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Estimating Abundance of Adult *Trachemys scripta* with Camera Traps: Accuracy, Precision and Probabilities of Capture for a Closed Population

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ABSTRACT

Low and variable rates of capture are common problems when estimating abundance of freshwater turtles with capture-mark-recapture (CMR). We speculated camera traps would allow us to obtain reliable estimates of abundance by re-sighting marked *Trachemys scripta elegans* (Sliders) as they basked on man-made rafts during a 20-day surveillance period. We evaluated the method by releasing Sliders in a fenced enclosure to compare estimates from CMR to true abundance. We also evaluated probabilities of detection and retention of marks. Permanence of marks applied with marine epoxy satisfied assumptions for CMR. Camera traps detected 23 of 25 Sliders. Our ability to discern marks from photos was good (110 of 114 re-sightings). The proportion of marked Sliders detected per day was 0.22; detection varied with day of surveillance (1–20) and maximum air temperature the preceding day. All CMR models providing valid estimates of abundance included the true number of marked Sliders in their confidence intervals and yielded point estimates within 27% of the true value. An estimate of abundance from the top CMR model exceeded the true value by 22%, with a wide confidence interval. Model averaging improved the point estimate (17% over true) and produced a narrower confidence interval. A favorable comparison of estimated and true abundance validated camera traps as a tool for estimating abundance of adult Sliders. We believe camera traps could prove useful for detecting biases caused by primary methods of capture, refining estimates of abundance from other methods and collecting data at multiple locations consistently, simultaneously and frugally compared to manual methods alone.

Key Words: camera trap, capture-mark-recapture, abundance, *Trachemys scripta*, closed population, basking

INTRODUCTION

Capture–mark–recapture (CMR) is a common approach for estimating abundance of freshwater turtles. Unfortunately, estimates obtained from CMR are often biased or lack precision because of low and heterogeneous rates of capture (Lindeman 1990; Reese and Welsh 1998; De Lathouder et al. 2009; Martins and Souza 2009). Such estimates are a poor basis for assessing declines, threats and ecological relationships (Robson and Regier 1964; Begon 1983).

Strategies for improving reliability of population estimates include increasing probabilities of capture (e.g., by using efficient collection methods) and reducing sources of heterogeneity (White et al. 1982). We speculated camera traps might fulfill this need by allowing us to re-sight marked *Trachemys scripta elegans* (Red-eared Slider, hereafter referred to as Slider) on basking rafts during a 20-day surveillance period. Like others (e.g., Edwards and Eberhardt 1967), we captured Sliders from the wild and released them in a fenced enclosure to validate the method by comparing estimates from CMR to a known number of marked individuals.

Retention of marks is a key assumption for CMR (Pollock 1981). Therefore, we used two criteria to evaluate "loss" of marks: all marks are legible for ≥ 20 days and all marks can be discerned from photographs. We also used high standards of performance to evaluate "capture" (i.e., unequivocal identification) of individuals by camera traps: 1) all marked individuals are detected at least once during a 20-day sampling session, 2) the mean daily probability of capture exceeds 0.2, 3) probabilities of capturing males and females are equal, 4) probabilities of capture are constant over time, 5) estimated abundance from the top CMR model includes the true number of turtles (N = 25) within its 95% confidence limits, and 6) a point estimate of abundance from the top CMR model is ±25% of the true number of turtles.

STUDY AREA

Our study took place at a 23-ha private property near Springfield, Illinois, USA. The area has 11 man-made ponds. One pond (0.54 ha) was enclosed fully by a welded wire fence (5.08 X 10.16 cm-mesh; height = 1.83 m) erected 3–6 m from the shoreline. During April 2012, we closed all gaps between the bottom of the fence and the ground by digging shallow trenches, attaching welded wire extensions and filling trenches with soil to bar movements of large turtles [carapace width (CW) > 10.16 cm] in or out of the fenced area. Turtles within the enclosure used patches of bare shoreline for basking. Elsewhere, turtles basked on bare shorelines or debris (e.g., concrete rubble, collapsed wooden bridge).

