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# USING REFERENCE SITES TO ACCOUNT FOR DETECTION PROBABILITY IN OCCUPANCY SURVEYS FOR FRESHWATER TURTLES

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***Abstract.*—Occupancy monitoring is particularly suitable for freshwater turtles because many species are relatively easy to detect due to their basking behavior. However, the probability of detecting turtles can be highly variable. There are sophisticated methods available for accounting for detection probability in occupancy monitoring, but standard sampling designs involve surveying all sites several times. Here I illustrate a method whereby an accessible reference site was repeatedly surveyed to obtain models of detection probability for three turtle species, and these models then applied to surveys of 23 water bodies in two nearby conservation reserves with similar habitat. The explanatory variables for detection probability included the date, time of day, and a set of environmental measurements designed to capture the key factors likely to affect basking. The estimated probability of detecting a species present at a water body ranged from 0.10–0.99 for Painted Turtles (*Chrysemys picta*), 0.03–0.84 for Blanding's Turtles (*Emydoidea blandingii*), and 0.01–0.60 for Snapping Turtles (*Chelydra serpentina*). All species were unlikely to be detected in overcast conditions, but the other factors affecting detection varied among species. I used Bayesian inference to estimate the posterior (post-survey) occupancy probabilities for water bodies where a species was not detected, illustrating that the surveys gave strong evidence of absence in some cases but provided little information in others. I believe the method could be usefully applied to regional monitoring programs for some turtle species, as the field surveying does not require specialist equipment or training, so lends itself to citizen science.**

*Key Words.*—Bayesian inference; Blanding's Turtle; Chelonia; detection probability; occupancy monitoring; OpenBUGS; Painted Turtle; Snapping Turtle

## INTRODUCTION

Ecological monitoring is conducted throughout the world, usually with the aim of improving management of species and ecosystems (Nichols and Williams 2006). There are many possible monitoring protocols, and these can vary greatly in intensity. For species monitoring, the least-intensive protocols involve collecting data on occupancy or presence-absence of species in defined sampling sites (MacKenzie et al. 2006). Because it is much easier to monitor occupancy than abundance or vital rates (survival and reproduction), occupancy monitoring is particularly suitable for broad-scale long-term programs such as the Amphibian Research and Monitoring Initiative (ARMI; Muths et al. 2005) and North American Amphibian Monitoring Program (NAAMP; Weir et al. 2014) of the U.S. Geological Survey. For many species, occupancy data can be collected without capturing animals or disturbing habitat, and without specialized equipment. Occupancy monitoring therefore lends itself to citizen science (Bonney et al. 2014), where data are collected by non-specialists.

Monitoring of freshwater turtles lends itself to citizen science because the animals are large and charismatic, and many species can be detected by visual observation due to their basking behavior. Broad-scale long-term monitoring programs are also particularly relevant to turtles, as their slow life histories make them vulnerable to long-term declines that are difficult to detect (Congdon et al. 1993, 1994). Consequently, many schemes have been developed where members of the public are encouraged to submit records of turtles. For example, in Ontario, Canada, records can be submitted to the Ontario Turtle Tally (www.torontozoo.com/adaptapond/TurtleTally.asp) and the Ontario Reptile and Amphibian Atlas Project (www.ontarionature.org/atlas).

Although such reporting schemes are valuable for engaging the public, data are difficult to interpret (Muths et al. 2005). The key limitation is that data are presence-only, i.e., they show where a species is present but not where it is absent. Although presence-only data can interpreted using methods such as maximum entropy modeling (MaxEnt), which generate pseudo-absences (Phillips et al. 2006), the more powerful approach is to collect data on absence as well as presence. However, it is rarely possible to be 100% confident that an undetected species is absent from a site. It is therefore necessary to account for detection probability when interpreting occupancy data, and sophisticated modeling methods are available for doing this (Muths et al. 2005; MacKenzie et al. 2006). Such methods have been successfully applied to turtle monitoring (Rizkalla and Swihart 2006; Cosentino et al. 2010; Guzy et al. 2013; Stokeld et al. 2014). However, the sampling designs used to date do not lend themselves to citizen science, as they have involved multiple surveys of all sites, and used trapping rather than visual observation.

The essential data requirements for occupancy modeling are that detection or non-detection is recorded for all sites surveyed, and that at least one site is surveyed repeatedly to obtain information on detection probability. Although the standard design is to survey all sites an equal number of times, the appropriate design for a particular monitoring program will depend on the objectives, the constraints, and the factors likely to affect detection (MacKenzie et al. 2006). For programs involving non-scientists, the sites are often chosen by participants, and it is unrealistic to expect them to be surveyed repeatedly, especially if sites are difficult to access. One approach could be to repeatedly survey one or more reference sites to obtain the information on detection probability.

For surveys of freshwater turtles, detection probability will vary over time (season and time of day) and with environmental variables affecting basking behavior (air temperature, water temperature, solar radiation; Boyer 1965; Crawford et al. 1983), so it is essential to model the effects of these factors and account for them when interpreting survey data. However, detection might otherwise be similar among sites if observers can get a clear view of well-defined basking habitat, so it may be reasonable to believe that information on detection probability can be extrapolated among sites. In this paper I illustrate how I used multiple surveys of a single reference site to account for detection probability when conducting visual occupancy surveys of Painted Turtles (*Chrysemys picta*), Blanding's Turtles (*Emydoidea blandingii*) and Snapping Turtles (*Chelydra serpentina*) in two conservation reserves.

## Materials and Methods

***Study area***.—The study area was in the Stanhope and Sherborne Townships of Haliburton County, south-central Ontario, Canada. This area is near the southern edge of the Canadian Shield, and has a high density of small lakes, ponds, and bogs. All lakes and ponds I surveyed were surrounded by mixed hardwood-coniferous forest. Except for bogs, which were excluded from the analysis, all sites I surveyed had good vantage points for observing all basking turtles, so it was reasonable to believe that sites would have similar detection probability under the same conditions.

The reference site (UTM 17T, E675105, N4991297) was a beaver pond on private land adjacent to Kushog Lake Road in Haliburton County, Ontario, Canada. It had a total surface area of 2.7 ha, but the basking habitat (where logs are found) was all on the eastern portion of the pond (about 0.90 ha). I selected this pond as the reference site because it was easily accessible and was known to have Blanding's Turtles as well as the more common Painted Turtles and Snapping Turtles.

The two reserves I surveyed were Clear Lake Conservation Reserve (CLCR), which is 12.7 km NNE of the reference site, and Dawson Ponds and Plastic Lake Conservation Reserve (DPPLCR), which is 12.5 km NNW of the reference site (Ontario Ministry of Natural Resources [OMNR] 2012). No previous turtle surveys had been collected in these reserves except for ad hoc observations (OMNR 2012). The CLCR was 1,307 ha, and had 28 water bodies ranging from 0.1 to 100 ha. I surveyed 17 of these, excluding water bodies that were particularly difficult to access as well as the two large (> 50 ha) lakes. The DPPLCR was 200 ha, and had six water bodies ranging from 0.1 to 32 ha, all of which I surveyed. Four of the 23 water bodies I surveyed had extensive bog mat that was likely to obscure basking turtles, so I excluded these from the analysis; however, I recorded the turtles seen in these bogs.

