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Maximizing the efficacy of intra-installation translocations to mitigate human-rattlesnake conflicts

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OVERVIEW

The eastern diamondback rattlesnake (EDB; *Crotalus adamanteus*), a federal candidate species, occurs on 28 military installations. Concerns about recruit safety during training activities in habitats used by EDBs has prompted natural resource managers to use intra-installation translocation as a tool to reduce the probability of human-rattlesnake conflicts, ensuring safe, continued access to training areas. However, translocation distances may interact with EDB movement ecology, affecting the efficacy of translocations. Two biologically relevant scales of translocation distances (i.e., intra home-range translocation and extra home-range translocation) were used on free-ranging, telemetry-equipped EDBs (n = 36 adults) to assess snake-response to translocation at the Marine Corps Recruit Depot Parris Island (MCRDPI). The effect of translocation was examined on EDB home-range size, movement, habitat use (specific to high-risk habitats), and survival. Treatment did not affect EDB home-range size; however, translocated females moved greater distances within their home ranges as compared to controls (i.e., snakes that were not translocated). Survival was high (99%), and low mortality prevented analyses that examined the effect of treatment on EDB survival. Home-range size was positively associated with the proportion of high-risk habitats within ranges, indicating that high-risk habitats were of low quality, forcing EDBs to use larger ranges for resource selection. Rattlesnakes were more likely to use low-risk habitats, regardless of translocation treatment; however, EDBs in the extra home-range translocation group were more likely to use high-risk habitats as compared to the intra home-range translocation group. The results of this study provide the DoD with a regionally-applicable protocol detailing EDB response to translocation, maximizing the efficacy of EDB intra-installation translocations as a means of conserving the species while mitigating for potential training-rattlesnake conflicts.

BACKGROUND

Venomous snake management on military installations often incorporates human dimensions, particularly when venomous snakes are of conservation concern. Translocation, removing snakes from point of capture to a location that is less likely to result in human-snake encounters, is a primary tool used to manage human-snake interactions (Sullivan et al. 2015; Wolfe et al. 2018). Uncertainties about the efficacy of snake translocation largely stem from erratic movement patterns exhibited by snakes following translocation, which potentially place snakes in situations that increase their exposure to human activity (Germano and Bishop 2009). Erratic post- translocation movement patterns are attributed to homing behavior within a novel landscape (e.g., Reinert and Rupert 1999; Wolfe et al. 2018). Translocation sites and distances from point of capture, therefore, are important components of developing effective translocation protocols for managing human-snake encounters.

The EDB occurs on various military installations in the southeastern United States. The EDB is a species of concern currently under review by the United States Fish and Wildlife Service for protection under the Endangered Species Act. Since 2008, natural resources personnel at the MCRDPI have used an adaptive strategy to compile a robust long-term data set of EDB demographics, movement ecology, and habitat use. Habitat modifications (i.e., forest thinning and fire prescription) in training areas were implemented in 2012-2013 on the MCRDPI, significantly altering habitat structure and, consequently, increasing the amount of suitable EDB habitat in training areas. Consequently, possible changes in EDB habitat use within the home-range scale prompted concern about the potential for increased human-rattlesnake encounters in training areas. Therefore, the MRCDPI expressed interest in using translocation to mitigate human-rattlesnake encounters in training areas.

Study Species. The EDB is the largest rattlesnake species, and habitat loss and indiscriminate killing are the primary causes of the species decline and imperilment (Martin and Means 2000). Eastern diamondback rattlesnakes have been detected at 28 military sites (Petersen et al. 2018). The EDB is unconfirmed, but potentially present on 22 additional military sites (Peterson et al. 2018). As such, the EDB is a species of conservation interest for the DoD. The historic range of the EDB closely mirrors that of pine savannas and woodlands associated with the Longleaf Pine (*Pinus palustris*) ecosystem, and the species also inhabits coastal islands, particularly along the Atlantic Coast. The species distribution runs from eastern Louisiana to southern North Carolina and south throughout Florida, including the Keys and several other sea and barrier islands (Martin and Means 2000; Timmerman and Martin 2003). Eastern diamondback rattlesnakes are selective of pine savanna structure (i.e., open-canopied pine woodlands maintained by high-frequency fire) at the home range, within home range, and microhabitat scales (Waldron et al. 2006; Waldron et al. 2008; Fill et al. 2015a). Prescribed fire is vital for maintaining EDB habitats and military installations that use fire for habitat management or training operations are likely to harbor EDB populations.

Study Site. Parris Island is a sea island of approximately 3,256 ha that includes residential areas, military recruit training areas, office buildings, and a public golf course. The MCRDPI is located along the confluence of the Broad and Beaufort Rivers, and the majority of upland habitats are developed and used for recruit training, residences, administrative buildings, and facility maintenance structures. A large part of the island is coastal marsh habitat, and thinning practices and fire management are used to manage open canopy pine woodlands for military training activities. The EDB population on the island has been monitored since 2008 using mark-recapture and radio-telemetry surveys.

Long-term EDB monitoring data collected at the MCRDPI were an important component of this project. Specifically, mark-recapture surveys and radio-telemetry monitoring have been conducted nearly annually since 2008 to monitor the EDB population at the MCRDPI. We used the long-term dataset in this study to estimate baseline home ranges and movement parameters that were appropriate for developing biologically relevant translocation treatments, as well as serving as pre-treatment control data. For example, we used radio telemetry data collected prior to the onset of this study to ensure that translocation distances of < 400 m were unlikely to occur outside of a home range at the study area. Furthermore, long-term mark-recapture and radio telemetry data provided insight into seasonal phenology, allowing us to identify distinct active and inactive seasons for the study population. In this study, we used radio telemetry data from 34 snakes that were telemetrically monitored between 2015 and August 2018 (Table 1). We used data from two snakes in the control group that were monitored with radio telemetry in 2011 and 2012 (Table 1).

