



Original Article

A Generalized Method to Determine Detectability of Rare and Cryptic Species Using the Ornate Box Turtle as a Model

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ABSTRACT Estimates regarding population parameters are often based on data from surveys. To ensure that such estimates are as accurate as possible, it is important to know the detectability resulting from the particular survey method used. We used radiotelemetry to measure detectability of ornate box turtles (*Terrapene ornata*), using visual-encounter surveys in a sand prairie in northwestern Illinois, USA. We found that the overall detection probability of visual-encounter surveys was 0.03, and our high frequency of nondetection was due to a failure to detect visible turtles rather than turtles being underground or hidden in dense vegetation. Despite the substantial population density at our study site, visual-encounter surveys failed to detect box turtles on most visits, which resulted in a prohibitively high number of surveys that would be required to accurately estimate population size or to infer absence of the species from a site. Our method of using radiotelemetry to measure detection probability of a survey method could be easily applied to other small, cryptic, or rare species. However, our low detection probability and high frequency of nondetections recommend against use of visual-encounter surveys alone in estimating population parameters for ornate box turtles. © 2011 The Wildlife Society.

KEY WORDS detectability, detection probability, Illinois, mark–recapture, ornate box turtle, radiotelemetry, sand prairie, *Terrapene ornata*, visual-encounter survey.

Managers often rely on wildlife survey data to identify management techniques to conserve wildlife and habitat. For example, presence–absence survey data are included in occupancy models to assess habitat use patterns and to model population dynamics (e.g., MacKenzie et al. 2006), while count–survey data can be used to estimate trends in population growth (e.g., Peterjohn et al. 1995). Many models based on occupancy or count data make the assumption that detection probability is 1 (i.e., if a species is present at a site, it will be detected). Although detection probabilities for nearly all species are certain to be <1, population models based on count–survey data often fail to incorporate correction factors for species detectability. Failure to detect species at occupied

sites, and failure to correct for detectability during count surveys, will likely lead to poorly constructed habitat and population models (Gu and Swihart 2004) and could result in poorly informed management and conservation decisions. For survey data to be truly informative, it is critical to know the detection probability of the species in question, in the habitat under study, and with the method(s) used to survey the species.

Study designs that allow the direct determination of detection probability will result in more precise estimates of population size than designs that rely on an index of population size (Lancia et al. 2005). One way of directly determining detection probability is to combine a method for estimating population size (such as a visual-encounter survey or aerial survey) with a method in which exact population size is known (such as radiotelemetry or use of a captive population). By determining the proportion of a known population detected during a survey, the detection probability associated with that survey method can be estimated.

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Detectability studies combining a standard survey technique with radiotelemetry have the advantage of meeting the assumption of geographic closure because, in every survey period, the number and identity of radiomarked individuals both in and out of the survey area will be precisely known, thereby ensuring that the exact value for the number of individuals present and available for detection during the survey is known (Miller et al. 1997).

Studies using radiotelemetry to test the precision of standard survey methods have traditionally been conducted on large mammals (e.g., Floyd et al. 1979, Packard et al. 1985, Hein and Andelt 1995) because advances in radiotelemetry technology have only recently allowed very small animals to be radiomarked. Underestimation of both occupancy and abundance are likely to be particularly problematic for species that are small, cryptic, or rare, traits characteristic of many reptile species. Failure to detect a rare or cryptic species when it is actually present may be substantial (Gu and Swihart 2004), and for such species it is especially important to acquire accurate detection probabilities for inclusion in occupancy and population models to correct for survey bias. Unfortunately, many studies of amphibians and reptiles continue to use a count statistic or mark–recapture return rate uncorrected for detection probability (Mazarolle et al. 2007). Several studies on reptiles have estimated relatively low detection probabilities (0.06–0.35 for the grass snake [*Natrix natrix*; Kéry 2002]; 0.07–0.12 for juvenile geometric tortoises [*Pseudemys geometricus*; Gardner et al. 1999]), as well as detection probabilities strongly affected by observer bias (Anderson et al. 2001), habitat type (Gardner et al. 1999), and time of year (Kéry 2002). These studies clearly illustrate the importance of adequately accounting for detectability in occupancy and population models for reptiles in order to make sound management and conservation decisions.

The ornate box turtle (*Terrapene ornata*), exemplifies the importance of accounting for detectability when determining conservation strategies. This species inhabits sand prairies in the central and southern United States and northern Mexico (Ernst and Lovich 2009), but is declining in many parts of its range due to habitat loss (Doroff and Keith 1990, Converse et al. 2005) and collection for the pet trade (U.S. Fish and Wildlife Service 1995). In addition to the rarity of this species in many areas, ornate box turtles are difficult to observe. They are cryptically colored, spend considerable time underground (Nieuwolt 1996), and spend much of their time above ground inactive in dense vegetation or forms (a shallow depression excavated in the soil or at the base of a grass tussock; Converse et al. 2002). Moreover, box turtle activity tends to be confined to early morning or evening (Nieuwolt 1996, Converse and Savidge 2003), including nesting, which generally takes place after dark (Flitz and Mullin 2006). Mating also occurs secretly, with copulating pairs often hidden in dense vegetation (J. M. Refsnider, personal observation). In the northern portion of their range, ornate box turtles spend ≥ 4 months/yr overwintering underground (Converse et al. 2002). In combination, box turtles' rarity and cryptic nature make them difficult to observe using survey methods such as line or distance transects.