***Data collection***.—I surveyed the reference site 53 times between 4 May and 28 June 2013 (Appendix 1), the period I believed was best for observing turtles based on previous experience. I usually conducted these surveys daily, but I surveyed twice per day on four occasions to compensate for days I was away or it was raining (I did not make observations in the rain at any site). I chose survey times at random between 0800 and 1800. Each survey involved scanning the pond for 10 min with binoculars from a vantage point at the north end. This vantage point gave a good view of all basking habitat on the pond, but I scanned from two positions 10 m apart to ensure turtles were not obscured by vertical trunks of drowned trees. Although the vantage point could be approached with minimum disturbance, I always first checked the area near the vantage point from the adjacent forest to detect any turtles likely to be disturbed. Because I could see all basking habitat, I counted the number of turtles seen of each species rather than simply recording whether the species was seen or not. Such counts are not essential for modelling detection probability, but they allow stronger inference from the data and make it possible to account for the likely effects of turtle abundance on detection probability (see below).

For each survey, I recorded the date, time, air temperature (° C), water temperature (0.2 m depth, 1.2 m from shore), cloud cover (%), and whether it was noticeably windy (yes or no). I converted the cloud cover scores to three categories (≤ 10%, 11–90%, or > 90%) that I believed I could judge consistently; a complete layer of thin cloud (shadows visible) was considered to be in the intermediate (11–90%) category. These explanatory variables were chosen to capture key factors likely to affect basking (Boyer 1965; Crawford et al. 1983), but were also chosen for their simplicity and lack of specialist equipment, meaning the scheme would be accessible to amateur observers.

I conducted rapid surveys of CLCR from 25–27 May 2013 and the DPPLCR on 18 June 2013 (Appendix 2). Some of the water bodies in these reserves had two or more discrete basking sites, meaning areas where emergent logs were present and sometimes small areas of bog mat. Other water bodies, such as beaver ponds, had a single basking site that often covered the whole pond. I considered there to be 36 discrete basking sites among 19 water bodies that could be surveyed using same method as for the reference pond. I surveyed each of the 36 sites separately, meaning I approached the site carefully by canoe or on foot, scanned for turtles for 10 min, and recorded the same variables as for the reference site. At the end of each survey, I used a GPS to record approximate boundaries around the area of water with the emergent logs, and I used these data to calculate the area of the site.

***Analysis***.—I first analyzed the data from the reference site to assess which factors affected the counts of each species. I used the resulting model to estimate the probability of each species being detected at the reference site under any conditions, and extrapolated this to the basking sites in the conservation reserves, accounting for differences in site area as well as the date, time, and conditions. I then used the detection probabilities for the individual sites to obtain the overall probability of the species being detected in each water body if it were present, and used this to infer probability of occupancy if the species was not seen.

I analyzed the count data for the reference site using log-linear modeling (Poisson error term, log link function). The full model took the form

$$n_j \sim P(\lambda_j) \qquad \text{Eq(1)}$$

where $n_j$ is the number seen on survey *j*, and

$$\log(\lambda_j) = \alpha + \beta_{Ta}T_a + \beta_{Tw}T_w + \beta_C C + \beta_O O + \beta_V V + \beta_{d1}d + \beta_{d2}d^2 + \beta_{t1}t + \beta_{t2}t^2 \qquad \text{Eq(2)}$$

where $T_a$ and $T_w$ are air and water temperature; *C* and *O* are binary variables indicating cloud cover ($C = 1$ if cover > 10%, $O = 1$ if cover > 90%); *V* indicates windiness ($V = 1$ if windy); *d* is the date (number of days since 30 April); *t* is the time of day (number of hours since 0800); and $\alpha$, $\beta_{Ta}$, $\beta_{Tw}$, $\beta_C$, $\beta_O$, $\beta_V$, $\beta_{d1}$, $\beta_{d2}$, $\beta_{t1}$ and $\beta_{t2}$ are the parameters estimated. I used the quadratic functions for time and date to allow flexibility in those relationships, i.e., to allow the maximum or minimum detection probability to occur at a midpoint rather than steadily increasing or decreasing. I removed parameters from the model if their 95% credible intervals included zero.

I then used the reduced model for each species to estimate its probability of being detected (if present) at each site in the conservation reserves. Because $n_j$ was taken to be Poisson distributed, the probability of a species being detected ($n_j > 0$) in a survey of the reference site was given by

$$P_j = 1 - \exp(-\lambda_j) \qquad \text{Eq(3)}$$

where $\lambda_j$ is the expected count based on date, time, and conditions.

When extrapolating to the conservation reserves, I assumed that the expected counts at occupied sites would be proportional to their areas of basking habitat. The detection probability for basking site i was therefore

$$P_i = 1 - \exp\left(-\lambda_j \frac{A_i}{A'}\right) \qquad \text{Eq(4)}$$

where $\lambda_j$ is the expected count for the date, time, and conditions if the area was the same as the reference site, and $A_j$ and $A'$ are the respective areas of the current site and the reference site. For water bodies with more than one basking site, the overall detection probability for the water body was given by

$$P = 1 - \prod(1 - P_i) \qquad \text{Eq(5)}$$

I then inferred occupancy probabilities using Bayes' theorem (MacKenzie et al. 2006: McCarthy 2007). Here the term probability refers to the relative belief in two hypotheses; that the species is present (hypothesis 1) or that it is absent (hypothesis 2). If a species was detected on a water body, it was then known to be present, meaning the posterior (post-survey) occupancy probability ($\psi_{condl}$) was 1. If it was not detected, its posterior occupancy probability was

$$\psi_{condl} = \frac{\psi(1-P)}{(1-\psi)+\psi(1-P)} \qquad \text{Eq(6)}$$

where $\psi$ represents the prior belief that that the water body would be occupied. In this case I had no prior belief about occupancy so I set $\psi$ to 0.5, representing complete ambiguity about the two hypotheses. The posterior probabilities ($\psi_{condl}$) therefore ranged from 0–0.5 if a species was not detected, with lower values showing greater confidence it was truly absent.

I used the Bayesian updating software OpenBUGS 3.2.3 (Spiegelhalter et al. 2014) for the analysis. The code (Appendix 3) integrated the analysis of the two data sets (Appendix 4), allowing variance and covariance in the detection parameters to be accounted for in the occupancy estimates. I used uninformative priors (mean = 0, tau = $10^{-6}$) for all detection parameters, and ran two chains to check for convergence. I checked the fit of the reduced models to the reference site data by examining model fit plots and by estimating overdispersion using parametric bootstrapping ($\hat{c}$ = observed deviance divided by mean deviance from simulated data sets).

## Results

On average I counted 1.43 Painted Turtles, 0.38 Blanding's Turtles, and 0.23 Snapping Turtles at the reference site per 10-min survey. Counts of all species were strongly reduced when cloud cover was > 90%, but it did not make a significant difference whether cloud cover was ≤ 10% or between 10–90% (Table 1). The other factors affecting counts differed among the three species (Table 1; Fig. 1–3). Painted Turtle counts increased with air temperature and decreased with water temperature, with the latter having the strongest effect. This means that Painted Turtles were most likely to be detected when water temperature was low, and air temperature was higher than water temperature (Fig. 1). In contrast, Blanding's Turtle counts were best predicted by the time of day, with detection highest in mid-afternoon (Fig. 2). Snapping Turtle counts were best predicted by water temperature and date, with detection highest on days with high water temperature in early June (Fig. 3). The reduced models all gave a good fit to the count data, as indicated by lack of overdispersion ($\hat{c} \leq 1.03$ for all species) and conformance of distributions to those generated by bootstrapping.