Objective – The goal of this study was to examine the utility of intra-installation translocation to manage potential human-rattlesnake interactions. The successful integration of intra-installation translocation into EDB management on the MCRDPI hinged on insight into post-translocation movement behaviors. Thus, we used an experimental approach to examine the utility of EDB translocations on the MCRDPI at two scales that were relevant to EDB biology. Specifically, we moved telemetry-equipped EDBs to locations that either occurred outside of the snake's home range (i.e., extra home-range translocation) or within the home range (i.e., intra home-range translocation). We compared post translocation movement, survival, home-range size, and within home range habitat between treatments and controls (i.e., snakes that were not translocated) to quantify how translocation distances interacted with EDB movement ecology.

Table 1. Snakes that were monitored with radio telemetry at the MCRDPI, the years they were monitored, study treatment, and sex. Intra = Intra home range translocation, Extra = extra home range translocation.

Snake ID	Sex	Treatment	Years Monitored at MCRDPI
YVN	F	Intra	2014, 2015, 2016, 2017*, 2018*
SPK	M	Intra	2017*, 2018*
LSA	F	Intra	2017*, 2018*
KTE	F	Intra	2017*
CSN	M	Intra	2016*, 2017*
MRK	M	Intra	2016*, 2017*
MKE	M	Intra	2017*, 2018*
SWT	M	Intra	2017*, 2018*
DWT	M	Intra	2017*, 2018*
PCH	F	Intra	2017*, 2018*
RSE	F	Intra	2017*, 2018*

Table 1, continued

SWE	M	Intra	2017*, 2018*
AMA	F	Extra	2017*, 2018*
CSW	M	Extra	2017*, 2018*
GLT	M	Extra	2016*, 2017*, 2018
LLN	F	Extra	2016*, 2017*
CNC	F	Extra	2016, 2017*, 2018*
OLV	F	Extra	2016*, 2017*
KGN	M	Extra	2017*, 2018*
FRN	M	Extra	2017*, 2018*
TMS	M	Extra	2017*
HNH	F	Extra	2014, 2015, 2016*, 2017*, 2018
LNN	F	Extra	2016, 2017*, 2018*
STN	F	Extra	2010, 2011, 2017*
BTA	F	Extra	2016, 2017*, 2018
CZE	F	Control	2014, 2015*, 2016*, 2017
EMA	F	Control	2012, 2014, 2015*, 2016*
GG	F	Control	2009, 2010, 2011, 2014, 2015*, 2016*
HGA	F	Control	2017*, 2018*
HGO	M	Control	2016*, 2017*
PDO	M	Control	2010, 2011, 2012, 2015, 2016*, 2017*

Table 1, continued.

PNC	M	Control	2016*, 2017*
RUS	M	Control	2015, 2016*
CNA	M	Control	2010, 2011*, 2012*
HSY	F	Control	2009, 2010, 2011*, 2012*, 2013, 2014
PLY	M	Control	2015*, 2016*, 2017

Data from years 2016-2018 was used in this study.

METHODS

Landscape classification. We used digital imagery and ArcMap 10.1 GIS software to classify the landscape based on the risk of negative human-rattlesnake interactions. Our landscape risk classification was used to generate the GIS-based models for the movement analyses. We obtained high resolution areal imagery from 2017 from Beaufort County, SC GIS department. We used an unsupervised classification to identify spectral signatures of important landscape features (e.g., mowed lawns, forested areas). Our use of the unsupervised classifications divided spectral signatures into equal bins and allowed us to visually identify relevant landscape features. Spectral data were visually inspected and edited by overlaying them on areal imagery and reclassifying them to generate a 1.5-m grid of EDB-risks based on current land covers. Paved roads and parking lots were assumed to pose a high risk of EDB mortality through vehicular traffic. Frequently mowed grassy areas along roadsides, training areas, yards, and the golf course were assumed to pose a high risk to EDBs because of increased visual exposure to humans and wanton killing. Other areas on the depot were considered low risk because naturalized vegetation and motor vehicles exclusions reduced EDB exposures to negative human-rattlesnake interaction. High-risk areas and low-risk areas were combined to generate the final landscape classification for our spatial model (Fig. 1).