METHODS

We used a basking trap and two to four baited hoop nets (diameter = 0.91 m; 3.81 X 3.81-cm mesh) to attempt to remove all resident turtles from the compound on 18–27 April, 14–18 May and 4–6 June. We released turtles in a nearby pond without marking them. Some of the Sliders removed from the enclosure in April or May might have been recaptured and used for our CMR study; those removed from the enclosure in June were not.

On 18 May, we deployed two basking rafts with two cameras each in the enclosed

Figure 1. Marked *Trachemys scripta* recaptured by a camera trap during a pilot study of a closed population near Springfield, Illinois, USA.

pond. Cameras were positioned to provide opposing fields of view of rafts. Bluett and Cosentino (2013) described rafts and cameras (Wingscapes® Timelapse Plantcam™; Alabaster, Alabama, USA) in detail. Briefly, we programmed the time-lapse cameras to take high resolution photos (2560 X 1920 pixels) at 0900, 1200 and 1500 hrs and set focus distance to infinity. Photos were imprinted with time lapse interval, date, time, and a code that allowed us to distinguish individual rafts and cameras (Fig. 1). We used data from the first 20 days of deployment (until 6 June) to estimate the minimum number of turtles remaining in the fenced pond after removals.

On 4 June, we deployed two to four hoop nets in each of seven ponds on the property. We used calipers to measure plastron length (PL) and CW of Sliders captured on 5–6 June. Sliders with CW > 10.2 cm and PL indicative of sexual maturity (> 10 cm for males, > 19.5 cm for females; Cagle 1944; Readel et al. 2008) were marked by drilling unique combinations of holes in marginal scutes and placed in coolers for our CMR study. Sliders captured on 5 June (N = 16) were stored overnight so they could be marked and released in the enclosure with those captured the next day (N = 9). Sexes were determined from secondary sexual traits (Ernst and Lovich 2009).

We cleaned carapaces of Sliders with a scrub brush, tap water and dishwashing soap. The second and third vertebral scutes were abraded lightly with a foam sanding block and wiped with isopropyl alcohol. We applied unique letters, numbers or symbols to this area using a paintbrush, marine epoxy (Loctite®, Henkel Corporation, Rocky Hill, Connecticut, USA; Auth 1975) and stencils (height = 5.08 cm). We placed Sliders in individual containers, allowing epoxy to cure for 4–5 hrs before they were released at 1700–1730 hrs on 6 June.

Cameras yielded 12 photographic records per day for 20 consecutive days beginning on 7 June. We lumped data to obtain a single daily capture history for each individual. In other words, a Slider photographed multiple times during the same day counted as a single observation. For consistency, we censored observations of Sliders in the water approaching rafts rather than on them. When necessary, we adjusted brightness and contrast of photos or zoomed in to identify marks. We obtained data for weather variables from a meteorological station located in Springfield (Illinois Climate Network; http://www.isws.illinois.edu/warm/datatype.asp).

We set two hoop nets and two fyke nets (0.9-m X 1.8-m box, 2.54-cm mesh, 12.2-m leads) in the fenced pond after 1500 hrs on 26 June and continued trapping until 0900 hrs on 29 June. Photographs of Sliders captured in these traps served as records of permanence and legibility of marks.

