

Postrelease Survival of *Eleutherodactylus coqui*: Advancing Managed Translocations as an Adaptive Tool for Climate-Vulnerable Anurans

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ABSTRACT: Translocating amphibians to alternative, suitable habitat is a climate adaptation strategy aimed at minimizing the risk of extinction due to projected global warming and drying. Projected conditions could undermine their physiological performance, and thus survival and reproduction. Translocations minimize risks of extinction by increasing spatial redundancy across climate-resilient habitats, particularly for dispersal-limited species. However, outcomes of amphibian translocation attempts are poorly documented, and their effectiveness remains unclear. We released and tracked 34 *Eleutherodactylus coqui* to determine early postrelease survival of a control (nontranslocated) group ($n = 14$) and experimental (translocated) group ($n = 20$) moved 0.8 km from their capture location in west-central Puerto Rico in 2021. We defined “initial” as the first 17 d postrelease, a period during which we hypothesized that experimental individuals would have lower survival rates because they transitioned from known-familiar to novel-unfamiliar habitat. We found no evidence in the data to support our hypothesis. Daily survival rates were better explained by a model with no group effect but negatively influenced by in situ temperature. However, the effect of in situ temperature (proxy of operative temperature) was weak (95% confidence intervals overlapped 0). After 17 d, all but one of the recaptured frogs lost weight for a combined weight loss of 0.28 ± 0.13 g. However, weight loss was significantly higher in translocated frogs (0.81 ± 0.33 g). Average daily movements did not hinder survival even though experimental individuals traveled farther (\sim eight times) than control ones. Our findings suggested that managed translocations have the potential to become a useful conservation tool, not an additive source of mortality. We outline challenges that remain before translocations of *Eleutherodactylus* species can be broadly applied.

Key words: Adaptation strategy; Climate change; Frog; Puerto Rico; Telemetry

PROJECTED global warming and drying are considered dominant threats to anuran biodiversity because anuran skin is prone to desiccation and anurans exhibit a narrow range of optimal physiologic performance (Bernardo et al. 2007; Calosi et al. 2008; Luedtke et al. 2023). This threat is more pronounced in tropical regions because amphibians, like other ectotherms, are generally operating closer to their upper thermal temperature limits than their temperate counterparts (Deutsch et al. 2008; Nowakowski et al. 2017). Arguably, the risks of reaching thermal limits in the tropics could be exacerbated by land use practices (e.g., agriculture) as structural changes lead to altered thermal conditions unfavorable to amphibians (Nowakowski et al. 2018).

Many of the species experiencing the effects of tropical warming trends belong to the genus *Eleutherodactylus* (Luedtke et al. 2023), a major contributor (\sim 200 species) to the assemblage of Greater Caribbean land frogs (Blackburn et al. 2020). Within this region, Puerto Rico harbors 17 species, of which 15 are endemics and 2 are native. Most of the endemics (9/15) are high-elevation, mesic habitat specialists characterized by low vagility (Joglar 1998; Everman and Klawinski 2013). These traits make them particularly vulnerable to the effects of rising temperatures, which have been increasing during evening hours over the last 60 yr (PRCCC 2022). Indeed, there is consensus among researchers that increasing temperatures are implicated with shifting or restricting distributions, disease, and population declines of *Eleutherodactylus* frogs (Joglar and Burrowes 1996; Burrowes et al. 2004; Joglar

et al. 2011; Barker and Ríos-Franceschi 2014; Campos-Cerqueira and Aide 2017; Scheele et al. 2019; Campos-Cerqueira et al. 2021; Ríos-López and Heatwole 2023).

Prevailing global patterns of land use, as well as projected warming and drying, prompted consideration of adaptation strategies to help maximize species persistence (Stuart et al. 2004; Lawler 2009; Mawdsley et al. 2009; Morelli et al. 2016; Nowakowski et al. 2018). In the context of conservation planning, the term adaptation refers to human activities intended to minimize the adverse effects of climate change on sensitive aspects of the natural environment (Mawdsley et al. 2009). Most recommendations to date focus on land management strategies such as expanding existing protected areas, connecting protected areas, or implementing habitat management actions aimed at increasing climate resiliency. Recommendations are aimed at alleviating or preventing potential decoupling of coevolved interactions, reductions in population size, or detrimental effects on survival and reproduction (Mawdsley et al. 2009). Connected habitats, including gradients, also facilitate effective niche or positive tracking, i.e., reinforcing a species' option to disperse into suitable habitats in response to changing environmental conditions (Pearman et al. 2008; Lawler 2009; Thurman et al. 2020).