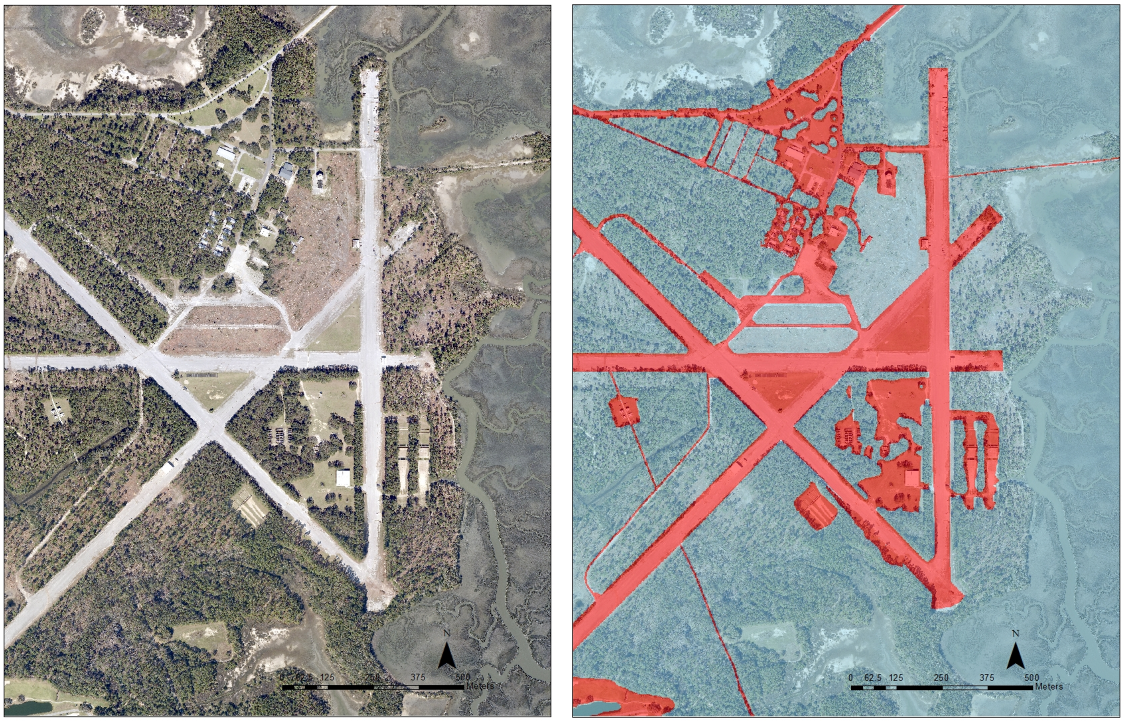

Figure 1. Aerial images show high risk (in red) and low risk (shaded) habitat areas identified through landscape risk classification for the EDB in a MCRDPI training area.

Radio Telemetry. Radio telemetry data used in this study were collected from EDBs (n=36) that were equipped with internal or external radio transmitters. We assigned 13 snakes to the extra home-range translocation group, 12 snakes to the intra home-range translocation group, and 11 snakes were used as controls (Table 1). Internal transmitters (Holohil Systems SI-2 radio transmitter; 11-13g) were surgically implanted by a veterinarian following procedures modified from Reinert and Cundall (1982). External transmitters were attached to EDB rattles following Jungen et al. (2019). Translocation treatments (intra home-range, extra home-range, and controls) were randomly assigned to snakes that were captured at the onset of the study, or to snakes that were being monitored with radio telemetry at the onset of this project. For snakes in the intra-translocation treatment, a random bearing and random distance between 100 and 400 m from the capture location were used to identify drop-off locations. We used this distance range because it was unlikely to place translocated EDBs outside of their home ranges, based on data collected on telemetry-equipped EDBs on the MCRDPI between 2009 and 2015. Snakes (n = 7) that were encountered by military training personnel or by utility workers (i.e., nuisance snakes) were included in this study. Of these nuisance snakes, one was in the intra-installation translocation group, five were in the extra-translocation group, and one was in the control group. For extra home-range translocations, snakes were moved to one of two areas on the MCRDPI that were not used for training activities, and the specific release location was similarly determined randomly (Fig. 2). All snakes were translocated during the active season (Mar-Nov) to avoid stressing rattlesnakes during colder months.

Rattlesnakes were radio-located approximately 2-3 times weekly during the active season (Apr - Nov) and once weekly during the inactive season (Dec - Mar), and GPS data were recorded during each radio location. Each time a snake was located, it was considered to have moved if they were more than 4 meters away from their previous location. This approach accounted for GPS-unit error (Trimble Juno 3B; 3-4m). Snakes were processed using a snake hook and clear restraining tubes and measured snout-to-vent length (SVL; cm), total length (TL; cm) and mass (g). Morphometric data were collected to make inferences about rattlesnake body condition and reproductive status (e.g., whether females were pregnant). Pregnant females were not translocated and any control data collected from pregnant females was not used in this study.