We analyzed detection histories for the 25 marked Sliders over 20 days to assess whether day- or individual-specific detection rates differed with weather, time, sex or body size. Because detectability likely differed among individuals, we analyzed the data with mixed-model logistic regression, using Slider ID as a random clustering variable (package glmmML in R v. 2.13.0). The fixed-effect explanatory variables were the individual-specific variables sex and plastron length, plus the following day-specific variables: solar irradiance, minimum daily temperature, maximum daily temperature, total evaporation, average wind speed, and day (June 7 = Day 1, to account for any consistent trend in detection probability). In predicting detection probability for each day, we examined weather variables for the same day and the previous day, to account for potential lagged effects. We used a forward stepwise model building approach, including variables with $p < 0.05$. An apparent temporal trend in detection probability could result from a behavioral response to first detection (e.g., after a Slider had hauled out on a basking platform once, it might be more inclined to do so again), so we repeated this analysis using only detection history data for each Slider after its first detection.

Based on the results of the initial analysis of factors influencing detection probability, we used Program MARK (White and Burnham 1999) to estimate the number of marked Sliders in the study pond under a closed-population CMR framework. The input dataset for this analysis included only those marked Sliders with ≥1 confirmed detection, because CMR abundance estimation is typically used when the number of undetected animals is unknown, and therefore estimated. Detections of unmarked Sliders and uncertain detections of marked Sliders were excluded, so the true population being estimated is the number

of marked Sliders (i.e., 25).

Our initial analysis provided evidence that detectability of Sliders changed after they first used basking platforms, so we considered models with a behavioral response to initial "capture." We also included heterogeneity among individuals (finite-mixture with 2 groups), daily detection probabilities co-varying with maximum daily temperature the previous day, and an effect of Day. Starting with this 4-variable additive (on a logit scale) base model, we considered all reduced models (3, 2, or 1 of the variables) as well as models with 2-way interactions. Based on results indicating weak support for detection probability varying with Day, we dropped Day from the top model, and then explored whether adding interactions among the remaining variables would result in better-supported models. We used Akaike's Information Criterion for small samples (AIC_c) to assess relative support for models (Burnham and Anderson 2002).

RESULTS

We removed 18 resident Sliders from the enclosure during 48 trap-nights of effort. No turtles were captured during the last two days of the May session, and only one Slider was captured during the June session. However, camera traps revealed seven resident (unmarked) Sliders that remained in the enclosure during our CMR study. Four were juveniles, three of which (PL = 5.5, 5.8, 6.0 cm) were captured after the CMR study (i.e., during recovery of Sliders to evaluate loss of marks). One resident adult and two sub-adults were observed regularly in photos taken during the CMR study, but none was captured afterward.

We released 25 Sliders in the enclosure (17 male, 8 female). Most of these (N = 17) came from a single pond. Camera traps yielded 114 recaptures of 23 of the marked Sliders (Table 1). We could discern marks for 110 capture events. In one case, excessive glare kept us from identifying the mark confidently. In three cases, our views of marks were obscured partially by Sliders basking atop the backs of other Sliders. In one case, a Slider basking atop another blocked our view of its carapace too completely to determine if it was marked.

The raw mean detection rate (proportion of marked Sliders detected per day) was 0.22. Mixed-model logistic regression results indicated strong rejection of the null hypothesis of equal detectability among Sliders (all $p < 10^{-5}$). We found no evidence that detection probability was associated with either sex or size (PL) of the Sliders ($p > 0.43$). The final detection probability model included only a negative effect of maximum temperature the previous day ($B = -0.14$, $p < 0.0001$) and a positive effect of Day ($B = 0.057$, $p = 0.0077$), indicating a general trend toward increasing detection probability (Fig. 2). However, when only data after each Slider's initial detection were included, the effect of Day disappeared ($p > 0.44$) and the final model included only the negative effect of maximum temperature the previous day ($B = -0.14$, $p = 0.0002$; Fig. 3).

Table 1. Recaptures of adult *Trachemys scripta* released in a fenced enclosure near Springfield, Illinois, USA and monitored with camera traps from 7–26 June, 2012.