Although strategies focused on land conservation practices are important, dispersal-limited species might require additional assistance to persist. Dispersal limitation could lead to local extinctions or extirpation of range-restricted or isolated species and populations (Mawdsley et al. 2009). Thus, managed or conservation translocations have gained attention as they make it possible to introduce species into alternative

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suitable habitats, or supplement local isolated populations to enhance the species' persistence (Harding et al. 2016; Linhoff et al. 2021). Translocations can be framed as a spatiotemporal decision problem for managers, who need to determine when and where translocations should be implemented (McDonald-Madden et al. 2011; Butt et al. 2021; Linhoff and Donnelly 2022). Informing these decisions benefit from bottom-up studies that help link species requirements (e.g., physiological thresholds) to climatic projections that help identify climate-resilient habitats (Morelli et al. 2016; Collazo et al. 2019; Barrows et al. 2020; Bowden et al. 2021; Campos-Cerqueira et al. 2021). However, despite multiple attempts to tackle the complexities in quantifying the outcomes of translocations, previous studies have provided limited information on their effectiveness and reliability in the field (Dodd and Seigel 1991; Germano and Bishop 2009; Linhoff et al. 2021). Improving guidelines for practitioners is needed to promote progressive learning and a basis to adjust and improve the efficacy of managed translocations (Nichols and Williams 2006; Butt et al. 2021; Linhoff et al. 2021).

In this work, we report on postrelease survival of common coqui frogs (*Eleutherodactylus coqui*) in west-central Puerto Rico in 2021. We used *E. coqui* as our focal species because, although widely distributed, it is also prevalent at high elevations (Rivera-Burgos et al. 2021). Thus, the species is a suitable surrogate for high-elevation amphibians (Joglar 1998; Ríos-López and Heatwole 2023). Of importance, the average size of *E. coqui* is among the largest eleutherodactylids on the island (Ríos-López and Heatwole 2023), minimizing the transmitter/harness-to-body weight ratio (Altobelli et al. 2022).

We focus on initial postrelease survival. We defined "initial" as the first 17 d postrelease, corresponding to the effective battery life of radio transmitters used, but also a sufficient period over which to document survival rates during early transitional periods or short-term survival critical for the success of translocation programs (Linhoff et al. 2021; Linhoff and Donnelly 2022). Our objective was to identify factors that may help improve postrelease survival rates. This is of interest because managed translocations should not represent a substantial additive source of mortality, particularly for a species like *E. coqui* that already exhibits low annual survival rates. Reported annual survival in Puerto Rico is 6%, whereas in Hawaii is 10–42% (Stewart 1995; Stewart and Woodbright 1996; Woolbright 1996; Beard et al. 2008).

We hypothesized that initial survival would be affected by factors associated with transitioning from a known, familiar environment to a novel, unfamiliar environment (e.g., finding retreats, predators, intraspecific territorial bouts; Gonser and Woolbright 1995; Germano and Bishop 2009). Hence, our prediction was that translocated individuals would have lower daily survival rates as compared with nontranslocated frogs. To test our prediction, we released and monitored daily two groups of frogs that were equipped with radio transmitters. The control group consisted of frogs released in the same location where they were captured. The experimental group consisted of frogs released in a suitable but different location. We discuss the implications of our results for conservation of climate-vulnerable *Eleutherodactylus* species but also highlight challenges that must be addressed to facilitate broader application and reliability of managed translocations.