Ornate box turtles were designated as Threatened in Illinois, USA in 2009 (Illinois Endangered Species Protection Board 2009) and are of high conservation concern in that state. In northwestern Illinois, management efforts at sites currently supporting viable populations of ornate box turtles include periodic prescribed burns that remove encroaching woody vegetation and thereby preserve native plant communities. Specifically pertaining to ornate box turtle conservation is the potential for translocating adults or head-started juveniles from populated sites to sites from which the species is believed to have been extirpated. To evaluate the efficacy of a potential head-start–translocation program, it is important to accurately estimate the size of the source population to determine how removal of adults or juveniles may affect population demography. Similarly, because translocation is a drastic measure that has not been widely successful for reptiles in general (Dodd and Seigel 1991, but see Germano and Bishop 2009) or box turtles specifically (Doroff and Keith 1990), it is critical to assess the necessity of translocation by first determining whether any individuals remain at sites from which the species is thought to be extirpated. If individuals are observed at such sites, population estimates should be attempted; if no individuals are observed, it is important to know whether the lack of observations is likely due to nondetection of present individuals, or true absence of the species. Thus, in order to make informed decisions regarding translocation as a management strategy for ornate box turtles, both presence–absence data and abundance data from the translocation site(s), as well as abundance data from the source population, are required.

In northwestern Illinois, ornate box turtle populations in many sand prairie sites began to decline in the 1940s due to construction activities and heavy grazing by cattle. Some of these sites are being considered for future translocations, and extensive survey efforts are underway to determine whether remnant populations exist. Because population parameters for both source and translocation sites are being determined primarily using visual-encounter survey data, it is critical to ensure that such data are as accurate as possible. Visual-encounter surveys are often used to detect reptiles (e.g., Burbrink et al. 1998, Doan and Arriaga 2002), including ornate box turtles (e.g., Kuo and Janzen 2004), as well as other small and cryptic animals (e.g., aquatic anuran larvae: Sewell et al. 2010; leaf litter salamanders: Pough et al. 1987; ground-nesting songbirds: Martin and Geupel 1993). Visual-encounter surveys are conducted by observers who move through a designated area and visually search for individuals of the target species, with data often expressed as individuals encountered per person-hours spent searching (Crump and Scott 1994). The effectiveness of visual-encounter surveys can vary widely, however, depending on factors such as observer experience and training, habitat characteristics, and vegetation density within the survey area (e.g., Packard et al. 1985, Gardner et al. 1999, Anderson et al. 2001).

The primary objective of our study was to directly measure visual-encounter survey detectability of ornate box turtles. To do so, we compared detection of turtles during a series of

surveys with the number of turtles known to be in the survey area via simultaneous (but independent) radiotelemetry of radiomarked individuals. Our secondary objectives were to 1) account for nondetection of individuals that were present during visual-encounter surveys; 2) estimate the number of person-hours required to detect a given proportion of the population; and 3) estimate the number of unsuccessful visual-encounter surveys required to infer the absence of ornate box turtles at a site. Studies that directly measure detectability of reptile species are rare, and although our estimates of detection probability may not be directly transferable to other species in other habitat types, our method for determining detection probability is relatively simple and should be applicable to other small, cryptic, or rare species for which surveys are used to estimate population parameters.

STUDY AREA

Our study site was a segment of native sand prairie habitat along the Mississippi River in northwestern Illinois. In addition to several open sand blowouts, the dominant vegetation in the study site was needlegrass (*Stipa* sp.); other common species included prickly pear cactus (*Opuntia humifusa*), skunkbrush (*Rhus aromatica*), and Ohio spiderwort (*Tradescantia obiensis*). A mark-recapture study of the ornate box turtle population at this site has taken place since 1990 (Bowen et al. 2004); thus, we have a detailed capture history for many individual turtles. The survey area was a 14-ha portion of a larger sand prairie (Fig. 1) and individual box turtles traveled in and out of the survey area on a daily and seasonal basis (J. M. Refsnider and J. T. Strickland,

unpublished data); thus, the survey area was not geographically closed. The survey area was delineated on the south and east by a road and a recreational trail, respectively, and on the west by the Mississippi River; the north end was determined arbitrarily and was marked so that surveyors knew where to end transects.