No. recaptures	No. individuals
0	2
1	3
2	3
3	4
4	2
5	4
6	1
8	3
9	1
10	1
12	1

The best-supported closed-population CMR model included a behavioral response to initial detection, heterogeneity in detection probabilities (mixture of two groups), and effects of maximum temperature the previous day that differed between detectability groups (Table 2). It estimated that the two detectability groups were basically equal in size (0.497 in the low-detection group, 0.503 in high). The mean initial detection probabilities for the two groups were 0.036 and 0.146, for a weighted average of 0.091. Mean subsequent detection probabilities for the two groups were 0.095 and 0.369 for a weighted average of 0.233. The best-supported model's estimate of abundance exceeded the true value (25) by 5.4 (22%), with a wide confidence interval (Table 2). Model averaging improved the point estimate (17% over true) and produced a narrower confidence interval.

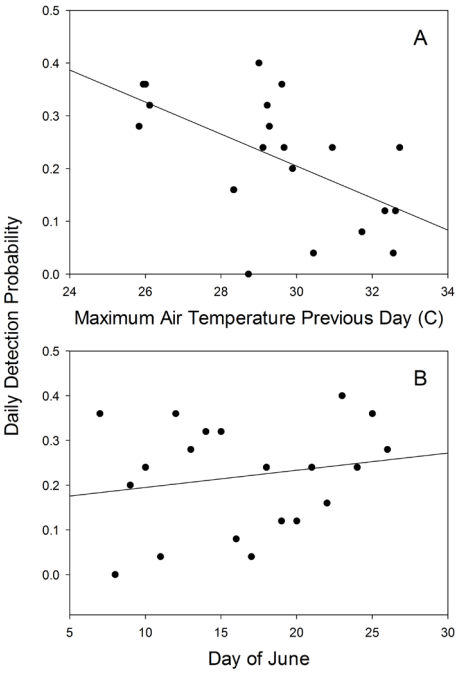

Figure 2. Relationship between daily detection probability (proportion of marked Sliders detected) as a function of (A) the maximum air temperature the previous day and (B) the day of the study.

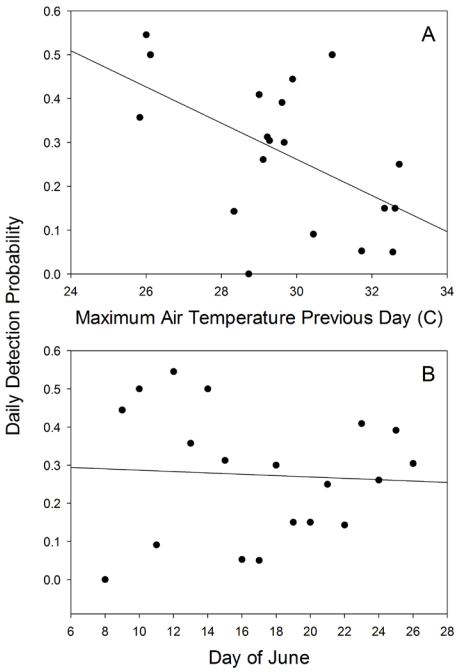

Figure 3. Relationship between daily detection probability of previously detected Sliders as a function of (A) the maximum air temperature the previous day and (B) the day of the study. Note that these plots show only data after each turtle's initial detection.

Table 2. Results of closed-population capture-mark-recapture estimation of Red-eared Slider abundance from basking camera detection of marked Sliders in an enclosed pond, incorporating potential effects of Day (June 7 = Day 1), maximum temperature the previous day ($MaxT_{t-1}$), heterogeneous detection probability among Sliders (Hetero) and behavioral response to initial detection (Behav).