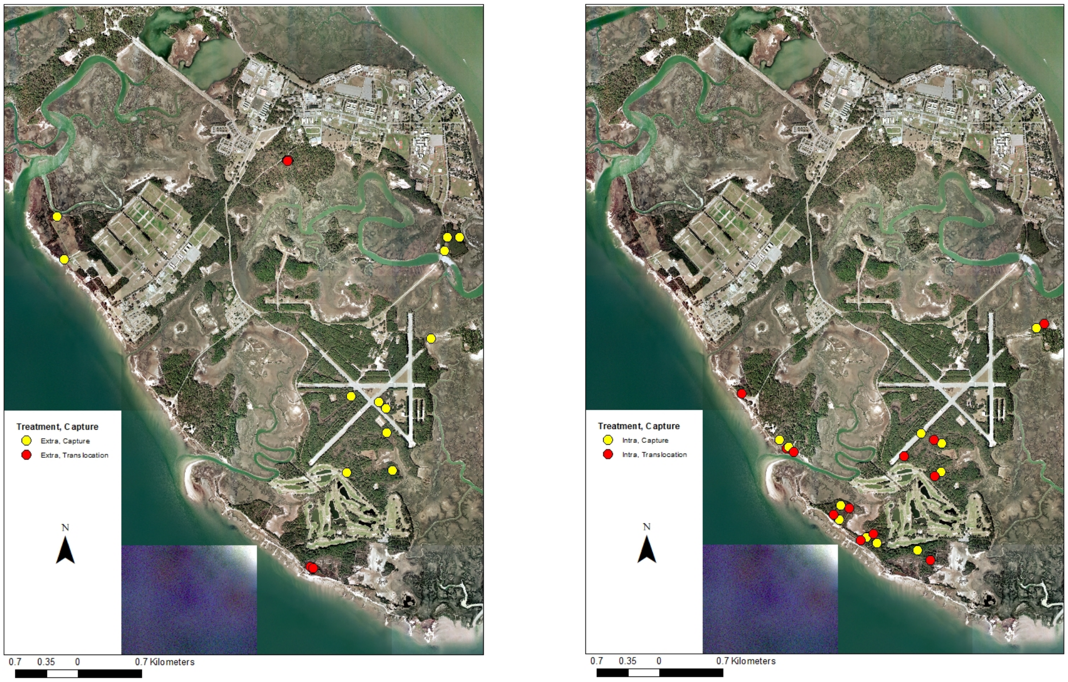

Figure 2. (Left) Capture locations (yellow) and drop-off locations (red) for EDBs in the extra-home range translocation treatment. **(Right)** Capture locations (yellow) and drop-off locations (red) for EDBs in the intra home range translocation treatment.

Home Range and Movement Analysis. We calculated post-translocation minimum convex polygons (100% MCP, 95% MCP, and 50% MCP) from radio telemetry observations recorded for up to one year following translocation. Fifty-percent polygons were considered core ranges, and 100% and 95% polygons were considered total ranges. Minimum Convex Polygons were used, as compared to kernel density estimates, to ensure that the analysis included conservative estimates of home-range size that would fully capture how EDBs used the post-translocation landscape. Home ranges were calculated for snakes that had a minimum of 32 radio locations within the study period. We compared post-translocation home-range size by sex and treatment using t-tests and ANOVA using log base 10 transformations of home-range size. Home-range estimates were log-transformed in all statistical analyses.

Distanced moved (m) between successive radio locations was calculated using ArcMap (10.3). Distances were standardized to m/day, such that measurements were averaged over the number of days between relocations. The interactive effects of sex and treatment on daily movements were examined using a mixed effect negative binomial regression model that included sex, treatment, and their interaction as predictors, and square-root transformed daily movement (m) as the response. We used the GLIMMIX procedure (SAS 9.4) for the analysis, using the Laplace approximation (Raudenbush et al. 2000) and specifying snake as a random effect to account for a lack of independence among observations from the same snake. An analysis of simple effects was performed on significant interactions to make inferences about the effect of treatment on sex.

Survival. Radio-telemetry data and the known-fate model in program MARK (White and Burnham, 1999) were used to estimate EDB survival. We monitored rattlesnakes over 1-2 years for this study, but telemetry data were collapsed into 22 monthly intervals to cover the dates of the study. The encounter history file included 12-14, 1-month live/dead entries per snake (n = 36). Survival as a function of treatment could not be examined because only one snake died during the study, and thus was insufficient power to compare covariate models. Thus, survival was modeled as a constant, $S(.)$, to estimate EDB annual survival probability.

Risk. Post-translocation EDB landscape use was examined relative to factors that were likely to affect EDB survival (e.g., road crossings) and human safety. The proportion of high-risk areas in EDB home ranges (50%, 95%, and 100%) was calculated and compared across treatments using parametric and nonparametric ANOVA using arcsine-transformed proportions of high risk habitats. A regression of arcsine transformed proportion of high risk habitats with home-range size (100% MCP) was used to examine how highly-modified anthropogenic areas influenced EDB ranges.

Randomly generated points and locations within post-translocation EDB home ranges were used to model the probability of EDBs using high-risk land categories at the within home-range scale (i.e., within home range selection). In addition to condensing high-risk land categories into one, high-risk land use category, the naturalized habitat classifications were combined into one low-risk land use category. As such, the land use variable used as a predictor in this analysis consisted of a binary (1 = high risk, 0 = low risk) classification of risk. We used a use-availability design to examine whether translocation treatments affected how snakes used their home ranges. The random point generator in ArcMAP 10.3 was used to generate random locations within home ranges in a 3:1 ratio for each snake (total random n = 7,371; total used n = 2,469). Binomial logistic regression in the GLIMMIX procedure with the Laplace approximation was used to examine the interactive effects of treatment and land-use risk on habitat use. Snake was treated as a random effect to account for a lack of independence among observations from the same snake.

RESULTS

Home Range and Movement Analysis. Sexually mature (n=36) EDBs were monitored with radio telemetry (18 males and 18 females). Snake radio locations averaged 67 locations per snake (range: 32-100). Intra home-range translocations averaged 137 m from the capture location, and extra home-range translocations averaged 3 km from the capture location. Post translocation core home ranges averaged 3.86 ha (standard deviation, SD = 6.51). Full home ranges averaged 24.93 ha (SD = 38.23) for 100% MCPs and 21.52 ha (SD = 33.98) for 95% MCPs. We failed to detect differences between male and female home-range size at any home range scale (50% MCP, 95% MCP, or 100% MCP; Table 2).

Table 2. Average (± SD) minimum convex polygon (MCP) estimates (ha) for adult male and female eastern diamondback rattlesnakes at the MCRDPI.