Painted Turtles always had a reasonably high (> 0.6) probability of being detected at the reference site unless the sky was overcast (Fig. 1), whereas Blanding's Turtles always had a lower detection probability (Fig. 2), and Snapping Turtles only had a high detection probability with warm water temperatures in early June (Fig. 3). Consequently, when surveying the conservation reserves, the estimated probability of detecting Painted Turtles was always much higher than for the other two species (Table 2). These probabilities were also strongly affected by the area of basking habitat in the water body (Table 2) due to the assumption that abundance would be proportional to this area, as well as changes in environmental variables, time and date (Appendix 1).

I found Painted Turtles in five of the 23 water bodies I surveyed in the conservation reserves, Blanding's Turtles in one water body, and Snapping Turtles in six water bodies. Due to their reasonably high detection probability, the posterior occupancy probabilities where Painted Turtles were not detected were often well below 0.5, meaning the survey gave reasonable confidence that the species was absent from some water bodies (Table 2). The confidence of absence was much lower for the other two species. For Snapping Turtles occupancy probabilities always remained near 0.5 if the species was not found, meaning that non-detection provided negligible information.

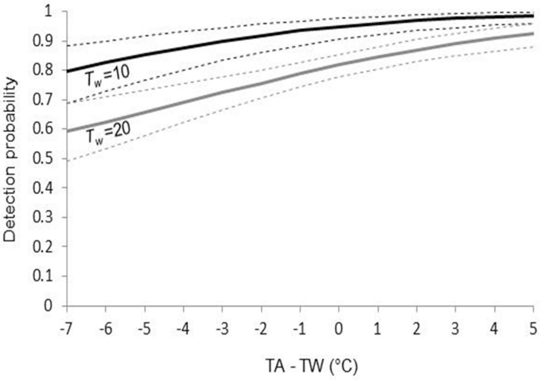

**Figure 1.** Estimated probability of one or more Painted Turtles being detected as a function of air temperature ($T_a$) and water temperature ($T_w$) if cloud cover is ≤ 90%. Dotted lines show standard errors.

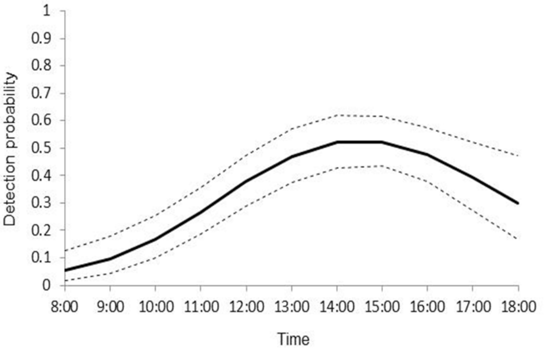

**Figure 2.** Estimated probability of one or more Blanding's Turtles being detected as a function of time of day if cloud cover is ≤ 90%. Dotted lines show standard errors.

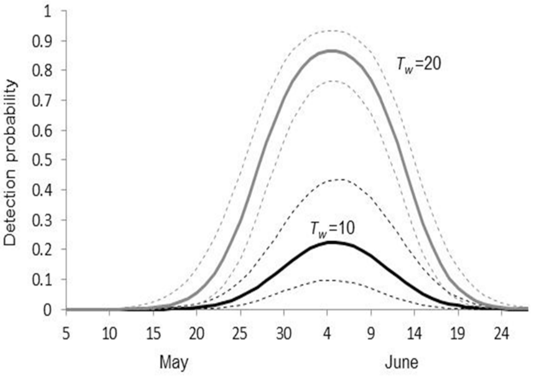

**Figure 3.** Estimated probability of one or more Snapping Turtles being detected as a function of water temperature ($T_w$) and date if cloud cover is ≤ 90%. Dotted lines show standard errors.

**Table 1.** Parameters affecting counts of three turtle species in 53 surveys of the reference site (a beaver pond in Haliburton County, Ontario) from May-June 2013.

| | | Full model | | | Reduced model[b] | | |
|---|---|---|---|---|---|---|---|
| Species | Parameter[a] | mean | 2.5% | 97.5% | mean | 2.5% | 97.5% |
| *Chrysemys picta* | $\alpha$ | 1.78 | -0.24 | 3.73 | 1.77 | 0.79 | 2.75 |
| | $\beta_{Ta}$ | 0.08 | -0.01 | 0.17 | 0.09 | 0.02 | 0.17 |
| | $\beta_{Tw}$ | -0.15 | -0.31 | 0.02 | -0.15 | -0.25 | -0.06 |
| | $\beta_C$ | 0.36 | -0.22 | 0.95 | — | — | — |
| | $\beta_O$ | -3.00 | -4.87 | -1.61 | -2.70 | -4.57 | -1.37 |
| | $\beta_W$ | -0.31 | -0.91 | 0.27 | — | — | — |
| | $\beta_{d1}$ | -0.01 | -0.08 | 0.07 | — | — | — |
| | $\beta_{d2}$ | 0.00 | 0.00 | 0.00 | — | — | — |
| | $\beta_{t1}$ | 0.20 | -0.18 | 0.57 | — | — | — |
| | $\beta_{t2}$ | -0.02 | -0.06 | 0.01 | — | — | — |
| *Emydoidea blandingii* | $\alpha$ | -5.17 | -10.10 | -0.91 | -3.48 | -6.44 | -1.41 |
| | $\beta_{Ta}$ | -0.15 | -0.36 | 0.05 | — | — | — |
| | $\beta_{Tw}$ | 0.11 | -0.23 | 0.41 | — | — | — |
| | $\beta_C$ | -0.49 | -1.72 | 0.67 | — | — | — |
| | $\beta_O$ | -26.71 | -71.30 | -3.08 | -26.66 | -71.36 | -2.91 |
| | $\beta_W$ | -0.77 | -1.98 | 0.33 | — | — | — |
| | $\beta_{d1}$ | 0.11 | -0.05 | 0.31 | — | — | — |
| | $\beta_{d2}$ | 0.00 | 0.00 | 0.00 | — | — | — |
| | $\beta_{t1}$ | 1.34 | 0.28 | 2.61 | 0.97 | 0.21 | 2.00 |
| | $\beta_{t2}$ | -0.11 | -0.21 | -0.02 | -0.07 | -0.16 | -0.01 |
| *Chelydra serpentina* | $\alpha$ | -31.99 | -60.11 | -13.59 | -26.18 | -40.07 | -15.03 |
| | $\beta_{Ta}$ | 0.08 | -0.37 | 0.65 | — | — | — |
| | $\beta_{Tw}$ | 0.42 | 0.00 | 0.87 | 0.25 | 0.06 | 0.46 |
| | $\beta_C$ | -0.11 | -2.67 | 2.74 | — | — | — |
| | $\beta_O$ | -25.82 | -71.29 | -1.51 | -26.46 | -71.32 | -2.57 |
| | $\beta_W$ | -1.08 | -3.35 | 0.95 | — | — | — |
| | $\beta_{d1}$ | 1.43 | 0.56 | 2.69 | 1.24 | 0.67 | 1.96 |
| | $\beta_{d2}$ | -0.02 | -0.04 | -0.01 | -0.02 | -0.03 | -0.01 |
| | $\beta_{t1}$ | 0.23 | -2.16 | 2.30 | — | — | — |
| | $\beta_{t2}$ | -0.06 | -0.25 | 0.14 | — | — | — |

[a] Predictors of log(mean count): α, intercept; $\beta_{Ta}$ and $\beta_{Tw}$, effects of air and water temperature (ºC); $\beta_C$, effect of cloud cover being > 10%, $\beta_O$, effect of cloud cover being > 90%; $\beta_W$, effect of windiness; $\beta_{d1}$ and $\beta_{d2}$, quadratic function of number of days since 30 April; $\beta_{t1}$ and $\beta_{t2}t^2$, quadratic function of number of hours since 0800.