METHODS

We measured detection probability of adult ornate box turtles at this site using the marked subsample method described by Lancia et al. (2005). We conducted a series of 8 visual-encounter surveys between 9 and 24 June 2010. During each survey, observers walked through the survey area following parallel transects, while scanning the ground for ornate box turtles and other reptiles present at the site. We made one pass through the survey area during each survey period, with observers spaced approximately equal distances apart; thus, in surveys with more observers, surveyors were spaced closer together (approx. 3–5 m) and, therefore, more total area along transect lines was surveyed than in surveys with fewer observers (approx. 6–8 m between observers). All surveys were conducted between 0700 and 1100 hours on precipitation-free days and lasted for 1–2 hr. The numbers of observers and person-hours were recorded for each survey. The entire survey area was walked during each visual-encounter survey, with the exception of the approximately 10-m-wide riparian zone, which was not surveyed due to dense stands of poison ivy (*Toxicodendron radicans*). We identified any radiomarked ornate box turtles (see below) observed on visual-encounter surveys, recorded their location

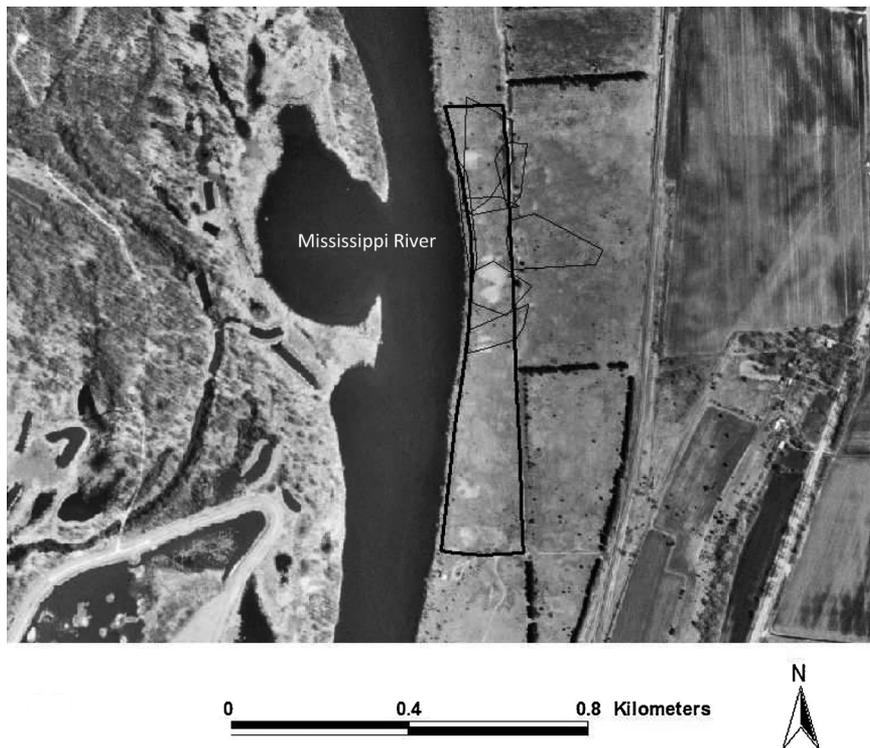


Figure 1. Ornate box turtle (*Terrapene ornata*) study site in northwestern Illinois, USA. The visual-encounter survey area is delineated by the thick outline, and the minimum convex polygon home ranges of 7 representative ornate box turtles included in this study are outlined by the thin lines (home range data are from May to Jun 2008; J. M. Refsnider, unpublished data).

using a handheld Global Positioning System unit and noted their activity, whether they were above or below ground, and the vegetation type and density (dense = no ground surface visible; moderate density = <50% ground surface visible; sparse = ≥50% of ground surface visible) in a 1-m-diameter circle centered around the turtle. The same data were recorded for any unmarked ornate box turtles observed during visual-encounter surveys.

For a separate study on the habitat use and movement patterns of this population, 27 adult ornate box turtles in the vicinity of the survey area were marked with radiotransmitters (R1670; Advanced Telemetry Systems, Isanti, MN) glued to the top of the carapace. Many of these turtles have been radiotracked for up to 2 yr and their activity centers and home ranges are known; most of these turtles' home ranges at least partially overlap the visual-encounter survey area (Fig. 1; J. M. Refsnider, unpublished data). To measure the accuracy of visual-encounter surveys for detecting ornate box turtles, J. M. Refsnider radiotracked all radiomarked box turtles while each visual-encounter survey was being conducted. The radiomarked turtles provided the marked subsample of the study population, and radiotracking these turtles during the survey period provided precise knowledge of how many radiomarked box turtles were present within the survey area and, thus, available for detection. Turtles determined by preliminary triangulation to be outside the survey area were not precisely located. We precisely located all radiomarked turtles within the survey area, and recorded the location, activity, above- or below-ground status, and vegetation type and density, as described for the visual-encounter surveys. To ensure that the visual-encounter surveyors were blind to the location of radiomarked individuals as well as to the number of radiomarked individuals present in the survey area on any given day, radiotracking was always conducted out of the sight of the visual-encounter surveyors and the surveyors were not informed about the location or number of radiomarked turtles observed during radiotelemetry until the entire series of surveys was completed. Animals were handled in accordance with Iowa State University's Institutional Animal Care and Use Committee (protocol no. 3-09-6705-J).

We calculated ornate box turtle detection probability, β_i , for each of the 8 survey periods using equation 12 in Lancia et al. (2005):

$$\beta_i = \frac{m}{n_1}$$

where m is the number of radiomarked box turtles observed during each visual-encounter survey and n_1 is the number of radiomarked box turtles present in the survey area at the time of each visual-encounter survey as confirmed by concurrent radiotelemetry. We used the average detection probability over the 8 survey periods as the overall detection probability, $\hat{\beta}$.