MCP	Male	Female
50%*	3.85 ± 3.69	3.88 ± 8.58
95%**	17.32 ± 8.64	25.71 ± 47.59
100%***	20.76 ± 8.92	29.11 ± 53.78

*t_{34} = -1.50, p = 0.1420
**t_{34} = -1.35, p = 0.1898
*** t_{34} = -1.42, p = 0.1694

We recorded 2,492 daily distance measurements in our movement analysis. The negative binomial regression model had sufficient fit (chi-square divided by degrees of freedom, χ^2/DF = 1.08). We detected significant effects of sex (test statistic$_{\text{degrees of freedom among, within}}$, $F_{2, 2456}$ = 15.82, $p < 0.0001$), treatment ($F_{2, 2456}$ = 8.63, $p < 0.001$), and their interaction ($F_{2, 2456}$ = 4.44, p = 0.0120) on daily EDB movement distances (Table 3). Translocated snakes moved greater distances than controls, and extra-translocation snakes moved greater distances than intra-translocation snakes (Fig 3). Males moved greater distances than females (Fig. 3), but male daily movements did not vary by treatment (Fig. 4). Translocated females moved greater distances than controls, but female movements did not vary between intra and extra home-range translocation treatments (Fig. 4).

Survival. One adult female died during the study due to unknown causes. The female was in the intra home-range translocation treatment, and was in poor body condition when she died, and thus it was suspected that she died of starvation. Adult EDB survival averaged 99.79% ± 0.01%, based on output from the constant survival model (regression coefficient, β = 6.107 ± 1.001, 95% confidence intervals, CI: 1.145 – 8.069).

Risk. No differences were detected among treatments in the proportion of home ranges that occupied high-risk habitats in 50% MCPs (Kruskal Wallis, $\chi^2 = 2.14$, df = 2, $p = 0.3431$), 95% MCPs (ANOVA, $F_{2, 33} = 1.18$, $p = 0.3213$), and 100% MCPs (ANOVA, $F_{2, 33} = 0.74$, $p = 0.4862$; Table 4). Home-range size was positively associated with the proportion of high-risk habitats in EDB ranges ($\beta = 0.6254 \pm 0.3029$, test statistic $t = 2.06$, significance at alpha = 0.05, $p < 0.05$; Figure 5). The proportion of home ranges (95 % and 100 % MCPs) that were comprised of high-risk habitats was ≤ 12 %. In core ranges (50% MCP), high risk habitats made up ≤ 7 % of range area.

Home-range selection was significantly affected by treatment ($F_{1, 9801} = 97.75$, $p < 0.0001$) and land use risk classification ($F_{1, 9801} = 3.23$, $p < 0.05$), and their interaction ($F_{1, 9801} = 3.05$, $p < 0.05$; Table 5). Rattlesnakes were more likely to select low-risk habitats, regardless of treatment (Fig. 6), but EDBs in the extra-translocation treatment had a higher probability of selecting high-risk habitats as compared to intra translocation snakes (Fig. 6).

Table 3. Regression coefficients (Estimate), standard error (SE), and 95% confidence intervals (lower = LCI, upper = UCI) from negative binomial mixed effect regression model assessing the effects of sex, treatment (extra home-range translocation, intra home-range translocation, and controls) and their interaction on post-translocation daily movement distances. Controls were used as the treatment reference and males were the reference sex. Significant (i.e., those with confidence intervals that do not include zero) regression coefficients either indicate a positive or negative relationship between the fixed effect on EDB movement distances. For example, female EDBs moved shorter distances as compared to males (fixed effect = Sex, F, estimate = -0.3688, confidence intervals = -0.5366—0.2009).

Fixed Effect		**Estimate**	**SE**	**LCI**	**UCI**
Intercept		1.1739	0.0565	1.0586	1.2892
Treatment	Extra	0.0711	0.0774	-0.0807	0.2228
	Intra	-0.0137	0.0720	-0.1549	0.1275
Sex	F	-0.3688	0.0856	-0.5366	-0.2009
Treatment*Sex	F Extra	0.3136	0.1098	0.0983	0.5290
	F Intra	0.2665	0.1124	0.0461	0.4870

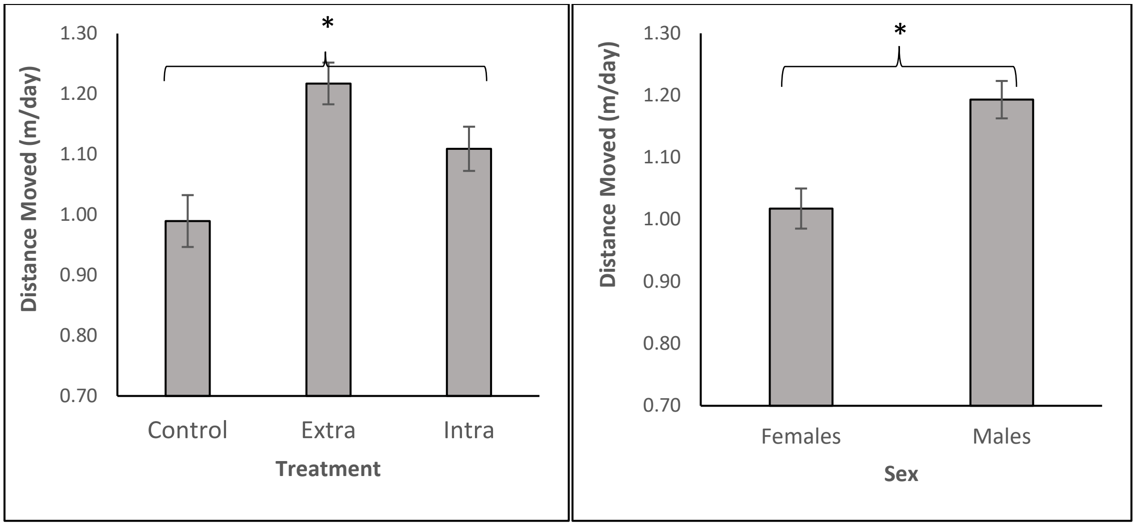

Figure 3. Translocation treatment (intra home-range and extra-home range translocation) and sex effects on estimated daily movement (m/day) based on output from negative binomial mixed effect model. Asterisk indicates significant differences between groups.