MATERIALS AND METHODS

Data Collection

We collected 34 *E. coqui* frogs at the Parque Ecológico Monte del Estado, near Maricao (18.1434N, 66.976100W; datum = WGS84 in all cases; Fig. 1). All but one of the frogs were males. We collected frogs by hand and placed them individually into 118-mL food-grade polypropylene cups. We recorded the frogs' in situ temperature with an infrared thermometer (Craftsman model 34-50455; accuracy = $\pm 1^\circ\text{C}$, and Fluke 62 Max infrared thermometer, -30°C to 500°C , $\pm 1.5^\circ\text{C}$). In situ temperature was defined as the temperature at the structure or substrate where frogs were located at capture. Given that our focal species has a high surface-to-volume ratio, in situ temperature was viewed as an approximation of the thermal condition experienced by the frog in the field (e.g., operative). Frogs remained in polypropylene food-grade cups with sterile napkins soaked in dechlorinated water for transport to the North Carolina State University (NCSU) field lab (Hacienda Ana Luisa, Las Marías; $18^\circ 12.645\text{N}$, $067^\circ 00.080\text{W}$, Fig. 1).

In the field lab, we fitted each frog with a harness (the same used by Harmon 2019) and a radio transmitter (ATS "tiny transmitters," model T-15, freq. 146–153.999, turned on). Transmitters weighed 0.15 g and had a maximum battery life of 21 d. Transmitters were within the 10% transmitter/body mass ratio standard used in amphibian studies (Altobelli et al. 2022). The ratio for control frogs was $0.09 \pm 0.003\%$, and for translocated frogs was $0.08 \pm 0.002\%$.

To ensure a proper harness fitting, frogs were transferred to a 15-L polyethylene holding unit for a maximum of 2 d. We kept the holding unit at ambient temperatures ($24.77^\circ\text{C} \pm 0.27^\circ\text{C}$) and under a natural photoperiod. We fed individuals daily ad libitum over the holding period using commercially available live house crickets (*Acheta domesticus*). The containers were lined with sterile napkins moistened with dechlorinated water, and daily cleaning was performed to prevent waste buildup.

After 1–2 d in the field lab, we weighed and released the telemetered frogs. We released all frogs between August and September 2021. The control group ($n = 14$) of *E. coqui* was released in the same location where the individuals were captured. The experimental group ($n = 20$) was released in the Centro Vacacional del Monte del Estado (18.1403N, 66.972032W). These locations were at 853 and 829 m in elevation, respectively, and at least 800 m apart (Fig. 1). Although both locations were occupied by *E. coqui*, the sites were deemed independent of each other because their separation was eight times the longest average distance from which territorial *E. coqui* males managed to return (100 m) when moved from their territories (Gonser and Woolbright 1995). We believed that using locations that were occupied by *E. coqui* prevented translocating the species into unsuitable habitat, reducing the likelihood of unusual or extreme conditions. All frogs were treated similarly (e.g., handling, captivity time, Institutional Animal Care and Use Committee [IACUC] protocols), further minimizing potential confounding factors.

We measured six parameters that helped characterize environmental and habitat conditions in both locations (Table 1). We acknowledge that sources of biological interactions (e.g., territories) or the availability of physical features (e.g., retreat sites) may influence survival, but these could not be measured and thus were not factored in our analyses. We placed a HOBO data