We used the immigration-emigration estimator in NOREMARK (White 1996) to estimate the population size in the survey area. This program incorporates the total

number of marked animals, the number of marked animals within the survey area during each survey, and the number of both marked and unmarked animals observed during each survey. The population size is then estimated using the joint hypergeometric maximum-likelihood estimator, which typically results in a smaller confidence interval than a Lincoln-Petersen estimate (White and Garrott 1990). We used the resulting population estimate, and our calculation of ornate box turtles observed per person-hour, to determine the number of person-hours that would be required to detect 10%, 30%, and 50% of the box turtle population within the survey area.

Finally, we estimated the minimum number of unsuccessful surveys, N_{min} (i.e., visual-encounter surveys during which no ornate box turtles are observed), necessary to infer the absence of the species from the site using equation (4) in Kéry (2002)

$$N_{min} = \frac{\log \alpha}{\log(1-p)}$$

where α is 0.05 and p is equivalent to Lancia et al.'s (2005) $\hat{\beta}$.

RESULTS

During each of the 8 visual-encounter surveys, 21–23 radiomarked ornate box turtles were located via telemetry in the vicinity of the survey area, and 4–11 ($\bar{x} = 7.4$) of these turtles were confirmed via telemetry to be within the survey area and, therefore, available for detection, during the visual-encounter surveys (Table 1). Although unmarked individuals were observed during 4 of the 8 visual-encounter surveys, only one radiomarked box turtle was observed during the entire series of 8 visual-encounter surveys. This resulted in a detection probability of 0.25 for the single survey period in which the marked turtle was observed, 0 for the other 7 survey periods, and an overall detection probability of 0.03 (Table 1). All box turtles detected in this study, regardless of method, were adults (straight carapace lengths of 91–117 mm); thus, our results are not biased due to the inclusion of smaller, more cryptic juveniles.

Using radiotelemetry, we confirmed the activity of 76.2% of all radiomarked box turtles within the survey area throughout this study. Turtles without visual confirmation were usually tracked to extremely dense stands of tall grass where they could not be precisely located without disturbing the turtle. These turtles were likely on the ground surface but hidden inside the base of grass tussocks (J. M. Refsnider, unpublished data). Of the turtles for which we had visual confirmation of activity, all but one (97.8%) were on the ground surface rather than underground (Fig. 2). Of all above-ground turtles, 36.4% were resting in or under dense vegetation, and 11.4% were partially or completely hidden in forms under grass tussocks. The remaining 52.3% of above-ground turtles were located in moderately or sparsely vegetated patches (Fig. 3). The single radiomarked box turtle observed during visual-encounter surveys was observed basking in grass of moderate density. Thus, the majority of undetected box turtles within the survey area should have

Table 1. Ornate box turtles (*Terrapene ornata*) observed using visual-encounter surveys (VES) in northwestern Illinois, USA in June 2010. The number of turtles in the survey area during each survey period was confirmed using simultaneous but independent radiotelemetry. Detection probability was calculated using equation 12 in Lancia et al. (2005).

Survey date	No. marked turtles radiotracked	No. marked turtles in survey area (n_1)	No. unmarked turtles seen on VES	No. marked turtles seen on VES (m)	Detection $P(\beta)$
9 Jun	22	4	1	1	0.25
11 Jun	21	6	1	0	0
13 Jun	23	6	0	0	0
15 Jun	23	9	1	0	0
16 Jun	22	7	1	0	0
19 Jun	23	11	0	0	0
21 Jun	22	8	0	0	0
24 Jun	21	8	0	0	0
					$\bar{x} = 0.031$

been visible to the observers conducting the visual-encounter surveys.

The immigration–emigration estimator in NOREMARK produced a population estimate for the 14-ha survey area of 89 individuals, resulting in a population density of 6.4 turtles/ha. Due to the low proportion of marked animals observed during each visual-encounter survey, however, the 95% confidence interval for this population estimate was 28–1,360 individuals. The daily population estimate of 29.4 individuals had a narrower confidence interval of 9.6–448 individuals.

Visual-encounter surveys lasted from 1 hr to 2 hr ($\bar{x} = 1.25$ hr), were conducted with 5–8 ($\bar{x} = 6$) observers, and resulted in 5–16 ($\bar{x} = 7.8$) person-hours/survey (Table 2). Because only 1–2 ($\bar{x} = 0.63$) total box turtles were observed during any given survey, this resulted in a total catch per unit effort (CPUE) of 0.08 turtles/person-hour. Using the population estimate of 89 individuals and the CPUE estimate of 0.08 turtles/person-hour, we estimated the number of person-hours needed to detect 10%, 30%, and 50% of the population using visual-encounter surveys. Approximately 111 person-hours would be required to detect 10% of the box turtles within the survey area, 334 person-hours to detect 30%, and 556 person-hours to detect 50%. If each visual-encounter survey totaled 10 person-hours, approximately 11 visual-encounter surveys would be required

to detect 10%, 33 surveys to detect 30%, and 56 surveys to detect 50% of the population.

Finally, we calculated the number of unsuccessful visual-encounter surveys that would be necessary before we could infer the absence of the species from the survey area with 95% confidence (assuming equivalent effort and conditions to the surveys conducted here). With $\alpha = 0.05$ and using our detection probability of 0.03, we estimate that approximately 98.4 unsuccessful visual-encounter surveys would be necessary to infer the absence of ornate box turtles from the survey area.