[b] Effects removed if 95% credible intervals included zero.

## Discussion

Occupancy modeling can be used to improve our understanding of habitat and landscape variables driving freshwater turtle distributions (Rizkalla and Swihart 2006; Cosentino et al. 2010; Guzy et al. 2013; Stokeld et al. 2014), and can potentially facilitate the long-term distributional monitoring essential for conservation. However, such modeling needs to account for detection if it is to give reliable inferences. Here I have presented a relatively simple method for accounting for detection in rapid visual surveys. I believe this method provides a useful compromise between the standard design (MacKenzie 2006), which is rigorous but labor-intensive, and public reporting schemes, which facilitate broad-scale monitoring but are difficult to interpret.

The effectiveness of rapid visual surveys will vary depending on the basking habits of the turtle species,

**Table 2.** Estimated detection and occupancy probabilities for three turtle species in water bodies surveyed in two conservation reserves in Haliburton County, Ontario: Clear Lake Conservation Reserve (CLCR) and Dawson Ponds & Plastic Lake Conservation Reserve (DPPLCR). The methodology for estimating detection probability was not applicable to water bodies with extensive bog mat rather than discrete basking areas; the data for these water bodies are therefore marked N/A unless the species was recorded, in which case occupancy probability was known to be 1. Detection Probabilities are the probability of each species being detected if it were present. Occupancy Probabilities are posterior probabilities inferred from Bayesian inference, with prior probabilities set to 0.50. Abbreviations for species are *C. p.* = Painted Turtle, *E. b.* = Blanding's Turtle, and *C. s.* = Snapping Turtle.

| | | | Detection Probability | | | Occupancy Probability | | |
|---|---|---|---|---|---|---|---|---|
| Reserve | Water Body | Basking area (ha) | *C. p.* | *E. b.* | *C. s.* | *C. p.* | *E. b.* | *C. s.* |
| CLCR | Snowshoe Lake | 0.31 | 0.48 | 0.10 | 0.03 | 1 | 0.47 | 0.49 |
| CLCR | Midway Lake | 0.42 | 0.65 | 0.28 | 0.04 | 0.25 | 0.42 | 0.49 |
| CLCR | Chico Pond | 0.16 | 0.28 | 0.09 | 0.03 | 0.42 | 0.48 | 0.49 |
| CLCR | Pond SE of Chico | 0.43 | 0.62 | 0.25 | 0.07 | 0.27 | 0.43 | 0.48 |
| CLCR | Black Cat Lake | 0.04 | 0.10 | 0.03 | 0.01 | 0.47 | 0.49 | 0.50 |
| CLCR | Bog NE of Black Cat | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| CLCR | Pond NNW of Black Cat | 0.95 | 0.90 | 0.54 | 0.09 | 0.09 | 0.31 | 0.48 |
| CLCR | Pond NNE of Black Cat | 0.21 | 0.41 | 0.16 | 0.02 | 0.37 | 0.46 | 0.49 |
| CLCR | Buckskin Lake | 0.13 | 0.26 | 0.10 | 0.01 | 0.42 | 0.47 | 0.50 |
| CLCR | Pond S of Buckskin | 0.95 | 0.98 | 0.52 | 0.04 | 0.02 | 0.32 | 0.49 |
| CLCR | Pond N of Sampson | 0.95 | 0.71 | 0.50 | 0.17 | 0.22 | 0.33 | 0.45 |
| CLCR | Sampson Pond | 0.37 | 0.51 | 0.23 | 0.07 | 0.33 | 0.43 | 0.48 |
| CLCR | Pond W of Sampson | 0.57 | 0.75 | 0.05 | 0.12 | 0.20 | 0.49 | 0.47 |
| CLCR | Pond WW of Sampson | 0.67 | 0.87 | 0.13 | 0.11 | 0.11 | 0.47 | 0.47 |
| CLCR | Delia Pond | 0.77 | 0.79 | 0.21 | 0.25 | 0.18 | 0.44 | 1 |
| CLCR | Rabbit Lake | 0.63 | 0.87 | 0.09 | 0.07 | 1 | 0.47 | 0.48 |
| CLCR | Pond N of Rabbit | 0.11 | 0.40 | 0.08 | 0.01 | 0.37 | 0.48 | 0.50 |
| DPPLCR | Main Dawson Pond | N/A | N/A | N/A | N/A | 1 | N/A | N/A |
| DPPLCR | West Dawson Pond | N/A | N/A | N/A | N/A | 1 | N/A | 1 |
| DPPLCR | Pond W of E Dawson | 0.09 | 0.25 | 0.07 | 0.02 | 0.43 | 0.48 | 1[a] |
| DPPLCR | East Dawson Pond | 2.34 | 0.99 | 0.84 | 0.60 | 1 | 1 | 1 |
| DPPLCR | Plastic Lake | 0.29 | 0.35 | 0.22 | 0.14 | 0.40 | 0.44 | 1[a] |
| DPPLCR | Bog NE of Plastic | N/A | N/A | N/A | N/A | N/A | N/A | 1 |

[a] Turtle or nest detected, but not in surveyed basking areas.

as illustrated by the results. It was most effective for Painted Turtles due to their high detection probability in good conditions, and would probably be effective for sliders (*Trachemys* spp.) and map turtles (*Graptemys* spp.), which are also predictable baskers. It was semi-effective for Blanding's Turtles, and similar results might be expected for pond turtles (*Emys* and *Actinemys* spp.), and possibly softshell turtles (*Apalone* spp.) and Spotted Turtles (*Clemmys guttata*). It was ineffective for Snapping Turtles due to their low detection probability, as was expected given that they are infrequent baskers (Obbard and Brooks 1979; Spotilla and Bell 2008) and often bask on lakeside rocks or the water surface rather than on emergent logs. Visual surveys are completely ineffective for musk turtles (*Sternotherus* spp.) and mud turtles (*Kinosternon* spp.) because they are rarely seen.

The results also showed that the factors affecting detection differed among the three turtle species studied, although not surprisingly all of them were unlikely to be detected in overcast conditions. Changes in Painted Turtle counts were well explained by air and water temperature, consistent with thermoregulatory basking based on operative environmental temperatures (Boyer 1965; Crawford et al. 1983; Schwarzkopf and Brooks 1985). Changes in Blanding's Turtle counts were best explained by the time of day, with counts highest in early afternoon, consistent with radio-tracking data showing this species to be most active in morning and evening (Rowe and Moll 1991). Snapping Turtle counts were best explained by the date, but this was entirely due to four individuals seen basking 12–13 June (Appendix 1). Given that four nests were found on the adjacent roadside in the next few days, this basking appeared to be associated with egg laying, as suggested by Obbard and Brooks (1979) for Snapping Turtles and documented in Blanding's Turtles (Millar et al. 2012) and Painted Turtles (Carrière et al. 2008; Krawckuk and Brooks 1998). The same seasonal pattern would therefore not be expected to occur at other sites, given that Snapping Turtles in that region nest any time from late May to early July (Congdon et al. 2008).