Model#	Step	Model	k[a]	AIC_c	δ-AIC_c	Weight	$\hat{N}$	%True[b]	LCL	UCL
1	Base	Day + $MaxT_{t-1}$ + Hetero + Behav	7	379.24	4.61	0.041	23.2	92.8	23.0	32.8
2	Base - 1 variable	Day + $MaxT_{t-1}$+Hetero	6	377.22			23.0[c]			
3	Base - 1 variable	Day + $MaxT_{t-1}$ + Behav	5	387.67	13.04	<0.001	23.3	93.2	23.0	32.6
4	Base - 1 variable	Day + Hetero + Behav	6	397.42			23.0[c]			
5	Base - 1 variable	$MaxT_{t-1}$ + Hetero + Behav	6	378.45	3.82	0.061	31.7	126.8	24.5	74.9
6	Base + Interaction	Day*$MaxT_{t-1}$ + Hetero + Behav	8	379.18	4.55	0.042	31.1	124.4	24.0	89.1
7	Base + Interaction	Day*Hetero + $MaxtT_{t-1}$ + Behav	8	378.43			23.0[c]			
8	Base + Interaction	Day*Behav + $MaxT_{t-1}$ + Hetero	8	380.04			23.0[c]			
9	Base + Interaction	Day + $MaxT_{t-1}$*Hetero + Behav	8	375.73	1.10	0.236	27.9	111.6	23.8	53.1
10	Base + Interaction	Day + $MaxT_{t-1}$*Behav + Hetero	8	381.29	6.66	0.015	23.2	92.8	23.0	34.7
11	Base + Interaction	Day + $MaxT_{t-1}$ + Hetero*Behav	8	379.13	4.50	0.043	23.4	93.6	23.0	34.6
12	**#9 - Day**	**$MaxT_{t-1}$*Hetero + Behav**	**7**	**374.63**	**0**	**0.410**	**30.4**	**121.6**	**24.4**	**62.3**
13	#12 + Interaction	$MaxT_{t-1}$*Hetero + $MaxT_{t-1}$*Behav	8	376.70	2.07	0.146	30.4	121.6	24.4	62.3
14	#12 + Interaction	$MaxT_{t-1}$*Hetero + Hetero*Behav	8	383.20	8.57	0.006	26.7	106.8	23.4	54.5
Model Averaged							29.2	116.8	23.0[d]	44.1

[a]Number of parameters in model
[b]Percentage of the true number of marked Sliders (25)
[c] $\hat{N}$ not estimable, so this model is not considered in the candidate set
[d]Lower confidence limit set at the number of marked Sliders detected (lowest sensible value). The model-averaged LCL value provided by MARK = 14.3.

However, it is worth noting that all models providing valid estimates of abundance included the true number of marked Sliders in their confidence intervals.

We captured 17 of our 25 marked Sliders after the CMR study ended, including one that had not been detected by camera traps. Fourteen marks were whole and unblemished. Growth of algae was apparent on three marks, two of which were observed readily in photos taken by camera traps on 24–25 June (days 18 and 19).

DISCUSSION

Replacing resident with translocated Sliders allowed us to evaluate retention of marks during a finite period of time while maintaining a density of animals similar to the original population. Permanence of marks met our expectations and satisfied assumptions for CMR. Our ability to discern marks from photos was good (96.5% of capture events) but imperfect. Failure to identify marks because of poor photographic quality is not a problem if events occur randomly (O'Brien 2011) or are addressed by robust solutions (e.g., Stevick et al. 2001; da-Silva 2009).

Use of distinctive marks was helpful. For example, we used "C" but not "G" because of similarities in appearance. We also recommend using eight-megapixel cameras, which were not available from the manufacturer when we purchased our gear. Doing so would accrue a total cost ($USD) of ~$230 per station for two cameras, a raft and other materials. Adding a grid or ruler to the raft might allow distinction of age classes of unmarked turtles by using image analyses to estimate shell size from photos (Lambert et al. 2012).

Expending a large amount of effort in a small area can yield high probabilities of capture (Kendall 1999). Even so, the proportion of marked individuals we recaptured with camera traps (92%) fell short of our goal (100%). Rates of recapture vary from 3–64% for traditional methods of collecting Sliders (e.g., hoop and fyke nets; Readel and Phillips 2008; Tucker and Lamer 2008). Rates of 17–18% are typical for studies with large numbers of marked Sliders (Cloninger 2007; Glorioso et al. 2010).