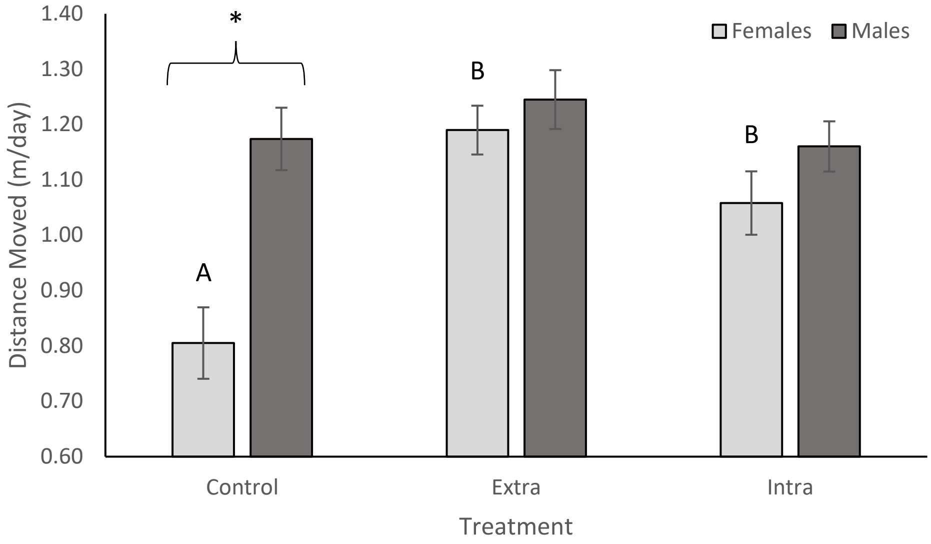

Figure 4. Interactive effects of treatment (intra home-range and extra home-range translocation) and sex on movement distances (meters moved per day), based on output from negative binomial mixed effects model. Asterisk indicates significant differences between sex, and treatment groups that share letters did not differ. Male movements were not affected by treatment, but females in the extra home range and intra home range translocation treatments moved longer distances, on average, as compared to control females.

Table 4. Average (± SD) proportion of high-risk habitats occurring in 50%, 95%, and 100% minimum convex polygon (MCP) EDB home ranges. Intra = intra home-range translocation; extra = extra home-range translocation, and control = control group.

Treatment	50% MCP	95% MCP	100% MCP
Intra	0.06 (0.11)	0.05 (0.07)	0.06 (0.07)
Extra	0.07 (0.10)	0.12 (0.13)	0.12 (0.13)
Control	0.04 (0.06)	0.12 (0.21)	0.12 (0.20)

Table 5. Regression coefficients, standard error (SE), and 95% confidence intervals (lower = LCI, upper = UCI) from mixed effect logistic regression model assessing the effects of land use risk classification (risk), treatment (extra home-range translocation, intra home-range translocation, and controls) and their interaction on EDB within home-range selection. Controls were used as the treatment reference, and low-risk land classification was used as the reference for risk.

Fixed Effect			**Estimate**	**SE**	**LCI**	**UCI**
Intercept			-2.801	0.266	-3.342	-2.260
Risk	Low		1.827	0.270	1.297	2.357
Treat	Extra		0.367	0.323	-0.297	1.001
	Intra		-0.942	0.572	-2.063	0.178
Risk*Treat	Extra	Low	-0.389	0.329	-1.034	0.257
	Intra	Low	0.889	0.575	-0.283	2.016