DISCUSSION

Management and conservation strategies are often based on estimates of parameters such as population size or models of habitat occupancy (e.g., Gu and Swihart 2004). To ensure that such strategies are based on the most accurate parameter estimates possible, it is important to know the detection probability of the study species, in the habitat(s) being managed, and with the method(s) being used to make the parameter estimates. Radiotracking a subsample of a population allowed us to measure the detectability of a rare species using the visual-encounter survey method and, thereby, to evaluate the efficacy of this survey method for estimating population size and assessing species presence at a surveyed site.

Our extremely low estimate (0.03) of detection probability for ornate box turtles suggests that visual-encounter surveying is not an effective method for estimating population size of this species, even in situations where population density is relatively high. Overall, only 1.7% of all turtles within our survey area were detected during visual-encounter surveys. Although ornate box turtles spend considerable time underground (Nieuwolt 1996), during 45 direct observations of radiomarked turtles in this study, only one turtle was underground. Therefore, turtles being underground and out of surveyors' sight did not contribute to the high rate of non-detection in this study. Moreover, only 4.3% of turtles that were above ground, not in forms, and in sparse to moderate vegetation, were detected during surveys. Together, these results suggest that ornate box turtles, even when on the ground surface and seemingly readily visible, are extremely cryptic and difficult to observe visually.

We can make several recommendations that may improve detectability when using visual-encounter surveys. First, it is

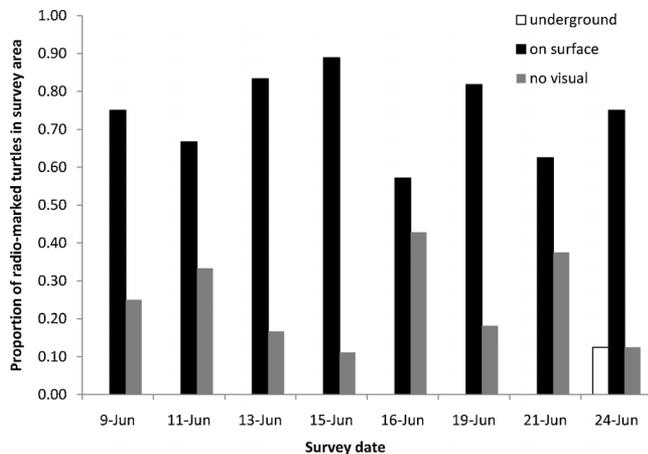


Figure 2. Proportion of radiomarked ornate box turtles (*Terrapene ornata*) confirmed via radiotelemetry to be within the survey area and underground, above ground, or not visually confirmed, during 8 visual encounter surveys in June 2010 in northwestern Illinois.

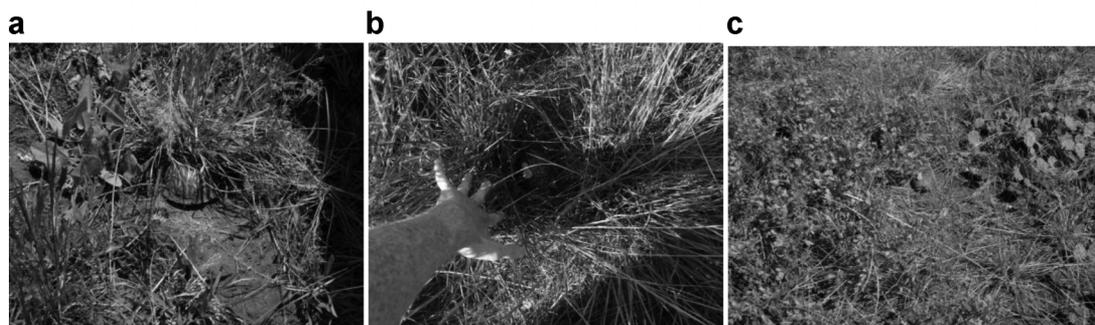
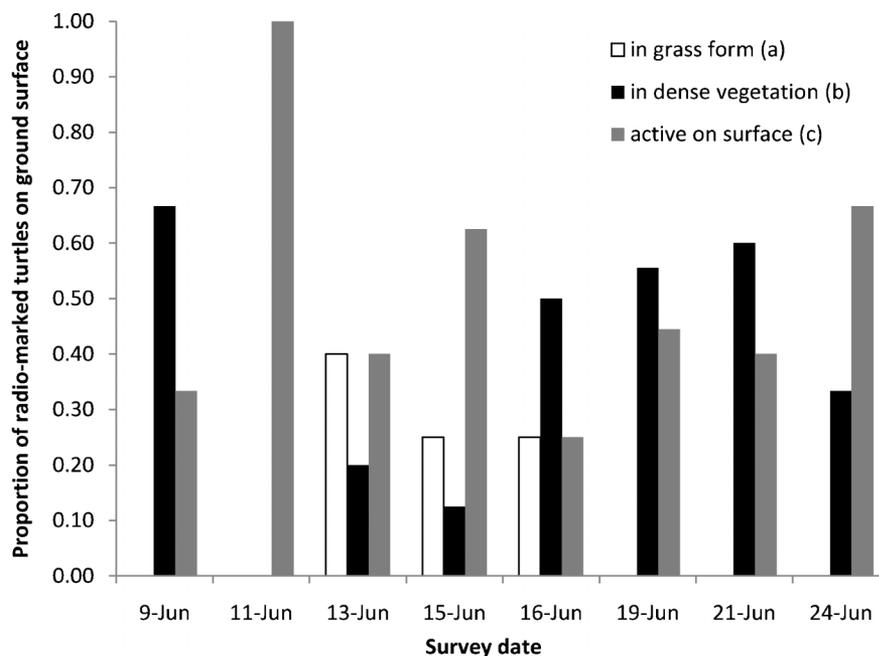