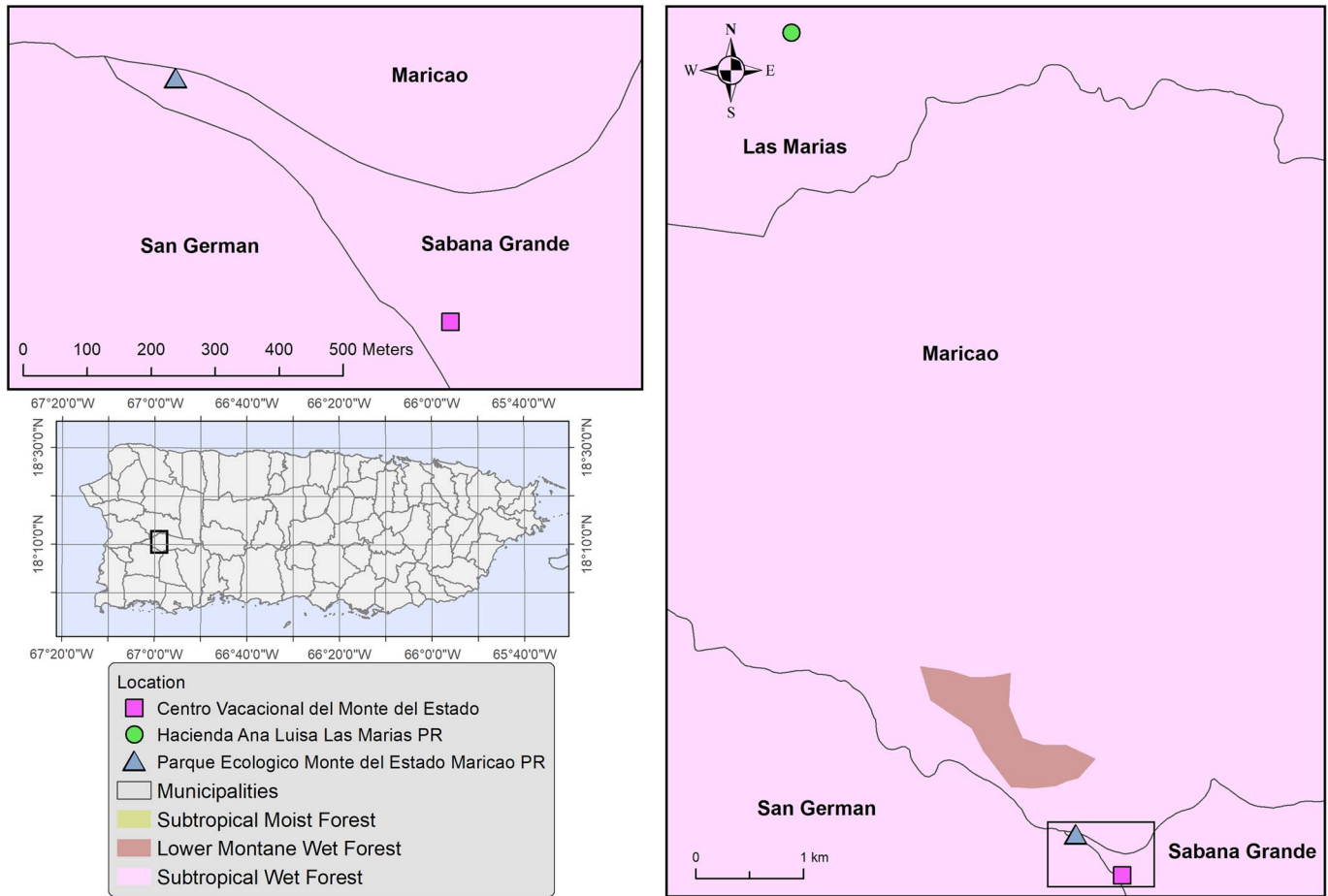


FIG. 1.—Map of Puerto Rico (lower center left) with a black rectangle depicting the location of the study. Thirty-four *Eleutherodactylus coqui* (top left) frogs were collected from one site (blue triangle). Frogs were transported to a laboratory (right) where they were held and instrumented (green dot). Fourteen (14) individuals were released in the same habitat in which they were captured (control group, blue triangle); 20 were translocated and released in a location 0.8 km away (experimental group, pink square). Both locations were in subtropical wet forest.

logger (Onset’s HOBO U23 Pro v2 temperature/relative humidity data logger U23-001; accuracy = ±0.21°C, ±2.5%) at the control and translocation locations to record temperature (°C) and relative humidity (%) for the duration of the study. Upon downloading the data, we recorded the values of temperature and relative humidity corresponding to the time frogs were

relocated. We measured soil moisture using a soil moisture sensor (Delta-T Devices SM300; accuracy = ±2.5%, depth of 50.8 mm) and a soil moisture meter (Delta-T Devices HH2 moisture meter). We weighed frogs in the field using a calibrated portable top-loading scale (VWR; Model 123P).

TABLE 1.—Average (±SE) of *Eleutherodactylus coqui* weight, habitat, and environmental parameter values collected where *E. coqui* individuals were released and re-encountered over 17-d postrelease in west-central Puerto Rico.

Using an ATS R410 scientific receiver (three-element folding Yagi antenna), we tracked individual frogs by “homing” or visually locating the frog twice daily, recording habitat and environmental variables, as well as the frog’s fate (dead, alive, censored). Censored refers to frogs whose fate could not be ascertained. We used morning (0700–0900 h) surveys to ascertain the location of daytime refuges and used evening (1800–2300 h) surveys to determine the fate of individual frogs and daily movement (recorded as distance from the previous known position). We monitored frogs for 17 d because this enabled us to collect sufficient data while avoiding losing signal due to battery failure and maximized opportunities to recapture frogs for harness removal and weigh them where they were last encountered.