Although the results illustrate that variation in detection probability can be potentially accounted for using data from a reference site, it must be reasonable to believe that detection probability is similar among sites as long as the weather, time or day, and date are accounted for. This assumption could be tested by comparing the results obtained to those using a standard design where each site is surveyed multiple times to obtain site-specific detection probabilities. However, such validation would only apply to that particular set of sites, as the factors affecting site differences will vary among study areas. For the current method to be valid, the key criterion is so have a clear view of potential basking sites. Surveying may therefore need to be restricted to spring, when there is less vegetation, especially for species such as Blanding's Turtles, which tend to keep hidden later in the season (Millar et al. 2012). It is also important to be aware that estimates of detection probability reflect assumptions about population density, as is always the case with occupancy modeling (MacKenzie et al. 2006). In the current method, I have assumed that densities at occupied sites would be similar to those of the reference site, with habitat area measured based on basking habitat.

There are three obvious modifications to the method. First, researchers may wish to change the assumption that the number of turtles present at an occupied site will be proportional to the amount of basking habitat available. It might, for example, be better to assume that abundance is proportional to some measure of the available foraging habitat, or to consider several measures and test the sensitivity of the conclusions to the measure used. Abundance estimates from mark-recapture (e.g. Rizkalla and Swihart 2006) could potentially resolve this issue, but such research is labor-intensive. Second, researchers might incorporate prior information on occupancy probabilities based on previous research (e.g., Rizkalla and Swihart 2006; Cosentino et al. 2010; Guzy et al. 2013; Stokeld et al. 2014) or expert opinion (Martin et al. 2012), or model factors affecting occupancy based on the data. Third, researchers may need to assess identification competence among observers, and account for potential misidentification in the analysis (Miller et al. 2011).

The exact details of the method used will depend on local goals, opportunities and constraints, and for programs involving citizen science, must reflect a compromise between rigor and accessibility. A trained wildlife researcher will be essential for guiding, coordinating, and especially for modeling the data. However, any keen participant with a set of binoculars and a thermometer could contribute to the field observations.

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**Appendix 1**. Counts of three turtle species and environmental variables recorded in surveys of the reference site, which is a beaver pond W of Kushog Lake Road in Haliburton County, Ontario. The 0.95 ha portion of the pond considered to be basking habitat was surveyed from a vantage point at the NE edge of the pond (UTM 17T E675105, N4991297). Abbreviations for species are *C. p.* = Painted Turtle, *E. b.* = Blanding's Turtle and *C. s.* = Snapping Turtle. For environmental variables $O$ = overcast (1 if cloud cover > 90%), $C$ = cloud cover (1 if cover > 10%), $T_a$ = air temperature (° C), $T_w$ = water temperature (° C), and $V$ = wind (1 if windy).

| | | Count | | | Environmental Variables | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Time | *C. p.* | *E. b.* | *C. s.* | $O$ | $C$ | $T_a$ | $T_w$ | $V$ |
| 4/05/2013 | 1130 | 3 | 0 | 0 | 0 | 0 | 21 | 18 | 0 |
| 5/05/2013 | 1530 | 0 | 0 | 0 | 0 | 1 | 25 | 23 | 0 |
| 6/05/2013 | 0930 | 4 | 0 | 0 | 0 | 0 | 15 | 15 | 0 |
| 6/05/2013 | 1300 | 1 | 0 | 0 | 0 | 0 | 21 | 20 | 0 |
| 7/05/2013 | 0800 | 1 | 0 | 0 | 0 | 0 | 7 | 14 | 0 |
| 7/05/2013 | 1645 | 2 | 0 | 0 | 0 | 0 | 25 | 23 | 0 |
| 8/05/2013 | 1745 | 1 | 0 | 0 | 0 | 1 | 24 | 24 | 0 |
| 9/05/2013 | 0905 | 1 | 0 | 0 | 1 | 1 | 18 | 19 | 0 |
| 11/05/2013 | 1330 | 0 | 0 | 0 | 1 | 1 | 9 | 13 | 0 |
| 12/05/2013 | 1100 | 0 | 0 | 0 | 1 | 1 | 5 | 11 | 0 |
| 13/05/2013 | 1125 | 3 | 1 | 0 | 0 | 1 | 6 | 11 | 1 |
| 14/05/2013 | 1510 | 4 | 1 | 0 | 0 | 1 | 11 | 16 | 0 |
| 15/05/2013 | 1030 | 0 | 0 | 0 | 1 | 1 | 8 | 10 | 0 |
| 16/05/2013 | 0840 | 4 | 0 | 0 | 0 | 0 | 11 | 11 | 1 |
| 17/05/2013 | 1000 | 4 | 2 | 0 | 0 | 0 | 12 | 14 | 0 |
| 18/05/2013 | 1200 | 4 | 0 | 0 | 0 | 0 | 22 | 17 | 0 |
| 19/05/2013 | 1430 | 6 | 1 | 0 | 0 | 1 | 23 | 19 | 0 |
| 20/05/2013 | 0840 | 2 | 0 | 0 | 0 | 0 | 17 | 16 | 0 |
| 20/05/2013 | 1545 | 1 | 1 | 0 | 0 | 0 | 26 | 23 | 0 |
| 21/05/2013 | 1710 | 0 | 0 | 0 | 1 | 1 | 16 | 19 | 0 |
| 22/05/2013 | 1245 | 3 | 1 | 0 | 0 | 1 | 19 | 20 | 0 |
| 23/05/2013 | 1400 | 0 | 0 | 0 | 1 | 1 | 9 | 15 | 0 |
| 24/05/2013 | 1705 | 3 | 1 | 0 | 0 | 1 | 11 | 15 | 0 |
| 25/05/2013 | 0815 | 0 | 0 | 0 | 0 | 0 | 5 | 10 | 1 |
| 27/05/2013 | 1615 | 1 | 0 | 1 | 0 | 0 | 22 | 20 | 0 |
| 28/05/2013 | 1414 | 0 | 0 | 0 | 1 | 1 | 18 | 16 | 1 |
| 3/06/2013 | 1720 | 1 | 1 | 1 | 0 | 0 | 12 | 17 | 1 |
| 4/06/2013 | 1350 | 1 | 0 | 1 | 0 | 0 | 19 | 22 | 1 |
| 5/06/2013 | 1520 | 0 | 0 | 0 | 0 | 1 | 15 | 18 | 0 |
| 6/06/2013 | 1015 | 0 | 0 | 0 | 1 | 1 | 13 | 15 | 1 |
| 7/06/2013 | 1315 | 0 | 0 | 0 | 1 | 1 | 15 | 16 | 1 |
| 8/06/2013 | 0930 | 0 | 0 | 0 | 1 | 1 | 14 | 15 | 0 |
| 9/06/2013 | 0830 | 1 | 0 | 0 | 0 | 0 | 14 | 14 | 0 |
| 9/06/2013 | 1200 | 1 | 0 | 1 | 0 | 0 | 22 | 18 | 0 |
| 10/06/2013 | 1630 | 0 | 0 | 0 | 1 | 1 | 18 | 18 | 1 |
| 11/06/2013 | 1815 | 1 | 0 | 0 | 1 | 1 | 17 | 19 | 0 |
| 12/06/2013 | 1155 | 1 | 0 | 4 | 0 | 1 | 18 | 22 | 0 |
| 13/06/2013 | 1245 | 3 | 2 | 4 | 0 | 0 | 23 | 21 | 0 |
| 14/06/2013 | 0815 | 1 | 0 | 0 | 0 | 0 | 14 | 17 | 1 |