Figure 3. Proportion of radiomarked ornate box turtles (*Terrapene ornata*) confirmed via radiotelemetry to be above ground within the survey area and inactive in a grass form (a), inactive in dense vegetation (but not in a form; b), or active and visible on the ground surface (c), during 8 visual encounter surveys in June 2010 in northwestern Illinois.

likely that any given ornate box turtle is only visible from a narrow angle, and observers approaching from most directions may have their views of the turtle obscured by ground vegetation. Turtles are also unlikely to be visible far from an observer's transect line. Detectability may be improved by encouraging surveyors to periodically turn around and look behind them for turtles on their transect line that they may have passed. Second, surveyor experience may affect detectability (e.g., Sewell et al. 2010), and many of our surveyors had little experience surveying for ornate box turtles and may not have had time to develop an effective search image during

the study period. Increasing search effort by increasing the number of surveyors may also improve detectability. Third, surveyors in our study were searching for all reptiles along their transect lines, not solely for ornate box turtles, and lack of a search image for a single target may decrease detectability for that target. Studies in which visual-encounter surveys are used in assessing species richness or in detecting the presence of multiple species (e.g., Burbrink et al. 1998, Doan and Arriaga 2002) may fail to accurately estimate the density of any individual species because the survey effort is focused too generally. Finally, time of year is likely to affect

Table 2. Search effort for ornate box turtles using visual-encounter surveys in northwestern Illinois, USA in June 2010. All surveys were conducted between 0700 hour and 1100 hour on precipitation-free mornings.

Survey date	Survey duration (hr)	No. observers	No. person-hours	Total no. turtles observed
9 Jun	1	6	6	2
11 Jun	1	5	5	1
13 Jun	1	5	5	0
15 Jun	1.25	6	7.5	1
16 Jun	1	5	5	1
19 Jun	2	8	16	0
21 Jun	1.25	6	7.5	0
24 Jun	1.5	7	10.5	0
Mean	1.25	6	7.81	0.625

detectability of this species. Detectability of ornate box turtles is likely to be slightly higher in May, when turtles are generally more active and females spend considerable time basking in open sites as their eggs develop, and before vegetation has become more dense (J. M. Refsnider and J. T. Strickland, unpublished data). Detectability probably becomes lower later in the summer as temperatures rise and turtles become inactive, either sheltering underground or in dense vegetation (e.g., Converse and Savidge 2003).

For any survey method, a high frequency of nondetections makes it difficult to estimate population size, because the product of 0 observations and even a high detection probability is still 0. We estimated the population density in our survey area to be 6.4 turtles/ha, but despite this high density, 7 of our 8 surveys resulted in nondetection of the species. Our high frequency of nondetections combined with extremely low detectability indicates that visual-encounter surveys alone are inadequate for assessing ornate box turtle population status or even species presence, with the possible exception of very long-term mark-recapture studies (e.g., Bowen et al. 2004). Other methods that rely less on visual cues are likely to be much more successful, particularly in short-term studies lasting only 1 yr or a few years. One possible alternative is to use dogs trained to find box turtles. In May 2010, search teams made up of both human observers and 3–5 Boykin spaniels surveyed 7 sand prairie sites in northwestern Illinois. Over 10 days, these teams located 97 box turtles, of which 90 were found by dogs and only 7 by humans (J. T. Strickland, unpublished data). Thus, a combination of multiple survey methods may increase overall detectability of this species (e.g., Sewell et al. 2010).

Our population estimate of 89 turtles in the survey area is in close agreement with earlier estimates from this site (Bowen et al. 2004). However, our estimate resulted from a study of much shorter duration: our estimate from a single year incorporated the number of marked individuals known to be within the survey area via radiotelemetry, whereas Bowen et al.'s (2004) analyses included 8 yr of mark-recapture data. When dealing with conservation of rare species, improving the accuracy of shorter term methods is often preferable to initiating long-term studies that may take years to yield results. Nonetheless, the low detectability of our marked turtles resulted in an extremely wide 95% confidence interval around our population estimate. Smaller confidence intervals and more precise population estimates could have been achieved if a higher proportion of the total population had been observed during the surveys (Hein and Andelt 1995). However, we estimated that 334 person-hours, or approximately 33 of our surveys, would be required to detect even 30% of our study population. Because ornate box turtles are most active and, therefore, most detectable during May and June (e.g., Bernstein et al. 2007), it would be difficult to conduct enough surveys within that time frame to adequately estimate population size. Similarly, because surveys conducted in July or August are unlikely to detect ornate box turtles at all, because the turtles become inactive during hot weather (Converse and Savidge 2003), surveys intended to demonstrate presence or absence of the species should also be