Parameter	Nontranslocated control (n = 14)	Translocated experimental (n = 20)
Initial weight (g)	2.29 ± 0.08	2.68 ± 0.14*
End weight (g)	2.16 ± 0.22	1.72 ± 0.60
Weight gain (+)/loss (-) (g)	-0.21 ± 0.12	-0.81 ± 0.33*
Transmitters lost (days)	6.6 ± 1.50	6.4 ± 1.47
In situ temperature (°C)	20.14 ± 0.23	19.86 ± 0.15
Ambient temperature (°C)	20.76 ± 0.03	20.96 ± 0.07
Relative humidity (%)	100.00 ± 0.00	97.16 ± 0.50*
Maximum distance traveled (m)	2.36 ± 2.13	17.15 ± 5.57*
Daily movement (m)	0.15 ± 0.12	1.19 ± 0.35*
Horizontal cover (%)	54.68 ± 4.81	29.30 ± 3.21*
Canopy cover (%)	98.22 ± 0.15	96.09 ± 2.21
Leaf-litter depth (mm)	40.71 ± 3.64	71.70 ± 4.58*
Soil moisture (%)	35.41 ± 1.87	26.34 ± 1.01*

* Significantly different from controls, Wilcoxon test, P < 0.05.

At each point where frogs were relocated, we recorded in situ and ambient (air) temperature, relative humidity (%), soil moisture (%), leaf-litter depth (mm), canopy cover (%), and horizontal cover (%), which we used to model daily survival rates. We measured canopy cover with a Spherical Crown densiometer, concave model C (Forestry Suppliers);

horizontal cover (i.e., understory) was estimated with a density pole 50.8 mm wide and 1.52 m tall, segmented into three sections, each measuring 0.46 m in length (sensu Nudds 1977), and leaf litter was measured with a digital caliper (Husky 6 in three-mode digital fractional caliper; accuracy ± 0.001 in ± 0.02 mm). We conducted all work under the NCSU IACUC permit 21-262-O.

Data Analysis

We used the known-fate framework in program MARK to analyze our survival data (White and Burnham 1999). Survival is expressed as daily survival rates. Period survival rate, which in this study is 17 d, was calculated as daily survival rate raised to the 17th power. One of the advantages of this analytical technique is that individuals whose fate cannot be ascertained in a given sampling occasion are censored. Their removal on occasion does not preclude estimating daily survival rates as the model uses the remaining frogs in the pool whose fate is known. Censored individuals could re-enter the cohort if relocated and their fate determined (alive or dead). This feature helps prevent the prospect of generating biased estimates of survival. If researchers knew unambiguously the fate of every animal, the estimate of survival would be obtained by dividing the number of frogs alive by the number of frogs released. The problem is that such a strong assumption is seldom met, and the estimate is limited to a one-time interval with constant survival. We know, however, that survival varies over time, multiple factors impinge on survival, and the fate of all individuals is not always known (e.g., transmitter fails or falls). The known-fate approach allows the researcher to account for these factors, minimizing the risks of generating spurious results and inferences. The flexibility and advantages of the known-fate or failure-time models in telemetry studies were reported by Pollock et al. (1989), White and Garrott (1990), and Murray (2006).

We used a hierarchical, multimodel approach to explain variation in daily survival of released frogs to restrict the model set given the large number of possible covariate combinations. Model building occurred in two steps. We began by modeling variation in daily survival as a function of time using four basic model structures: (1) constant survival $\{S(\cdot)\}$, (2) constant survival by treatment $\{S(g)\}$, (3) time-specific survival $\{S(t)\}$, and (4) time-specific survival by treatment $\{S(g \times t)\}$. We then used the best-supported model structure in step 1 (on the basis of Akaike's information criterion corrected for small sample size [AICc] weight [w_i]) to create a suite of candidate models making sure that the set included models that reflected our working hypotheses using covariates singly. We used the AIC to evaluate the support in the data for each competing model in the candidate set, as well as the direction and strength of each covariate on *E. coqui* daily survival (Burnham and Anderson 2002). Models with Δ AICc ≤ 2 were considered substantially supported by the data. The effect of covariates (i.e., β coefficients) on daily survival was considered strong if the 95% confidence interval (CI) did not overlap 0, and weak otherwise.