**Appendix 1 (continued)**. Counts of three turtle species and environmental variables recorded in surveys of the reference site, which is a beaver pond W of Kushog Lake Road in Haliburton County, Ontario. The 0.95 ha portion of the pond considered to be basking habitat was surveyed from a vantage point at the NE edge of the pond (UTM 17T E675105, N4991297). Abbreviations for species are *C. p.* = Painted Turtle, *E. b.* = Blanding's Turtle and *C. s.* = Snapping Turtle. For environmental variables *O* = overcast (1 if cloud cover > 90%), *C* = cloud cover (1 if cover > 10%), $T_a$ = air temperature (° C), $T_w$ = water temperature (° C), and *V* = wind (1 if windy).

| | | Count | | | Environmental Variables | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Time | *C. p.* | *E. b.* | *C. s.* | *O* | *C* | $T_a$ | $T_w$ | *V* |
| 15/06/2013 | 1625 | 1 | 3 | 0 | 0 | 0 | 22 | 25 | 1 |
| 16/06/2013 | 1515 | 2 | 1 | 0 | 0 | 1 | 21 | 23 | 0 |
| 17/06/2013 | 1450 | 3 | 3 | 0 | 0 | 1 | 21 | 22 | 0 |
| 18/06/2013 | 0845 | 1 | 0 | 0 | 0 | 0 | 13 | 17 | 0 |
| 19/06/2013 | 1050 | 2 | 1 | 0 | 0 | 0 | 17 | 17 | 0 |
| 20/06/2013 | 1355 | 1 | 0 | 0 | 0 | 1 | 24 | 24 | 1 |
| 21/06/2013 | 0955 | 2 | 0 | 0 | 0 | 1 | 21 | 20 | 0 |
| 22/06/2013 | 1410 | 2 | 0 | 0 | 0 | 1 | 24 | 25 | 1 |
| 23/06/2013 | 1605 | 1 | 0 | 0 | 0 | 1 | 29 | 29 | 1 |
| 24/06/2013 | 1150 | 2 | 0 | 0 | 0 | 0 | 29 | 28 | 1 |
| 25/06/2013 | 1250 | 0 | 1 | 0 | 0 | 1 | 23 | 27 | 1 |
| 26/06/2013 | 1030 | 1 | 0 | 0 | 0 | 0 | 24 | 25 | 0 |
| 27/06/2013 | 0830 | 0 | 0 | 0 | 0 | 1 | 20 | 24 | 0 |
| 28/06/2013 | 1805 | 0 | 0 | 0 | 0 | 1 | 20 | 26 | 0 |

**Appendix 2**. Records of three turtle species from surveys of basking sites in two conservation reserves in Haliburton County, Ontario: Clear Lake Conservation Reserve (CLCR) and Dawson Ponds & Plastic Lake Conservation Reserve (DPPLCR). Grid references are UTM 17T. Each basking site consisted of several emergent logs in the same location. The areas shown are the approximate surface areas of water surrounding these groups of logs. Some water bodies had several discrete basking sites, whereas others had only one basking site that sometimes covered the whole water body. The variable "Recorded" indicates whether each species was seen, where *C. p.* = Painted Turtle, *E. b.* = Blanding's Turtle and *C. s.* = Snapping Turtle. For environmental variables *O* = overcast (1 if cloud cover > 90%), *C* = cloud cover (1 if cover > 10%), $T_a$ = air temperature (° C), $T_w$ = water temperature (° C), and *V* = wind (1 if windy). Water bodies with extensive bog mat were not including in the analysis because basking turtles could be obscured in these habitats, so the Area and Environmental Variables are therefore marked "N/A" for these sites.

| | | Grid Reference | | Area | | | Recorded | | | Environmental Variables | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reserve | Basking Site | E | N | (ha) | Date | Time | *C. p.* | *E. b.* | *C. s.* | *O* | *C* | $T_a$ | $T_w$ | *V* |
| CLCR | Snowshoe Lake 1 | 679928 | 5004198 | 0.22 | 25/05/2013 | 1100 | 0 | 0 | 0 | 0 | 0 | 11 | 14 | 1 |
| CLCR | Snowshoe Lake 2 | 680362 | 5004535 | 0.09 | 25/05/2013 | 1530 | 1 | 0 | 0 | 0 | 0 | 11 | 14 | 1 |
| CLCR | Midway Lake 1 | 680091 | 5004663 | 0.21 | 25/05/2013 | 1220 | 0 | 0 | 0 | 0 | 0 | 13 | 14 | 1 |
| CLCR | Midway Lake 2 | 680345 | 5005029 | 0.21 | 25/05/2013 | 1240 | 0 | 0 | 0 | 0 | 0 | 13 | 14 | 1 |
| CLCR | Chico Pond | 680576 | 5005344 | 0.16 | 25/05/2013 | 1335 | 0 | 0 | 0 | 0 | 0 | 14 | 16 | 1 |
| CLCR | Pond SE of Chico 1 | 680619 | 5005255 | 0.32 | 25/05/2013 | 1358 | 0 | 0 | 0 | 0 | 0 | 15 | 16 | 1 |
| CLCR | Pond SE of Chico 2 | 680757 | 5005323 | 0.11 | 25/05/2013 | 1415 | 0 | 0 | 0 | 0 | 0 | 16 | 16 | 1 |
| CLCR | Black Cat Lake 1 | 681197 | 5005741 | 0.03 | 25/05/2013 | 1500 | 0 | 0 | 0 | 0 | 0 | 15 | 15 | 1 |
| CLCR | Bog NE of Blackcat | 681231 | 5005844 | N/A | 25/05/2013 | 1520 | 0 | 0 | 0 | 0 | 0 | N/A | N/A | N/A |
| CLCR | Black Cat Lake 2 | 680869 | 5006024 | 0.01 | 25/05/2013 | 1537 | 0 | 0 | 0 | 0 | 0 | 13 | 14 | 1 |
| CLCR | Pond NNW of Black Cat | 680874 | 5006116 | 0.95 | 25/05/2013 | 1552 | 0 | 0 | 0 | 0 | 0 | 13 | 14 | 1 |
| CLCR | Pond NNE of Black Cat | 680989 | 5006161 | 0.21 | 25/05/2013 | 1612 | 0 | 0 | 0 | 0 | 0 | 13 | 14 | 1 |
| CLCR | Buckskin Lake 1 | 681359 | 5006704 | 0.05 | 26/05/2013 | 0830 | 0 | 0 | 0 | 0 | 0 | 9 | 13 | 1 |

**Appendix 2 (continued).** Records of three turtle species from surveys of basking sites in two conservation reserves in Haliburton County, Ontario: Clear Lake Conservation Reserve (CLCR) and Dawson Ponds & Plastic Lake Conservation Reserve (DPPLCR). Grid references are UTM 17T. Each basking site consisted of several emergent logs in the same location. The areas shown are the approximate surface areas of water surrounding these groups of logs. Some water bodies had several discrete basking sites, whereas others had only one basking site that sometimes covered the whole water body. The variable "Recorded" indicates whether each species was seen, where *C. p.* = Painted Turtle, *E. b.* = Blanding's Turtle and *C. s.* = Snapping Turtle. For environmental variables $O$ = overcast (1 if cloud cover > 90%), $C$ = cloud cover (1 if cover > 10%), $T_a$ = air temperature (° C), $T_w$ = water temperature (° C), and $V$ = wind (1 if windy). Water bodies with extensive bog mat were not including in the analysis because basking turtles could be obscured in these habitats, so the Area and Environmental Variables are therefore marked "N/A" for these sites.