conducted during May and June. We determined that 98 surveys would be required to infer the absence of this species from our study site, and the time frame within which ornate box turtles are active and detectable is too short to allow this number of surveys to be conducted in a year. Detectability is also likely to differ depending on vegetation characteristics. Areas with generally sparse ground vegetation would likely have higher detection probability and, therefore, fewer surveys would be required to infer absence of ornate box turtles, whereas sites with extensive sedge tussocks or thick raspberry (*Rubus occidentalis*) patches, such as our study site, would have lower detection probability and would require more surveys to infer absence.

Interestingly, in addition to the radiomarked turtles within the survey area, during each survey 7–10 ($\bar{x} = 8.75$) marked turtles were radiotracked to the narrow riparian zone immediately adjacent to the survey area. In 6 of the 8 surveys, more radiomarked turtles were located in this riparian zone than in the much larger survey area. The high number of turtles found in this habitat suggests that the riparian zone is an important component of ornate box turtle habitat. However, the vegetation in the riparian zone is extremely dense with ground cover dominated by tall grass, poison ivy, and thick stands of raspberry bramble; therefore, even if visual-encounter surveys were conducted through the riparian zone, ornate box turtles would be extremely unlikely to be detected. Again, dogs trained to locate turtles via olfaction may be useful in detecting turtles within the riparian zone.

MANAGEMENT IMPLICATIONS

We used radiotelemetry to determine the detectability of ornate box turtles when sampled using visual-encounter surveys. Incorporating radiotelemetry into our methods allowed us to directly measure detection probability and, thus, assess the utility of our sampling method for estimating population size and making inferences about occupancy. We found that our sampling method results in extremely low detection probability (0.03) and would require a prohibitively large number of surveys to achieve modest precision in population estimates and to infer the absence of this species from a site. We encourage other researchers to measure detectability using their survey methods to ensure awareness of the limitations of both their sampling methods and the population estimates resulting from those methods; it is also likely that detectability differs throughout the year as animals shift their activity levels and habitat use and, therefore, differences in detectability across time and space should also be considered. Our method of using radiotelemetry to measure detectability of a survey method could be easily applied to other small, cryptic, or rare species. However, our low detection probability and high frequency of nondetections recommend against use of visual-encounter surveys as the sole method of sampling ornate box turtle populations. In particular, management activities such as prescribed burns could cause high mortality if conducted at a time of year when turtles are sheltered in grass tussocks, but would likely be harmless if conducted instead when

turtles were buried underground. However, based on our results, visual-encounter surveys conducted before such a prescribed burn in either situation would fail to detect box turtles, which could have serious consequences in the former situation when turtles were, in fact, above ground and vulnerable to fire. Instead of visual-encounter surveys, we recommend use of multiple survey methods, such as trained dogs, for assessing presence-absence and population size of ornate box turtles.

