T. J., and J. M. Arnemo. 2007. Handbook of wildlife chemical immobilization. Third edition. Terry J. Kreeger, Laramie, Wyoming, USA.

Lee, S. M., and A. Chao. 1994. Estimating population size via sample coverage for closed capture-recapture models. Biometrics 50:88–97.

Melchior, H. R., and F. A. Iwen. 1965. Trapping, restraining, and marking Arctic ground squirrels for behavioral observations. Journal of Wildlife Management 29:671–678.

Nadin-Davis, S. A., G. Torres, M. D. L. A. Ribas, M. Guzman, R. C. De La Paz, M. Morales, and A. I. Wandeler. 2006. A molecular epidemiological study of rabies in Cuba. Epidemiology and Infection 134:1313–1324.

National Rabies Management Program [NRMP]. 2011. Density index to raccoon population and abundance. U.S. Department of Agriculture, Concord, New Hampshire, USA.

National Weather Service. 2011. October 2011 climate report for Puerto Rico and the US Virgin Islands. http://www.srh.noaa.gov/sju/?n=oct2011cr. Accessed 12 May 2015.

National Weather Service. 2012. March 2012 climate report for Puerto Rico and the US Virgina Islands. http://www.srh.noaa.gov/sju/?n=mar2012cr. Accessed 12 May 2015.

Nellis, D. W. 1989. *Herpestes auropunctatus*. Mammalian Species 342:1–6.

Nichols, J. D., and K. H. Pollock. 1983. Estimation methodology in contemporary small mammal capture-recapture studies. Journal of Mammalogy 64:253–260.

Otis, D. L., K. P. Burnham, G. C. White, and D. R. Anderson. 1978. Statistical inference from capture data on closed animal populations. Wildlife Monographs 62:3–135.

Parmenter, R. R., T. L. Yates, D. R. Anderson, K. P. Burnham, J. L. Dunnum, A. B. Franklin, M. T. Friggens, B. C. Lubow, M. Miller, G. S. Olson, C. A. Parmenter, J. Pollard, E. Rexstad, T. M. Shenk, T. R. Stanley, and G. C. White. 2003. Small-mammal density estimation: a field comparison of grid-based vs. web-based density estimators. Ecological Monographs 73:1–26.

Petrie, A., and P. Watson. 1999. Statistics for veterinary and animal science. Blackwell Science, Malden, Massachussets, USA.

Pimentel, D. 1955. Biology of the Indian mongoose in Puerto Rico. Journal of Mammalogy 36:62–68.

Pitt, W., R. Sugihara, and A. Berentsen. 2015. Effect of travel distance, home range, and bait on the management of small Indian mongooses, *Herpestes auropunctatus*. Biological Invasions 17:1743–1759.

Pocock, M. J. O., A. C. Frantz, D. P. Cowan, P. C. L. White, and J. B. Searle. 2004. Tapering bias inherent in minimum number alive (MNA) population indices. Journal of Mammalogy 85:959–962.

Pollock, K. H., J. D. Nichols, T. R. Simons, G. L. Farnsworth, L. L. Bailey, and J. R. Sauer. 2002. Large scale wildlife monitoring studies: statistical methods for design and analysis. Environmetrics 13:105–119.

Pollock, K. H., and M. C. Otto. 1983. Robust estimation of population size in closed animal populations from capture-recapture experiments. Biometrics 29:1035–1049.

Quinn, J. H., and D. A. Whisson. 2005. The effects of anthropogenic food on the spatial behaviour of small Indian mongooses (*Herpestes javanicus*) in a subtropical rainforest. Journal of Zoology 267:339–350.

Ramey, P. C., B. F. Blackwell, R. J. Gates, and R. D. Slemons. 2008. Oral rabies vaccination of a northern Ohio raccoon population: relevance of population density and prebait serology. Journal of Wildlife Diseases 44:553–568.

R Core Team. 2014. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Simberloff, D., T. Dayan, C. Jones, and G. Ogura. 2000. Character displacement and release in the small Indian mongoose, *Herpestes javanicus*. Ecology 81:2086–2099.

Slate, D., T. P. Algeo, K. M. Nelson, R. B. Chipman, D. Donovan, J. D. Blanton, M. Niezgoda, and C. E. Rupprecht. 2009. Oral rabies vaccination in North America: opportunities, complexities, and challenges. PLoS Neglected Tropical Diseases 3:e549.

Slate, D., C. E. Rupprecht, D. Donovan, J. Badcock, A. Messier, R. Chipman, M. Mendoza, and K. Nelson. 2008. Attaining raccoon rabies management goals: history and challenges. Developements in Biologicals (Basel) 131:439–447.

Slate, D., C. E. Rupprecht, J. A. Rooney, D. Donovan, D. H. Lein, and R. B. Chipman. 2005. Status of oral rabies vaccination in wild carnivores in the United States. Virus Research 111:68–76.

Symonds, M. E., and A. Moussalli. 2011. A brief guide to model selection, multimodel inference and model averaging in behavioural ecology using Akaike's information criterion. Behavioral Ecology and Sociobiology 65:13–21.

Taylor, R. 1990. Interpretation of the correlation coefficient: a basic review. Journal of diagnostic medical sonography 6:35–39.

Tierkel, E. S., G. Arbona, A. Rivera, and A. de Juan. 1952. Mongoose rabies in Puerto Rico. Public Health Report 67:274–278.

U.S. Fish and Wildlife Service. 2011. Draft comprehensive conservaton plan and environmental assessment: Cabo Rojo National Wildlife Refuge. Department of the Interior, Cabo Rojo, Puerto Rico.

Vilella, F. J. 1998. Biology of the mongoose (*Herpestes javanicus*) in a rain forest of Puerto Rico. Biotropica 30:120–125.

Vilella, F. J., and P. J. Zwank. 1993. Ecology of the small Indian mongoose in a coastal dry forest of Puerto Rico where sympatric with the Puerto Rican nightjar. Caribbean Journal of Science 29: 24–29.

Vos, A., A. Kretzschmar, S. Ortmann, I. Lojkic, C. Habla, T. Müller, C. Kaiser, B. Hundt, and P. Schuster. 2013. Oral vaccination of captive small indian mongoose (*Herpestes auropunctatus*) against rabies. Journal of Wildlife Diseases 49:1033–1036.

Weaver, P. L., and J. J. Schwagerl. 2008. Secondary forest succession and tree planting at the Laguna Cartagena and Cabo Rojo Wildlife Refuges in southwestern Puerto Rico. AMBIO: A Journal of the Human Environment 37:598–603.

White, G. C., D. R. Anderson, K. P. Burnham, and D. L. Otis. 1982. Capture-recapture and removal methods for sampling closed populations. Los Alamos National Laboratory, Los Alamos, New Mexico, USA.

White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46: 120–139.

Wilson, K. R., and D. R. Anderson. 1985. Evaluation of two density estimators of small mammal population size. Journal of Mammalogy 66:13–21.

Associate Editor: Terry Messmer.