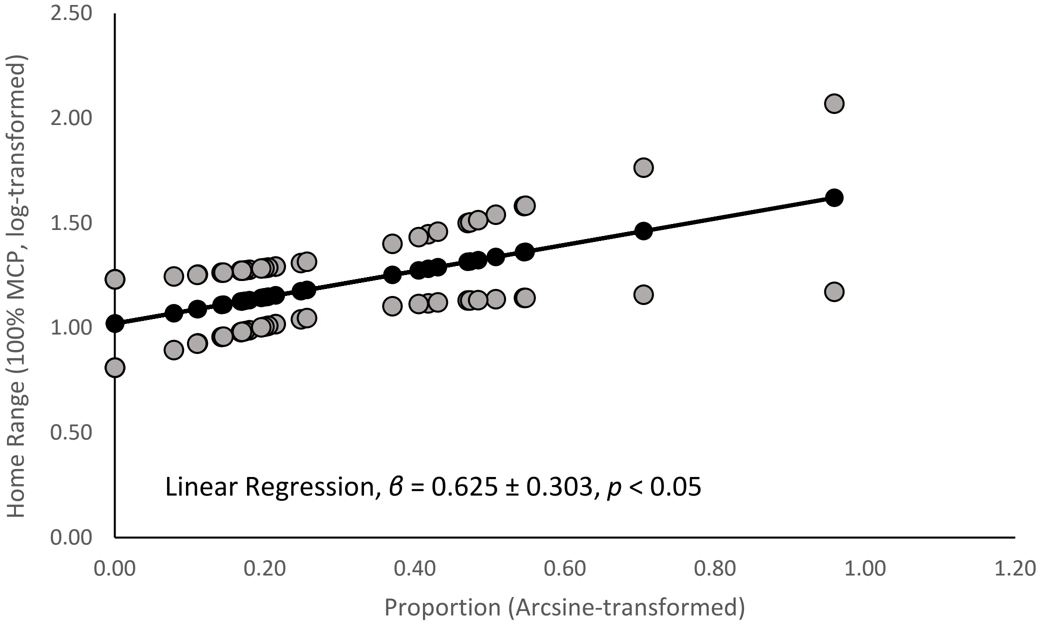

Figure 5. Predicted relationship (linear regression) between EDB home-range size (100% minimum convex polygons) and the proportion of high risk habitats occurring in their ranges. Outer bands represent 95% confidence intervals.

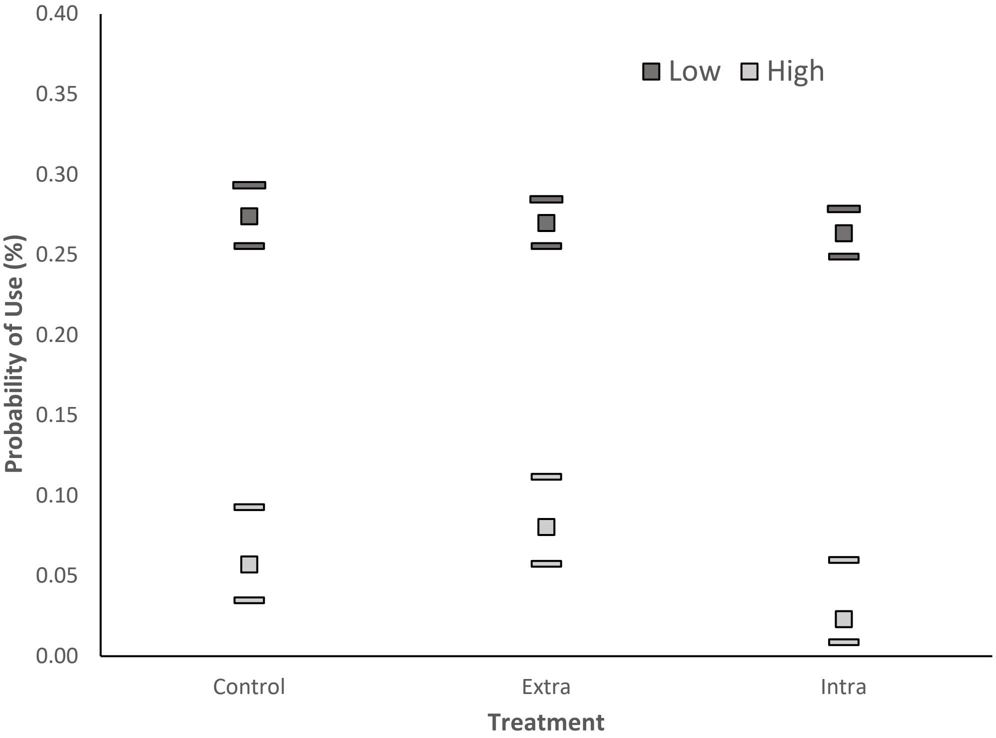

Figure 6. Predicted probabilities of using high risk habitats at the within home-range scale, based on output of a mixed binomial logistic regression examining the effects of risk and treatment on EDB within home range selection. Bars represent 95% confidence intervals.

DISCUSSION

In general, adult male EDBs have larger home ranges and move greater distances than females, reflecting the species' reproductive ecology. Males typically breed annually, whereas females breed every 2-3 years (Waldron and Welch 2014), and males must search for receptive females during the breeding season (Fill et al. 2015b). Approximately 32% of adult females breed per year, reproducing every 2-3 years, on average (Waldron and Welch 2014), requiring that males move greater distances to find mates. In this study, an effect of sex and treatment on home-range size (core and full home ranges) was not detected, but EDB daily movement was negatively affected by translocation. Within the control group, males moved greater distances than females; however, in the treatment groups, females moved similar to males, nearly doubling the distance moved as compared to females in the control group. In 2018, a subset of MCRDPI EDBs was moved to another study site (> 45 km) as part of a separate study examining the effects of long-distance translocation on EDBs (Kelley 2020). Long-distance translocation yielded results that were more typical of reptile translocation studies, in which translocated EDBs had larger home ranges and moved greater distances, on average, compared to pre-translocation home ranges (Kelley 2020). Further data are needed to assess the costs of increased movement in translocated females, which are the most important demographic for maintaining healthy EDB populations in light of the species' slow life history (Waldron et al. 2013). For example, the energetic costs associated with increased movement patterns in translocated snakes could reduce the amount of energy females allocate to reproduction, leading to longer birthing intervals and ultimately affecting population viability.