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LITERATURE CITED

- Anderson, D. R., K. P. Burnham, B. C. Lubow, L. Thomas, P. S. Corn, P. A. Medica, and R. W. Marlow. 2001. Field trials of line transect methods applied to estimation of desert tortoise abundance. *Journal of Wildlife Management* 65:583–597.
- Bernstein, N. P., R. J. Richtsmeier, R. W. Black, and B. R. Montgomery. 2007. Home range and philopatry in the ornate box turtle, *Terrapene ornata ornata*, in Iowa. *American Midland Naturalist* 157:162–174.
- Bowen, K. D., P. L. Colbert, and F. J. Janzen. 2004. Survival and recruitment in a human-impacted population of ornate box turtles, *Terrapene ornata*, with recommendations for conservation and management. *Journal of Herpetology* 38:562–568.
- Burbink, F. T., C. A. Phillips, and E. J. Heske. 1998. A riparian zone in southern Illinois as a potential dispersal corridor for reptiles and amphibians. *Biological Conservation* 86:107–115.
- Converse, S. J., J. B. Iverson, and J. A. Savidge. 2002. Activity, reproduction and overwintering behavior of ornate box turtles (*Terrapene ornata ornata*) in the Nebraska Sandhills. *American Midland Naturalist* 148:416–422.
- Converse, S. J., J. B. Iverson, and J. A. Savidge. 2005. Demographics of an ornate box turtle population experiencing minimal human-induced disturbances. *Ecological Applications* 15:2171–2179.
- Converse, S. J., and J. A. Savidge. 2003. Ambient temperature, activity, and microhabitat use by ornate box turtles (*Terrapene ornata ornata*). *Journal of Herpetology* 37:665–670.
- Crump, M. L., and N. J. Scott, Jr. 1994. Standard techniques for inventory and monitoring: visual encounter survey. Pages 85–92 in W. R. Heyer, M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster, editors. *Measuring and monitoring biological diversity: standard methods for amphibians*. Smithsonian Institution Press, Washington, D.C., USA.
- Doan, T. M., and W. A. Arriaga. 2002. Microgeographic variation in species composition of the herpetofaunal communities of Tambopata Region, Peru. *Biotropica* 34:101–117.
- Dodd, C. K., Jr., and R. A. Seigel. 1991. Relocation, repatriation, and translocation of amphibians and reptiles: are they conservation strategies that work? *Herpetologica* 47:336–350.
- Doroff, A. M., and L. B. Keith. 1990. Demography and ecology of an ornate box turtle (*Terrapene ornata*) population in south-central Wisconsin. *Copeia* 1990:387–399.
- Ernst, C. H., and J. E. Lovich. 2009. *Turtles of the United States and Canada*. Second edition. Johns Hopkins University Press, Baltimore, Maryland, USA.
- Flitz, B. A., and S. J. Mullin. 2006. Nest-site selection in the eastern box turtle, *Terrapene carolina carolina*, in Illinois. *Chelonian Conservation and Biology* 5:309–312.
- Floyd, T. J., L. D. Mech, and M. E. Nelson. 1979. An improved method of censusing deer in deciduous-coniferous forests. *Journal of Wildlife Management* 43:258–261.
- Gardner, S., E. H. W. Baard, and N. J. le Roux. 1999. Estimating the detection probability of the geometric tortoise. *South African Journal of Wildlife Research* 29:62–71.
- Germano, J. M., and P. J. Bishop. 2009. Suitability of amphibians and reptiles for translocation. *Conservation Biology* 23:7–15.
- Gu, W., and R. K. Swihart. 2004. Absent or undetected? Effects of non-detection of species occurrence on wildlife-habitat models. *Biological Conservation* 116:195–203.
- Hein, E. W., and W. F. Andelt. 1995. Estimating coyote density from mark-resight surveys. *Journal of Wildlife Management* 59:164–169.
- Illinois Endangered Species Protection Board. 2009. Checklist of endangered and threatened animals and plants of Illinois. Illinois Endangered Species Protection Board, Springfield, USA.
- Kéry, M. 2002. Inferring the absence of a species—a case study of snakes. *Journal of Wildlife Management* 66:330–338.
- Kuo, C., and F. J. Janzen. 2004. Genetic effects of a persistent bottleneck on a natural population of ornate box turtles (*Terrapene ornata*). *Conservation Genetics* 5:425–437.
- Lancia, R. A., W. L. Kendall, K. H. Pollock, and J. D. Nichols. 2005. Estimating the number of animals in wildlife populations. Pages 106–153 in C. E. Braun, editor. *Techniques for wildlife investigations and management*. The Wildlife Society, Bethesda, Maryland, USA.
- MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. L. Bailey, and J. E. Hines. 2006. *Occupancy estimation and modeling*. Academic Press, San Diego, California, USA.
- Martin, T. E., and G. R. Geupel. 1993. Nest-monitoring plots: methods for locating nests and monitoring success. *Journal of Field Ornithology* 64:507–519.
- Mazarolle, M. J., L. L. Bailey, W. L. Kendall, J. A. Royle, S. J. Converse, and J. D. Nichols. 2007. Making great leaps forward: accounting for detectability in herpetological field studies. *Journal of Herpetology* 41:672–689.
- Miller, S. D., G. C. White, R. A. Sellers, H. V. Reynolds, J. W. Schoen, K. Titus, V. G. Barnes, Jr., R. B. Smith, R. R. Nelson, W. B. Ballard, and C. C. Schwartz. 1997. Brown and black bear density estimation in Alaska using radiotelemetry and replicated mark-resight techniques. *Wildlife Monographs* 133.
- Nieuwolt, P. M. 1996. Movement, activity, and microhabitat selection in the western box turtle, *Terrapene ornata luteola*, in New Mexico. *Herpetologica* 52:487–495.
- Packard, J. M., R. C. Summers, and L. B. Barnes. 1985. Variation of visibility bias during aerial surveys of manatees. *Journal of Wildlife Management* 49:347–351.
- Peterjohn, B. G., J. R. Sauer, and C. S. Robbins. 1995. The North American Breeding Bird Survey and population trends of Neotropical migrant birds. Pages 3–39 in T. E. Martin and D. Finch, editors. *Neotropical migrant birds*. Cambridge University Press, New York, New York, USA.
- Pough, F. H., E. M. Smith, D. H. Rhodes, and A. Collazo. 1987. The abundance of salamanders in forest stands with different histories of disturbance. *Forest Ecology and Management* 20:1–9.
- Sewell, D., T. J. C. Beebe, and R. A. Griffiths. 2010. Optimising biodiversity assessments by volunteers: the application of occupancy modelling to large-scale amphibian surveys. *Biological Conservation* 143:2102–2110.
- U.S. Fish and Wildlife Service. 1995. Changes in the list of species in appendices to the Convention on International Trade in Endangered Species of Wild Fauna and Flora. *Federal Register* 60:73–80.
- White, G. C. 1996. NOREMARK: population estimation from mark-resighting surveys. <<http://welcome.warnercnr.colostate.edu/~gwhite/software.html>>. Accessed 21 Jul 2010.
- White, G. C., and R. A. Garrott. 1990. *Analysis of wildlife radio-tracking data*. Academic Press, New York, New York, USA.

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