We used 10 frog, habitat, and environmental covariates collected over 17 d to model their hypothesized influence on daily survival (Table 1). Frog covariates were in situ temperature ($^{\circ}$ C), maximum distance traveled (m, longest distance away from release point), daily movement (m, distance from one night to the next night), and weight (g). Habitat covariates were ambient temperature ($^{\circ}$ C), relative humidity (%),

TABLE 2.—Model selection table for known-fate models used to estimate daily survival rates (*S*) of *Eleutherodactylus coqui* released in west-central Puerto Rico in 2021. All were collected from the same location. Fourteen frogs were released in the location where they were originally collected (nontranslocated or control group); 20 were released in a different location, 0.8 km away from where they were originally collected. Models were ranked by Δ AICc values. We also list model weight (AICc w_i), number of parameters (*k*), and model deviance [$-2\log(L)$]. Survival probabilities were modeled as constant $\{S(\cdot)\}$, by time $\{S(t)\}$, by treatment $\{S(g)\}$, and by treatment and time $\{S(g \times t)\}$. We also used 10 covariates to model daily survival.

Models	AICc	Δ AICc	AICc w_i	<i>k</i>	$-2\log(L)$
$\{S(\text{in situ})\}$	11.78	0.00	0.41	2	7.72
$\{S(\cdot)\}$	14.46	2.68	0.11	1	12.44
$\{S(\text{horizontal cover})\}$	14.93	3.14	0.08	2	10.86
$\{S(g)\}$	15.03	3.25	0.08	2	10.97
$\{S(\text{relative humidity})\}$	15.03	3.25	0.07	2	10.96
$\{S(\text{temperature})\}$	15.68	3.90	0.06	2	11.62
$\{S(\text{max. distance})\}$	15.93	4.15	0.05	2	11.86
$\{S(\text{soil moisture})\}$	16.05	4.27	0.05	2	11.99
$\{S(\text{daily movement})\}$	16.20	4.42	0.04	2	12.13
$\{S(\text{canopy cover})\}$	16.40	4.62	0.04	2	12.33
$\{S(\text{initial weight})\}$	16.41	4.63	0.04	2	12.35
$\{S(\text{leaf litter})\}$	16.44	4.66	0.04	2	12.38
$\{S(t)\}$	45.15	33.37	0.00	17	7.48
$\{S(g \times t)\}$	78.11	66.33	0.00	30	6.03

canopy cover (%), horizontal cover (%), leaf-litter depth (mm), and soil moisture (%). We compared averaged values for each group (control vs. experimental) using a Wilcoxon test because some covariates did not meet homogeneity of variance assumption. Tests were conducted using JMP statistical software package (2016, v13.2.1, SAS Institute Inc, Cary, NC). We report means (SE) and use an alpha level of 0.05.

RESULTS

Control and translocation locations differed in four of six environmental/habitat variables (Table 1). Greatest differences were recorded for horizontal cover and soil moisture, which were both higher in the control location. Relative humidity was slightly higher in the control site (3%). In contrast, leaf-litter depth (mm) was much higher in the translocation location. In terms of frog variables, on average, all frogs lost weight (0.28 ± 0.13 g), with the loss being significantly higher for translocated frogs (0.81 ± 0.33 g; Table 1). Average ambient temperature and in situ temperature did not differ statistically.

The model structure explaining most of the variation in the data (*S* [in situ], AICc $w_i = 0.41$) was one where daily survival rates were constant over time, but negatively influenced by in situ temperature (Table 2). There was no support in the data to treat control and experimental groups separately ($\{S(g)\}$, Δ AICc = 3.25). There were no other competing models (Δ AICc ≤ 2) in the candidate set of 14 (Table 2). The estimated daily postrelease survival rate was 0.999 ± 0.001 , with a period survival of 0.992 ± 0.024 over 17 d. The influence of in situ temperature on daily survival was negative (-3.27 ± 2.09), but the effect was weak (95% CI = -7.37 to 0.83). We recorded only one death in the control group during the 17-d study period. We lost a total of 10 transmitters, five in each cohort, after which the individual frogs were censored. On average, frogs in both groups lost their transmitters 6 d postrelease (range = 2–11 d; Table 1). Average daily movements of experimental *E. coqui* individuals were significantly greater (1.19 ± 0.35 m) than for the control group (0.15 ± 0.12 m). Average

maximum distance traveled by individuals was also significantly greater for experimental individuals (17.15 ± 5.57 m) than for control individuals (2.36 ± 2.13 m; Table 1). On average, experimental individuals moved about eight times farther than control frogs, either daily or maximum distance.