Thomas et al. (1999) reported male-biased sex ratios for captures with hoop nets and female-biased samples for basking traps. As with other relative comparisons (Ream and Ream 1966; Gamble 2006), it is difficult to say which sample, if any, represented the true population. Probabilities of capturing males and females were similar and presumably unbiased for camera traps.

After accounting for changes in temperature, estimated daily detectability increased by about 0.15 during the course of our CMR study. This trend was caused by recruitment of new individuals using rafts to bask. Underlying causes of differences between groups of Sliders with high or low rates of detection are a matter of speculation. Perhaps some turtles basked sooner than others because they had fed recently (Gatten 1974; Hammond et al. 1988; Polo-Cavia et al. 2012) or used similar substrates in the past. Allowing turtles to acclimate to rafts before rather than during surveillance with camera traps might avoid effects of Day, especially if novelty of rafts contributed to differences in behavior.

Some studies have demonstrated strong relationships between ambient conditions and basking behavior (e.g., Crawford et al. 1983). Others have not (Kornilev 2008; Selman and Qualls 2011). In our study, environmental variables were uninformative except for a strong negative relationship between probability of capture and maximum air temperature the preceding day. We suspect this relationship was mediated by water temperature. In other words, atmospheric conditions (e.g., air temperature) on one day affected water temperature the next day, eliciting or suppressing basking activity by Sliders. Auth (1975) noted that atmospheric conditions (light intensity, mean air temperature, cloud cover) affected aerial basking by *T. s. scripta*, but he considered water temperature a more important variable.

Modern CMR analyses require large amounts of data for selection of appropriate models and outputs with reasonable precision. Ideally, probabilities of capture should exceed 0.1 for simple CMR models, 0.2 for moderately complex models, and 0.3 for those that include several sources of heterogeneity (Otis et al. 1978; Pollock 1981; Harmsen et al. 2011). In our study, camera traps yielded adequate probabilities of capture, model selection was relatively straightforward and all closed-population CMR models produced point estimates within 27% of the true value. Model averaging improved accuracy and precision.

Our study was the second attempt to validate methods of capture by comparing estimates of abundance from CMR to a known population of freshwater turtles. We fared better than Koper and Brooks (1998), who reported violations of assumptions about equal catchability caused inaccurate and imprecise estimates of abundance when collecting *Chrysemys picta* by hand, basking trap, hoop net and all methods combined. Part of our success can be attributed to innovations in CMR analyses that allow probabilities of capture to differ over time and among individuals if sources of variability are identified and modeled (Chao and Huggins 2005).

Our study design limited sources of variability that could prove important when estimating probabilities of detection under a broader range of conditions. For example, Auth (1975) reported *T. s. scripta* with CL < 10 cm (N = 11) basked more frequently and were more likely to lose marks applied to carapaces than larger individuals. Our study did not evaluate seasonal differences in aerial basking activity of Sliders (e.g., Spotila et al. 1990). Grayson and Dorcas (2004) reported seasonal patterns of basking related to water temperature, which they monitored with data-loggers to prevent disturbance of basking turtles by observers.

Our study validated camera traps as a tool for estimating abundance of adult Sliders with CMR (Rodda 2012). Value of the method for other studies will depend on their objectives, designs, target species and logistical constraints. Some overarching drawbacks include possibility of theft or tampering (Karanth et al. 2004) and need to re-apply marks during multi-year studies (Bayless 1975). Advantages include detection of biases caused by primary capture methods and collection of data during additional sampling sessions with little disturbance or extra cost. Camera traps might be well suited for spatially explicit CMR study designs (Nichols et al. 2011) and studies of meta-populations that occur in large or widely dispersed patches of habitat because data can be collected simultaneously, consistently and frugally at multiple sites compared to manual methods alone.

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