Like other pitviper species, EDBs exhibit high survival (Waldron et al. 2013). The initial goal of this study was to examine the effects of translocation on EDB survival, but only one of the 36 telemetry-equipped EDBs died during the study. Thus, covariate effects on survival could not be assessed. A constant survival model was used to estimate survival, which indicated that survival probability was 99%. Most snake translocation studies have indicated that snake survival decreases in response to survival (Devan-Song et al. 2016; Wolfe et al. 2018; Roe et al. 2010; Plummer and Mills 2000). Kelley (2020) failed to detect an effect of long-distance translocation on EDB survival, although survival estimates of translocated EDBs were lower (i.e., 61% ± 13%) than that observed in this study.

Though on a sea island, the MCRDPI maintains a balance of open and closed canopy naturalized habitats as well as human-dominated areas that resemble urban landscapes. The interface between urban and naturalized habitats is suited for human-wildlife conflicts, highlighting how habitat fragmentation and human presence lead to unwanted encounters with wildlife (Gehrt et al. 2009). We classified MCRDPI land use into two categories that reflected low-risk habitats (i.e., open and closed canopy woodlands, marshes, and waters) and high-risk habitats (i.e., high-use paved roads and medians, mowed lawns, and other roadways and trails). This approach allowed us to examine whether EDB translocation increased the probability that snakes used high-risk habitats, and the implications for how high-risk habitats influenced home-range size. The proportion of high-risk habitats that occurred in EDB home ranges did not differ by treatment. The proportion of high-risk habitats were positively associated with 100% MCP size, suggesting that high-risk habitats are of lower quality. In general, resource quality is predictive of home-range size, such that home ranges tend to be larger when resources are inadequate (Gittleman and Harvey 1982), and high-risk habitats may be an indicator of lower habitat quality for EDBs.

Our analysis of within home range habitat selection indicated that EDBs were more likely to use low-risk habitats relative to availability, regardless of translocation treatment. Snakes in the extra home-range translocation group were more likely to use high-risk habitats as compared to the intra home-range translocation treatment group, potentially placing snakes in the extra home range translocation group in greater risk of predation or increasing the probability that they encountered humans. Snakes in the extra home-range translocation group moved greater distances as compared to intra home-range translocation and control snakes, possibly reflecting their tendency to use higher-risk habitats while trying to home or learn a novel landscape. Translocated white-lipped pit vipers (*Trimeresurus albolabris*) exhibited unidirectional movements away from release points without trying to return to their point of capture (Devan-Song et al. 2016). Unpredictable post-translocation movement patterns might increase the probability that snakes encounter high-risk habitats, which is an important consideration for efforts to manage human-rattlesnake conflicts. More research is needed for insight into how extra-home range translocations lead to greater selection for high-risk habitat.

This study provides insight into the efficacy of using intra and extra home-range translocations on military installations to manage human-rattlesnake conflicts. Study results indicated that intra home-range translocations are less likely to place snakes in high-risk habitats; however, female EDB movement patterns were significantly affected by both translocation treatments, and tradeoffs specific to the potential negative effects on reproduction should be considered in installation translocation protocols. Specifically, successful translocations will depend on prior insight into EDB population demography to ensure that populations are stable before initiating translocation efforts. The EDB population at the MCRDPI has been studied since 2008, providing detailed information about EDB movement ecology and demography before translocation were implemented.

Eastern diamondback rattlesnake translocation at the MCRDPI indicated that translocation distance is an important consideration in efforts to manage human-rattlesnake conflicts on military installations. Post-translocation home ranges did not differ across treatments, but females in both treatment groups moved greater distances per day as compared to snakes in the control group. This study took place on a sea island, and EDB home ranges tend to be smaller, in general, in island settings (Waldron and Welch 2012; Waldron and Welch 2015; Kelley 2020). The development and application of EDB translocation protocols on other southeastern military installations need to incorporate knowledge of installation-specific EDB movement ecology in order to assign appropriate translocation distances. Eastern diamondback rattlesnake home ranges are variable, reflecting habitat availability and prey densities. Inland EDB populations exhibit large home ranges, ranging from 8 to > 300 ha (Timmerman 1995; Timmerman and Martin 2003; Waldron et al. 2006; Hoss et al. 2010; Means 2017). Several installations within the range of the EDB could support inland EDB populations, increasing the probability that adults use larger home ranges than reported in this study. Furthermore, translocation release sites will need to be carefully considered within installations by military and natural resources stakeholders to ensure project success.

Benefits.

1. Management protocols that address how human-rattlesnake encounters are handled will help lessen interruptions to training activities.
2. Identification of intra home range and extra home range translocation scales for any venomous species will enable military planners to work with natural resource managers to identify installation-specific scales of venomous snake translocation that can be incorporated into natural resource management protocols.
3. In this study, EDBs in the intra home range translocation were less likely to occupy risky habitats that would place them in closer contact to human activity. As such, EDB management at up to 41 DoD installations can use this study to justify incorporating intra home range translocations that are scaled to the movement ecology of installation EDB populations into natural resource management plans.
4. Insight into how rattlesnakes and other venomous snakes use military landscapes will aid installations in developing biologically relevant scales of translocation, maximizing DoD personnel safety and continuous access to training areas.
5. EDB home ranges are larger when they are forced to occupy high-risk habitats, suggesting that risky habitats are of low quality. Translocation protocols will benefit from considerations of habitat quality at translocation sites to decrease the probability that large home ranges place rattlesnakes in close contact with humans.
6. Translocation, regardless of scale, appears to increase female movement distances, potentially stressing adult females. EDB management plans can incorporate this information into installation-specific management protocols to ensure that translocations do not place excessive stress on the most important demographic for maintaining viable EDB populations.

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