DISCUSSION

We hypothesized that survival of experimental individuals of *E. coqui* would be lower than those in the control group because of the novel setting and possible differences in environmental conditions experienced by translocated frogs. Contrary to our prediction, we found no evidence to support a difference in daily survival rates between control and experimental groups. Our results suggested that increasing in situ temperature, our proxy of operative temperature, might induce a reduction in daily survival. However, its influence was weak. It was noteworthy that we did not find support in the data for any other modeled covariate to account for daily survival, regardless of whether they differed between locations or study groups. Our findings suggest that habitat and environmental conditions in the translocation location were within the range of field conditions that support *E. coqui* (Rivera-Burgos et al. 2021).

We observed that translocated frogs traveled about eight times farther than the control group, but there was no indication of increased mortality despite the greater exposure to desiccation and predation often associated with movement (Gonser and Woolbright 1995; Hillman et al. 2009; Castellón et al. 2022). This finding was consistent with a lack of support from covariates that could trigger frog movement as they seek shelter (e.g., temperature, relative humidity, soil moisture, or availability of retreats (Scheffers et al. 2013; Nowakowski et al. 2017; González-del-Pliego et al. 2020; Hoffmann et al. 2021)). We surmise that higher movements of translocated frogs were likely driven by individuals encountering unfamiliar surroundings, possibly induced by factors such as unexpected territorial defense by resident frogs, search for food and shelter, and homing toward their original territory (Gonser and Woolbright 1995; Bodinof et al. 2012; Castellón et al. 2022). In contrast, control frogs did not move as much. A plausible explanation for their short-distance movements was that we released control frogs to the same location where captured (i.e., their territory). Hence, frogs most likely engaged in typical activities for resident frogs, such as foraging bouts characterized by a sit-and-wait strategy (Taigen and Pough 1983). We acknowledge that the impact on survival of some factors might not be discernable in 17 d. For example, it remains unclear what factors may have induced weight loss, which was higher in translocated frogs, and whether weight loss represents a source of mortality for frogs over a longer time horizon.

It was beyond the scope of our objectives to extrapolate daily estimates of survival to a longer period (e.g., 1 yr). The effective life of the batteries (17 d) did not allow monitoring of frogs long enough to evaluate seasonal variations in weather or other factors that have been observed to affect *E. coqui* annual survival (Stewart 1995; Stewart and Woolbright 1996; Woolbright 1996; Beard et al. 2008). Rather, our postrelease daily survival estimates provide evidence that it is possible to have similar survival rates between translocated (experimental) and nontranslocated (control) individuals during a critical transitional period. Thus, we believe this work is an important first step in the development of translocation strategies for

Eleutherodactylus species because it suggests that translocations can be implemented without additional burden on survival rates. This outcome is valuable for the most climate-sensitive *Eleutherodactylus* species (e.g., *E. portoricensis*, *E. wightmanae*; Heatwole et al. 1965; Beuchat et al. 1984; Delgado-Suazo and Burrowes 2022; Chaparro 2023) because no data exist on their survival; thus, conservation approaches that minimize sources of mortality are desirable. Admittedly, additional experimental releases over longer periods of observation are necessary to confirm our inference, including conducting releases in nonoccupied habitats.

Our review of the literature suggested that restricted geographic distributions and shifts in elevation by *Eleutherodactylus* frogs are purportedly driven by gradual increases in temperatures (see PRCCC 2022) coupled with continued habitat fragmentation (Joglar and Burrowes 1996; Burrowes et al. 2004; Barker and Ríos-Franceschi 2014; Campos-Cerqueira and Aide 2017; Ríos-López and Heatwole 2023). We believe that the impacts of these drivers will likely be amplified by continued drying and warming projected for the island (Bowden et al. 2021). Because dispersal limitation characterizes *Eleutherodactylus* frogs (Joglar 1998; Everman and Klawinski 2013), and many species occur over highly fragmented landscapes in Puerto Rico (Gould et al. 2017), we believe the value of managed translocations has gained importance as a tool to promote species persistence. For this reason, improving the efficacy and reliability of translocations is of utmost importance.