| | | Grid Reference | | Area | | | Recorded | | | Environmental Variables | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Reserve | Basking Site | E | N | (ha) | Date | Time | *C. p.* | *E. b.* | *C. s.* | $O$ | $C$ | $T_a$ | $T_w$ | $V$ |
| CLCR | Buckskin Lake 2 | 681586 | 5006632 | 0.03 | 26/05/2013 | 0958 | 0 | 0 | 0 | 0 | 0 | 11 | 13 | 1 |
| CLCR | Buckskin Lake 3 | 681806 | 5007091 | 0.05 | 26/05/2013 | 1047 | 0 | 0 | 0 | 0 | 0 | 13 | 14 | 1 |
| CLCR | Pond S of Buckskin | 681495 | 5006466 | 0.95 | 26/05/2013 | 0930 | 0 | 0 | 0 | 0 | 0 | 11 | 9 | 1 |
| CLCR | Pond N of Sampson | 678765 | 5006412 | 0.95 | 26/05/2013 | 1315 | 0 | 0 | 0 | 0 | 0 | 11 | 17 | 1 |
| CLCR | Sampson Pond 1 | 678738 | 5006216 | 0.16 | 26/05/2013 | 1335 | 0 | 0 | 0 | 0 | 0 | 15 | 17 | 1 |
| CLCR | Sampson Pond 2 | 678675 | 5006100 | 0.13 | 26/05/2013 | 1350 | 0 | 0 | 0 | 0 | 0 | 15 | 17 | 1 |
| CLCR | Sampson Pond 3 | 679079 | 5006060 | 0.08 | 26/05/2013 | 1500 | 0 | 0 | 0 | 0 | 0 | 16 | 17 | 1 |
| CLCR | Pond W of Sampson | 678557 | 5005870 | 0.57 | 26/05/2013 | 1412 | 0 | 0 | 0 | 0 | 0 | 16 | 16 | 1 |
| CLCR | Pond WW of Sampson | 678367 | 5005785 | 0.67 | 26/05/2013 | 1427 | 0 | 0 | 0 | 0 | 0 | 17 | 15 | 1 |
| CLCR | Delia Pond 1 | 679173 | 5006273 | 0.11 | 26/05/2013 | 1529 | 0 | 0 | 0 | 0 | 0 | 18 | 18 | 1 |
| CLCR | Delia Pond 2 | 679207 | 5006375 | 0.24 | 26/05/2013 | 1538 | 0 | 0 | 1 | 0 | 0 | 17 | 19 | 1 |
| CLCR | Delia Pond 3 | 679461 | 5006367 | 0.42 | 26/05/2013 | 1609 | 0 | 0 | 1 | 0 | 0 | 18 | 18 | 1 |
| CLCR | Rabbit Lake 1 | 677523 | 5006135 | 0.21 | 27/05/2013 | 0853 | 1 | 0 | 0 | 0 | 0 | 10 | 13 | 0 |
| CLCR | Rabbit Lake 2 | 677615 | 5005932 | 0.05 | 27/05/2013 | 0925 | 0 | 0 | 0 | 0 | 0 | 12 | 15 | 0 |
| CLCR | Rabbit Lake 3 | 677993 | 5006073 | 0.37 | 27/05/2013 | 0940 | 0 | 0 | 0 | 0 | 0 | 15 | 12 | 0 |
| CLCR | Pond N of Rabbit | 677593 | 5006256 | 0.11 | 27/05/2013 | 1223 | 0 | 0 | 0 | 0 | 0 | 16 | 12 | 0 |
| DPPLCR | Main Dawson Pond | 670729 | 5004189 | N/A | 18/06/2013 | 1000 | 1 | 0 | 0 | 0 | 1 | N/A | N/A | N/A |
| DPPLCR | West Dawson Pond | 670049 | 5004433 | N/A | 18/06/2013 | 1025 | 1 | 0 | 1 | 0 | 1 | N/A | N/A | N/A |
| DPPLCR | Pond W of E Dawson | 670889 | 5004154 | 0.09 | 18/06/2013 | 1150 | 0 | 0 | 1[a] | 0 | 1 | 19 | 16 | 0 |
| DPPLCR | East Dawson Pond | 670999 | 5004144 | 2.34 | 18/06/2013 | 1210 | 1 | 1 | 1 | 0 | 1 | 19 | 19 | 0 |
| DPPLCR | Plastic Lake 1 | 670721 | 5004765 | 0.075 | 18/06/2013 | 1348 | 0 | 0 | 1[a] | 0 | 1 | 16 | 19 | 0 |
| DPPLCR | Plastic Lake 2 | 670945 | 5004610 | 0.015 | 18/06/2013 | 1404 | 0 | 0 | 0 | 0 | 1 | 16 | 19 | 0 |
| DPPLCR | Plastic Lake 3 | 671029 | 5004503 | 0.02 | 18/06/2013 | 1410 | 0 | 0 | 0 | 0 | 1 | 17 | 19 | 0 |
| DPPLCR | Plastic Lake 4 | 671029 | 5004453 | 0.09 | 18/06/2013 | 1420 | 0 | 0 | 0 | 0 | 1 | 17 | 20 | 0 |
| DPPLCR | Plastic Lake 5 | 671447 | 5005267 | 0.05 | 18/06/2013 | 1425 | 0 | 0 | 0 | 0 | 1 | 17 | 20 | 0 |
| DPPLCR | Plastic Lake 6 | 671206 | 5005404 | 0.04 | 18/06/2013 | 1600 | 0 | 0 | 0 | 0 | 0 | 17 | 20 | 0 |
| DPPLCR | Bog NE of Plastic L | 671527 | 5005206 | N/A | 18/06/2013 | 1500 | 0 | 0 | 1 | 0 | 0 | N/A | N/A | N/A |

[a] Turtle or nest found, but not in basking sites surveyed.

**Appendix 3**. OpenBUGS code for modeling detection probability and occupancy of turtle species in rapid surveys of water bodies, where the detection model is based on count data from multiple surveys of a reference site. Here the model is set up for Painted Turtles, so the factors not found to affect detection of that species are commented out.

```
Model
{
          # Priors for parameters affecting detection probability
          a ~ dnorm(0,1.0E-6)           # intercept (mean of log no. turtles seen)
#         b.C ~ dnorm(0,1.0E-6)         # binary effect of some cloud (> 10% cover)
          b.O ~ dnorm(0,0.001)          # binary effect of being overcast (> 90% cover)
          b.Ta ~ dnorm(0,1.0E-6)        # linear effect of air temperature
          b.Tw ~ dnorm(0,1.0E-6)        # linear effect of water temperature
#         b.W ~ dnorm(0,1.0E-6)         # binary effect of wind
#         b.t1 ~ dnorm(0,1.0E-6)        # quadratic effect of time-of-day
#         b.t2~ dnorm(0,1.0E-6)
#         b.d1 ~ dnorm(0,1.0E-6)        # quadratic effect of date
#         b.d2 ~ dnorm(0,1.0E-6)

          # Model data from reference site
          for (i in 1:n.obs.ref) {                          # for each observation...
                    count[i] ~ dpois(mu.ref[i])             # no. turtles seen sampled from Poisson
                    log(mu.ref[i]) <- a+b.O*O.ref[i]+b.Ta*Ta.ref[i]+b.Tw*Tw.ref[i]    # predicted no. seen
#                   +b.C*C.ref[i] b.t1*t.ref[i]+b.t2*pow(t.ref[i],2)+b.d1*d.ref[i]+b.d2*pow(d.ref[i],2)+b.W*W.ref[i]
          }

          # Model survey data
          for (wb in 1:n.wb) {          # for each water body surveyed....
                    p.present[wb] <- 0.5          # prior probability that species present
                    present[wb] ~ dbern(p.present[wb])        # whether species is actually present
                    p.missed.wb[wb,first[wb]] <- 1

                    for (i in first[wb]:last[wb]) {         # for each individual site in that water body...
                              recorded[i] ~ dbern(p.recorded[i])                # whether species seen or not
                              p.recorded[i] <- present[wb]*p.detection[i]       # probability it would be seen
                              p.detection[i] <- 1-exp(-mu.sur[i]*A[i]/A.ref) # prob. detection if present
                              log(mu.sur[i]) <- a+b.O*O.sur[i]+ b.Ta*Ta.sur[i]+b.Tw*Tw.sur[i] # predicted no. seen
#
          +b.C*C.sur[i]+b.t1*t.sur[i]+b.t2*pow(t.sur[i],2)+b.d1*d.sur[i]+b.d2*pow(d.sur[i],2)+b.W*W.sur[i]
                              p.missed.wb[wb,i+1] <-  p.missed.wb[wb,i]*(1-p.detection[i])
                    }
                    p.detection.wb[wb] <- 1-p.missed.wb[wb,last[wb]+1] # prob. detection for whole water body
          }
}
```

**Appendix 4**. Raw data from the reference site (Appendix 1) and conservation reserves (Appendix 2) re-formatted so the model (Appendix 3) could be fitted to these data.

```
list(

# Data for reference site

A.ref=0.9,          # area (ha) of basking habitat on reference site
n.obs.ref=53,       # number surveys of reference site

# counts for each species at each survey; comment out data for species not being analysed
# painted
count=c(3,0,4,1,1,2,1,1,0,0,3,4,0,4,4,4,6,2,1,0,3,0,3,0,1,0,1,1,0,0,0,0,1,1,0,1,1,3,1,1,2,3,1,2,1,2,2,1,2,0,1,0,0),

# Blandings
#count=c(0,0,0,0,0,0,0,0,0,0,1,1,0,0,2,0,1,0,1,0,1,0,1,0,0,0,1,0,0,0,0,0,0,0,0,0,0,2,0,3,1,3,0,1,0,0,0,0,0,1,0,0,0),

# snappers
#count=c(0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,1,1,0,0,0,0,0,1,0,0,4,4,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0),

# date of each survey, recorded as number of days after 30 April
d.ref=c(4,5,6,6,7,7,8,9,11,12,13,14,15,16,17,18,19,20,20,21,22,23,24,25,27,28,34,35,36,37,38,39,40,40,41,42,
43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59),

# time of each survey, recorded as number of hours since 08:00
t.ref=c(3.50,7.50,1.50,5.00,0.00,8.75,9.75,1.08,5.50,3.00,3.42,7.17,2.50,0.67,2.00,4.00,6.50,0.67,7.75,9.17,
4.75,6.00,9.08,0.25,8.25,6.23,9.33,5.83,7.33,2.25,5.25,1.50,0.50,4.00,8.50,10.25,3.92,4.75,0.25,8.42,7.25,
6.83,0.75,2.83,5.92,1.92,6.17,8.08,3.83,4.83,2.50,0.50,10.08),

# whether cloud cover > 90%
O.ref=c(0,0,0,0,0,0,0,1,1,1,0,0,1,0,0,0,0,0,1,0,1,0,0,0,1,0,0,0,1,1,1,0,0,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0),

# whether cloud cover > 10%
C.ref=c(0,1,0,0,0,0,1,1,1,1,1,1,1,0,0,0,1,0,0,1,1,1,1,0,0,1,0,0,1,1,1,1,0,0,1,1,1,0,0,0,1,1,0,0,1,1,1,1,0,1,0,1,1),

# air temperature (C)
Ta.ref=c(21,25,15,21,7,25,24,18,9,5,6,11,8,11,12,22,23,17,26,16,19,9,11,5,22,18,12,19,15,13,15,14,14,22,
18,17,18,23,14,22,21,21,13,17,24,21,24,29,29,23,24,20,20),

# water temperature (C)
Tw.ref=c(18,23,15,20,14,23,24,19,13,11,11,16,10,11,14,17,19,16,23,19,20,15,15,10,20,16,17,22,18,15,16,15,
14,18,18,19,22,21,17,25,23,22,17,17,24,20,25,29,28,27,25,24,26),

# whether windy
W.ref=c(0,0,0,0,0,0,0,0,0,0,1,0,0,1,0,0,0,0,0,0,0,0,0,1,0,1,1,1,0,1,1,0,0,0,1,0,0,0,1,1,0,0,0,0,1,0,1,1,1,1,0,0,0),


# Data for rapid surveys of conservation reserves

n.wb=19, # number of water bodies

# first and last site for each water body (there were 1-6 basking sites per water body)
first=c(1,3,5,6,8,10,11,12,15,16,17,20,21,22,25,28,29,30,31),
last=c(2,4,5,7,9,10,11,14,15,16,19,20,21,24,27,28,29,30,36),

# area (ha) of basking habitat for each individual site in conservation reserves
A=c(0.22,0.09,0.21,0.21,0.16,0.32,0.11,0.03,0.01,0.95,0.21,0.05,0.03,0.05,0.95,0.95,0.16,0.13,0.08,0.57,0.67,
0.11,0.24,0.42,0.21,0.05,0.37,0.11,0.09,2.34,0.075,0.015,0.02,0.09,0.05,0.04),

# whether each species was recorded at each site; comment out data for species not being analysed
# painted
recorded=c(0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,1,0,0,0,0,0,0,0),
```

**Appendix 4 (continued)**. Raw data from the reference site (Appendix 1) and conservation reserves (Appendix 2) re-formatted so the model (Appendix 3) could be fitted to these data.

```
# Blandings
#recorded=c(0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0),

# snappers
#recorded=c(0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,0,0,0,0,0,1,0,0,0,0,0,0),

# variables below same as above, but here recorded for each site in the conservation reserves

d.sur=c(25,25,25,25,25,25,25,25,25,25,25,26,26,26,26,26,26,26,26,26,26,26,26,27,27,27,27,49,49,49,49,
49,49,49,49),

t.sur=c(3.00,7.50,4.33,4.67,5.58,5.97,6.25,7.00,7.62,7.87,8.20,0.50,1.97,2.78,1.50,5.25,5.58,5.83,7.00,6.20,
6.45,7.48,7.63,8.15,0.88,1.42,1.67,4.38,3.83,4.17,5.80,6.07,6.17,6.33,6.42,8.00),

O.sur=c(0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0),

C.sur=c(0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,1,1,1,1,1,0),

Ta.sur=c(11,11,13,13,14,15,16,15,13,13,13,9,11,13,11,11,15,15,16,16,17,18,17,18,10,12,15,16,19,19,16,
16,17,17,17,17),

Tw.sur=c(14,14,14,14,16,16,16,15,14,14,14,13,13,14,9,17,17,17,17,16,15,18,19,18,13,15,12,12,16,19,19,
19,19,20,20,20),

W.sur=c(1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0)

)
```