Here, we share recommendations to improve the utility of translocations for eleutherodactylids. Our top recommendation is that researchers provide detailed methods and findings of experimental studies to progressively learn and improve translocation designs, implementation, and monitoring (Linhoff and Donnelly 2022). As noted by Altobelli et al. (2022), practitioners also await advances in technology. In our case, advances directed at tracking small-sized, low-body-mass species would be most useful. These advances would permit tracking even smaller-bodied amphibians (e.g., *E. wightmanae*) or released animals over longer periods of time. In the short term, a longer monitoring period would be valuable to determine if factors with a potential protracted impact (e.g., weight loss) would undermine survival beyond the time horizon evaluated in this study. An obvious longer-term benefit would be estimating annual rates of vital parameters (e.g., survival) to truly gauge translocation outcomes and potential demographic benefit (e.g., recruitment; Nichols and Armstrong 2012; Linhoff and Donnelly 2022).

Transmitter loss can be a concern (sensu Wayne 2001; Groff et al. 2015). We lost 29% of transmitters overall, five in each group, but we were also able to monitor those frogs for an average of 6 d (range = 2–11 d) before they were censored. We do not believe that censoring was a problem in our study because the effective sample size for parameter estimation was 24, and we were still able to extract daily information on daily survival from the other 10 censored frogs over multiple days, helping to define the survival trajectory of cohorts over the 17-d observation period. In these types of studies, large samples are always better, but minimum sample sizes for Kaplan–Meier-type analyses is 25 individuals (Pollock et al. 1989). We suspect that using smaller transmitters might help reduce tag loss as size and weight could translate to lighter, simpler harnesses. As Altobelli et al. (2022) indicated, the relationship between the ratio and survival has not been properly quantified. Our concern is that high-elevation species are deemed most vulnerable to climatic changes, but they are also among the smallest-sized

species on the island (Ríos-López and Heatwole 2023). If we had used the same setup (0.15-g transmitter) for species like *E. wightmanae* (0.62 ± 0.02 g) or *E. juanariveroi* (0.28 ± 0.01 g; A. Rivera-Burgos, personal observation), the transmitter/harness weight would have represented 24% and 51% of their body weight, respectively. These values are substantially higher than the standard threshold of 10% (Altobelli et al. 2022) and could be detrimental to frogs (Indermaur et al. 2008).

We note that there are multiple marking techniques available, but some raise concerns and obvious limitations. For example, progress in miniaturizing solar transmitters is noteworthy (e.g., 0.06 g), but practically useless for nocturnal species. Broadly used, toe clipping has been shown to induce mortality (McCarthy and Parris 2004), and believed to have been a major cause of postrelease mortality of *E. coqui* in Hawaii (Beard et al. 2008). Safer techniques (e.g., visible implant elastomer; Matlaga et al. 2021) are available, but they require locating individuals without the aid of signals, making determining the fate of individuals more difficult.

We close by emphasizing that Puerto Rico's landscape has been altered historically, and fragmentation is pervasive (Martinuzzi et al. 2007; Gould et al. 2017). Nowakowski et al. (2017, 2018) stressed the consequential implications (e.g., to demography, distribution) of altered habitats on amphibian conservation as modifications could result in adverse thermal and hydric environments. Altered conditions could expose frogs to desiccation and predation risks as they seek thermal refuges or engage in positive tracking (Hillman et al. 2009; Nowakowski et al. 2018; Hoffmann et al. 2021; Matlaga et al. 2021). These risks are exacerbated because *Eleutherodactylus* frogs are poor dispersers (Joglar 1998; Everman and Klawinski 2013). Thus, we cannot overemphasize the importance of selecting sites that fall within the range of conditions that support a species of interest. In this sense, we advocate for mechanistic studies (e.g., assessing physiological performance curves) to make more informed decisions about site selection for translocations, as well as interpret responses by released frogs to make better inferences about demographic and distribution implications (Barrows et al. 2020; Matlaga et al. 2021; Linhoff and Donnelly 2022).

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